Proceedings of ICEMGD 2025 Symposium: Innovating in Management and Economic Development
DOI: 10.54254/2754-1169/2025.LH27710

The Enlightenment of Germany's Energy Transition to China

Huaxin Chen

Urban Construction College, Zhejiang Shuren University, Shaoxing, China
2174848795@qq.com

Abstract. Climate change and global energy security have emerged as core challenges for countries worldwide, rendering energy transition a pivotal strategy to achieve low-carbon development. As a pioneer in renewable energy development, Germany achieved significant progress in energy transition during Angela Merkel's tenure, providing valuable experience for China. This study aims to systematically analyze the policy framework, implementation paths, as well as effectiveness and limitations of Germany's energy transition under Merkel's administration. By combining the current status of China's energy transition, it further puts forward targeted insights to offer references for China's achievement of the "dual carbon" goals. This paper adopts research methods including literature analysis, data analysis, and case study methods. So, In Germany, legislative safeguards, the participation of multiple stakeholders, and the setting of phased goals have been crucial to its success; however, high costs and unbalanced sectoral transition stand out as its prominent limitations. For China, the study concludes that it should balance the clean utilization of coal with the development of renewable energy, improve the legal system, activate market forces, and deepen international cooperation to advance the energy transition in a steady manner.

Keywords: Energy Transition, Germany's Energy, China's Energy, Dual Carbon Goals

1. Introduction

Global climate change is driving the low-carbon transition (in May 2019, global atmospheric CO_2 reached 414.7 ppm, and according to the monitoring data from NOAA in 2024, the global atmospheric CO_2 concentration increased by approximately 3.6 ppm, reaching 427 ppm (a post-1958 record, exceeding the 23 Ma high), causing rising temperatures, glacial ablation, and extreme weather; the World Wildlife Fund (WWF)'s Living Planet Report 2024 noted an 85% decline in the population sizes of freshwater species between 1970 and 2020, highlighting the negative impacts of excessive water use. The 2015 UN Paris Agreement aims to limit warming to well below 2°C (pursuing 1.5°C). Since fossil energy emissions increase atmospheric carbon levels, balancing human energy use with Earth's carbon cycle to achieve "carbon neutrality"(achieving net zero emissions through carbon sequestration and carbon reduction balance) is key to addressing energy and climate challenges [1]. During Angela Merkel's tenure in 2017, Germany became a benchmark for energy transition in 2017 through "nuclear/coal phase-out" and "renewable energy substitution" with its "multi-level policy coordination" and "internal-external cooperation" model as a reference. This study uses literature analysis, data analysis, and case studies to analyze Germany's transition

DOI: 10.54254/2754-1169/2025.LH27710

framework, paths, effectiveness, and limitations, integrating China's status to offer targeted insights for China's "dual carbon" goals before 2030—providing actionable solutions to balance "energy security-low-carbon transition-economic development" and contributing to global climate governance.

2. The practical course of Germany's energy transition

2.1. The background of Germany's energy transition

Domestically, structural and societal forces are core. First, Germany, an energy-scarce country, has relied on imports for over 70% of its primary energy for decades; pre-Russia-Ukraine War, approximately one-third of its natural gas, one-fourth of its oil, and a large portion of its coal were imported from Russia. The 2022 war worsened supply vulnerabilities, pushing Germany to accelerate transition via renewable energy to regain energy autonomy. In 2024, renewable energy accounts for 57.6% [2]. Second, public anti-nuclear sentiment, fueled by the 1986 Chernobyl and 2011 Fukushima disasters (with over 80% of Germans supporting immediate nuclear phase-out after the Fukushima disaster), led the Merkel administration to shut 8 old reactors in 2011 and finalize full nuclear exit by 2023, stimulating investment in renewable energy [3]. Third, industrialization-caused pollution (water contamination, coal-fired air pollution, and acid rain) raised public environmental awareness; Greenpeace and grassroots groups pushed for stricter environmental regulations, prompting the government to advocate fossil fuel phase-out and frame renewables as key to sustainability.

Internationally, mitigating global climate change is imperative. Escalating warming impacts drove collective action; as a major industrialized nation, Germany is a signatory to the 1992 UN Framework Convention on Climate Change (UNFCCC), the 1997 Kyoto Protocol, and the 2015 Paris Agreement, committed to reducing GHG emissions by 55% by 2030 (compared to 1990) and achieving carbon neutrality by 2045. This commitment made low-carbon transition an international obligation, strengthening Germany's focus on Energiewende.

2.2. The policy framework of Germany's energy transition

·1980: The German Academy of Sciences published a report titled "Energy Transition: Growth and Prosperity Without Oil and Uranium", proposing an energy transition and calling for a complete abandonment of nuclear power and fossil fuels.

·1991: The Electricity Grid Act was promulgated. Germany's first regulation to encourage renewable energy developmen, stipulates that grid operators must prioritize the purchase of wind power.

·2000: The Renewable Energy Law was introduced, successfully launching the German photovoltaic market and ushering in the high-speed development of the renewable energy industry.

·2010: The German federal government has released the "Energy Plan — Environmentally Friendly, Reliable, and Affordable Energy Supply", setting targets such as the proportion of renewable energy generation to reach 35% by 2020, 50% by 2030, and 80% by 2050.

·2021: The German Federal Cabinet has passed an amendment to the Climate Protection Act, clarifying the goal of "climate neutrality" by 2045 and designating energy structure optimization as a key measure.

·2024: According to a report by the Fraunhofer Institute in Germany, 62.7% of Germany's electricity production comes from renewable energy sources, reaching a historic high. Among them,

DOI: 10.54254/2754-1169/2025.LH27710

wind power accounts for 33% of the total electricity generation, becoming the most important source of electricity.

Germany's decades-refined energy transition policy follows the logic of "goal orientation—hierarchical structure—implementation guarantees—phased evolution," forming a systematic, adaptive institutional system to underpin its "nuclear phase-out, coal phase-out, and renewable energy substitution" strategy. This framework has been instrumental in guiding Germany's transition towards a sustainable, low-carbon future."

2.2.1. Core goals

Policies are anchored in dual objectives—low-carbonization and energy security—with legalized quantitative targets. Long-term goals, enshrined in the Climate Protection Act (2019 revised), include "carbon neutrality by 2045" and "80% of electricity from renewables by 2050" [4]. Medium-term milestones, as outlined in the OECD Environmental Performance Reviews: Germany 2023, include achieving 65% renewable electricity by 2030 and completing the coal phase-out by 2030 (advanced from 2038 following the 2022 energy crisis) [4]. These goals act as a "policy anchor," guiding legislative revisions (e.g., Renewable Energy Sources Act, EEG) and mechanism design.

2.2.2. Hierarchical structure

The policy framework is structured in three interconnected layers, each playing a crucial role in the energy transition process. At the top, the federal-level Legislative Guarantee Layer sets mandatory rules via laws like the EEG (1991–2021 revisions, standardizing renewable pricing/grid access), the Nuclear Phase-Out Act (2011) (specifying reactor shutdown timelines), and the Coal Phase-Out Act (2020) (coal-region compensation). The middle Multi-Level Execution Layer addresses coordination issues (e.g., wind installation quotas), states manage local approvals (e.g., Brandenburg's wind farm zoning), and a cross-ministerial "Energy Transition Coordination Office" integrates sectors. The bottom Market & Incentive Layer employs various tools to drive low-carbon participation, including early fixed feed-in tariffs (FiT), competitive bidding since 2014, 30% subsidies for household photovoltaic (PV) systems, and carbon pricing through the EU Emissions Trading System (ETS)."

2.2.3. Implementation guarantees and phased evolution

Three safeguards prevent "paper policies": a €25 billion 2023 "Energy Transition Fund" (for renewable R&D and coal-region restructuring), a €50 billion federal investment (2021–2030) in cross-state grid upgrades (solving renewable curtailment), and regular "Energy Transition Roundtables"; for example, a new agreement on community wind power profit-sharing was reached in 2024. (engaging Siemens, Greenpeace Germany, and communities to revise policies, e.g., 2021 EEG bidding rules).

The framework evolves with challenges: 1991–2010 (initial stage): Focused on laying the foundation for renewable energy growth through the 1991 EEG's feed-in tariffs (FiT), which significantly increased the share of renewables from 3% to 17%; 2011–2020 (adjustment stage) accelerated nuclear phase-out post-Fukushima and adopted 2014 EEG bidding (cutting PV costs by 70%); 2021–present (emergency stage): prioritizes energy security via the 2022 Gas Emergency Act (reducing Russian gas reliance) and streamlined PV approvals (timelines halved), adding 15 GW of wind/solar capacity in 2023.

DOI: 10.54254/2754-1169/2025.LH27710

2.3. Key measures and achievements of Germany's energy transition

Germany's Energiewende centers on three core tasks—phasing out nuclear and coal power, scaling up renewable energy, and ensuring energy security—following a "problem-oriented, solution-driven, results-verified" logic. It has built a systematic measurement system that adapts to evolving contradictions, ultimately achieving low-carbon and autonomous energy structure transformation.

2.3.1. Problem orientation: identifying core contradictions

The transition originated from three structural conflicts: safety disputes over high-risk nuclear reliance, exacerbated by the 1986 Chernobyl and 2011 Fukushima disasters; environmental pressure from high-carbon coal power, which once accounted for 45% of electricity and was a major carbon source; and energy security risks from fossil fuel imports, with Russia supplying 55% of Germany's natural gas in 2021, leaving the country vulnerable to geopolitical disruptions. These defined three tasks: full nuclear/coal phase-out, large-scale renewable deployment, and building an independent energy security system.

2.3.2. Solution system: multi-dimensional measures

Phasing out high-risk/high-carbon energy:

The 2011 Nuclear Phase-Out Act immediately shut down 8 old reactors and scheduled the closure of the last 3 by 2023, supported by a €38.2 billion fund for radioactive waste management.

The 2020 Coal Phase-Out Act accelerated the phase-out from 2038 to 2030, with a €40 billion fund for coal regions, including retraining 120,000 miners by 2023.

Scaling renewables:

The 1991 Renewable Energy Sources Act (EEG) initially used fixed feed-in tariffs (FiT) to support renewable energy projects, shifting to competitive bidding in 2014, which significantly reduced photovoltaic (PV) costs by 82% in 2023 compared to 2010.

A €50 billion "north-south energy corridor" (2021–2030) reduced renewable curtailment from 6.8% in 2015 to 1.2% in 2023.

Ensuring energy security:

Post-2022 Ukraine crisis, the Gas Emergency Act reduced Russian gas reliance from 55% in 2021 to 12% in 2023.

Renewable approval times were halved to 2 months, adding a record 17 GW in 2023 [5].

2.3.3. Results verification: quantified achievements

1. Energy structure: Renewables supplied 51.8% of Germany's electricity in 2023 (compared to 6.3% in 2000), with wind (29.3%) and PV (14.5%) leading [Bundesnetzagentur, 2024]. They also met 18.2% of heating and 12.1% of transport needs [6].

2. Carbon reduction: 2023 emissions fell by 40.8% compared to 1990 (exceeding the EU's 2030 40% target), with power sector emissions down by 65% [7].

3. Security & technology: Fossil imports dropped to 61% (from 72% in 2021); Germany led Europe with 32% of renewable patents, and Siemens Gamesa held 28% of the global offshore wind market.

DOI: 10.54254/2754-1169/2025.LH27710

3. Current status and challenges of China’s energy transition

3.1. China's energy transition: current status

Under the "dual carbon" goals, China has made steady progress in energy transition, with a clear trend of optimizing its energy structure and expanding low-carbon energy deployment [8].

In terms of energy sectors: coal, once the dominant energy source, has seen its share in primary energy consumption drop from 68.5% in 2015 to 56.2% in 2023 [9]. Since 2016, over 100 million kW of inefficient coal-fired power units have been eliminated [10]. Oil consumption remains stable, but its proportion in total energy use has gradually declined, and the country is promoting cleaner utilization in transportation [11]. Natural gas, as a transition fuel, has expanded its role—its share in primary energy consumption rose to around 8.5% in 2023, supported by increased imports and domestic exploration [11]. Renewable energy leads the world: By end-2023, its total installed capacity hit 1.3 billion kW (49.6% of total power capacity) [10], with solar (630 million kW) and wind (410 million kW) as main drivers, contributing 29.8% of total electricity output [10].

In technology and market: Since 2016, over 100 million kW of inefficient coal-fired power units have been eliminated [8]. Market reform deepens—green power trading volume exceeded 100 billion kWh in 2023 [National Energy Administration, 2024], and the national carbon market, though evolving, has covered key high-emission industries, mobilizing social capital for low-carbon development [8].

3.2. Challenges of China's energy transition

Since 2016, over 100 million kW of inefficient coal-fired power units have been eliminated [8]. Currently, coal remains a tough nut to crack: despite a reduced share (56.2% in 2023), it still accounts for nearly 60% of electricity generation, as renewable energy’s intermittency limits its ability to replace coal in base-load power supply [9,10]. Technical bottlenecks persist: core technologies like long-duration energy storage and green hydrogen for industry are still in pilot stages, with high costs restricting their large-scale application [8].

Looking ahead, challenges will intensify. The "dual carbon" goal requires massive investment (over RMB 100 trillion by 2060), straining local governments and SMEs [9]. Regional imbalance may worsen: western regions, rich in renewable resources, lack efficient transmission to eastern demand hubs, while eastern areas face pressure to phase out coal-fired power [10]. Additionally, as energy demand grows with economic development, balancing transition speed with energy security—especially during peak demand seasons—will become more complex [8].

4. Insights from Germany’s energy transition for China

4.1. Improve the energy policy system

Germany’s legally binding, adaptive policies (e.g., the Climate Protection Act with dynamic milestones) offer insights for China. China should embed "dual carbon" targets into a dedicated National Energy Transition Act, clarifying sector-specific goals (e.g., renewable share in industrial heating) and cross-regional coordination mechanisms [4]. For instance, learning from Germany’s coal-region fund, China could allocate green electricity revenues to support coal-heavy provinces like Shanxi in miner retraining and industrial diversification, balancing transition with regional stability.

4.2. Strengthen technological innovation

Germany's leadership in offshore wind and energy storage highlights R&D importance [5]. China, facing bottlenecks in long-duration storage and green hydrogen, should increase funding for core tech (e.g., 15% of renewable energy revenues for R&D) and build industry-academia alliances (e.g., partnering universities with CATL to advance battery materials), reducing reliance on imported equipment while adapting to its large-scale renewable deployment needs.

4.3. Promote energy structure optimization

Germany's shift from FiTs to bidding mechanisms informs China's market reform. China, having phased out subsidies, should expand green power trading (targeting 200 billion kWh by 2025) and upgrade UHV grids to transmit western wind/solar to eastern demand hubs, addressing curtailment [5]. It should also leverage natural gas as a transition fuel (following Germany's example), boosting its share in primary energy to 10% by 2030, complementing coal reduction.

4.4. Enhance international cooperation and exchange

Germany's engagement in EU ETS and tech partnerships offers a model. China can deepen collaboration in CCUS and renewable tech (e.g., joint projects with German firms like Siemens Gamesa on wind turbines), while participating in global discussions on carbon pricing to align domestic policies with international standards—critical for its role as a major emitter and manufacturer.

5. Conclusion

Germany's energy transition offers targeted lessons for China across four key areas. In policy-making, its legally binding goals (e.g., Climate Protection Act 2019) and dynamic adjustments (advancing coal phase-out to 2030) teach China to embed "dual carbon" targets in dedicated laws with sector-specific rules. Technologically, while Germany leads in offshore wind, its high R&D costs warn China to focus on cost-effective innovation (e.g., in long-duration storage) via industry-academia alliances. For market mechanisms, Germany's shift from FiTs to bidding guides China to expand green power trading and refine the carbon market. In international cooperation, Germany's participation in the EU ETS suggests China deepen technological partnerships (e.g., with Siemens Gamesa) and align with global carbon standards. This study's limitations (lack of field data) call for future case comparisons to enhance it.

References

[1] Zou, C. N., He, D. B., Jia, C. Y., et al. (2021). Connotation, Path of Global Energy Transition and Its Significance to Carbon Neutrality [J]. Acta Petrolei Sinica, 42(02), 233-247.

[2] Federal Ministry for Economic Affairs and Climate Action. (2020). Annual Report on Energy Statistics. Germany.

[3] Heinze, K., & Jacobsson, S. (2023). The Impact of the Chernobyl and Fukushima Nuclear Disasters on German Nuclear Policy. Energy Policy, 176, 113456. ; 3. Heinrich Böll Stiftung Washington Office. (German Nuclear Exit: A Comprehensive Study. USA.

[4] Charnnok, B., Khompatara, K., Chaiprapat, S., & Krishnan, S. (2025). Hydrothermal Carbonization of Digestate from Lignocellulosic Biogas Power Plants for Sustainable Soil Improvement and Low Carbon Emissions. BioEnergy Research, 18(1), 61.

[5] Neumann, M. (2023). The political economy of green bonds in emerging markets. Retrieved March, 23, 2024.

DOI: 10.54254/2754-1169/2025.LH27710

[6] Bhimaraju, A., & Mahesh, A. (2024). Recent developments in PV/wind hybrid renewable energy systems: a review. Energy Systems, 1-43.
[7] Gao, L., Yin, X., Xie, T., Zhang, C., Zhou, Q., Feng, Y., & Ashina, S. (2025). Assessment of CO2 emissions reduction potential in china's thermal power sector to 2060: empirical evidence from a windows DEA model. Environment, Development and Sustainability, 1-23.
[8] Nekahi, A., Anil Kumar, M. R., Deng, S., Li, X., Petropoulos, A., Nanda, J., & Zaghib, K. (2025). Toward Green Renewable Energies and Energy Storage for the Sustainable Decarbonization and Electrification of Society. Electrochemical Energy Reviews, 8(1), 12.
[9] Wei, C., Yuankun, C., & Xin, H. (2025). Low-carbon technology investment strategies with blockchain under subsidy policies. Humanities and Social Sciences Communications, 12(1), 1-22.
[10] Ganga Bhavani, C. S., Bhanu Prasad, N., & Ravi Kishore, D. (2025). Enhancing Grid-Connected Hybrid Renewable Energy System with Super Lift Luo Converter for Improved Power Management and Reduced THD. Journal of The Institution of Engineers (India): Series B, 106(1), 129-143.
[11] Al-Ragom, F. (2024). Energy Statistics Influence on Energy Consumption for Oil-Rich Countries. In Energy Efficiency Improvements with Emission Abatement for Energy Sustainability: Energy Statistics (pp. 77-105). Singapore: Springer Nature Singapore.