OECONOMIA
COPERNICANA

VOLUME 17 ISSUE 1 MARCH 2026

p-ISSN 2083-1277, e-ISSN 2353-1827
www.oeconomia.pl

EDITORIAL

Citation: Balcerzak, A. P., Igliński, B., Pietrzak, M. B., Dutta, A., & Uddin, G. S. (2026). Harnessing wind energy: Can it become a strategic driver of national energy security and the global energy transition? *Oeconomia Copernicana, 17*(1), 15–29. https://doi.org/10.24136/oc.4234

Contact to corresponding author: Adam P. Balcerzak, a.balcerzak@uwm.edu.pl

Article history: Received: 3.03.2026; Accepted: 25.03.2026; Published online: 30.03.2026

Adam P. Balcerzak
Brno University of Technology, Czechia
Centre for Business Research, Pan-European University, Czechia
orcid.org/0000-0003-0352-1373

Bartłomiej Igliński
Nicolaus Copernicus University in Toruń, Poland
orcid.org/0000-0002-2976-6371

Michał Bernard Pietrzak
Gdańsk University of Technology, Poland
orcid.org/0000-0002-9263-4478

Anupam Dutta
University of Vaasa, Finland
orcid.org/0000-0003-4971-3258

Gazi Salah Uddin
Linköping University, Sweden
orcid.org/0000-0002-5744-0192

Harnessing wind energy: Can it become a strategic driver of national energy security and the global energy transition?

The pursuit of unconventional energy sources is not a recent phenomenon. However, in the contemporary era, the advancement of research and development in green technologies has become not only politically feasible but also increasingly economically advantageous (Balcerzak *et al.*, 2025; Kędzior-Laskowska *et al.*, 2025). With global energy demand continuing to rise and fossil fuel reserves diminishing, which is accompanied by escalating extraction costs, consequently, higher costs of conventional energy sources (Pavláková Dočekalová *et al.*, 2024), there is an urgent need to identify alternative energy sources capable of meeting future consumption requirements. These alternatives include wind, solar, geothermal, tidal, hydropower, and biomass energy (Liu, 2026; Dincă *et al.*, 2025).

Among these sources, wind energy, despite its relatively high final cost and the problem of instability, has emerged as one of the most technologically mature and industrially scalable solutions. Its scalability makes it particularly suitable for integration into energy-intensive industrial processes (Sharma *et al.*, 2026). Furthermore, from a technological standpoint, wind energy can be effectively utilized to produce green hydrogen via electrolysis, thereby enabling long-term energy storage and supporting the decarbonization of emission-intensive industries. In this way, wind energy may serve a strategic role by linking renewable electricity generation to broader industrial transformation processes (Sten *et al.*, 2024; Balcerzak *et al.*, 2024).

Increasing the share of renewable energy in a national energy mix, while maintaining system stability, enhances energy security, reduces reliance on imported fuels, and helps preserve conventional energy reserves (Igliński *et al.*, 2024; Jin, 2025; Nihal *et al.*, 2024). This becomes particularly critical in an era of heightened geopolitical volatility, which undermines the energy security of nations worldwide.

From an economic perspective, the transition toward renewable energy sources may, under favorable conditions, strengthen national competitiveness and innovation capacity. It can stimulate the adoption of technological and organizational innovations within energy-related sectors (Tian *et al.*, 2025; Zábojník & Branch, 2025; Wang *et al.*, 2025). In addition, the expansion of renewable energy provides significant environmental benefits by reducing emissions of pollutants associated with fossil fuel combustion and supporting natural ecosystem preservation, thereby facilitating progress toward low-carbon economic structures (Hasan *et al*., 2026; Yavuz *et al*., 2025; Trinh, 2025).

The global energy transition represents one of the most formidable challenges confronting the international community in the 21st century (Popescu *et al*., 2025). Governments and societies worldwide are implementing policies aligned with the Sustainable Development Goals, despite the considerable costs of transforming carbon-intensive economies (Chen & Guang, 2026; Bai *et al*., 2024). The primary objective, however, should be a just transition, one that safeguards national security, avoids deepening energy poverty, prevents social degradation at local and regional levels, and ensures environmental protection (Mariev *et al*., 2025). Within this context, the energy transition should foster new opportunities for economic diversification, supporting the evolution of global industries, agriculture, and services, while simultaneously advancing the renewable energy sector (Wu *et al*., 2026; Delcea *et al*., 2024; Jareño *et al*., 2025). Ultimately, a well-executed energy transition is expected to stimulate economic development and growth on an international scale (Pietrzak *et al*., 2021; Amin *et al*., 2024; Ghaffar *et al*., 2025).

The expansion of renewable energy sources and the strategic management of energy portfolios grounded in these technologies significantly reinforce national energy security by reducing systemic vulnerability to disruptions and crises (Xiong *et al*., 2025). Distributed renewable energy systems, in particular, provide high levels of supply security. In contrast to centralized energy infrastructures, which are dependent on a limited number of large-scale power plants and thus exposed to natural disasters, physical attacks, or cyber threats, distributed systems composed of numerous independent energy units (e.g., biogas plants, wind turbines, photovoltaic installations) demonstrate considerably higher resilience. This resilience is analogous to the robust, decentralized architecture of the Internet, originally designed to withstand partial system failures (Xie *et al*., 2025).

Wind energy is especially important in this context due to its scalability and technological maturity. It is well-positioned to enhance and complement distributed energy architectures (Boadu & Otoo, 2024). Consequently, in highly distributed systems, the probability of a nationwide blackout becomes significantly lower (Etanya *et al*., 2025). As a result, wind energy has become one of the fastest-growing renewable technologies globally, driven by rising energy demand, decarbonization efforts, energy-security imperatives, and technological innovations that facilitate smoother grid integration (Wang *et al.*, 2024; Ahmed *et al.*, 2025).

An examination of global wind energy trends indicates that China maintains its dominant position in the international market, accounting for 68.3% of all new capacity additions in 2024. Wind power projects were commissioned in at least 55 countries during the year, mirroring the geographical spread observed in 2023. Asia registered the most dynamic expansion, which was driven primarily by China's large-scale deployment, while Africa and the Middle East achieved a doubling of their installed wind capacity. This latter growth was mainly driven by substantial investments in Egypt and Saudi Arabia, underscoring the growing strategic importance of wind energy in emerging regional markets (REN21, 2025; Zhu & Sigitov, 2025; Graham *et al.*, 2025).

In China alone, a record 79.8 GW of new wind capacity was connected to the grid in 2024, helping achieve regional renewable energy targets by the end of 2025. China's share of global wind installations rose from 48.5% in 2022 to 65% in 2023 and 68.3% in 2024. By year's end, the country's total installed wind capacity had reached approximately 520.6 GW—representing nearly 46% of the global total. Wind energy is estimated to have contributed around 10% of China's electricity generation in 2024, up from 9.2% in 2023 (REN21, 2025; Zhu & Sigitov, 2025; Gau *et al.*, 2026).

Despite a deceleration in growth, the United States remained the second-largest contributor to global annual and cumulative wind installations. In 2024, around 4.1 GW of new capacity was added, bringing the total to 154.8 GW. The slowdown primarily resulted from prolonged permitting processes and delays in federal tax credit guidance. Nonetheless, onshore development increased modestly by 1%, and the number of new power purchase agreements rose by 31% compared to 2023 (Mayyas, 2023; Parton *et al.*, 2024; REN21, 2025).

India advanced to fourth place globally in new wind turbine installations in 2024. Following a 52% increase in 2023, an additional 21% growth (3.4 GW) was recorded in 2024, bringing total installed capacity to 48.2 GW. The rapid expansion of India's wind sector is attributed to policy reforms, government incentives, strengthened domestic turbine manufacturing, and rising demand for renewable energy to meet Renewable Purchase Obligations (Kumar & Prakash, 2023; REN21, 2025; Shah, 2024).

In Brazil, annual wind energy investment declined, causing the country to fall to fifth place after four consecutive years as the world's third-largest market. The primary obstacle to further development remains insufficient transmission infrastructure, which has not kept pace with new wind capacity additions. Nonetheless, 3.3 GW of new capacity was connected to the grid in 2024, raising total installed capacity to 33.7 GW (REN21, 2025; Cacciuttolo *et al*., 2025; Ferreira *et al*., 2023).

As a region, Europe again ranked second globally in new wind power additions, installing 15 GW in 2024—83% of which were onshore. Total wind capacity in Europe reached 271.1 GW. Expansion was mainly driven by efforts to enhance energy independence and industrial decarbonization, although grid bottlenecks, administrative barriers, and restrictive financing conditions tempered growth (Wasilczuk *et al*., 2025; Wojtaszek *et al*., 2025). The European Union forecasts that wind energy will supply 43% of electricity consumption by 2030, up from the current 17%, necessitating the construction of approximately 35 GW of new capacity annually (Jung & Schindler, 2022).

In 2024, several countries, including at least 9 in Europe and Uruguay, derived at least 25% of their electricity from wind energy. Denmark remains the global leader, with wind providing 56% of its electricity supply. Overall, wind energy accounted for nearly 20% of electricity generation in the European Union in 2024 (Bórawski *et al*., 2020; REN21, 2025).

Within Europe, Germany maintains its position as the regional leader in installed wind capacity, reaching 72.7 GW after adding more than 4 GW in 2024, which gives an increase of 5.2% compared to 2023. The year marked a breakthrough in permitting and auction performance, driven by government measures to reduce barriers to wind development. New installations increasingly supply energy-intensive industries, including steel and chemicals, thereby facilitating decarbonization while sustaining industrial competitiveness (REN21, 2025; Reichartz *et al*., 2025; Schrader *et al*., 2025).

Following Germany, the highest capacity additions in Europe occurred in the United Kingdom, France, and Finland, ranking sixth to eighth globally. In cumulative capacity, Germany remains first, followed by the United Kingdom (31.6 GW), Spain (31.2 GW), France (24.4 GW), and Sweden (17.2 GW) (REN21, 2025; Wang *et al*., 2025; Pérez-Pérez *et al*., 2026).

Globally, offshore wind energy has emerged as one of the fastest-growing segments of the renewable energy sector and is increasingly critical to the transition to low-carbon energy systems (Nagababu *et al*., 2026). By the end of 2024, global offshore wind capacity reached 83.1 GW, with new installations concentrated in Europe, Asia, and North America. In total, four Asian countries, three European countries, and one North American country added 7.9 GW of offshore capacity in 2024. Offshore systems accounted for 6.7% of new wind installations and 7.3% of total installed wind capacity, underscoring the rising significance of this technology in the global energy mix (Xue *et al*., 2026).

Europe remains the largest offshore wind market, though growth slowed in 2024 compared to the record-setting year of 2023. Only 2.6 GW of new offshore capacity was added, primarily because of construction delays and grid connection challenges (Dedecca *et al*., 2016). All new installations occurred in the United Kingdom, Germany, and France, raising Europe's operational offshore capacity by 78% to 36.7 GW. Several European states, including Denmark, Germany, and the UK, already generate substantial shares of electricity from wind, and the European Union intends to expand offshore capacity significantly so that wind energy will supply 43% of electricity demand by 2030 (Wind Europe, 2025).

In Asia, the offshore wind sector continues to grow rapidly, led by China, which holds 41.8 GW of installed capacity, which is more than half of the global total (Ren *et al*., 2026). Taiwan, Japan, and South Korea also contribute to regional expansion, supported by strategic policy frameworks, long-term planning, and substantial investment. For the seventh consecutive year, China accounted for more than half of global offshore additions, installing 4 GW in 2024 (Lin *et al*., 2026).

Offshore wind in North America is still in its early stages, but growth is accelerating. In the United States, offshore capacity increased from 42 MW to 174 MW in 2024 following the commissioning of the country's first large-scale offshore wind project. Nevertheless, policy adjustments in early 2025 temporarily constrained sectoral momentum (Hansen *et al*., 2026).

Technological progress has been central to offshore wind deployment. Innovations in turbine scale, floating foundation designs, and grid integration have facilitated access to deeper waters and more remote areas, significantly expanding global offshore wind potential. Floating wind technologies, in particular, are expected to unlock hundreds of additional gigawatts in regions characterized by deep coastal waters, including Japan, the U.S. West Coast, and parts of Europe (Xing *et al*., 2026).

Offshore wind development also yields substantial economic benefits. Investments in offshore projects stimulate industrial activity, create employment opportunities, and build specialized capabilities in manufacturing, construction, and maintenance. Moreover, economies of scale and technological advancements reduce generation costs, enhancing offshore wind's competitiveness relative to conventional power sources (Ferrarese *et al.*, 2026).

Offshore wind is also increasingly important for energy security. As coal and gas plants retire, offshore wind farms offer a stable, reliable source of renewable electricity. Fully harnessing offshore potential could provide hundreds of additional gigawatts of capacity globally, supporting greenhouse gas reductions, grid stability, and the rising electricity demand associated with economic development (Warder & Piggott, 2025).

In the coming years, Europe and Asia intend to expand offshore wind substantially, while other regions, including North America and emerging economies, are also expected to accelerate project development. Achieving these targets will require effective policy support, streamlined administrative procedures, and enhanced international cooperation. Offshore wind is poised to become a foundational element of the global energy system, underpinning sustainable development, energy security, and long-term economic resilience (Yang *et al.*, 2025).

Wind energy, both onshore and offshore, has therefore become a fundamental component of the global energy mix, playing a pivotal role in the energy transition, decarbonization, and strengthening national energy security (Guo *et al.*, 2026). Over the long term, the coordinated development of both onshore and offshore wind technologies will be central to achieving decarbonization targets, advancing sustainable development, and facilitating the global energy transition (Yang *et al.*, 2024).

The global wind energy sector is undergoing an unprecedented transformation, revealing both its vast untapped potential and its rapidly increasing strategic importance for the international energy transition. As demonstrated throughout this editorial, the scale and pace of wind energy expansion, across both onshore and offshore segments, underscore that wind power has evolved from a supplementary component of national energy strategies to a fundamental pillar of modern, secure, and low-carbon energy systems. At the same time, this dynamic expansion introduces complex challenges that extend beyond engineering and technological considerations.

The anticipated scale of future wind deployment demands robust governance frameworks that support long-term planning, efficient regulatory systems, and transparent permitting procedures. Policymakers must balance energy security objectives with social acceptance and environmental protection while ensuring regulatory flexibility in response to rapidly evolving technologies and market conditions. Simultaneously, national and regional institutions are increasingly required to coordinate strategic investments in modern grid infrastructure, strengthen supply chains, and manage the growing interconnections between energy, industrial, and climate policies.

The academic sector faces a correspondingly expanding research agenda. Addressing persistent uncertainties related to grid integration, resource variability, environmental impacts, and socio-economic implications requires interdisciplinary collaboration that spans energy engineering, economics, environmental science, data analytics, and public policy. Emerging challenges, such as large-scale energy storage, sector coupling, digitalization of energy systems, and the development of resilient offshore infrastructure, further underscore the need for strengthened cooperation between universities, industry stakeholders, and public authorities. Academic research will be indispensable for informing evidence-based policies, guiding long-term investment strategies, and supporting the just and inclusive character of the global energy transition.

In conclusion, the remarkable potential of wind energy, which is combined with the accelerating pace of its global deployment, opens substantial opportunities for sustainable economic development, industrial innovation, and enhanced energy security. However, realizing this potential requires coordinated action across policy, institutional, and scientific domains. Only through an integrated, forward-looking, and collaborative approach can wind energy fully realize its transformative role in shaping the future global energy landscape.

References

Ahmed, Z., Caglar, A. E., & Pinzon, S. (2025). Pathways to decarbonization: Assessing the influence of government effectiveness, economic dynamics, and wind and solar energy adoption on CO_2 emissions. *Journal of Environmental Management, 394*, 127413. https://doi.org/10.1016/j.jenvman.2025.127413.

Amin, M. B., Asaduzzaman, M., Debnath, G. C., Rahaman, M. A., & Oláh, J. (2024). Effects of circular economy practices on sustainable firm performance of green garments. *Oeconomia Copernicana, 15*(2), 637–682. https://doi.org/10.24136/oc.2795.

Bai, T., Xu, D., Bi, S., Zhu, K., & Dávid, L. D. (2024). Impact of green fiscal policy on the collaborative reduction of pollution and carbon emissions: Evidence from energy saving and emission reduction policy in China. *Oeconomia Copernicana, 15*(4), 1263–1302. https://doi.org/10.24136/oc.3159.

Balcerzak, A. P., Igliński, B., Uddin, G. S., Dutta, A., & Pietrzak, M. B. (2025). Towards cleaner energy transition: Small modular reactors as a feasible revolutionary step in the economics of nuclear energy. *Equilibrium. Quarterly Journal of Economics and Economic Policy, 20*(1), 35–47. https://doi.org/10.24136/eq.3602.

Balcerzak, A., Uddin, G. S., Dutta, A., Pietrzak, M. B., & Igliński, B. (2024). Energy mix management: A new look at the utilization of renewable sources from the perspective of the global energy transition. *Equilibrium. Quarterly Journal of Economics and Economic Policy, 19*(2), 379–390. https://doi.org/10.24136/eq.3158.

Benalcazar, P., Trzeciok, M., & Kamiński, J. (2023). A GIS-based framework for evaluating technical and economic prospects of onshore wind energy: Case study of Poland. *Energies, 18*(23), 6230. https://doi.org/10.3390/en18236230.

Boadu, S., & Otoo, E. (2024). A comprehensive review on wind energy in Africa: Challenges, benefits and recommendations. *Renewable and Sustainable Energy Reviews, 191*, 114035. https://doi.org/10.1016/j.rser.2023.114035.

Bórawski, P., Bełdycka-Bórawska, A., & Jankowski, K. J. (2020). Development of wind energy market in the European Union. *Renewable Energy, 161*, 691–700. https://doi.org/10.1016/j.renene.2020.07.081.

Cacciuttolo, C., Navarrete, M., & Cano, D. (2025). Advances, progress, and future directions of renewable wind energy in Brazil (2000–2025–2050). *Applied Sciences, 15*(10), 5646. https://doi.org/10.3390/app15105646.

Chen, J., & Guang, F. (2026). The impact of digital inclusive finance on green low-carbon energy transition: Evidence from China. *Energy Strategy Reviews, 63*, 102019. https://doi.org/10.1016/j.esr.2025.102019.

Chomać-Pierzecka, E. (2024). Investment in offshore wind energy in Poland and its impact on public opinion. *Energies, 17*(16), 3912. https://doi.org/10.3390/en17163912.

Dedecca, J. G., Halvoort, R. A., & Ortt, J. R. (2016). Market strategies for offshore wind in Europe: A development and diffusion perspective. *Renewable and Sustainable Energy Reviews, 66*, 286–296. https://doi.org/10.1016/j.rser.2016.08.007.

Delcea, C., Oprea, S.-V., Dima, A. M., Domenteanu, A., Bara, A., & Cotfas, L.-A. (2024). Energy communities: Insights from scientific publications. *Oeconomia Copernicana, 15*(3), 1101–1155. https://doi.org/10.24136/oc.3137.

Dinca, V. M., Dima, A. M., Moagăr-Poladian, S., Săseanu, A. S., & Dinu, V. (2025). Energy consumption and savings behavior under the pressure of energy security, sustainability and cleaner energy transition: The case of Romania. *Oeconomia Copernicana, 16*(2), 489–521. https://doi.org/10.24136/oc.3749.

Etanya, T. F., Tsafack, P., & Ngwashi, D. K. (2025). Grid-connected distributed renewable energy generation systems: Power quality issues and mitigation techniques – A review. *Energy Reports, 13,* 3181–3203. https://doi.org/10.1016/j.egyr.2025.02.050.

Ferrarese, A., Marocco, P., Mattiazzo, G., & Santarelli, M. (2026). A method for spatially resolved techno-economic assessment of offshore wind-to-hydrogen systems: A northern Adriatic Sea case study. *Energy Conversion and Management, 350*, 120948. https://doi.org/10.1016/j.enconman.2025.120948.

Ferreira, M. M., Santos, J. A., da Silva, L. R., Raphael Abrahao, R., Gomes, F. da S. V., & Braz, H. D. M. (2023). A new index to evaluate renewable energy potential: A case study on solar, wind and hybrid generation in Northeast Brazil. *Renewable Energy, 217*, 119182. https://doi.org/10.1016/j.renene.2023.119182.

Gao, L., Zhao, F., & Sun, Y. (2026). Economic impact of wind energy technology adoption in China's renewable power markets: Implications for energy security and financial development. *Renewable Energy, 258,* 124811. https://doi.org/10.1016/j.renene.2025.124811.

Ghaffar, A., Tayyab, M., & Umair, M. (2025). Integrating energy efficiency, economic growth, and regulatory compliance for China's clean energy transition: A route to net-zero emissions. *Next Research, 2*(4), 101017. https://doi.org/10.1016/j.nexres.2025.101017.

Goddijn-Murphy, L. (2026). 10 things to consider before approving another offshore wind farm: A case study for Highland, Scotland. *Ocean & Coastal Management, 271*, 107956. https://doi.org/10.1016/j.ocecoaman.2025.107956.

Graham, K., Marais, L., & Cloete, J. (2025). Goal dependency and environmental impact assessments in the establishment of wind energy facilities in South Africa. *Journal of Environmental Management, 396,* 128054. https://doi.org/10.1016/j.jenvman.2025.128054.

Guo, L., Wang, Y., & Teng, Y. (2026). Operation optimization of integrated energy system coupled with wind power and power to gas. *Applied Thermal Engineering, 284*(2), 129123. https://doi.org/10.1016/j.applthermaleng.2025.129123.

Hansen, T. A., Lenhart, S., & Muller, A. T. (2026). Institutional learning in the energy transition: The case of offshore wind in the United States. *Energy Research & Social Science, 131*, 104475. https://doi.org/10.1016/j.erss.2025.104475.

Hasan, M., Eiti, H. T., Hossain, M. S., Amin, M. B., Rahaman, M. A., & Oláh, J. (2026). Evaluating the role of renewable energy and government consumption in reducing CO_2 emissions: A dynamic panel data analysis. *Sustainable Horizons, 17*, 100164. https://doi.org/10.1016/j.horiz.2025.100164.

Igliński, B., Kiełkowska, U., Mazurek, K., Drużyński, S., Pietrzak, M. B., Kumarc, G., Veeramuthu, A., Skrzatek, M., Zinecker, M., & Piechota, G. (2024). Renewable energy transition in Europe in the context of renewable energy processes in the world: A review. *Heliyon, 10,* e40997. https://doi.org/10.1016/j.heliyon.2024.e40997.

Jareño, F., Tolentino, M., & Fernández, M. del V. (2025). Energy-agriculture market linkages: Asymmetric effects in the context of the Russia–Ukraine conflict. *Oeconomia Copernicana, 16*(1), 163–196. https://doi.org/10.24136/oc.3313.

Jin, T. (2025). Disillusioning the benefits of renewable energy in energy intensity: Global panel analysis. *Sustainable Futures, 10,* 100960. https://doi.org/10.1016/j.sftr.2025.100960.

Jung, C., & Schindler, D. (2022). Projections of energy yield- and complementarity-driven wind energy expansion scenarios in the European Union. *Energy Conversion and Management, 269,* 116160. https://doi.org/10.1016/j.enconman.2022.116160.

Kedzior-Laskowska, M., Szczubełek, G., & Lulińska, A. (2025). Generation Z's attitudes towards environmental changes and renewable electricity: Evidence based on the New Ecological Paradigm. *Equilibrium. Quarterly Journal of Economics and Economic Policy, 20*(2), 713–743. https://doi.org/10.24136/eq.3532.

Kumar, N., & Prakash, O. (2023). Wind energy potential and its current status in India. *Wind Engineering, 47*(6), 2023. https://doi.org/10.1177/0309524X231183373.

Lin, S., Xu, Y., & Chen, Y. (2026). Untangling multi-level efficiency evolution in China's offshore wind power: From project development to electricity generation. *Sustainable Energy Technologies and Assessments, 85*, 104756. https://doi.org/10.1016/j.seta.2025.104756.

Liu, Y. (2026). Reviewing the EKC hypothesis: Does renewable energy reduce carbon emissions and environmental–economic impact? *Energy Reports, 15*, 108917.

Mariev, O. I., Iliyasu, J., & Mamman, S. O. (2025). Clean energy transition and income poverty in sub-Saharan Africa: Fiction or factual? *Renewable Energy, 250*, 123259. https://doi.org/10.1016/j.renene.2025.123259.

Mayyas, M. (2023). Wind energy in USA. *European Journal of Sustainable Development, 7*(1), em0203. https://doi.org/10.29333/ejosdr/12538.

Nagababu, G., Patwa, P., Puppala, H., Kachhwaha, S. S., Sricharan, V.V.S., Prasad, K.M.V.V., Kumar, S. V. V. A, & Sharma, R. (2026). Refining offshore wind energy potential estimates through the integration of technological evolution and climate change projections. *Energy, 342,* 139673. https://doi.org/10.1016/j.energy.2025.139673.

Nihal, A., Areche, F. O., Araujo, V. G. O. S., & Ober, J. (2024). Synergistic evaluation of energy security and environmental sustainability in BRICS geopolitical entities: An integrated index framework. *Equilibrium. Quarterly Journal of Economics and Economic Policy, 19*(3), 793–839. https://doi.org/10.24136/eq.3088.

Parton, L. C., Phaneuf, D. J., Taylor, L. O., & Lutzeyer, S. (2024). Bidding against the wind: A choice experiment in green energy, green jobs and offshore views in North Carolina, USA. *Journal of Environmental Management, 351,* 119821. https://doi.org/10.1016/j.jenvman.2023.119821..

Pavláková Dočekalová, M., Luňáček, J., Radil, L., Balcerzak, A. P., Meluzín, T., Łapińska, J., & Zinecker, M. (2024). Determinants of the relationship between wholesale and retail energy prices in the Czech Republic. *Acta Montanistica Slovaca, 29*(2), 332–342. https://doi.org/10.46544/AMS.v29i2.08.

Pérez-Pérez, B., Rodríguez-Segura, F. J., Osorio-Aravena, J. C., Díaz-Cuevas, P. & Frolova, M. (2026). Winds of change: Surfing prospects for offshore wind energy in coastal Spain (Cádiz). *Renewable and Sustainable Energy Reviews, 226*, 116451. https://doi.org/10.1016/j.rser.2025.116451.

Pietrzak, M. B., Igliński, B., Kujawski, W., & Iwański, P. (2021). Energy transition in Poland: Assessment of the renewable energy sector. *Energies, 14*(8), 2046. https://doi.org/10.3390/en14082046.

Popescu, G. H., Fortea, C., Nica, E., Antohi, V. M., Andrei, J. V., & Szpilko, D. (2025). Investments in the green transition and their impact on economic growth and competitiveness in the European Union. *Oeconomia Copernicana, 16*(4), 1665–1725. https://doi.org/10.24136/oc.3963.

Polskie Stowarzyszenie Energetyki Wiatrowej. (2024). *Wind energy reinvented: Necessary legislative changes and an analysis of onshore potential*.

Polskie Stowarzyszenie Energetyki Wiatrowej. (2025). *Wind energy in Poland*.

Reichartz, T., Jacobs, G., Hoffmann, J., Halber, J., Besseling, J., Blickwedel, L., Frings, D., & Schelenz, R. (2025). Techno-economic wind energy potential of Germany considering state-specific regulations. *Journal of Physics: Conference Series, 3025*, 012003. https://doi.org/10.1088/1742-6596/3025/1/012003.

Ren, Z., Zhang, S., & Yuan, Y. (2026). Beyond energy transition: Quantifying the multidimensional impacts of offshore wind power expansion in China. *Renewable Energy, 259*, 125155. https://doi.org/10.1016/j.renene.2025.125155.

REN21. (2025). *Renewables 2025: Global status report*.

Rybak, A., Rybak, A., & Kolev, S. D. (2024). Development of wind energy and access to REE: The case study of Poland. *Resources Policy, 90*, 104723. https://doi.org/10.1016/j.resourpol.2024.104723.

Schrader, T., Hornig, J., Kumme, R., Kniel, K., Jacob, S., & Härtig, F. (2025). Research to support the energy transition: Metrology for the expansion of wind energy in Germany. *Measurement: Sensors, 38*, 101851. https://doi.org/10.1016/j.measen.2025.101851.

Shah, R. (2024). *Redirecting wind energy in India*. https://ember-energy.org/app/uploads/2024/10/Report-Redirecting-wind-energy-in-India-2024.pdf.

Sharma, H., Wang, W., Huang, B., She, B., & Ramachandran, T. (2026). Control co-design under uncertainty for offshore wind farms: Optimizing grid integration, energy storage, and market participation. *Renewable Energy Focus, 10*, 100806. https://doi.org/10.1016/j.ref.2025.100806.

Sten, M., Mäkite, T., Hanson, J., *&* Normann, H. E. (2024). Developing the industrial capacity for energy transitions: Resource formation for offshore wind in Europe. *Environmental Innovation and Societal Transitions, 53*, 100925. https://doi.org/10.1016/j.eist.2024.100925.

Tian, G., Hua, X., Li, D., & Tian, J. (2025). How energy intensity and global energy dynamics shape renewable energy transition in APEC economies. *Geoscience Frontiers, 15*(6), 102134. https://doi.org/10.1016/j.gsf.2025.102134.

Trinh, L. D. (2025). Renewable energy and sustainable development: Evidence from lower middle-income countries. *Equilibrium. Quarterly Journal of Economics and Economic Policy, 20*(3), 905–926. https://doi.org/10.24136/eq.3440.

Wang, X., Ali, D. A., & Zhao, W. (2024). Urban energy transition and quality of life: A comprehensive statistical study on the nexus of wind clean energy adoption, job creation, and livability. *Sustainable Cities and Society, 108*, 105436. https://doi.org/10.1016/j.scs.2024.105436.

Wang, Y., Wang, X., Li, N., Balezentis, T., & Streimikiene, D. (2025). How does the digital economy drive CO_2 reduction in China? Evidence from a novel decomposition model and scenario analysis. *Oeconomia Copernicana, 16*(1), 247–281. https://doi.org/10.24136/oc.3168.

Warder, S. C., & Piggott, M. D. (2025). Mapping global offshore wind wake losses, layout optimisation, and climate change effects. *Energy, 331*, 136573. https://doi.org/10.1016/j.energy.2025.136573.

Wasilczuk, F., Kasprzak, P., Rybiński, M., Flaszyński, P., Dzierwa, P., Ziędalska, K., Kowalczyk, S., & Taler, D. (2025). Positive effect of wind farm control on energy production and revenue in European markets. *Energy, 326*, 136159. https://doi.org/10.1016/j.energy.2025.136159.

WindEurope. (2025). *Wind energy in Europe: Statistics and outlook for 2025–2030*.

Wojtaszek, H., Borowski, P. F., Handschke, M., Miciuła, I., Stecyk, A., Bielawa, A., Ozdyk, S., Kowalczyk, A., & Czepło, F. (2025). Wind energy transition: Development, socio-economic impacts, and policy challenges in Europe. *Energies, 18*(11), 2811. https://doi.org/10.3390/en18112811.

Wu, X., Xiao, Y., Xie, Y., Lan, Y., Li, J., Zhao, Y., & Xu, M. (2026). Uncovering the indoor health co-benefits of rural residential energy transition in Northern China. *Sustainable Production and Consumption, 63*, 1–18. https://doi.org/10.1016/j.spc.2025.12.013.

Xie, H., Gao, S., Zheng, J., & Huang, X. (2025). Distributed coordination of electricity–hydrogen–ammonia integrated energy system with aggregated distributed energy resources under high renewable penetration. *Energy, 339*, 139044. https://doi.org/10.1016/j.energy.2025.139044.

Xing, J. T., Zhang, G., & Sun, Z. (2026). Theoretical and numerical investigations on an integrated sea-wave-floating wind turbine energy harvesting system. *Ocean Engineering, 349*, 124223. https://doi.org/10.1016/j.oceaneng.2026.124223.

Xiong, S., Attar, R. W., & Ullah, S. (2025). Energy security risk and private sector development: A pathway to renewable energy investment in emerging economies. *Energy Strategy Reviews, 63,* 102012. https://doi.org/10.1016/j.esr.2025.102012.

Xue, Z., Zhang, Y., He, L., He, H., Wang, Z., Ding, Y., Wei, S., Zhang, X., & Zhang, Y. (2026). Numerical simulation of the aerodynamic characteristics of floating offshore wind turbines under inflow turbulence. *Results in Engineering, 29*, 109005. https://doi.org/10.1016/j.rineng.2026.109005.

Yang, G., Zha, D., Cao, D., & Zhang, G. (2024). Time for change: Rethinking the global renewable energy transition from the Sustainable Development Goals and the Paris Climate Agreement. *Innovation, 5*(2), 100582. https://doi.org/10.1016/j.xinn.2024.100582.

Yang, R., Xu, Y., Yi, Z., Li, Z., Tu, Z., & Wu, J. (2025). Adaptive multi-objective Bayesian optimization approach for capacity planning of interconnected offshore wind farms. *Energy, 337*, 138284. https://doi.org/10.1016/j.energy.2025.138284.

Yavuz, H. B., Aytun, C., & Cengiz, O. (2025). Energy efficiency, human development, and renewables as drivers of the load capacity factor: New evidence from Bucharest Nine (B-9) countries. *Oeconomia Copernicana, 16*(4), 1725–1767. https://doi.org/10.24136/oc.3880.

Zábojník, S., & Branch, J. D. (2025). EU decarbonization and industrial export competitiveness in a small open economy: A surprising resilience. *Equilibrium. Quarterly Journal of Economics and Economic Policy, 20*(4), 1339–1385. https://doi.org/10.24136/eq.4035.

Zhu, Q., & Sigitov, O. Y. (2025). Development of an energy complex of wind farms and thermal power plants in China. *Journal of Engineering Research, 26*(2), 181–193. https://doi.org/10.22363/2312-8143-2025-26-2-181-193.

Funding information

The research leading to these results has received funding from the project titled "Cluster for innovative energy" in the frame of the program "HORIZON-MSCA-2022-SE-01" under the Grant agreement number 101129820.

Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by the authors. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement

All data generated or analyzed are included in the published article. The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation. The raw anonymized data can be provided by emailing the primary author.

Author contributions

All listed authors have made a substantial, direct and intellectual contribution to the work, and approved it for publication. The authors take full responsibility for the accuracy and the integrity of the source analysis.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note