

Review Report on Wind Energy

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1. Introduction

From the 1980s until now wind turbine technology has been going through a tremendous transformation and that's due to improvements in aerodynamics, structural design, and wind measurement. These innovations have found expression in an increasing turbine energy yield by 5 percent per year, which represents a huge leap in renewable energy production. The ongoing research projects are aimed at making the blades stronger, lighter, and smoother through the improvement of the designs and the use of new techniques. This never-ending journey has yielded significant results, as the energy output per turbine increased by more than 5 times in the last years, while the turbine weight and noise levels were cut by 50%, respectively.

The growth path of wind energy is lined with the opportunities that will be further explored to a great extent. Increased attention given to wind monitoring, careful site selection, and improved maintenance are the vital components of wind power generation rise. Furthermore, the use of bigger and taller turbines, enhanced through aerodynamics and construction, has the chance to significantly boost energy production. The most important role of governmental policies is to give the right boost that enables wind energy to be fully realized.

The position of wind power in the global energy system as a leading role is beyond doubt, demonstrated by its technological maturity, reliability, and cut in the costs compared to fossil fuels. The Greenpeace projections envision wind energy, which can supply 10% of the world electricity by 2020, while the experts see the share of the world energy market that is occupied by wind energy to be 5%. While the targets set to achieve this are realizable, they are dependent on the scale of adoption and implementation of the wind energy policies and regulations, which is one area that many countries are still slow to do.

The gains that wind and renewable energy bring in go beyond just environmental care. Sustainable energy sources that have been accepted may also be used as the key drivers of economic growth, job creation and strengthening of energy security. Additionally, they go some way to assist in alleviating the vagaries of fuel prices and play a decisive role in the reduction of the greenhouse effect, hence, being directly involved in the fight against climate change.

In the last decades, wind energy has seen a steep rise and has become the most valuable new source of energy, especially in Europe and North America. This meteoric ascent signifies a global movement toward a brighter, greener tomorrow, and in this atmosphere, wind energy is a symbol of the innovation of people used to meet sustainability and progress.

2. Earlier and Present day Technology

Earlier Technology: From Windmills to Early Wind Turbines

The usage of wind for mechanical power goes back to thousands of years ago with windmills being the first wind-powered devices to mine this energy. These windmills, which were of a vertical axis and had sails or blades, were mainly used for grinding grain, water pumping and other mechanical jobs that were fundamental for the early civilizations. The move to the early wind turbines for electricity generation was made in the 19th and the early 20th centuries with the invention of the electric generator. Such early turbine models, represented by the 1887 Scottish Wind Turbine, differed greatly from their modern counterparts in terms of the small amount of energy they produced, their inefficiency, and the limited materials they were made of, which included wood and steel.

Present-Day Technology: Modern Wind Turbines

Modern wind turbines have grown in size, power and efficiency, and they are completely different from the ones used before. The rotor diameter of the wind turbines has now reached 200 meters and the capacity is higher than 5 megawatts (MW), which means that they are able to catch a lot of wind energy and contribute a lot to the electricity generation. Sophisticated materials such as fiberglass and carbon fiber are the backbone of blade construction, which nowadays allows to create large and powerful blades that can operate even in the most unfavorable weather conditions. In addition to that, modern control systems with variable speed drives are utilized to manage the turbine operation by altering the rotor speed to the variations in the wind speed. This way, the energy harvested is maximized and the turbine performance is guaranteed to be safe and efficient.

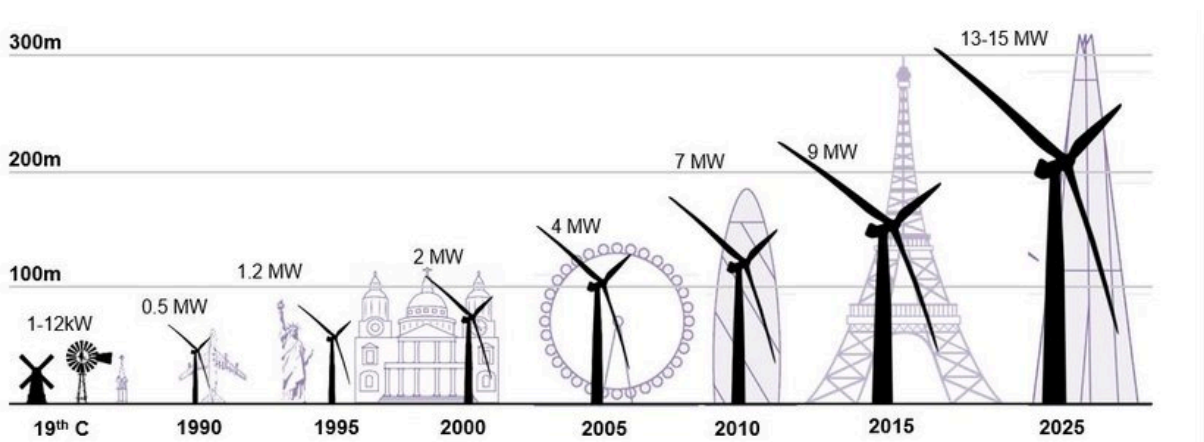


Fig. 1.: Evolution of Wind energy from Windmills to wind Turbines[6]

Key Technological Advancements

Several key technological advancements have been instrumental in propelling the progress of wind turbine technology to its current state: Several key technological advancements have been instrumental in propelling the progress of wind turbine technology to its current state:

Aerodynamics:

Blade designs that are far more advanced, with CFD simulations and wind tunnel tests as their basis, achieve the maximum amount of energy capture from wind whilst minimizing aerodynamic losses.

Generators: The development of highly efficient permanent magnet generators (PMGs) and doubly fed induction generators (DFIGs) has greatly facilitated the conversion of the mechanical energy from the rotor into electricity.

Gearboxes: Innovations in gearbox development, such as direct drive systems, have been implemented as well as other innovative lubrication technologies, which have led to improved power transmission efficiency and reliability, reduced maintenance requirements and downtime.

Control Systems: Complicated control algorithms, taking into account the data from the various sensors and weather forecasting data, adjust the turbine operation parameters, such as the blade pitch and the yaw angle, in real-time to produce the highest power output while maintaining safe and stable operation in varying wind conditions.

Monitoring Systems: Condition monitoring and predictive maintenance systems that are in real-time make use of the advancements in sensor technology, data analytics, and machine learning algorithms to detect the early signs of component degradation or performance anomalies and thus enable proactive maintenance interventions and minimize unplanned downtime.

Implications and Future Outlook

The developments in wind turbine technology not only have reduced the cost of wind energy generation but have also improved the efficiency, reliability, and scalability of wind power generation infrastructure. The consequence is that wind energy has become one of the most competitive and quickly expanding renewable energy sources worldwide, contributing significantly to the transition to a low-carbon economy and the fight against climate change. Going forward, wind power's future looks bright, with ongoing research and development efforts being focused on developing better performing turbines, trying out alternative design concepts like vertical axis wind turbines (VAWTs) and airborne wind energy systems (AWES), and utilizing the benefits of new technologies like additive manufacturing (3D printing) and advanced materials (e. g. nanomaterials). g. (e. g. , carbon nanotubes, graphene) to enable the development of new wind turbine technologies, manufacturing processes and deployment methods.

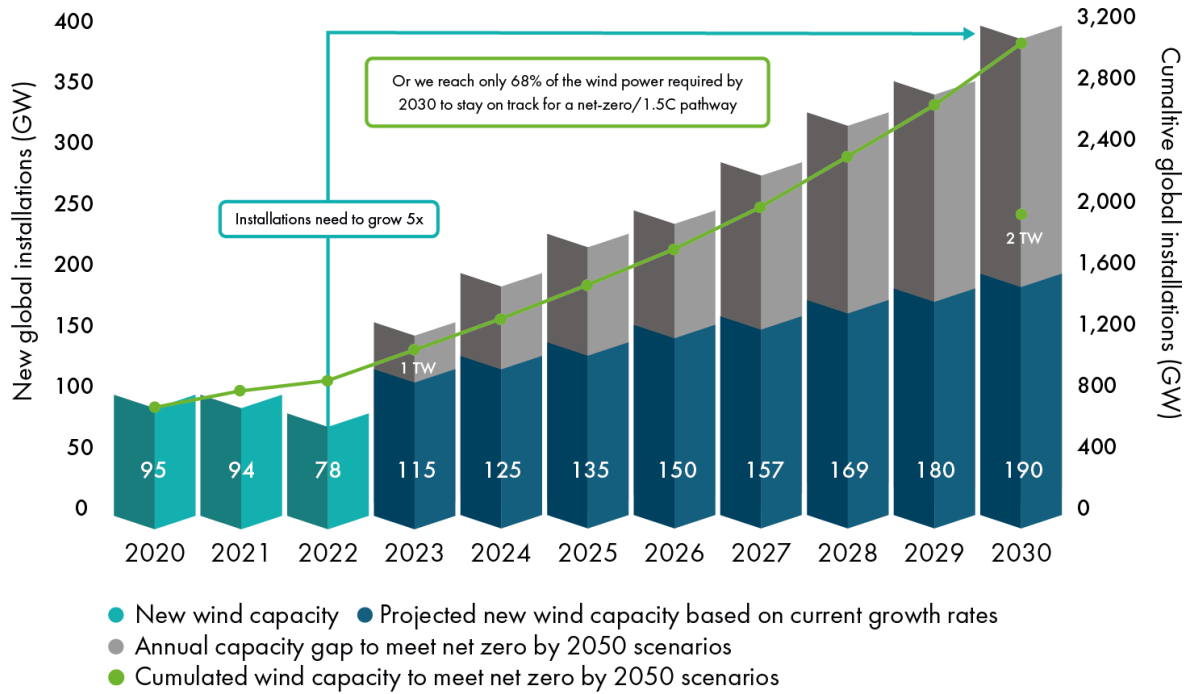


Fig. 2.: Total installed Wind Energy Capacity current and expected[5]

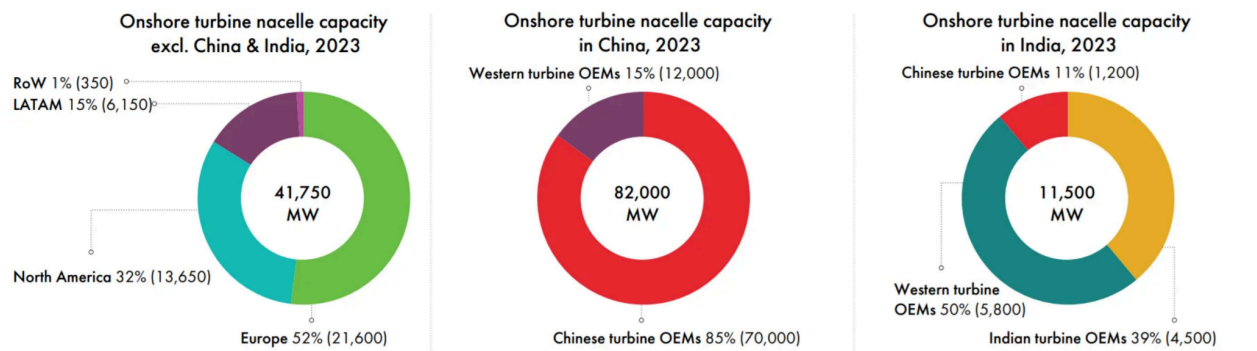


Fig. 3.: Onshore wind demand and supply benchmark, 2023-2031 (MW)[5]

3. Establishment of Wind Energy Industry: A Worldwide Scenario

The spread of wind energy as the main effective source of electricity worldwide is a result of the success stories of some countries. These milestones demonstrate the decent and growing progress of wind energy industry, which is a worldwide effort to utilize the renewable energy sources. Below is a comprehensive overview of significant establishments in the wind energy sector:

Denmark: The Prodigy of the Current Wind Energy.

Date Established: 1970s, Location: Denmark

Significance: It is in Denmark that modern wind energy was born with the Tvindkraft wind turbine being set up in the early 1970s which remains a defining moment in the industry. This initial work was a basis for further improvements in wind turbine technology, and at the same time it became a catalyst for Denmark's development in the sphere of wind energy production and innovation on a global scale.

California: Speeding up the expansion of wind energy in the U. S.

Date Established: 1980s, Location: California, United States

Significance: The Altamont Pass Wind Farm, started in the 1980s, brought about the country-wide adoption of wind energy in the United States. The wind farm situated in the Bay Area California represented the ability of wind energy to meet the energy needs in an eco-friendly manner. With its construction, different wind farms sprang up all over the country, which marked the beginning of the boom in the wind energy sector of the U. S.

Germany: Pioneering Wind Farms on Shore and Off Shore.

Date Established: 1990s, Location: Germany

Significance: Germany has been the pioneer in both onshore and offshore wind energy by building such wind farms as BARD Offshore 1 and Alpha Ventus in North Sea during the 1990s and early 2000s. These projects were not only the representation of the country's determination to renewable energy transformation but also the reason behind Germany's leadership in the world wind energy growth.

China: The rapid expansion and innovation are the key factors of the success of digital marketing.

Date Established: 2000s, Location: Several areas in China

Significance: The early 2000s were a time when China skyrocketed, becoming the wind energy industry leader in terms of both growth and innovation. The development of the massive wind farms of Gansu and Jiuquan Wind Power Base was a clear indication that China intended to be a world leader in renewable energy. The speedy technological developments and the government policy that were in support of the country's expansion in the wind energy sector continue to make the country a key player in the world wind energy landscape.

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