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Review Article

A detailed analysis of the utilization of wind energy globally and specifically in the nation of Türkiye

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ABSTRACT

The investigation of wind energy extraction for the production of electricity is becoming more significant in light of the pressing issues presented by climate change and population expansion. In the previous twenty years, notable advancements have been observed in the wind power industry, characterized by a considerable increase in turbine capacity and a general enhancement in trust in wind energy markets and data. Despite these developments, the acquisition and application of wind power pose distinctive obstacles, chiefly as a result of the intricacies involved in precisely simulating wind patterns and their influence on energy generation. Wind energy extraction is a complex opportunity that relies on numerous crucial elements. A crucial component in optimizing the utilization of wind power is the precise prediction of wind velocity and the total wind potential, both of which play a significant role in the strategic planning and operational productivity. Advancements in turbine structure, storage of energy, and integration with the grid contribute significantly to improving the efficacy and dependability of wind power systems. Furthermore, the utilization of hybrid forecasting methodologies, integrating various data sources and predictive frameworks, has surfaced as a prospective strategy to enhance the predictability and oversight of wind resources. Additionally, non-technological factors play a substantial role in influencing the extraction of wind energy. Regulatory standards, policies for grid integration, and the oversight of system non-synchronous penetration (SNSP) represent crucial domains necessitating consideration to guarantee the smooth integration of wind power into established energy frameworks.

Keywords: Growth of renewable energy, Wind energy farms, Adapting to wind energy

1. Introduction

Wind energy is a significant renewable energy source, following hydropower, with a history dating back centuries but gaining modern prominence during the 1970s oil crisis [1]. The fundamental principles of wind energy pertain to the transformation of wind power into rotational motion of turbines, where key factors impact the overall efficiency. Two primary categories of wind turbines exist: horizontal axis and vertical axis. Progress in this field is cantered on improving efficiency and durability under different wind conditions, covering a range of power ratings from 10kW to 1MW [2]. The wind energy sector on a worldwide scale has experienced a swift expansion during the current century, notably in the regions of Europe, Asia, and North America. However, the obstacle of attaining extensive grid parity with traditional fossil fuels persists as a significant challenge [3]. Students have the opportunity to delve into a thorough exploration of wind energy, encompassing its underlying principles and real-world uses, by consulting in-depth resources that delve into crucial topics such as thermodynamics, fluid mechanics, and a range of sustainable

International Journal of Energy Applications and Technologies, Year 2025, Vol. 11, No. 1, pp. 40-52

energy technologies [4]. Wind energy harnesses the power of wind to generate electricity. It is one of the fastest-growing sources of renewable energy globally, driven by advancements in technology, policy support, and the need to reduce greenhouse gas emissions. The primary mechanism involves wind turbines, which convert the kinetic energy of wind into electrical energy. These turbines can be installed onshore or offshore, depending on the geography and wind conditions.

2. Global Overview of Wind Energy

The Global Wind Report 2024 presents an optimistic outlook for the wind energy sector, highlighting a record-setting year in 2023 with 117 GW of new installations. This marked a substantial 50% increase from the previous year. The wind industry is experiencing accelerated growth driven by increased political ambitions, such as the COP28 agreement to triple renewable energy by 2030. Key insights from the report suggest a continued expansion, with an ambitious target set for 2030 to meet the 1.5-degree pathway by tripling the annual growth to at least 320 GW. Regionally, several countries are stepping up their efforts. The United States, China, and Europe continue to lead in terms of installed capacity. New markets, including Brazil, India, and countries in Africa and the Middle East, are rapidly emerging as significant contributors to the global wind capacity. The Global Wind Report 2023, reflecting on earlier developments, noted that 2022 was the third-best year for new capacity with 78 GW added globally, and total installed capacity reached 906 GW, up 9% from the previous year. Looking ahead, the industry forecasts significant growth, projecting an addition of 680 GW over the next five years, and aiming for a total of 1,221 GW by the end of 2030—a 13% increase from earlier projections. This optimism is fuelled by policy reforms, particularly in Europe, and enhanced commitments to renewable energy in major economies like China and the United States. For a detailed understanding and further statistics, you can explore more through the Global Wind Energy Council's reports for [2024] [5] and [2023] [6].

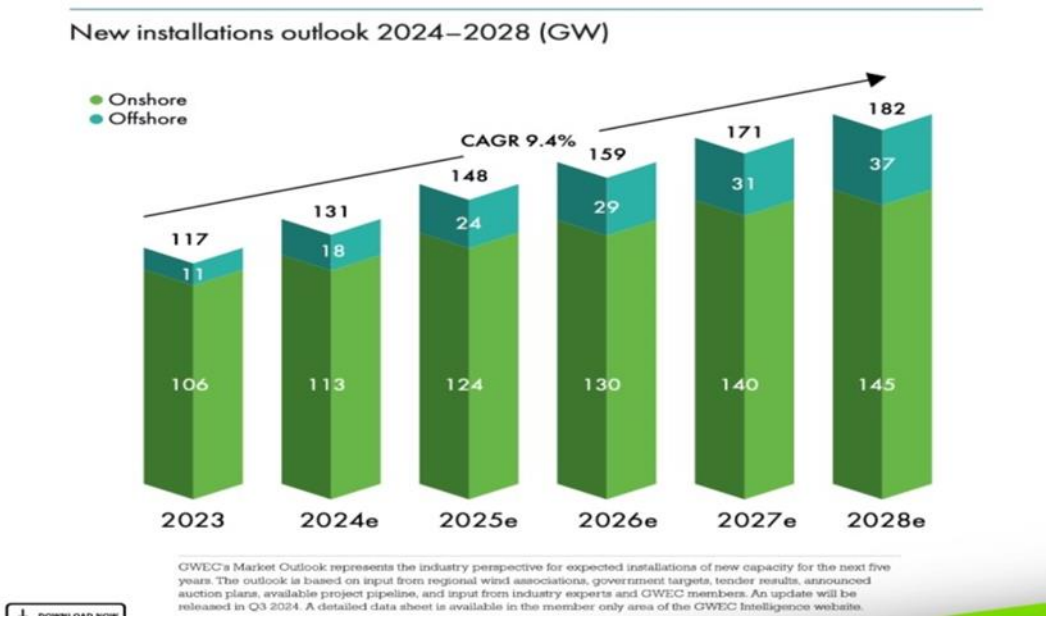

Fig. 1. The prospective capacity additions forecast for the years 2024 to 2028 in terms of gigawatts (GW) [5]

3. Advantages of Wind Power

Wind power offers numerous advantages, making it an attractive source of renewable energy.

- Wind power is a renewable energy source, meaning it won't deplete over time. As long as the wind blows, electricity can be generated.
- Wind power generation produces no greenhouse gas emissions or air pollutants, making it an environmentally friendly alternative to fossil fuels.
- By harnessing wind energy, the reliance on fossil fuels like coal, oil, and natural gas is reduced, contributing to energy security, and reducing geopolitical risks associated with energy supply.
- Wind power can create jobs in manufacturing, installation, and maintenance. It also stimulates local economies through the development of wind farms.
- Wind power systems can be scaled to meet different energy needs, from small residential turbines to large commercial wind farms.
- Once a wind turbine is installed, the operating and maintenance costs are relatively low compared to conventional power plants.

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International Journal of Energy Applications and Technologies, Year 2025, Vol. 11, No. 1, pp. 40-52

- Wind power provides a hedge against volatile fuel prices, as the "fuel" (wind) is free and abundant.
- Countries and regions with abundant wind resources can harness local energy, reducing dependence on imported fuels and enhancing energy security.
- Overall, wind power plays a crucial role in the transition to a cleaner, more sustainable energy future.

4. Renewable Energy Indicators

The renewable energy sector is witnessing substantial growth and transformation as we head into 2024, marked by significant developments and trends that are reshaping the industry worldwide and the specific impacts and advancements in countries like Türkiye. Globally, the push towards decarbonization has seen renewable energy receiving a historic level of investment, spurred by regulatory support and ambitious carbon reduction targets by states, utilities, and corporations. For instance, the U.S. has seen an increase in jurisdictions with renewable portfolio standards and clean energy standard policies, which are expected to require additional clean electricity. Moreover, corporations are increasingly committing to renewable energy procurement, with many joining initiatives like RE100, aiming for electricity entirely from renewable sources. In terms of technology, solar and storage have seen remarkable growth due to investments catalysed by policy measures such as the Inflation Reduction Act (IRA) in the U.S., highlighting the significant role of government action in driving clean energy transitions. These policy measures have enabled innovative project configurations to overcome siting and grid constraints, further accelerating the deployment of solar and storage solutions [7]. The International Energy Agency's Clean Energy Market Monitor for March 2024 underlines the rapid growth of clean energy, particularly solar PV and wind, which have seen annual additions grow by 85% and 60% respectively in 2023. This growth, however, remains concentrated in China and advanced economies, indicating a disparity in clean energy deployment across the globe. Electric car sales and hydrogen electrolyser capacity additions have also seen significant increases, reflecting a broader shift towards clean energy technologies. Nonetheless, energy efficiency improvements are lagging, highlighting areas that require further policy support [8]. For Türkiye, the renewable energy landscape is evolving, with the country experiencing unprecedented growth in renewable power capacity. The Renewable Energy Market Update Outlook for 2023 and 2024 by the IEA emphasizes a notable rise in the global capacity additions of renewable power, notably led by solar PV. This growth reflects a global trend towards renewable energy deployment, albeit with challenges such as energy affordability and the need for continued policy support to sustain growth [9]. These developments underscore the dynamic nature of the renewable energy sector, driven by policy support, technological advancements, and investment.

5. Renewable Energy by Country

The global renewable energy landscape has seen remarkable growth, with significant developments projected for the near future. In the year 2023, there was an increase of 50% in the global renewable energy capacity in comparison to the preceding year, highlighting a thriving clean energy industry. The escalation primarily stemmed from the expansion of solar photovoltaic technology, constituting 75% of the worldwide increments. Particularly noteworthy is the prominent role played by China in this trend.

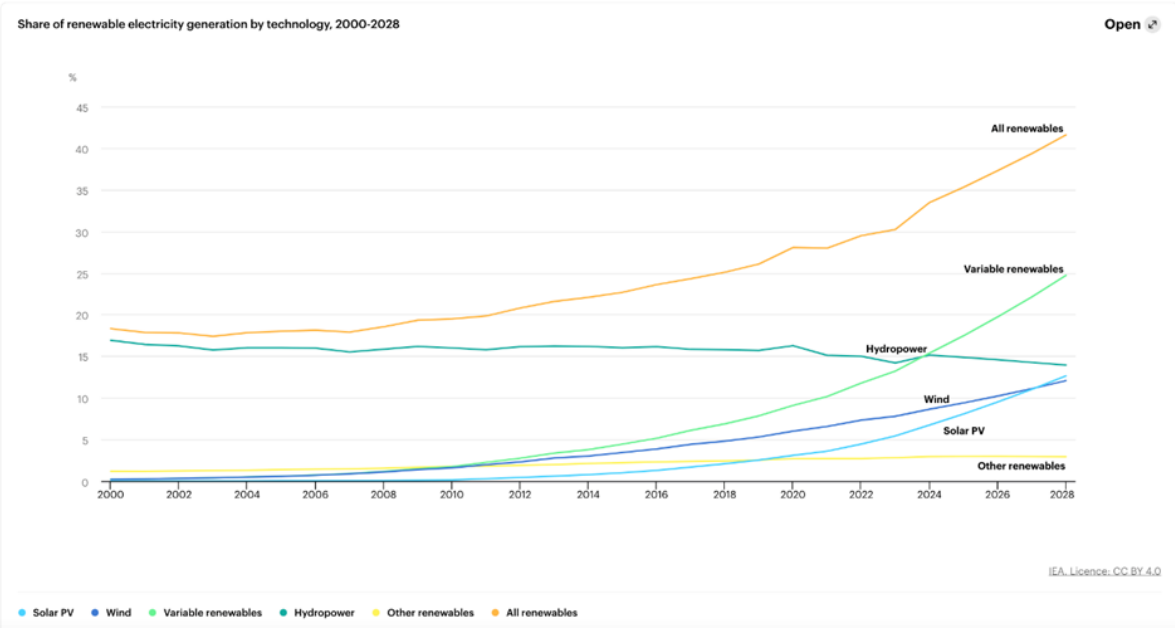

Fig.2. Renewable Electricity Capacity Additions by Technology and Segment [10]

doi: 10.31593/ijeat.1503875

International Journal of Energy Applications and Technologies, Year 2025, Vol. 11, No. 1, pp. 40-52

Expansion, in 2023, there is a plan for an extensive expansion and commissioning of solar PV equivalent to the global capacity in the previous year, coupled with a notable 66% rise in wind power installations. Furthermore, Europe, the United States, and Brazil have all experienced unprecedented growth in their renewable energy capabilities [11]. Looking ahead to 2024 and beyond, several milestones are anticipated in the renewable energy sector. By 2024, there is an expectation that wind and solar photovoltaic (PV) will produce a greater amount of electricity compared to hydropower, representing a significant shift in the sources of global energy generation. Projections indicate that by 2025, renewable energy sources are likely to exceed coal as the primary source of electricity generation, with both wind and solar PV anticipated to surpass nuclear electricity generation shortly thereafter. It is estimated that by 2028, renewable energy sources will constitute more than 42% of the total global electricity generation, with wind and solar PV together expected to double to 25%. Various nations are currently engaged in efforts to address obstacles and expedite the growth of renewable energy. For instance, the United States and the European Union have adopted measures such as the US Inflation Reduction Act and the EU's targets for decarbonization and energy security in order to promote the expansion of renewable energy. India has also made advancements in policy, while Latin America is experiencing growth due to higher retail prices and supportive governmental policies. The International Energy Agency (IEA) stresses the importance of prompt government actions to tackle challenges related to grid connection, permitting, policy formulation, and financing in order to further accelerate the development of renewable energy. These actions include streamlining permitting processes, investing in grid infrastructure, standardizing power purchase agreements, and adjusting auction mechanisms to align with changing economic conditions. These initiatives have the potential to unlock opportunities for the advancement of renewable energy. significant additional renewable capacity, making a considerable contribution to global energy sustainability [12].

Table 1. Renewable Energy Percentage by Country [13]

Country	Total Renewable Energy Generation in 2022	Renewable Energy Generation by Wind in 2022	Renewable Energy Generation by Solar in 2022	Renewable Energy Generation by Other Sources in 2022	Total Renewable Energy Generation in 2021	Renewable Energy Generation by Wind in 2021	Renewable Energy Generation by Solar in 2021	Renewable Energy Generation by Other Sources in 2021
China	1367	762.7	427.7	176.6	1148.7	655.8	327	165.9
United States	719.5	439.2	206.2	74.2	622	382	166.1	73.9
Brazil	164.5	81.6	30.1	52.8	144.8	72.3	16.8	55.7
Germany	236.5	125.3	60.8	50.4	214.4	114.6	49.3	50.4
United Kingdom	129.5	80.2	13.9	35.5	116.7	64.7	12.1	39.9
India	205.9	70	95.2	40.7	173.2	68.1	68.3	36.8
Japan	152.1	8.2	102.4	41.5	136.4	8.2	92.4	35.8
Indonesia	38	0.4	0.3	37.3	31.5	0.4	0.2	30.9
Italy	72	20.7	27.5	23.8	68.2	20.9	25	22.2
Türkiye	71.4	35.1	15.9	20.3	64	31.4	13.9	18.6

6. Overview of Türkiye's Energy Sector

Türkiye's energy sector has been undergoing significant changes, aiming to diversify its energy sources and improve energy security while addressing the challenges of rapid economic and population growth. Türkiye's energy mix has seen a considerable shift towards renewable sources over the past decade. Renewable electricity generation, including wind, solar, and geothermal, has nearly tripled, with renewables now making up a significant portion of the energy mix. This diversification is further supported by the commissioning of Türkiye's first nuclear power facility [14]. Despite the growth in renewables, fossil fuels, particularly coal, natural gas, and oil, continue to play a dominant role in Türkiye's energy landscape. Coal remains widely used in electricity generation, though there is an ongoing need to develop more sustainable energy policies [15]. Türkiye has been proactive in enhancing its energy security by diversifying import sources and routes for natural gas and oil, and by increasing domestic production capabilities. The country has also focused on energy efficiency as a fundamental strategy to manage consumption growth, with various initiatives under the National Energy Efficiency Action Plan aiming to reduce primary energy consumption [16].Investments in liquefied natural gas (LNG) facilities and the expansion of natural gas storage capacity are priorities, reflecting efforts to boost energy security. Additionally, Türkiye continues to invest in the modernization and expansion of its energy infrastructure to support the growing demand and integration of diverse energy sources [16].

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International Journal of Energy Applications and Technologies, Year 2025, Vol. 11, No. 1, pp. 40-52

Türkiye has implemented policies to support the expansion of renewable energy, such as feed-in tariffs under the Renewable Energy Support Mechanism (YEKDEM). While this program expired in June 2021, new mechanisms are being considered to continue supporting the sector [17].

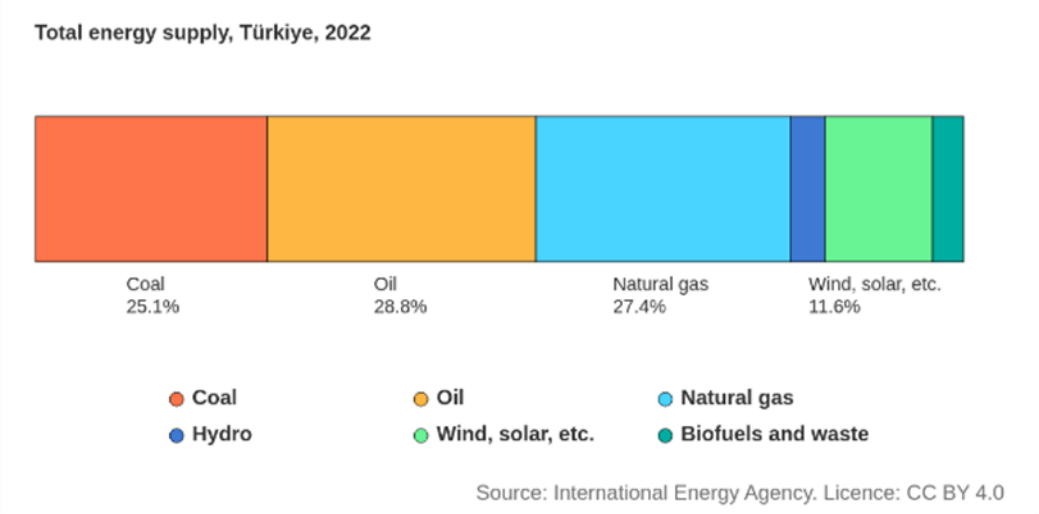

Fig. 3. The complete amount of energy provided in Türkiye for the year 2022 [14]

7. Türkiye Wind Energy Potential

The information provided highlights Türkiye's significant potential for offshore wind energy development, supported by various studies and assessments, including those by the Energy Sector Management Assistance Program (ESMAP) and Turkish researchers. These insights paint a promising picture of Türkiye's capability to harness wind energy from its surrounding seas, emphasizing the substantial untapped resources available for renewable energy generation. Let's delve into the key points and their implications for Türkiye's energy future. Overview of Türkiye's Offshore Wind Energy Potential High Wind Speeds and Extensive Potential.

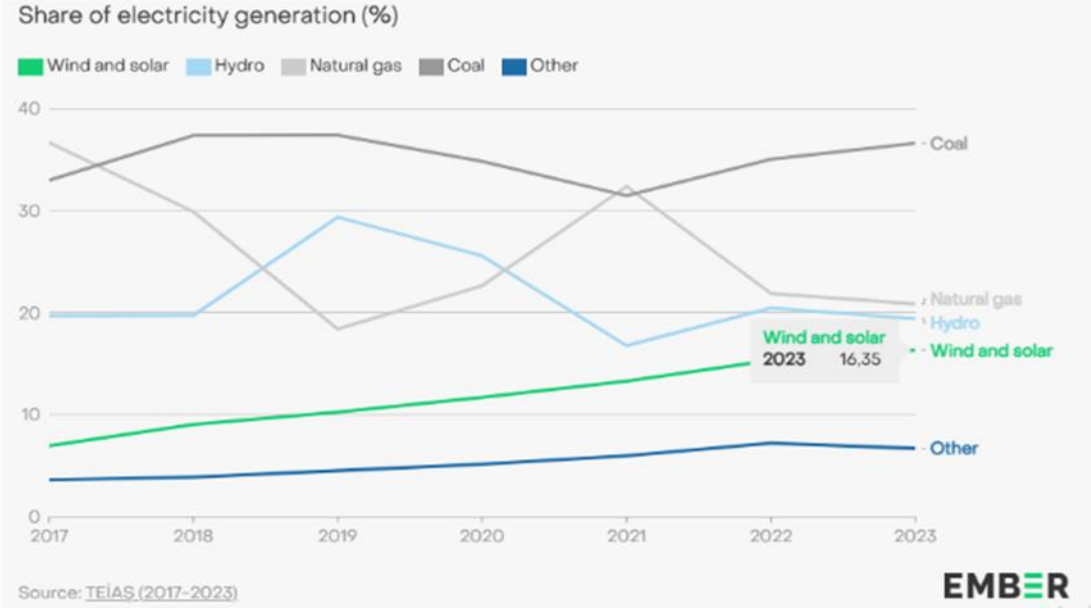

Fig. 4. The percentage of wind and solar energy combined surpasses 16% in the country of Türkiye [18]

The Aegean Sea's northwest regions and other parts of Türkiye's coastline, including the Marmara Sea and the Black Sea, exhibit wind speeds conducive to offshore wind energy production, with speeds ranging from 7 to 9 m/s. This indicates a high potential for both fixed and floating offshore wind farms. The technical potential for offshore wind energy in Türkiye is significant, with up to 6 GW from fixed turbines in shallower. waters and an impressive 19 GW from floating turbines in deeper areas identified by ESMAP and further analysis indicating up to 57 GW of potential from floating wind farms. This showcases the vast potential lying in Türkiye's deeper sea regions. Advantages of Offshore Wind

doi: 10.31593/ijeat.1503875

International Journal of Energy Applications and Technologies, Year 2025, Vol. 11, No. 1, pp. 40-52

Energy. The benefits of establishing offshore wind power in Türkiye are manifold, encompassing elevated wind speeds over the sea as opposed to land, consistent wind resources, absence of land acquisition requirements, and the financial advantages stemming from reduced costs in sea transportation for the setup and upkeep of wind turbine facilities. Research and Development Efforts, Özkol's TUBITAK 1001 Project: This project's examination of the mechanical behavior of floating-type wind turbines in deep seas contributes valuable knowledge to the engineering and feasibility studies needed to advance Türkiye's offshore wind energy sector. Özbahçeci's Analysis: The statement that approximately 70 gigawatts of Türkiye's offshore wind energy potential can be predominantly harnessed through floating wind turbines highlights the critical role these technologies will play in tapping into the deep-sea wind resources. In summary, Türkiye's seas hold a high potential for offshore wind energy generation, offering a path towards sustainable and secure energy production. The continued exploration of this potential, supported by research, development, and strategic investments, will be crucial for Türkiye to become a leader in renewable energy in the region and globally.

8. Wind Energy in Türkiye

Wind energy has become an integral part of Türkiye's energy strategy, contributing significantly to the country's renewable energy mix. Türkiye has achieved a milestone of 10 gigawatts (GW) of installed wind energy capacity. This capacity accounts for about 10% of the country's electricity production, making wind energy the second largest source of renewable energy in Türkiye after hydropower [19], [20]. Türkiye's wind energy generation is predominantly derived from land-based sources, with significant installations spread throughout its land, particularly in the Aegean region. Izmir, in particular, is a central hub for wind energy, hosting around 20% of the country's capacity. The largest onshore wind project in Türkiye is the Soma wind farm in the provinces of Manisa and Balikesir, with a capacity of 312 MW [20]. The nation possesses ambitious visions for the forthcoming period, with the objective of incorporating an additional 20 gigawatts by the year 2030. The progression is anticipated to primarily persist via land-based wind energy, notwithstanding the increasing curiosity in enhancing offshore wind potential. A roadmap published by the Izmir Development Agency has identified a potential for up to 70 GW of offshore wind capacity in Türkiye. Wind energy has spurred significant domestic and foreign investment in Türkiye. The country has developed a robust local supply chain for wind energy, hosting production facilities of major companies like TPI Composites and Enercon [20].

9. Major Wind Farms in Türkiye

Türkiye continues to expand its wind energy capacity in 2024, building on significant achievements in both onshore and offshore wind energy development.

1. Mut Wind Farm

Location: Mersin Province, Southern Türkiye Capacity: Eleven wind turbines. In Service Since: 2010 [20].

2. Şamlı Wind Farm

Location: Balıkesir Province, Western Türkiye

Capacity: 91 wind turbines with an installed capacity of 150 MW.

Output: Generates approximately 375 GWh annually [20].

3. Soma Wind Farm

Location: Manisa Province, Northwestern Türkiye

Capacity: 119 wind turbines with a total installed capacity of 140 MW.

Operator: Polat Energy, a joint venture between Polat Holding and EDF Energies Nouvelles.

Area: 123 km² [20].

Izmir Province: Leading wind energy deployment, hosting around 20% of Türkiye's wind energy capacity. Aegean Region: High wind energy capacity and favorable wind conditions contribute to significant onshore wind energy projects [19], [21].Türkiye is exploring its vast offshore wind potential, estimated at 70 GW. This includes 12 GW suitable for fixed installations and 57 GW for floating turbines. The Aegean Sea, Marmara Sea, and parts of the Black Sea are prime locations due to favorable wind speeds and appropriate water depths [22], [21].

Fig. 5. Wind turbines in Gokcedada in Çanakkale Province, Türkiye [23]

10. Installed Capacity of Global Renewable Energy

It's great to see the significant growth in renewable energy capacity both globally and specifically in Türkiye over the past decade. The global increase to 3,372 GW in 2022 represents a substantial expansion, reflecting the world's ongoing shift towards more sustainable energy sources. Similarly, Türkiye achievement of reaching 56.4 GW in renewable energy capacity, with a Compound annual growth rate (CAGR) of 10.3% since 2011, highlights the country's

doi: 10.31593/ijeat.1503875

International Journal of Energy Applications and Technologies, Year 2025, Vol. 11, No. 1, pp. 40-52

strong commitment to renewable energy. Such growth rates are indicative of technological advancements, decreasing costs of renewable energy installations, and an increasing emphasis on reducing carbon emissions globally.

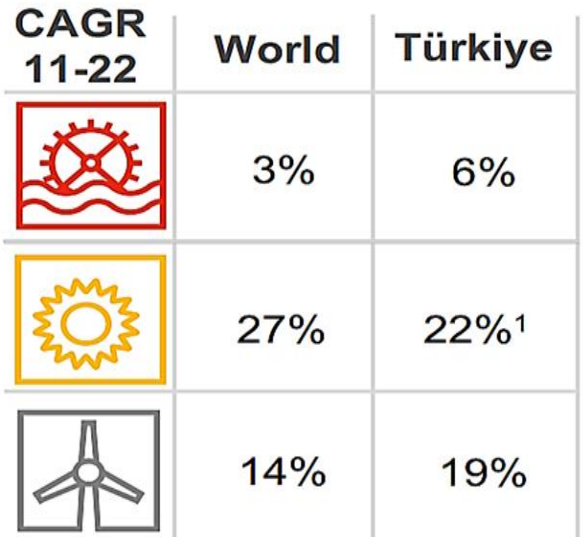

Fig. 6. Renewable electricity capacity growth can be analyses based on country or region in the main case [24]

Türkiye higher CAGR compared to the global average suggests that the country is moving at an accelerated pace in adopting renewable energy technologies, possibly due to its geographical advantages, government policies, and investments in renewables such as wind, solar, hydro, and geothermal energy. This transition towards renewable energy is crucial for mitigating climate change, improving energy security, and diversifying energy supplies. It also presents economic opportunities, such as job creation in new industries, while reducing dependency on imported fossil fuels [25].

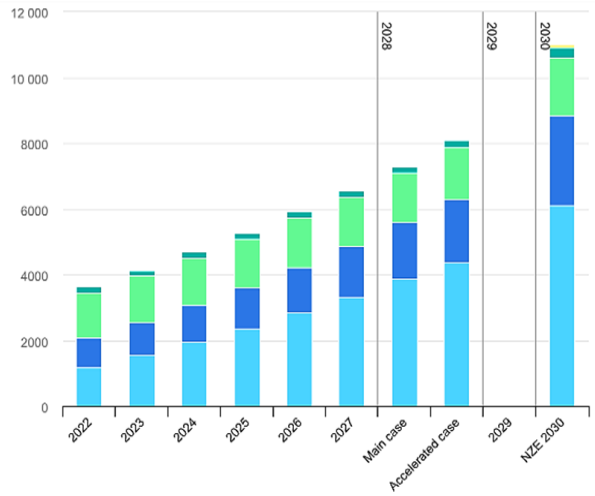

Fig. 7. The cumulative capacity of renewable electricity in the primary and expedited scenarios, as well as the Net Zero Scenario, is exam. [26]

11. Global Installed Capacity Rankings for Türkiye

Türkiye's ambitious objectives for renewable energy by 2035 encompass a substantial enhancement in solar and wind capabilities. As outlined in Türkiye's National Energy Plan, the nation is striving to augment its solar energy capacity by over five times, reaching 52.9 GW, and to nearly triple its wind capacity to 29.6 GW by the year 2035.

This is a substantial increase from 7.8 GW for solar and 10.6 GW for wind recorded in 2021. The plan also projects an increase in hydro capacity to 35.1 GW and introduces nuclear capacity, which Türkiye considers renewable, expected to reach 7.2 GW by 2035. Türkiye's overall installed capacity is anticipated to reach 189.7 GW by the year 2035. Renewable energy sources are expected to contribute significantly to this growth, representing 74.3% of the new power capacity added during this timeframe. Furthermore, renewables are forecasted to account for 64.7% of Türkiye's total installed capacity, a notable increase from the 54% recorded in 2021 [27]. Ember's Türkiye Electricity Review for 2023 highlights the steady rise in wind power, which continues to outpace solar, with wind and solar reaching almost 16% share of total generation. Wind power accounts for 11% of power generation, a significant increase from the 6% share it held in 2017, while solar power now represents 4.7% of the share, up from just 1% in 2017. This upward trajectory reflects a consistent pattern where the combined wind and solar share has more than doubled since 2017. Nevertheless, despite these notable advancements, the nation is perceived as not fully capitalizing on its substantial solar power potential [28].

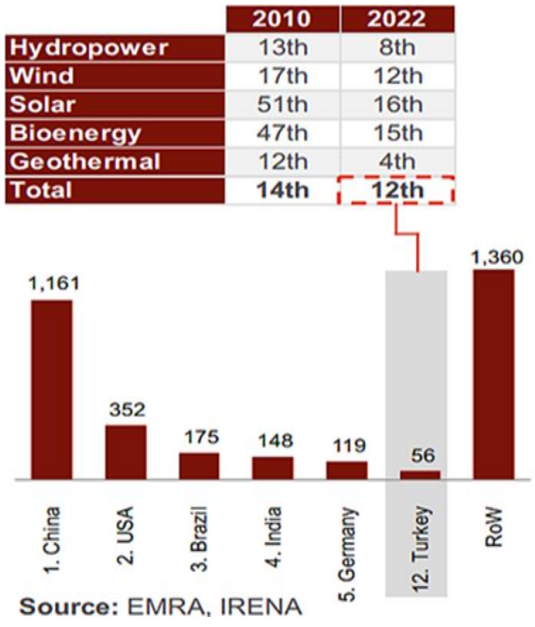

Fig. 8. Rankings of Countries Based on Their Capacity of Renewable Electricity Installation [24]

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International Journal of Energy Applications and Technologies, Year 2025, Vol. 11, No. 1, pp. 40-52

12. Installed Capacity of Renewable Energy in Europe

The total installed renewable power generation capacity has reached new highs, driven by substantial additions across European countries. Wind and solar energy collectively surpassed 27% of the EU's electricity mix in 2023, which contributed to renewable electricity reaching a record high of 44% of the total electricity generation in the EU. Specifically, the solar sector added 56 gigawatts (GW) of capacity in 2023, continuing strong growth from previous years [30].

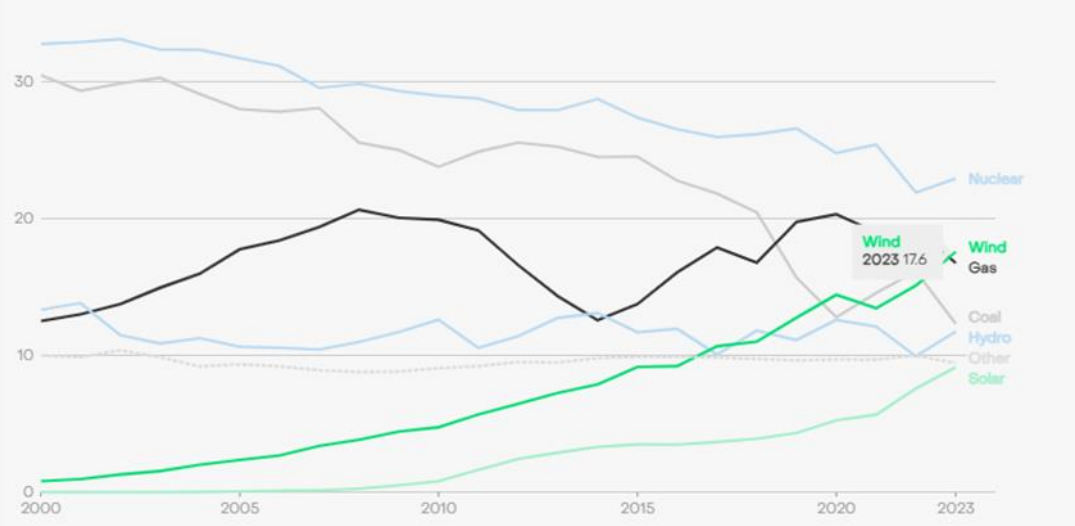

Fig. 2. In 2023, wind energy generated a greater amount of electricity in the European Union compared to gas for the first time [29]

13. The Proportion of Electricity Capacity Derived from Renewable Energy Sources

The growth in installed renewable energy capacity across Europe is a testament to the Continent's commitment to transitioning towards more sustainable energy sources. With a 6.6% increase since 2011, reaching 765 GW in 2022, Europe is making significant strides in harnessing renewable energy.

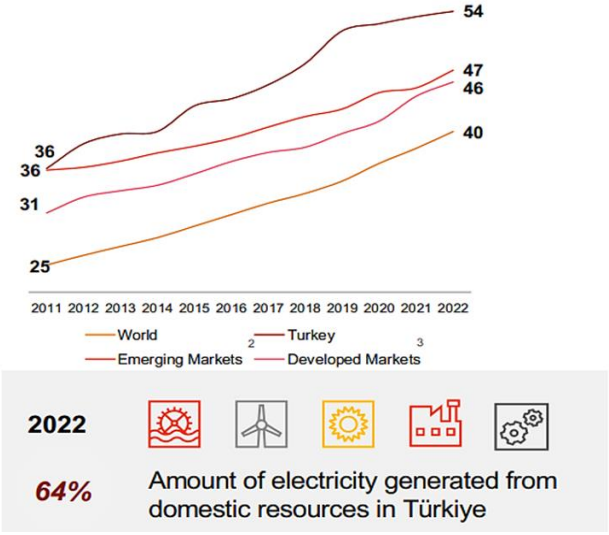

Fig. 10. The proportion of electricity capacity derived from renewable sources [24]

Wind produced more electricity in the EU than gas for the first time in 2023. Türkiye, in particular, has distinguished itself within this landscape, securing the position as the country with the fifth largest installed renewable energy capacity in Europe. This is a notable achievement, emphasizing Türkiye role in the broader European energy transition efforts. Moreover, Türkiye specific accomplishment in hydropower is especially noteworthy. Ranking second only to Norway, Türkiye has leveraged its geographical and hydrological advantages to become a leading force in hydropower within Europe. This not only highlights Türkiye strategic focus on hydropower as a pivotal component of its renewable energy portfolio but also underscores the country's capacity to harness its natural resources effectively for energy production [31], [24].

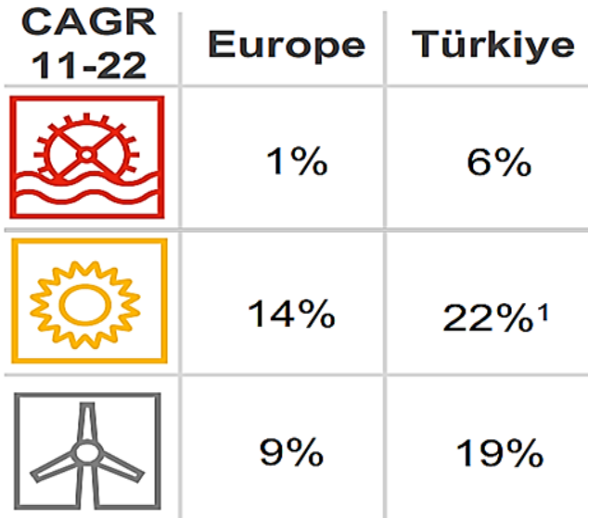

Fig. 11. Renewable energy is present in Europe [24]

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International Journal of Energy Applications and Technologies, Year 2025, Vol. 11, No. 1, pp. 40-52

14. Share of Total Renewable Energy Installed Capacity Addition in Europe

Türkiye has indeed been making significant strides in the renewable energy sector, particularly in wind. Over recent years, the country's efforts have positioned it among the leading nations in Europe in terms of renewable energy capacity additions. In the year 2023, an impressive 99.5% of the expansion in Türkiye's electricity capacity was attributed to renewable energy sources, as the nation sets its sights on elevating the proportion of renewables within its total installed capacity to 65% by the year 2035, a significant rise from the 56% recorded in 2023. This growth is underpinned by substantial additions in wind and solar capacities, reaching 11,803 and 11,315 megawatts, respectively, alongside significant contributions from biogas and geothermal sources [30] Despite these impressive advancements, the broader European context presents a challenging landscape for renewable energy deployment. The EU as a whole is grappling with accelerating the deployment of wind r to meet the ambitious targets aligned with the 1,5°C climate goal. In 2021, the EU deployed 34 GW of combined wind and solar capacity, but to align with the 1.5°C target, yearly additions need to increase significantly, aiming for 76 GW by 2026. However, forecasts indicate that the EU might only achieve half of this target by the specified year [32]. The rapid expansion of Türkiye renewable energy sector, particularly in wind energy, where it aims to reach a potential installed power of between 120,000 and 150,000 megawatts for onshore projects by 2028, highlights the country's commitment and the sector's potential for growth [33].

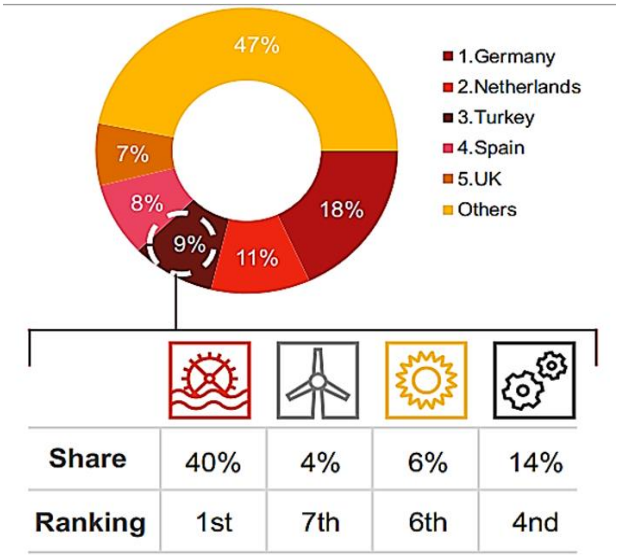

Fig. 12. Europe's portion of the total renewable energy installed capacity increase is being discussed [24]

This commitment is further emphasized by Türkiye plan to enhance its position in the wind industry, which is already ranked as the sixth-largest in Europe, demonstrating the country's ambition to be a leading player in the renewable energy landscape within the continent [33] Türkiye ambitious renewable energy growth, particularly in wind and solar, aligns with the broader need for Europe to enhance its renewable energy deployment. However, achieving these goals requires overcoming significant challenges, including accelerating deployment rates and addressing the long permitting processes that have been a bottleneck for both wind and solar projects across the EU [25].

15. From a Generational Perspective, Türkiye Ranks Fifth in Europe in Terms of Population Exploitation of Wind Energy Sources.

Türkiye has made significant strides in wind energy, positioning itself as a notable player in Europe's renewable energy landscape. The country celebrated reaching a cumulative wind energy capacity of 10 GW, a testament to its rapid development in the sector. This milestone underlines Türkiye commitment to diversifying its energy mix, with wind energy now constituting 10% of its electricity production, second only to hydro power in the renewable sector.

The majority of Türkiye wind energy installations are onshore, particularly concentrated in the Aegean region, with Izmir province leading in capacity. This accomplishment signifies a more extensive pattern observed in Türkiye's energy strategy, which prioritizes the utilization of renewable resources to strengthen energy resilience and diminish reliance on external fossil fuel supplies. Looking forward, Türkiye aims to further expand its wind energy capacity, with plans to add 20 GW by 2030, indicating a strong future growth trajectory in renewable energy [19]. Moreover, in 2021, Türkiye ranked fourth in Europe for wind energy installations, adding 1.4 GW of capacity, following a report by Wind Europe. This ranking highlights the country's active role in the renewable energy sector, contributing significantly to Europe's total installed wind power capacity. The U.K., Sweden, and Germany were ahead, with the U.K. leading the installations. The emphasis on wind energy aligns with Türkiye broader energy strategy, which seeks to secure its energy supply and transition towards a cleaner, more sustainable energy system. Wind energy, alongside other renewables, is pivotal in Türkiye efforts to diversify its energy mix and reduce its carbon footprint [34].

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International Journal of Energy Applications and Technologies, Year 2025, Vol. 11, No. 1, pp. 40-52

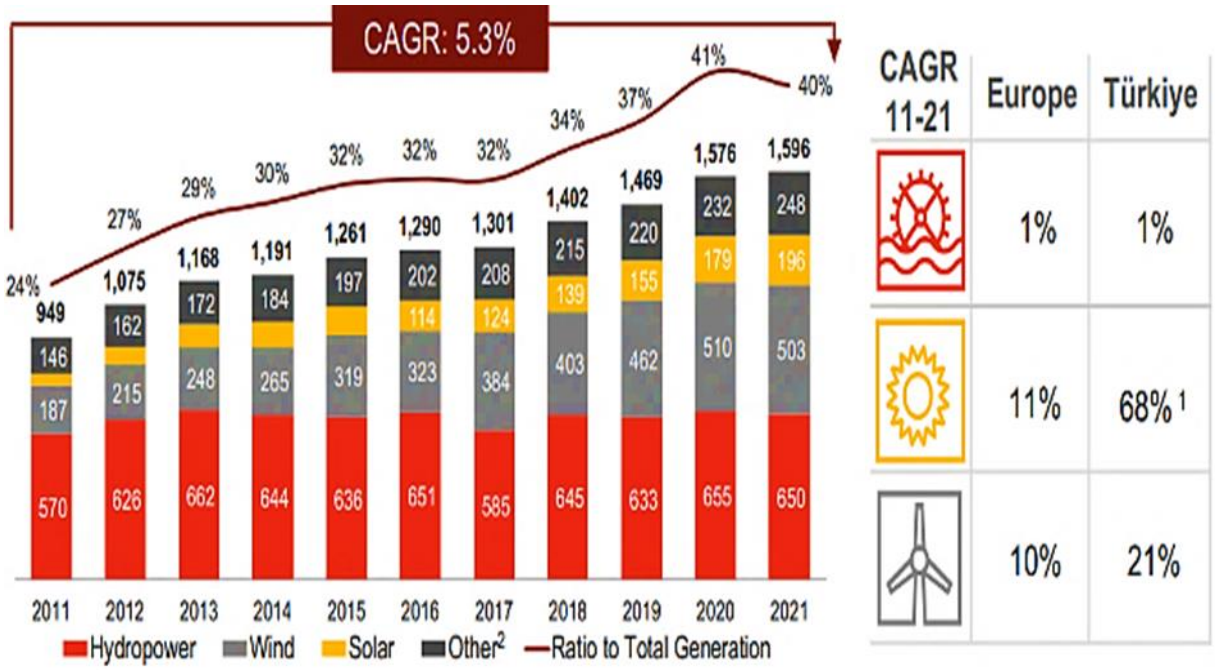

Fig. 13. Evolution of worldwide renewable power production [24]

16. Non-Hydro Renewable Installed Capacity in Türkiye Grew Substantially in The Last Decade Due to Continuous Government Support.

In the last decade, Türkiye non-hydro renewable installed capacity saw significant growth, largely supported by government initiatives like YEKDEM. This expansion is in line with Türkiye's overarching strategy to diversify its energy sources, with a specific focus on renewable sources in order to bolster energy security and diminish reliance on imported fossil fuels. The YEKDEM initiative, in particular, has been pivotal in stimulating the growth of renewable energy initiatives throughout the nation [20].

Development of Non-Hydro Renewables	December 2008	June 2023	% of Total Capacity as of June 2023
Wind Large amount of investments due to attractive FiT Schemes under YEKDEM	364 MW	11,566 MW	11.0%
Solar Strong growth in the past few years, mainly attributable to unlicensed generation	0 MW	10,192 MW	9.7%
Geothermal High number of geothermal sources in Türkiye which can be utilized for generation	30 MW	1,691 MW	1.6%
Biomass Less interest due to high CAPEX and dependency on external source factors (waste collection).	597 MW	2,031 MW	1.9%

Fig. 14. The capacity of renewable energy sources shows the maximum energy they can provide [24]

17. Growth in Global Renewable Energy (Wind Energy) Compared to Total Final Energy Consumption

The growth of wind energy, as part of the global renewable energy expansion, has been significant, especially when observed against the backdrop of total final energy consumption. In 2022, the wind energy sector added 78 GW of new capacity globally, marking it as the third best year for new capacity. The increase in capacity resulted in the expansion of the overall installed wind capacity globally to 906 GW, demonstrating a 9% growth compared to the previous year. Projections for 2023 suggest that the industry is poised to witness an addition of more than 100 GW in new capacity, indicating an anticipated annual growth of 15% [6]. Wind power generation experienced a remarkable surge of 265 TWh in 2022, representing a 14% increase and surpassing 2,100 TWh. This surge positioned it as one of the leading growth sectors within renewable energy, trailing only behind solar photovoltaic technology. Nevertheless, in order to adhere to the 2050 Net Zero Emissions Scenario, which envisions around 7,400 TWh of wind power generation by 2030, the industry must elevate its annual growth rate to approximately 17%. This ambitious goal underscores the need for significantly increased policy and private sector efforts to facilitate onshore wind permitting and reduce offshore wind costs [12].

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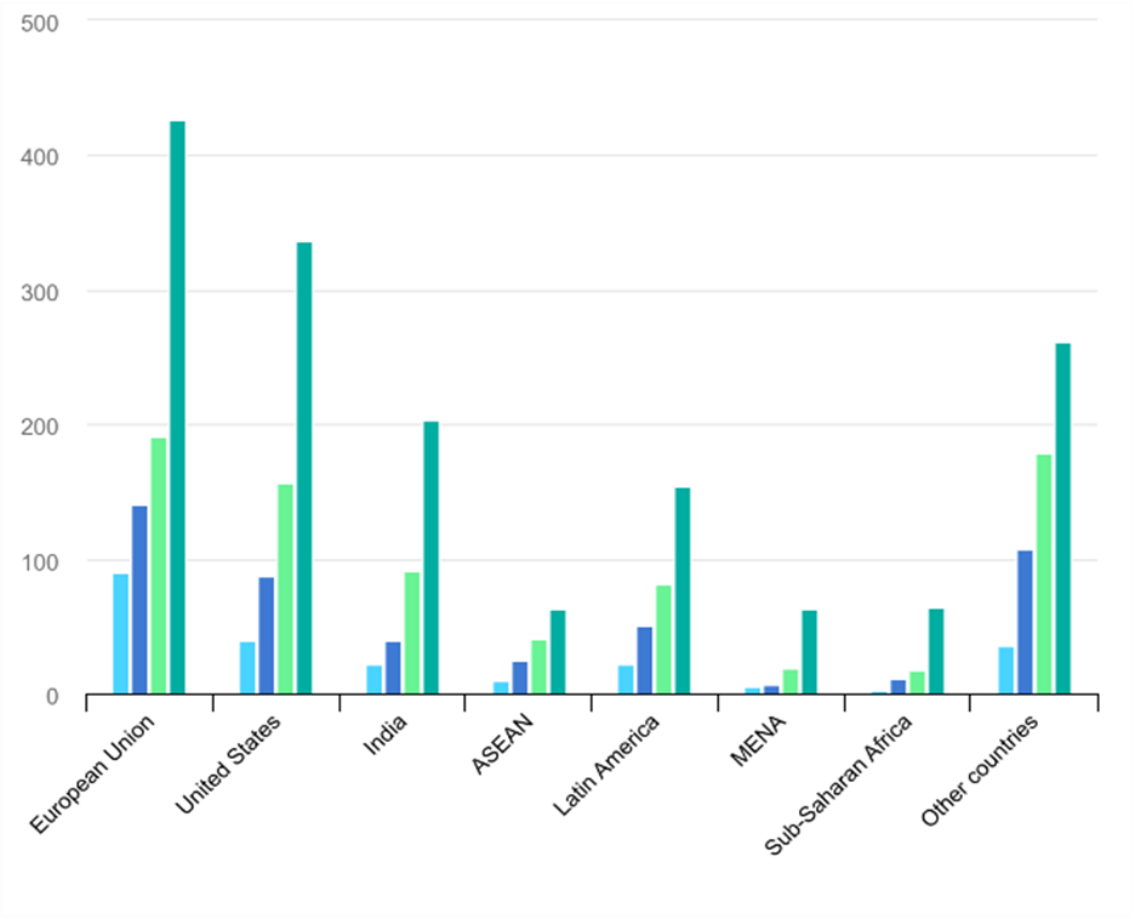

Fig. 15. Regional wind forecast for new onshore and offshore installations is presented in gigawatts [26]

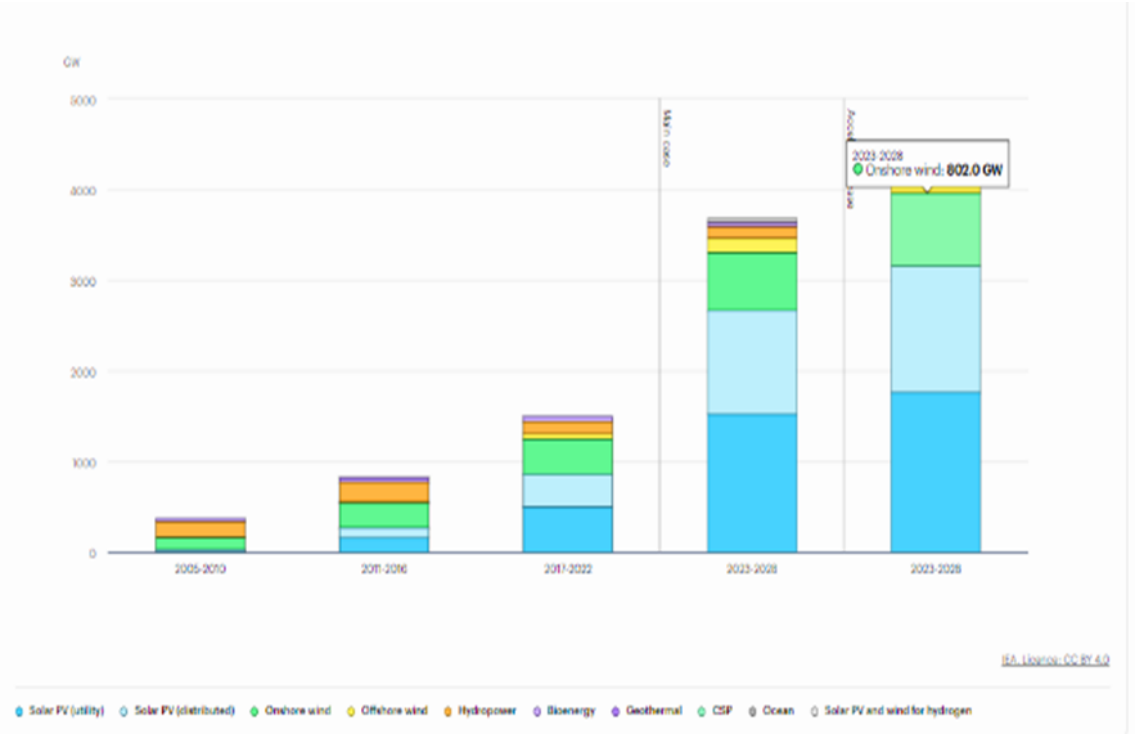

Fig. 16. Renewable capacity growth is analyzed by technology in main and accelerated cases for the period 2023-2028 [26]

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In the context of renewable energy's contribution to total final energy consumption, modern renewables (excluding traditional biomass usage) saw their proportion rise to 12.5% in 2020, an increase from 11.4% in 2019. This upward trend is highlighted by the robustness and expansion of renewable electricity sources during the pandemic, further accentuated by policy backing post the global energy crisis, resulting in another record-breaking year for renewable power in 2022. Notably, wind and solar photovoltaic technologies, being pivotal drivers of renewable electricity utilization, have accounted for more than half of the increment in renewable electricity usage observed in the last decade [35].

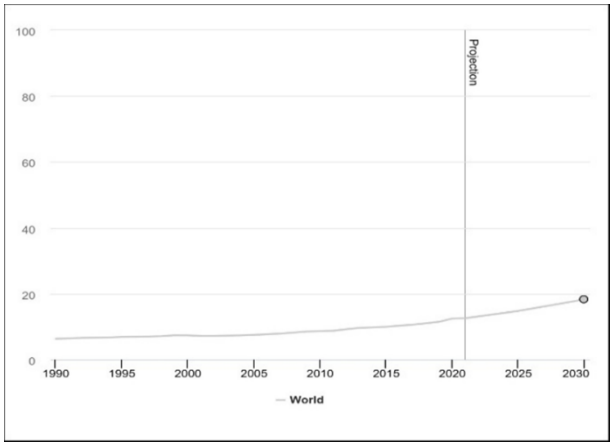

Fig. 17. The Stated Policies Scenario evaluates the percentage of modern renewable energy in total final energy usage [36]

This significant expansion of wind energy, both onshore and offshore, is integral to achieving broader renewable energy targets. With countries around the globe increasing their policy support for renewables in response to energy security concerns and climate change mitigation efforts, wind energy stands as a critical component of the global shift towards cleaner, more sustainable energy sources.

Conflict of interest

There is no conflict of interest

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