# Challenges and prospects for wind energy to attain 20% grid penetration by 2020 in India†

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*With wind energy being the most realistic large-scale renewable energy source in the near future, we examine the target for wind energy penetration in India for 2020. Achieving the target set by the Indian Wind Power Association of 20% wind power grid penetration by 2020 will act as a lighthouse, but will also depend on a number of factors such as suitable policies and regulation, appropriate wind turbine technology, availability of sites onshore and offshore, reliable and accurate wind resource assessment, grid capacity, power system management and market design in order to accommodate a large-scale integration of wind power. In the article, we discuss the trends in the development of wind energy and the factors which we consider decisive for the development of wind power in India. Experiences and policies from Europe and Denmark, where wind power already today contributes 20% to the total electricity production, are discussed in relation to India and the Indian 20% goal. Wind assessment studies that have been carried out presently and those required in the near future are elaborated. Numerical wind atlas simulations based on existing wind resource data in India are delineated. The Government policies and regulations that influence and sustain wind power are also outlined and discussed.*

**Keywords:** Efficient wind, farms, grid penetration, multi megawatt wind, policies and regulations, turbines, wind assessment.

As the most mature and presently the most cost-effective renewable energy source, wind energy is generally recognized as a key solution in the fight against climate change and the desire to free society from its dependence on fossil fuels. This is indeed the case in India, which in 2008 reached 9655 MW of installed wind power out of 147 GW cumulative installed capacity (6.5%), ranking fifth in the then global installed wind energy capacity of 121.19 GW (ref. 1). As of 2009, the installed wind turbine capacity in India grew to about 10.9 GW (ref. 2). The current potential for wind energy in India, assuming 1% land utilization, is at least 48 GW according to recent studies carried out[2]. Therefore in India, there is significant untapped potential for wind power.

Penetration can be measured in terms of installed capacity or in terms of the required energy. In 2010, the capacity penetration in India (vis-à-vis the peak load) was 8.5%, and the energy-wise penetration was less than 1% (refs 3 and 4). Assuming a growth rate of 9% in the overall generation capacity per year[3] and 10% growth in the annual electricity production, a wind power penetration target of 20% to the grid by 2020 corresponds to about 56 GW (capacity-wise) or 330,000 GWh (energy-wise) respectively. Improving the capacity factor to 20% in India, the energy penetration of 20% by 2020 corresponds to wind turbine installed capacity of 188 GW which may be feasible, provided rapid, well-planned measures are taken. As a perspective, the US markets are targeting to achieve this goal by 2030, wherein the electricity demand is predicted to grow by 39% over the 2005 levels[5]. Twenty per cent wind power in 2030 in the US means about 300 GW of power generation. Similar targets have been set in Europe[6], with 230 GW installed wind power by 2020 contributing up to 20% of the EU electricity and 400 GW by 2030 contributing as much as 33%.

Whereas the value of wind energy is associated with the power produced and hence with energy penetration rather than capacity penetration, moving from investment to production support is an important step that has already been initiated in India[7], putting emphasis on accurate siting, reliable technology, operation and maintenance, and adequate grid capacity. From Europe and the US, it appears that the most efficient and cost-effective wind installations use turbines in MW-size, situated in large wind farms. In India, most of this wind assessment has used meteorological masts up to 50 m in height, which is usually applicable only to the sub MW range turbines[2]. This means that the wind assessment shall be made for greater heights, 80–100 m, than for small machines, and the grid connection takes place to the transmission system

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and not distributed on the low to medium voltage level as was the case in the early days in Denmark, for example.

Studies done at Risoe[8,9] on the wind farm controls using wind speed fluctuations measured at various turbines on the site demonstrate usage of controls to support local grid requirements. Micro-grids and re-structured power systems are also beneficial, providing better control and distribution to regional markets. Use of micro-grids would again require an understanding of the right wind turbine system and the inertia requirements on the grid.

Conclusions from the European Trade wind study[10] on the requirements for large-scale integration of wind, including transmission capacity, power exchange and market design may also provide input to the Indian development in the grid integration issue. Whereas there are challenges ahead as illustrated by the reference scenario for the wind energy development[11], which predicts an almost constant wind energy penetration, with suitable and improved policies, technology, micrositing, grids and turbine technology, a 20% goal can be made feasible with realistic industrial growth rates, as shown in the advanced scenario.

## Current state of wind energy in India

The International Energy Agency predicts that by 2030, more than 28% of the world's energy consumption will be in India and China. This figure tallies with the overall population share of India and China. As depicted in Figure 1, the energy consumption by India and China exceeds that of the US and therefore, it is essential that a significant part of that energy comes from renewable sources.

There has been rapid growth in the installation of wind power in India, especially towards the southern and western states. Almost all the big global manufacturers of wind turbines are present in India with regard to design installation and production of their turbines. This has contributed to India being the fifth largest installation base for wind turbines in the world as of 2009 (ref. 2). Figure 2 describes the growth in wind energy installations in India in the past 15 years, which depicts the current installed capacity to be more than 10,000 MW. Also, most of the largest manufacturers of wind turbines in the world have their offices in India, which demonstrates the potential of the wind energy market in India. The presence of major wind turbine manufacturers also enables the latest wind turbine technology tailored to India's needs. As shown in Figure 2, there has been a rapid acceleration in the wind energy installation since 2003. However, mere installation of wind energy does not guarantee wind power penetration to the grid.

This has been the case in India, where the total power penetration to the grid from the wind energy installations has been little, as seen from Figure 3, wherein it is shown that the actual national electricity generated from wind energy is less than 1%. Whereas from installed capacity in Figure 2, if all that energy was converted into electricity with a capacity factor of 20%, it would amount to about 18,000 GWh, which is more than 3% of the present requirement for electricity in India. The key factors due to which the installed capacity is not being converted to production capacity is elucidated in the next sections, being mainly due to lack of comprehensive grid codes, less than required wind assessment at higher elevations and lack of coherent nationwide energy policy in the previous years.

Therefore, to move to 20% wind power by 2020, the main challenge lies in not just the installed capacity, but also in converting the capacity to consumed electricity. Applicable technologies and policies for wind energy should be directed to this goal in India, of significantly increasing energy-wise penetration.

In another related aspect, Figure 4 describes the mean wind assessment map of India as published by the Centre for Wind Energy Technology (CWET), Chennai[2]. As can be seen, very large areas of the country are shown in white, which means that they possess very low wind power densities at 50 m height, with some of the areas still to be assessed completely. Even the shaded regions that are shown have relatively low mean wind speeds, most of them less than 7 m/s. Also, as noted in the map, the wind assessments were done at 50 m height, which is significantly lower than the hub height of most wind turbines being installed today.

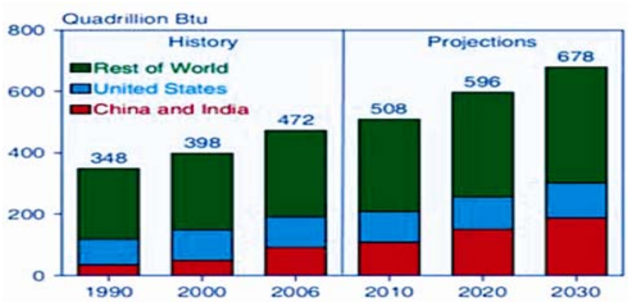


**Figure 1.** Projected global demand for energy. Sources: History: Energy Information Administration (EIA), International Energy Annual 2006 (June–December 2008), website: www.eia.doe.gov/iea. Projections: EIA, World Energy Projections Plus (2009).

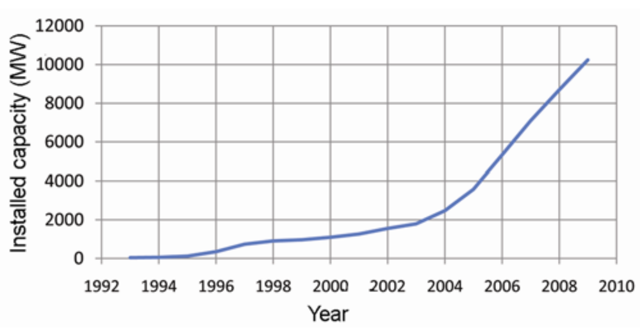


**Figure 2.** Installed wind energy capacity in India[2].

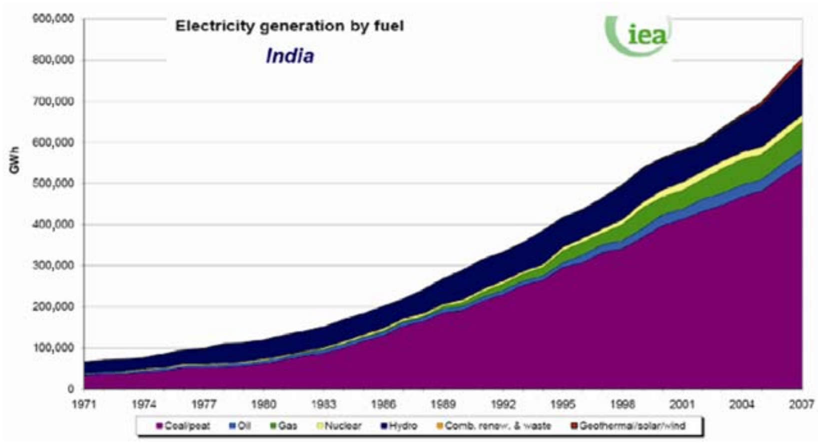


**Figure 3.** Breakdown of electricity generation fuel sources in India (Source: Statistics on the web; http://www.iea.org/statist/index.htm).

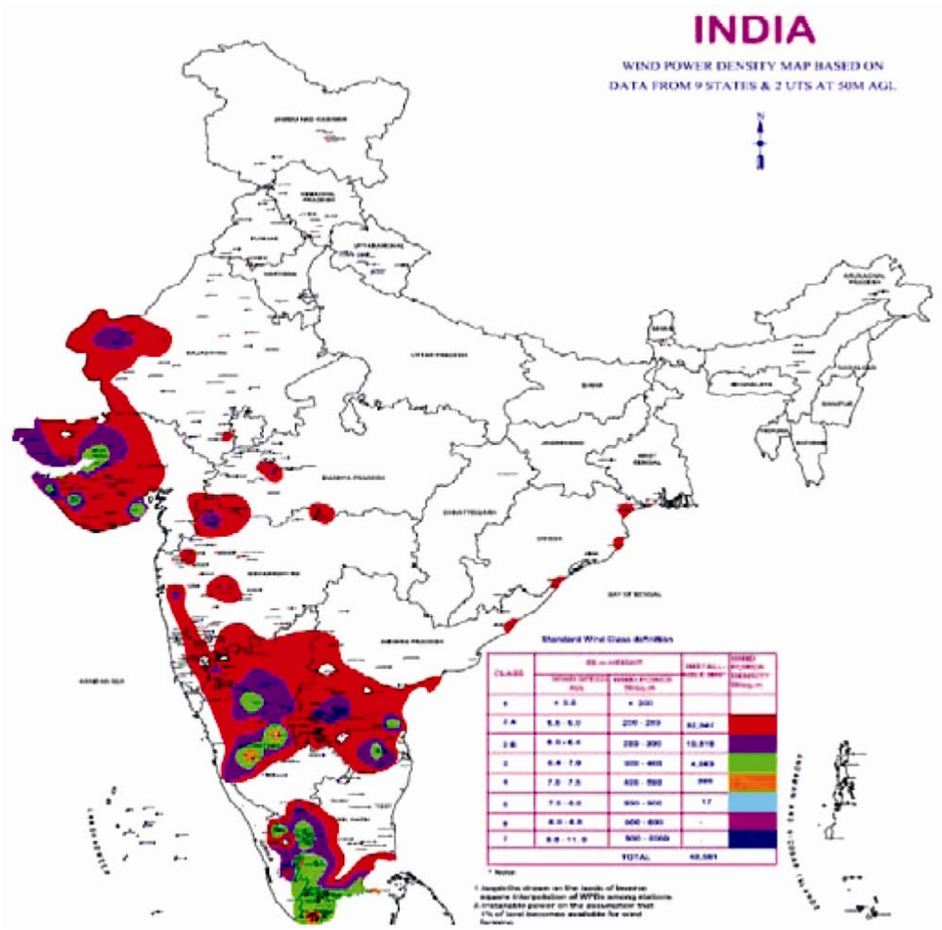


**Figure 4.** Wind assessment map of India, 2009 (from CWET[2]).

As is known, the lowest type wind class to which most wind turbines internationally are designed is International Electrochemical Commission (IEC) Class 3 or 7.5 m/s mean wind speed. For India, it appears that for most sites, the mean wind speed is even lower. This may be one of the reasons that approximately 80% of the wind turbine installations in India before 2009 was below 1 MW in rating, according to the information provided by CWET[2]. In the last few years, some of the manufacturers, such as Suzlon Energy, have installed wind turbines with ratings of 1.5 MW and above with close to 40% of the installations in 2009–2010 being above 1 MW, but this still accounts for modest numbers in comparison with the overall current installed capacity. As is known from wind energy application elsewhere, larger turbine ratings with modern designs are more cost-effective and this needs to be addressed in India so that a 20% wind energy penetration is economically feasible. Larger turbines possess higher hub heights with potentially higher mean wind speeds, generate higher power per square unit of land and involve fewer turbines for a given farm capacity, all of which facilitate reduction in cost of energy. To realize the 188 GW of installed capacity at 20% capacity factor in the next decade, as projected for a 20% wind power penetration, the economics will require all of that power installation at progressively larger megawatt turbines and with possible offshore installations. As an approximate measure of scale, a wind farm with nine turbines, each of 1 MW rating, would require at least 1 sq. km of land and thus reaching the additional 178 GW of installation by 2020 would require about 20,000 sq. km of land, which is not economical nor practical, thereby requiring simultaneous scale-up in turbine rating and some installations at offshore locations.

## Grid requirements for 20% wind energy penetration

Based on Figures 2 and 3, the most important critical factor for 20% wind energy penetration in India by 2020, seems to be the grid compatibility and stability to receive wind energy throughout the year. Reports[12] indicate that there are considerable fluctuations in the grid frequency and voltage, which make wind farm operation difficult and thereby reduce the chances for successful wind energy grid penetration. The India grid code proposal 2010 (ref. 13) details some of the requirements for wind farms, but the emphasis seems to be on wind farms limiting the active power output to meet the grid requirements. The apposite requirement also is needed in that the grid codes specify needed wind farm/wind generator control actions that facilitate active power generation.

As is well known for wind turbine operation, the stability of the grid voltage and frequency is essential for the operation of the wind turbine. The wind turbine and wind farm controls are necessary to output a compatible electric power to the grid. Thus the wind farm and the grid have mutual dependency on each other, which calls for sustainable wind farm controls and grid codes that match the requirement for high-energy penetration. Figure 5 discusses the recommended grid voltage ride-through rules for the wind turbine operation, wherein even if the grid voltage dips by a specified level within a specified time, the wind turbine will continue normal operation, thus supplying power back to the grid after the grid voltage returns to normal levels. This technology is conventionally known as low voltage ride through (LVRT)[14]. However, LVRT cannot support the turbine operation if the grid is not stable over longer durations of time in minutes. Therefore in India, technologies such as LVRT can help in maintaining wind turbine connectivity to the grid only if the long-term stability and compatibility of the grid is assured.

The fault ride-through requirements are briefly mentioned in the India electricity grid code document[13]. However, the voltage dip versus time need to be calibrated to the practical situation prevailing and also according to the IEC 61400-21 (2008) guidelines. For stable grid operations, different grid codes must be implemented which allow wind farm power output to be compatible with different grid load requirements. From an operational view, the ability to control active power is important during normal operation to avoid frequency excursions and during transient fault situations to guarantee voltage stability.

Figure 6 discusses the type of power controls that are required for the wind farm, such as implemented in the Horns Rev. 1 offshore wind farm, so as to operate in conjunction with the grid requirements and be supported by the grid codes[15].

Also in India, many rural areas do not have grid connectivity or have uncertain power supply. As seen in Figure 3, a significant portion of the non coal-based electricity produced is hydroelectric power and many a time during the summer months, this power source is drastically reduced, causing a large dependence on the thermal power plants and also resulting in unscheduled shutdown of the grid, especially affecting rural areas. Therefore, for rural electrification, different renewable power sources such as wind, solar, biogas, etc. could be interconnected using microgrids or virtual power plants. Such a concept is not unknown in India. Many households in India have battery-operated power for short power disruptions and the battery-operated network is basically the smallest example of a microgrid. Virtual power plants (VPP) are distributed systems that can supply energy to a larger rural grid and they offer great potential in many areas in Europe for renewable energy connectivity[16]. The applicability of VPP or microgrids in rural areas in India can be studied thoroughly to determine their benefits. Each VPP would incorporate real-time information systems to ensure that energy production matches demand at all times. Figure 7 depicts a type of VPP that could operate a variety of power sources. The key elements are the grid control

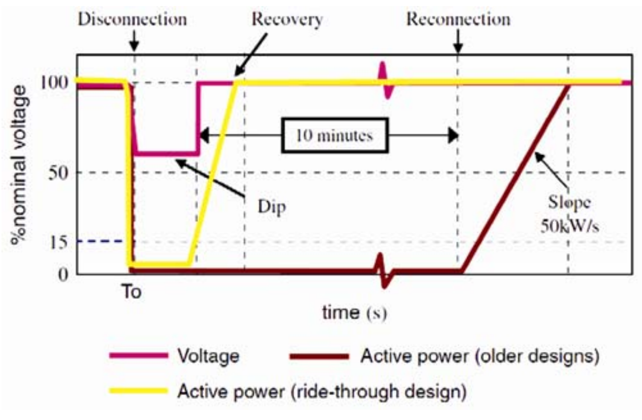


**Figure 5.** Active power ride-through for wind turbine operation during short grid intermissions[14].

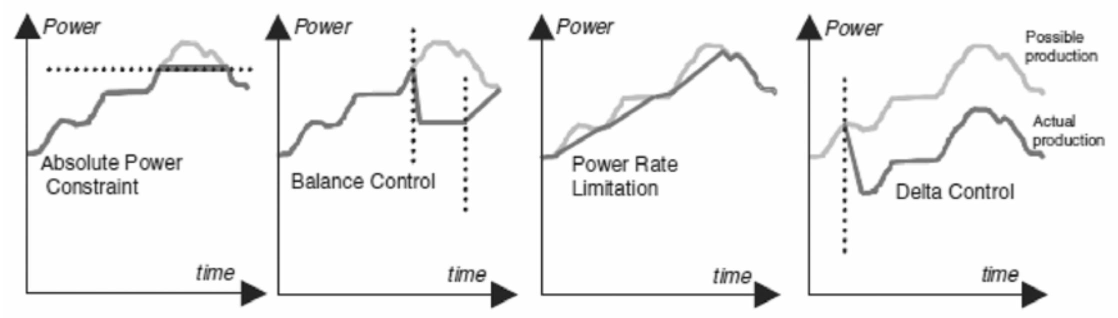


**Figure 6.** Potential wind farm control mechanisms to regulate grid loading[15].

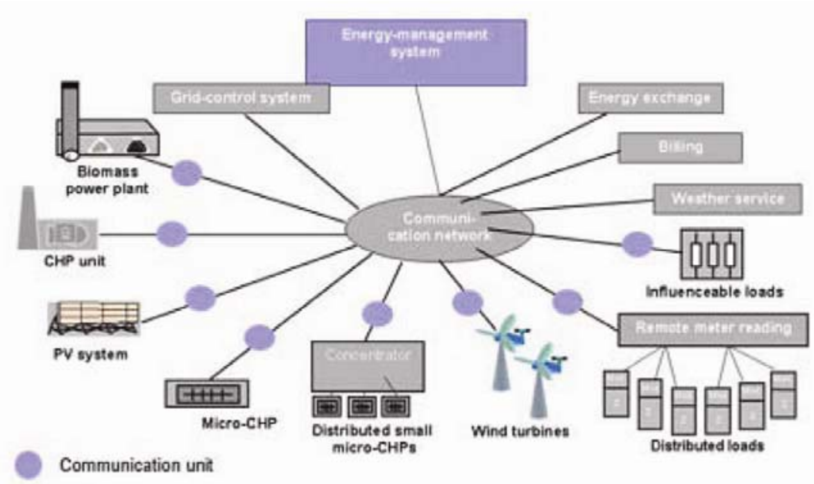


**Figure 7.** Depiction of a virtual power plant.

system and energy management unit which can forecast and use the appropriate energy source at the right loading.

## Wind assessment and micrositing

An assessment of the annual mean site conditions in terms of the wind energy capture feasible is required before any wind farm planning is economically justified. Traditionally the data used for this purpose represent measurement records of actual wind conditions, so that evaluations of the windiest areas in different terrains are known. Unfortunately, long-term historical measured wind data are not available for wind energy assessment purposes in all terrains in India, can be seen in Figure 4. This wind map of India shows large areas in very low wind speeds, which reflects the existing low wind speed conditions across many domains, as well as the fact that low meteorological mast heights of 50 m were used and that specific mast site conditions can prevent full assessment in all areas. As an alternative viable option, using appropriate mesoscale modelling methods, a numerical wind atlas of India has been generated[17]. Verification of the modelling results was carried out using wind measurements of speed and direction from CWET meteorological masts and the WAsP software[18]. Additionally, the numerical wind atlas results can be applied in WAsP for site-specific wind resource calculations at high resolution. The WAsP software accounts for orography, roughness and obstacle effects. The results of the mesoscale modelling contain approximately 200,000 geo-referenced files with generalized wind climate data over a regular grid covering all of India. The result of the numerical wind atlas is shown in Figure 8 and as can be seen, the wind resource for the entire country has been predicted.

Greater resolution in high wind speed locations where the wind power density needs to be computed can now be obtained using the WAsP models. These numerically generated wind maps can be validated against additional meteorological mast measured winds at locations that have not been used in the original verification process.

Important findings from the numerical wind atlas are the following:

- The general trend shown in the numerical wind atlas follows to some extent the earlier CWET wind atlas of India as shown in Figure 4.
- The coastal areas towards the southern regions of Kerala, Karnataka and Tamil Nadu, as well as the western regions of Gujarat show good wind energy potential.

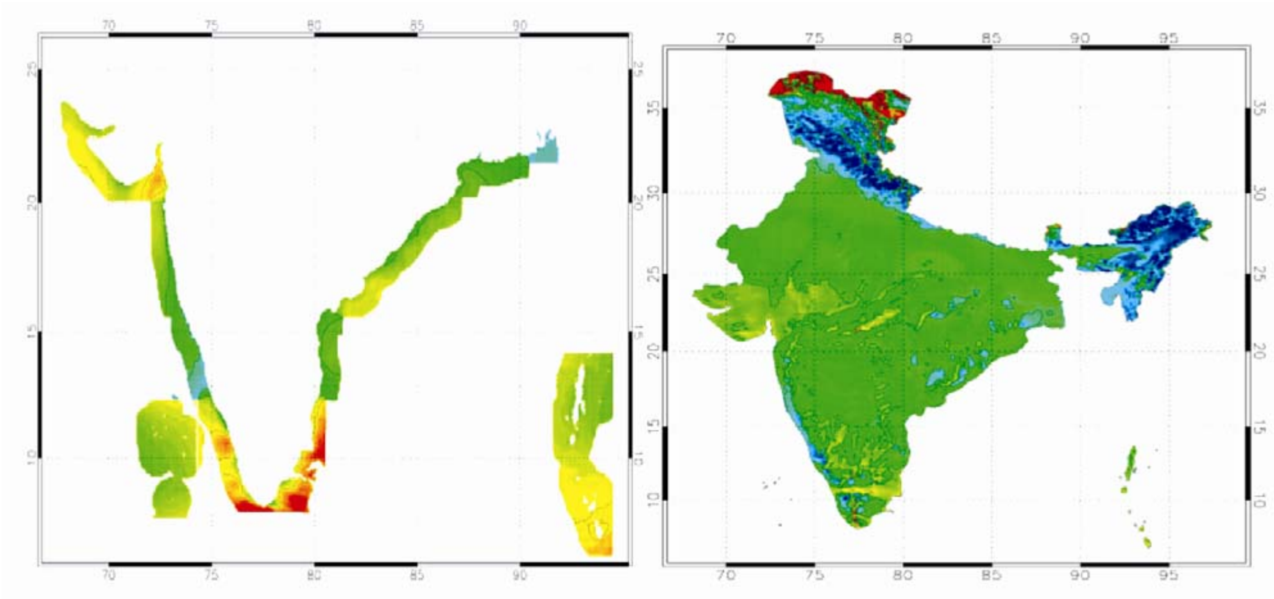

**Figure 8.** Numerically generated wind resource maps of India, including the coastline, with regions in red depicting mean wind speeds above 7 m/s, and blue and green colours depicting lower wind speed regions[17].

- There are interior regions in India such as in Madhya Pradesh which also show good wind speeds in small areas, that are not described in the measured wind atlas. This is a new and beneficial finding which should be corroborated with meteorological measurements in those sites in Central India.

The numerical wind atlas results are not comprehensive by themselves. So measurement and micrositing is required ultimately, to position one or more wind turbines on a parcel of land to maximize the overall energy output of the wind plant. However, WAsP analysis of potential wind farm sites selected based on the overall favourable wind regimes shown by the numerical atlas can benefit micrositing and site-specific optimizations for improved turbine efficiency. This will reveal site-specific loads and performance which need to be optimized to the environmental conditions. Moving forward, wind assessment of the coast of India needs to be analysed to ascertain the energy capture attainable using offshore wind farms and the distance from the coast that is required. India has a vast offshore area and no offshore wind farms to date have been installed. Particularly the coastal areas in the extreme south of the country can be analysed for offshore wind energy suitability studies and the appropriate installation capacity.

## Wind energy policies

The three most important requirements for a high degree of grid penetration are (1) a stable and compatible grid, (2) appropriate wind assessment and micrositing, (3) coherent and effective nationwide energy policy. The first two requirements have been already discussed. The third requirement of re-enforced coherent national policies that ensure sufficient expansion and penetration of wind energy is also important. Wind energy investments depend on stable policies, attractive tariffs and 'business case certainty'.

The wind energy policy in India with regards to tax credit initiatives in the past has been based on installed capacity. However, recent legislations enacted[7] describe that production based tax credit (PTC) and generation based incentives (GBI) have been implemented since 2009. This is an important decision made, which will drive towards sustainable electricity production from wind energy and not merely installations.

Figure 9 explains the required power production in 2020 based on reference data in 2008 as well as moderate and advanced expansion of wind energy, according to the Global Wind Energy Council (GWEC) report[11]. Even with highly optimistic expansion, only about 18% of the total electricity demand is forecasted to come from wind energy. Therefore, the task of developing 20% electricity penetration by 2020 through wind energy requires clear planning and rapid implementation.

The Electric Power Survey of India[3], published every few years, projects the demand for electricity for the next 10–12 years and also reflects the potential demand across different states. The wind energy policy must be coherent with this demand for energy across the various states in India, and this must also reflect on the grid power sharing between the states. The presence of a large grid across states is beneficial for wind power generation and the effective management of this grid structure is called for. This would also require harmonized grid codes that work

**SUMMARY OF GLOBAL WIND ENERGY OUTLOOK SCENARIO FOR 2020**

| Global Scenario | Cumulative wind power capacity [MW] | Electricity output [TWh] | Percentage of world electricity [Energy Efficiency] | Annual installed capacity [MW] | Annual investment [€ bn] | Jobs [million] | Annual $CO_2$ savings [m $tCO_2$] |
|---|---|---|---|---|---|---|---|
| Reference | 352,000 | 864 | 4.1% | 24,000 | 32.14 | 0.54 | 518 |
| Moderate | 709,000 | 1,740 | 8.2% | 82,000 | 89.39 | 1.30 | 1,044 |
| Advanced | 1,081,000 | 2,651 | 12.6% | 143,000 | 149.35 | 2.21 | 1,591 |

**SUMMARY OF WIND ENERGY OUTLOOK SCENARIO FOR 2020 – INDIA**

| Global Scenario | Cumulative wind power capacity [MW] | Electricity output [GWh] | Share of electricity demand | Annual installed capacity [MW] | Investment [mil Rs] | Jobs | Annual $CO_2$ savings [k $tCO_2$] |
|---|---|---|---|---|---|---|---|
| Reference | 20,332 | 40,665 | 2.6-2.8% | 610 | 30,498 | 15,317 | 40,025 |
| Moderate | 63,230 | 126,459 | 8.1-8.7% | 8,247 | 412,367 | 136,539 | 124,470 |
| Advanced | 134,828 | 269,656 | 17.3-18.6% | 9,438 | 471,899 | 177,074 | 265,415 |

**Figure 9.** Wind energy outlook for India and the world (Source: GWEC report[11]).

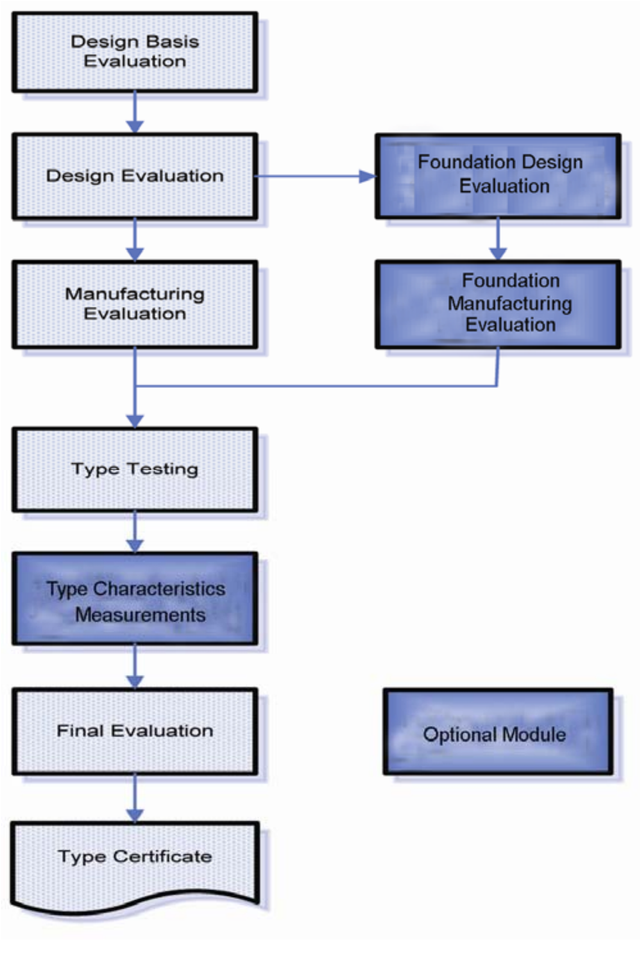


**Figure 10.** Type certification procedure according to IEC 61400-22.

synchronously with the wind farm control system. The Indian Government would need to look into these aspects of the policy that tie into the grid reliability, so that the efficiency of the wind power penetration with regards to the installed capacity increases. Further, the feasibility for offshore wind turbine installations around the vast coastline of India needs to be fully explored.

The efficiency with regard to the wind power supplied to the grid versus the potential wind power generation over one year should be greater than 20%. Currently, as mentioned in Figure 3, less than 1% of the overall electricity comes from wind power, whereas the installed capacity can produce 3–4% of the overall electricity needs. This implies poor efficiency of wind power penetration. Thus the key is improved efficiency of power penetration and not simply further installations; and where further installations are made, the appropriate turbine selections, location and specific wind farm controls must be made.

## Quality assurance

The wind farm developer and the customer for the wind power will be willing to invest in larger and more expensive wind parks only if the quality and reliability of the wind turbine installations are assured. Presently, CWET certifies wind turbines in India through Type Approval-Provisional Scheme (TAPS)[2]. Internationally, wind turbines are designed and certified to the IEC 61400 standards series, for which IEC has recently published the 61400-22 document with the certification procedure[19].

Figure 10 describes the certification process that needs to be followed, by which most wind turbine installations in Europe and USA are certified. Recognized certifying bodies exist internationally for providing wind turbine certifications such as Germanischer Lloyd (GL), Det Norske Veritas (DNV), etc. Wind farm financing and insurance often depend upon independent third-party verification of the technology and design, and hence upon the wind turbine manufacturers' ability to produce appropriate certification for their turbine designs. Site-specific project certification may also be necessary to manage risks and secure reduced interest rates, especially for offshore wind farms.

Certification according to IEC 61400-22 standards is a good step in ensuring the wind farm is designed according to internationally accepted norms, thereby enabling potential realization of the planned power for the desired period. This also paves the way for more international manufacturers and developers to invest in the wind power industry in India and the potential for more financial investors in wind farm growth.

Based on the micrositing and the site-specific assessments, the estimated cost of energy and the economical value for the wind farm developer will decide the best turbine type and capacity for the wind farm. This will reveal the return on investments that the wind farm developer will obtain over the years and the reliability of the wind power is a key requirement for this return. Thus by observing wind power penetration to the grid holistically along with the quality and economics of the wind farm, the efficiency of the wind power will improve to higher levels.

## Conclusion

The requirements for achieving 20% wind power penetration in India by 2020 have been discussed in this article. The current state of wind energy in India and the 2020 targets required if 20% penetration is to be achieved have been delineated. The most important factors upon which the power penetration depend have been outlined as (1) stable and compatible grid, (2) appropriate wind assessment and micrositing, (3) coherent and effective nation-wide energy policy and (4) installation of multi megawatt turbine base effective in low wind speed regimes.

All of the above factors need to be addressed sufficiently enough to demonstrate a viable market for high electricity penetration from wind energy. It is stressed that this requires a study of the European and American experience in wind energy and adapting that to the local needs. The requirement for grid codes that promote grid reliability and wind farm controls that work with the grid codes is essential. The consumption of wind energy through the grid and the compatible generation of wind power must be matched.

The assessment of the right regions in India for large wind turbine installations with technology to cater to lower wind speeds has also been discussed. Offshore wind energy has been untapped in India and this potential also needs to be actively explored. Finally, we have discussed the absolute necessity of coherent national policies that are production-based and enforce appropriate grid codes. Such a holistic approach to wind power generation and consumption in India, keeping in mind the quality and reliability of the wind farms and grid can enable the target of 20% wind power penetration by 2020 to be realistic and achievable.


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