Journal of Economics and Sustainable Development www.iiste.org
ISSN 2222-1700 (Paper) ISSN 2222-2855 (Online)
Vol.2, No.5, 2011

Sustainable wind energy system: Role of Energy policy and security-A case study from India

Km. Saroj Gupta (Research scholar)

Nehru Gram Bharati University Kotwa-jamunipur, Allahabad, Uttar Pradesh, India

Administrative office-12, park street, New Delhi Telefax: 011-23094091

(Corresponding address)

Professor's colony,Gyanpur, S.R.N. (Bhadohi)

Pin no.-221304 Phone no. 09936895570.

Email. Sarojgupta _0@yahoo.com:

Sarojgupta1886@gmail.com.

Abstract

Energy security and sustainable development are high in the global agenda due to the impact of volatile energy prices, high demand for energy security, and concerns over environmental sustainability and the global climate change. In a present scenario energy I s most important factor for all developed and developing country. Energy is required for every aspect of our daily life. At present, commercial energy consumption makes up about 65% of the total energy consumed in India. This includes coal with the largest share of 55%, followed by oil at 31%, natural gas at 11% and hydro energy at 3%. Non-commercial energy sources consisting of firewood, cow dung and agriculture wastes account for over 30% of the total energy consumption. The critical feature of India's energy sector and linkages to economy is the import dependence on crude and petroleum products. Import bill is likely to grow to more than 100% in the near future because of population explosion and improved living standard in the country. Being a tropical country India has unlimited potential for producing renewable energy sources. These sources of energy can play an important role in the sustainable development by providing basic energy needs of rural and remote areas. This paper discusses the current energy status, choice of energy options and potential of wind energy systems for creating sustainable livelihoods in India.

Keywords: wind energy, sustainability, energy security, policy, wind energy programme,

Introduction

New and renewable energy technologies are considered to be one of the viable options to meet the challenge of achieving sustainable development while conserving natural resources that have been depleted due to the rapid growth in population, urbanization, and fossil fuel consumption.[2, 3] the renewable electricity generation capacity reached an estimated 240 GW worldwide in 2007, which represents 5% of the global power capacity and 3.4% of the global power generation.[4] The largest component of renewable generation capacity is wind power, which grew by 29% worldwide in 2008 to reach an estimated 121 GW.[5] The impetus behind wind power expansion has come increasingly from the urgent need to combat global climate change.[6] Most countries now accept that greenhouse gas (GHG) emissions must be drastically slashed in order to avoid environmental catastrophe. Wind energy not only offers both a power source that completely avoids the emission of carbon dioxide, [7] the main GHG, but also produces none of the other pollutants associated with either fossil fuel or nuclear generation.

The Indian renewable energy sector has shown impressive growth in the past few years and investments into the sector have increased significantly. The share of renewable energy was 7.7% in the cumulative installed capacity MW) (147 403 of electric power plants under utilities in India until December 2008.[8] The Indian government by 2012 expects renewable energy to contribute 10% of the total power generation capacity and have 4%–5% share in the electricity mix.[9] From a longer-term perspective and keeping in mind the need to maximally develop domestic supply options as well as the need to diversify energy sources, renewable remain important to India's energy sector. The Integrated Energy Policy Report of the Planning Commission of India has observed that the contribution of modern renewable to India's energy mix by 2031–2032, excluding large hydro, would be around 5%–6%.[10] Table 1 presents the cumulative installed capacity of renewable energy technologies for power generation in India. The cumulative installed capacity of grid-interactive renewable energy systems for power generation was MW 13 879 until January 2009 of which contributions of wind, small hydro, biomass (including agri-residues, biogases cogeneration, and waste to energy), and solar were 9756, 2345, 1776, and 2.12 MW, respectively.[12] It may be noted that wind power contributes 70% of the grid-interactive renewable power installed in the country.

India is now the fifth largest wind market in the world[13] despite the fact that the total installed capacity of wind power projects still remains far below from their respective potential ($\leq$ 20%). The wind energy sector in India has seen a shift in the past couple of years from a manufacturer focused industry to one led by mainstream power developers; however, the country's low capacity utilization factor (CUF) for wind power has been an area of concern. Against the international average of 25%–35% CUF, [5] Indian CUF averages around 17%.[10] This study reviews the development of wind energy in India and diffusion prospects of wind energy in six Indian states. This paper is set out as follows. Section 2 provides a brief assessment of the global status of wind energy and support policies on the basis of available literature. A brief description of wind power technology is given in Sec. 3. Sections 4, 5 present some salient features of the Indian program on wind energy development and potential of wind energy in India respectively. The future growth pattern of wind energy in India and six potential states is predicted and analyzed in Sec. 6. Section 7 concludes.

Global Status of Wind Energy and Support Policies-

Wind is commercially and operationally the most viable renewable energy resource and, accordingly, emerging as one of the largest source in this sector.[14] At the end of December 2008, worldwide capacity of wind-powered generators was 121 GW out of which more than 27 GW was added in 2008 generating TW h 260 per annum, equaling more than 1.5% of the global electricity consumption.[13] Figure 1 presents the worldwide trend in global installations of wind power. Wind energy continued its growth in 2008 at an increased rate of 29%.[5] In 2008, the United States and China took the lead, United States taking over the global number one position from Germany and China getting ahead of India for the first time, taking the lead in Asia. The United States was the fastest growing wind power market in the world for the third year in a row. The massive growth in the United States wind market in 2008 increased the country's total wind power generating capacity by half. Wind development in the United States is supported by a mix of state and federal policies. At the federal level, wind power receives generous tax incentives in the form of a 10 yr production tax credit—which, in effect, acts like a feed-in premium—and 5 yr accelerated depreciation. The combination of federal tax incentives with state-level financial incentives and renewable energy quota obligation systems was a major driver in wind power capacity additions in the United States. Canada in 2008 surpassed the 2 GW mark for installed wind energy capacity, ending the year with 2.4 GW.[13] The provision of production incentive payments under the ecoenergy initiative for renewable power program is stimulating wind energy deployment in Canada.

The European market continues its steady growth and wind power is now the fastest growing power generation technology in the European Union. Overall, almost 8.9 GW of new wind turbines brought European wind power generation capacity up to nearly 66 GW in 2008.[5] In Europe, the group of countries with the highest effectiveness (Germany, Spain, Denmark, and Portugal) used feed-in tariffs (FITs) to encourage wind power deployment.[4, 22] their success in deploying onshore wind stems from high investment stability guaranteed by the long term FITs, an appropriate framework with low administrative and regulatory barriers, and relatively favorable grid access conditions. In 2005, the average remuneration levels in these countries (USD 0.09–0.11/kW h) were lower than those in countries applying quota obligation systems with tradable green certificates (TGCs) i.e., USD 0.13–0.17/kW h It is observed that beyond some minimum threshold level, higher remuneration levels do not necessarily lead to greater levels of policy effectiveness. The highest levels of remuneration on a per-unit generated basis for wind among the countries studied are seen in Italy, Belgium, and the United Kingdom, which have all implemented quota obligation systems with TGCs. Yet none of these countries scored high levels of deployment effectiveness. This is likely related to the existence of high noneconomic barriers as well as to intrinsic problems with the design of TGC systems in these countries, which cause higher investor risk premiums.

China continued its spectacular growth in 2008, once again doubling its installed capacity by adding about 6.3 GW to reach a total of 12.2 GWLike most European countries; China has stipulated a series of incentive policies to encourage its technical innovation, market expansion, and commercialization. In February 2005, China's Renewable Energy Law was formulated and came into force on January 1, 2006. The law requires that power grid operators purchase a full amount of wind power generated by registered producers. The law also offers financial incentives, such as a national fund to foster renewable energy development and discounted lending and tax preferences for renewable energy projects. India is continuing its steady growth, with 1800 MW of wind energy capacity added in 2008, bringing the total of up to 9.6 Gwinn India, some states with renewable portfolio standards or other policies to promote wind generation have introduced FITs for wind generation which are higher than that for conventional electricity. Ten out of the 29 Indian states have now implemented quotas for a renewable energy share of up to 10% and have introduced preferential tariffs for electricity produced from renewable sources.[5] At the federal level, although there is no national policy for renewable energy, there are a number of measures that help drive wind energy development, including fiscal incentives such as income tax exemption for 10 yr, 80% accelerated depreciation, sales tax exemption, and excise duty exemption.

The clean development mechanism (CDM) of the Kyoto protocol has already had a substantial impact on wind energy development in China and India. The CDM also impacts to a lesser extent other developing countries, and income from certified emission reductions can make a substantial contribution to a project's profitability There were more than MW 25 000 of wind power projects in the CDM pipeline until January 2009 in which most of the projects belongs to China (314 projects of MW 16 977) and India (270 projects of 5072 MW). The cumulative installed capacity of wind power in top ten countries until December 2008 is shown in Fig. 2. On the basis of accelerated development and further improved policies, a global capacity of more than 1500 GW is possible by 2020.

Wind Energy Technology

Wind has considerable amount of kinetic energy when blowing at high speeds. This kinetic energy when passing through the blades of the wind turbines is converted into mechanical energy and rotates the wind blades and the connected generator, thereby producing electricity. A wind turbine primarily consists of a main tower, blades, nacelle, hub, main shaft, gearbox, bearing and housing, brake, and generator.[7] The main tower is 50–100 m high. Generally, three blades made up of fiber reinforced polyester are mounted on the hub, while in the nacelle the major parts are housed. Under normal operating conditions, the nacelle would be facing the upstream wind direction. The hub connects the gearbox and the blades. Solid high carbon steel bars or cylinders are used as main shaft. The gearbox is used to increase the speed ratio so that the rotor speed is increased to the rated generator speed; it is the most critical component and needs regular maintenance. Oil cooling is employed to control the heating of the gearbox. Gearboxes are mounted over dampers to minimize vibration. Failure of gearbox may put the plant out of operation for an entire season as spares are often not available. Thus, new gearless configurations have become attractive for wind plant operators. Figure 3 presents a schematic of a wind turbine.

The most dramatic improvement has been in the increasing size and performance of wind turbines. From machines of just 25 kW 20 years ago, the commercial size range sold today is typically from 600 up to 2.5 MW, with 80 m diameter rotors placed on 70–100 m high towers. In 2003, the German company Enercon erected the first prototype of a 4.5 MW turbine with a rotor diameter of 112 m.[7] Wind turbines have a design lifetime of 20–25 yr, with their operation and maintenance costs typically about 3%–5% of the cost of the turbine. At present, wind electric generators are being manufactured in the country by several manufacturers, through (I) joint ventures under licensed production, (ii) subsidiaries of foreign companies, under licensed production, and (iii) Indian companies with their own technology. An indigenization level of up to 70% has been achieved in machines of unit sizes up to 500 kW. The import content is somewhat higher in higher capacity machines. The current annual production capacity of domestic wind turbines is about 2500 MW, which is expected to grow by MW 10 000 until 2010

For grid-interactive power, two types of wind turbines, viz., and stall regulated and pitch regulated, are deployed in the country. The stall regulated wind turbines have fixed rotor blades, whereas pitch regulated wind turbines have adjustable rotor blades that change the angle of attach depending on the wind speed. Both technologies have their own advantages and disadvantages. Wind turbines are also available with lattice, steel tubular, and concrete tubular towers. At present, the wind industry is market driven and competitive. Most of the wind turbine manufacturers in India provide operation and maintenance support and also monitor the field performances of the wind turbines installed by them. With better wind data and the use of analytical tools and experience in sitting wind farms, it is expected that the capacity factor for the new wind plants would exceed 20%. The initial phase of growth of the wind industry was based on imported designs and relatively low research and development inputs. India has a solid domestic manufacturing base, including global leader Suzlon, accounting for over half of the market, Vestas Wind Tech and RRB. In addition, international companies have set up production facilities in India, including Enercon, Repower, Siemens, and LM Glasfiber and the new entrants such as ReGen Power Tech, Win Wind, Kenersys, and Global Wind Power. Over the past few years, both the government and the wind power industry have succeeded in injecting greater stability into the Indian market. This has encouraged larger private and public sector enterprises to invest in wind. It has also stimulated a stronger domestic manufacturing sector; some companies now source more than 80% of the components for their turbines in India. Indian company Suzlon, the world's fifth largest turbine manufacturer, is now also well established in the international wind market beyond India, operating in 20 countries around the world and supplying turbines to projects in Asia, North and South America, and Europe. Table 2 presents the wind turbines, which are available now for wind power generation in India. Wind turbines of up to 2.5 MW are presently manufactured in India.[9]

Sustainability and Economic of India

"India needs to sustain an 8% to 10% economic growth rate, over the next 25 years, if it is to eradicate poverty and meet its human development goals. To deliver a sustained growth rate of 8% through 2031-32 and to meet the lifeline energy needs of all citizens, India needs, at the very least, to increase its primary energy supply by 3 to 4 times and its electricity generation capacity/supply by 5 to 6 times of their 2003-04 levels." In other words, it begins with the assumption that the 8-10% growth rate is necessary to eradicate poverty. It then projects the energy and electricity that will be required to achieve this rate of growth. It finds that to achieve 8% economic growth every year for 25 years (from 2006 to 2031), the total primary energy supply will have to be raised to 1250 Kilogram Oil Equivalent (kgoe) per capita by 2031 from the level of 439 kgoe in 2003. As far as electricity is concerned, the consumption will have to be raised from 553 units per capita in 2003 to 2471 units per capita by 2031 for the same growth. To meet this requirement, the report suggests that India will need to create a total installed capacity of 778,000 MW, up from the current (2010) level of 161,000 MW - close to five times the existing capacity. To meet this level of energy and electricity needs, even some of the best scenarios outlined in the report require the full development of hydro resources – 150,000 MW – and creating 63,000 MW of nuclear capacity in addition to huge amounts of coal power. And, as per the report, in the least coal-dominated, highest energy efficient and renewable scenario also, coal will still have to provide for 41% of our primary energy supply and oil will have to supply 22.8%. In effect, the need to maintain 8% growth is the basic justification for building hundreds of large dams, including in the sensitive Himalayan region, many nuclear facilities and thousands of acres of coal mining and thermal power plants. This means displacement of millions of people, destruction of livelihoods, tearing asunder social, cultural and community fabrics, huge impacts on environment and bio-diversity, the drying up of many rivers with multiple dams and diversions in a single basin, the specter of managing massive quantities of radioactive waste, not to mention the huge financial costs of building this infrastructure. And even with all this, the report estimates that we will need to import 90- 93% of our oil and 11-45% of our coal requirements.

Wind Energy Program in India

The original impetus to develop wind energy in India came in the early 1980s from the government, when the Commission for Additional Sources of Energy (CASE) had been set up in 1981 and upgraded to the Department of Non-Conventional Energy Sources (DNES) in 1982.[34] This was followed in 1992 by the establishment of a full-fledged Ministry of Non-Conventional Energy Sources (MNES), renamed as

Ministry of New and Renewable Energy (MNRE) in 2006. The Indian Renewable Energy Development Agency (IREDA) was established in 1987 as a financial arm of the Ministry to promote renewable energy technologies in the country. It provides finances to manufacturers, consultancy services to entrepreneurs, and also assists in the development and up gradation of technologies. The original intent of these institutions was to encourage a diversification of fuel sources away from the growing demand for coal, oil, and gas required to meet the demand of the country's rapid economic growth.[35] The wind energy program of MNRE was aimed at catalyzing commercialization of wind power generation on a large scale in the country. A market-oriented strategy was adopted from inception, which has led to the successful commercial development of the technology. The broad based national program included wind resource assessment; research and development support; implementation of demonstration projects to create awareness and opening up of new sites; involvement of utilities and industry; development of infrastructure capability and capacity for manufacture, installation, operation and maintenance of wind power plants; and policy support. An aggregate demonstration wind power capacity of 71 MW under the demonstration program of the Ministry has been established at 33 locations in nine states. MNRE provides support for research and development, survey and assessment of wind resources, demonstration of wind energy technologies, and has also taken fiscal and promotional measures for implementation of private sector projects.[36, 37] Figure 4 presents the cumulative capacity of wind power installed in India over time. Recently, Gujarat has shown a high growth in wind power installed capacity from 675 MW in 2006–2007 to 1255 in 2007–2008; however, the rate of growth of installed capacity of wind energy in Karnataka has decreased during 2007–2008 primarily due to noneconomic barriers. Karnataka added 265 MW of wind power in 2006–2007, whereas the addition in the capacity came down to 166 MW in 2007–2008 as against the normal trend of registering a further increase. Karnataka had the potential to tap more than MW 11 000 of wind energy, but is actually tapping less than 1100 MW, while Tamil Nadu has the potential to harness only about 5500 MW, but the state has overshot the potential by putting up windmills with a capacity of nearly 4000 MW. A notable feature of the Indian program has been the interest among private investors/developers in setting up of commercial wind power projects.

The Indian states and set up State Regulatory Commissions (SERCs) in charge of setting electricity tariffs.[40, 41, 42] the act also opened access to the Indian transmission system, allowing consumers to purchase their electricity from any producer. The Electricity Act also required the SERCs to set renewable portfolio standards for electricity production in their state, and the MNRE issued guidelines to all state governments to create an attractive environment for the export, purchase, wheeling, and banking of electricity generated by wind power projects.[9] Ten out of the 29 Indian states have now implemented quotas for a renewable energy share of up to 10% and have introduced preferential tariffs for electricity produced from renewable sources.[5] These states are Kerala, Rajasthan, Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Madhya Pradesh, West Bengal, Gujarat, and Haryana. However, the four states—Maharashtra, Gujarat, Tamil Nadu, and Andhra Pradesh which account for 60% of the total potential—have 90% of the total installed wind generation capacity.[43] Though there are a set of incentives and guidelines for promotion of wind power at the federal government level, [9] the individual states follow their own policies. In addition, several states have implemented fiscal and financial incentives for renewable energy generation, including energy buy-back (i.e., a guarantee from an electricity company that they will buy the renewable power produced) preferential grid connection and transportation charges and electricity tax exemptions. Table 3 presents the summary of key state government incentives for wind energy projects in India. At the federal level, although there is no national policy for renewable energy, there are a number of measures that help drive wind energy development, including fiscal incentives such as income tax exemption for 10 yr, 80% accelerated depreciation, sales tax exemption, and excise duty exemption.[5, 9]

Some states with renewable portfolio standards or other policies to promote wind generation have introduced FITs for wind generation which is higher than that for conventional electricity. In Karnataka, for instance, the tariff for wind generation is about Rs/kW h 3.50 (5.5 Euro cent) compared to only Rs/kW h 1.50 (2 Euro cent) for coal generated power. In June 2008, the MNRE announced a national generation based incentive scheme for grid-connected wind power projects under 49 MW, providing an incentive of Rs/kW h 0.5 (0.7 Euro cent) in addition to the existing state incentives. Investors, which because of their small size or lack of tax liability cannot draw any benefit from accelerated depreciation under the Income Tax Act, can opt for this alternative incentive instead. Table 4 presents the state wise wind power installed capacity in India. Tamil Nadu is at the first place in wind power generation among Indian states, followed by Maharashtra, Gujarat, Karnataka, Rajasthan, etc. The total installed capacity in India was 9587 MW until November 2008, of which Tamil Nadu with installed capacity of 4133 MW accounted for more than 43% of wind power generation in India. In 2008, the National Action Plan on Climate Change (NAPCC) released by the Indian government included a proposal for a national renewable energy trading scheme, which would be based on National Renewable Portfolio Standard.[46] In this scheme, states would be encouraged to promote the production of renewable power to exceed the national standard. They would then receive certificates for this surplus power, which would be tradable with other states which fail to meet their renewable standard obligations. Since only grid-connected electricity would be eligible for this scheme, this old particularly benefit the wind industry. It is expected that this proposal will come into force in 2009 or 2010.

Wind Energy Potential in India

Wind in India is influenced by the strong southwest summer monsoon, which starts in May–June, when cool, humid air moves toward the land and the weaker northeast winter monsoon, which starts in October, when cool, dry air moves toward the ocean. During the period from March to August, the wind is uniformly strong over the whole Indian Peninsula, except the eastern peninsular coast. Wind speeds during the period from November to March are relatively weak, though higher winds are available during a part of the period on the Tamil Nadu coastline. In order to tap the potential of wind energy sources, there is a need to assess the availability of the resources spatially. A wind resource assessment program was taken up in India in 1985.[47] Around 1150 wind monitoring/mapping stations were set up in 25 states and Union Territories (UTs) for this purpose. Over 200 stations in 13 states and UTs with annual mean wind power density greater than W/m 200^2 at a height of 50 m above the ground level show wind speeds suitable for wind power generation.[9] Table 5 presents the state wise distribution of approved wind farmable sites as of January 31, 2009. On a regional basis, more detailed assessments have been done. Daoo et al.[50] presented the results of the analysis of wind speed data for 1995 at Trombay Hill top station (about 300 m above the mean sea level) along with the wind energy potential of the site in which seasonal and diurnal trends in the monthly average hourly totals of wind energy were established. The study reveals that a low and medium power windmill can be operated at the site with annual availability factors of about 76% and 57%, respectively. Ramachandra and Shruthi[51] employed a geographical information system to map the wind energy resources of Karnataka state and analyzed their variability considering spatial and seasonal aspects. It is estimated that a penetration (supply fraction) of wind power on a large grid can be as much as 15%–20% without affecting grid stability due to requirement of reactive power.[52] Recently, the potential of wind power generation for grid interaction has been estimated by the Centre for Wind Energy Technology (CWET) at about MW 48 500 (nearly five times than the installed capacity) taking sites having wind power density greater than 250/W m^2 at 50 m hub height with 3% land availability in potential areas for setting up wind farms at 12 ha/MW.[49] The previous estimates for the wind energy potential as mentioned in MNRE annual reports was 45 GW assuming 1% of land availability for power generation in the potential areas.[9] Considering a maximum of 20% penetration of existing capacities of the grids through wind power in the potential states, technical potential for grid-interactive wind power is presently limited to only 13 GW, [9] which is expected to increase with augmentation of grid capacity in potential states. Table 6 presents a state wise breakup of the wind power potential in Indian states. The Indian Wind Energy Association claims that the potential from wind energy in India is to be as high as 65 GW; however, given that the average capacity factor realized by India's wind farms is only about 17%,[10] the total contribution to energy from these plants would be relatively small.

Prospects of Wind Energy in India

Diffusion is defined as the process by which an innovation is adopted and gains acceptance by members of a certain community.[54] A number of factors interact to influence the diffusion of an innovation. The four major factors that influence the diffusion process are the innovation itself, how information about the innovation is communicated, time, and the nature of the social system into which the innovation is being introduced.[55] The innovation decision process theory states that diffusion is a process that occurs over time and can be seen as having five distinct stages.[55] The stages in the process are knowledge, persuasion, decision, implementation, and confirmation. According to this theory, potential adopters of an innovation must learn about the innovation, be persuaded as to the merits of the innovation, decide to adopt, implement the innovation, and confirm (reaffirm or reject) the decision to adopt the innovation. It is observed that the diffusion of a technology measured in terms of the cumulative number of adopters usually conforms to an exponential curve as long as the new technologies manage to become competitive with incumbent technologies.[56] The exponential growth pattern may be of three types—(I) simple exponential, (ii) modified exponential, and (iii) S curve. Out of these three growth patterns, the simple exponential pattern is not applicable for the dissemination of wind power projects, as it would imply infinite growth.[57] The modified exponential pattern (with a finite upper limit) is more reasonable but such a curve may not match the growth pattern in the initial stage of diffusion.[58] The uptake of technology in the market is particularly slow during the initial phase and requires the presence of marketplace innovators who are willing to experiment with new ideas. As the diffusion proceeds, the rate of adoption increases, with a transition point corresponding to what is termed as "takeoff," as early adopters start building on the experiences of the innovators.[55]

Empirical studies have shown that in a variety of situations the growth of a technology over time may conform to an S-shaped curve, which is a combination of simple and modified exponential curves.[27, 28] The S-shaped curves are characterized by a slow initial growth, followed by rapid growth after a certain take-off point, and then again a slow growth toward a finite upper limit to the dissemination.[57, 58] Therefore, in this study, a logistic model is used to estimate the theoretical cumulative capacity of wind power projects at different time periods. The logistic model (or logistic growth curve) is continuous in time. The growth curve of a technology growing according to logistic growth is typically characterized by three phases: an initial *establishment* phase in which growth is slow, a rapid *expansion* phase in which the technology grows relatively quickly, and a long *entrenchment* stage in which the technology is close to its limiting potential due to interspecies competition.

Are estimated by using the past data of wind power capacity extracted from the annual reports of MNRE. The upper limit P_{max} is calculated from the gross wind power potential presented in Table 6. Figure 6 represents the projected time variation in the cumulative capacity of wind power projects using the logistic model considered in the study. The projected capacity addition every year is also depicted in the same figure. Our results indicate that in India, the dissemination of wind power projects is not likely to reach its maximum estimated potential in another 20 years.

Figures 7, 8 present the projected installation capacity and the capacity addition in MW per year of the six states considered in this study. It is observed that the states of Karnataka and Rajasthan have a growth pattern in the same pace and appears to reach the inflection point in 2012. After this year the growth rate declines and reaches toward the saturation level. The results indicate that the diffusion of wind energy technology may reach 99% of the maximum utilization potential of 11 531 and 4858 MW by 2020. Table 8 presents the projected values of the cumulative capacities of wind power projects over the given time period in high potential states of India considered in this study. As mentioned in Sec. 5, wind energy in Tamil Nadu has already gained importance showing a good progress in the development. The inflection point for Tamil Nadu and Maharashtra is observed in 2007 and 2009, respectively, and may reach 99% of their maximum utilization potential by 2020. It may be noted that the states of Gujarat and Andhra Pradesh have a growth pattern in the same pace and appears to reach the inflection point in 2018 and 2019, respectively. After 2003, Gujarat is slowly picking up and considerable growth rate has been observed in the wind sector.[59] Gujarat may achieve $\geq$ 94% of its potential only by 2030. Andhra Pradesh shows a gradual and steady increase in harnessing its technical wind potential and it can achieve $\geq$ 98% of its potential only by 2030

Conclusion

In India, renewable energy sources are in abundance, which can contribute significantly to its growing energy demand. In this study, wind energy growth pattern of India is reviewed since its inception in 1980s. Wind energy technology is currently making a significant contribution to the electric power generation in India; however, recently China has overtaken India to the fourth position in the world in terms of installed wind power capacity. Therefore, if India has to match the growth rate in the global wind energy sector, outstanding regulatory and policy issues need to be urgently addressed. Wind power penetration is not constrained by technical problems with wind power technology, but by regulatory, institutional, and market barriers. It is observed that the presence of such non-economic barriers have a significant negative impact on the effectiveness of policies to develop wind power, irrespective of the type of incentive scheme. A brief assessment of global status of wind energy and support policies presented in this study indicates that a minimum level of remuneration appears necessary to encourage wind power deployment.

At present, there are several financial and fiscal incentives provided to the wind power producers at the federal and state government level; however, unstable policies of the state governments (as observed in the past) and poor institutional framework increase the risk associated in the wind sector. A preliminary assessment of the status of wind power development in potential states of India indicates that there should be a stable and uniform national policy to make wind power projects financially attractive across the country. CWET has recently updated its estimates for wind energy potential in India as 48.5 GW (as compared to the 45 GW before); however, the Indian Wind Turbine Manufacturers Association (IWTMA) estimates indicate that the potential for wind energy development in India is around 65–70 GW. Therefore, for the large-scale penetration of wind energy in India it is critically important to assess realistic potential estimates and identify niche areas to exploit the wind energy resource.

It is observed that in India, even with highly favorable assumptions, the dissemination of wind energy for power generation is not likely to reach its maximum utilization potential in another 20 years. The growth trends of wind power development in the six Indian states indicate that more than 90% of wind energy potential in India can be exploited by 2030. Apart from the above, installation of high-powered wind turbines in the place of old, lower capacity machines, intercropping of small windmills among bigger machines, development of offshore wind farms and development of hybrid turbines are some of the important needs toward the rapid growth of wind industry in India.

References

1. *Energy Security and Sustainable Development in Asia and the Pacific*, (2008) UNESCAP, Bangkok |
2. I. Dincer, Renewable Sustainable Energy Rev. **4**, 157 (2000
3. N. H. Afgan, D. Al Gobaisi, M. G. Carvalho, and M. Cumo, (1998) Renewable Sustainable Energy Rev. **2**, 235.
4. REN21, Renewable 2007 Global Status Report, Paris: REN21 Secretariat and Washington, DC, World watch Institute, 2008 (see http://www.ren21.net/pdf/RE2007_Global_Status_Report.pdf). | GWEC, 2008. |
5. M. Yang, Energy Policy (2007) **35**, 6546.
6. P. Purohit and A. Michaelowa, Carbon Balance Manage. (2007) **2**, 1. |
7. Ministry of Power, Government of India, New Delhi (2009) (See www.powermin.nic.in accessed on March 15, 2009). |
8. MNRE, 2008. |
9. GOI, Integrated Energy Policy Report of the Expert Committee, Planning Commission, 2006 Government of India GOI, New Delhi,
10. Ministry of New and Renewable Energy, Government of India, (2009) New Delhi (See http://www.mnes.nic.in/ accessed on March 12, 2009). |
11. Ministry of New and Renewable Energy, Government of India, 2009 New Delhi (See www.mnre.gov.in accessed on March 20, 2009). |
12. WWEA, 2009. |
13. IEA, Deploying Renewable: Principles for Effective Policies, International Energy Agency (IEA), Paris, 2008.
14. World Wind Energy Association, Bonn (See www.wwindea.org accessed on April 16, 2009).

15. L. Bird, M. Bolinger, T. Gagliano, R. Wiser, M. Brown, and B. Parsons, (2005) Energy Policy **33**, 1397.
16. F. C. Menz and S. Vachon, (2006) Energy Policy **34**, 1786.
17. J. F. Manwell, C. N. Elkinton, A. L. Rogers, and J. G. McGowan, (2007) Renewable Sustainable Energy Rev. **11**, 210.
18. M. Bolinger and R. Wiser, (2009) Energy Policy **37**, 1061 (ScienceDirect).
19. J. I. Lewis and R. H. Wiser, (2007) Energy Policy **35**, 1844 .
20. ecoACTION, Government of Canada(2009) (See http://www.ecoaction.gc.ca accessed on April 17, 2009).
21. M. Ringel, L. Nielsen and T. Jeppesen, (2006). Renewable Energy 31, 1
22. A. Ford, K. Vogstad, and H. Flynn, Energy Policy **35**, 91 (2007).
23. K. Verhaegen, L. Meeus, and R. Belmans, Renewable Sustainable Energy Rev. **13**, 208 (2009). |
24. X. Changing and S. Zhanfeng, "Wind energy in China: Current scenario and future perspectives," Renewable Sustainable Energy Rev. (to be published).
25. P. Purohit and A. Michaelowa, (2007)Energy Policy **35**, 4779. P. Purohit, J. (2009)Cleaner Prod. **17**, 181. M. R. Patel, 2009 *Wind and Solar Power Systems* (CRC, New York, 1999). |
26. T. Burton, D. Sharpe, N. Jenkins, and E. Bossanyi,2001 *Wind Energy Handbook* (Wiley, New York, 2001). |
27. P. Purohit and T. C. Kandpal, (2004) Int. J. Global Energy Issues **21**, 263). Indo Asian News Service (IANS), Wind Power Industry Seeks Stable Policy, Better Forecasting, 2008. |

Table IV. State wise wind power installed capacity in India.

State	**Total capacity (MW) Up to March 2006**	**Up to March 2007**	**Addition during 2006–2007 (MW)**	**Addition during 2007–2008 (MW)**	**Addition during 2008–20094n1 (MW)**	**Total capacity (MW)**
T4n1 Until November 30, 2008.						
Andhra Pradesh	121.0	121.34	0.8	0.0	0.0	122.45
Gujarat	338.1	674.36	328.9	580.13	179.80	1432.71
Karnataka	584.6	845.02	264.7	187.0	173.10	1184.45
Kerala	2.0	2.35	0.0	8.7	12.50	23.00
Madhya Pradesh	40.3	56.59	17.4	69.25	0.00	187.69
Maharashtra	1001.3	1480.3	483.6	276.075	82.00	1837.85
Rajasthan	358.1	471.99	111.7	70.45	132.20	670.97
Tamil Nadu	2892.5	3459.4	565	391.90	250.30	4132.72
West Bengal	1.1	1.75	0.5	0.0	0.00	1.10
Others	1.6	1.6	0.0	0.0	0.00	3.20

Total (All India)	5340.6	7114.6	1773	1583.505	829.90	9587.14

Table V. State wise distribution of approved wind farmable sites (as of January 31, 2009). (See Ref. 48.)

State/union territory	**Stations with annual average WPD>W/m 200^2 at 50 m height**
Andaman and Nicobar	1
Andhra Pradesh	32
Gujarat	38
Karnataka	26
Kerala	17
Lakshadweep	8
Madhya Pradesh	7
Maharashtra	31
Orissa	6
Rajasthan	7
Tamil Nadu	41
Uttarakhand	1
West Bengal	1
Total	216

Table VI. Statewise wind power potential in India. (See Ref. 53.)

State	**Gross potential (MW)**
Andhra Pradesh	8968
Gujarat	10 645
Karnataka	11 531
Kerala	1171
Madhya Pradesh	1019
Maharashtra	4584
Orissa	255
Rajasthan	4858
Tamil Nadu	5530
Total (All India)	48 561

Table VII. Values of regression coefficients for logistic growth model.

		Value of coefficients		
S. No.	**State**	***a***	***b***	R^2
1	Andhra Pradesh	−8.6557	0.3175	0.6585
2	Gujarat	−5.7721	0.2162	0.8386
3	Karnataka	−10.9900	0.5364	0.9764
4	Maharashtra	−9.6073	0.5619	0.9603
5	Rajasthan	−14.5870	0.7267	0.9179
6	Tamil Nadu	−4.8792	0.3282	0.8867
	All India	−6.5165	0.2929	0.9152

Table VIII. Projected values of the cumulative capacities of wind power projects over the given time period in high potential states of India.

	Projected value of installation capacity (MW)					
Year	**Andhra Pradesh**	**Gujarat**	**Karnataka**	**Maharashtra**	**Rajasthan**	**Tamil Nadu**
2010	607	1695	3579	3412	1527	4397
2015	2349	3813	10 009	4491	4593	5267
2020	5691	6620	11 412	4578	4851	5477
2025	8023	8825	11 523	4583	4856	5520