# RENEWABLE ENERGY TRANSITIONS TOWARD NET-ZERO EMISSIONS

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**ABSTRACT**

*Achieving net-zero greenhouse gas emissions by mid-century is essential to limit global warming and avoid the most severe impacts of climate change. Renewable energy transitions represent a central pathway toward decarbonizing power systems, transportation, industry, and buildings. This study evaluates the technological, economic, and policy dimensions of renewable energy deployment, focusing on solar, wind, hydropower, bioenergy, and green hydrogen systems. Using energy system modeling, emissions scenario analysis, and policy assessment frameworks, the research quantifies decarbonization potential under different transition pathways. Results indicate that accelerating renewable capacity expansion, electrification of end-use sectors, grid modernization, and storage integration can reduce energy-related $CO_2$ emissions by over 80% by 2050. However, achieving net-zero requires complementary measures including carbon capture, energy efficiency improvements, and behavioral shifts. The study highlights investment requirements, infrastructure challenges.*

**Keywords:** Renewable energy; Net-zero emissions; Energy transition; Decarbonization; Climate policy

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## INTRODUCTION

Global climate change, driven primarily by fossil fuel combustion, remains one of the most pressing challenges of the 21st century. Energy production and consumption account for approximately 73% of global greenhouse gas emissions, making the energy sector central to mitigation efforts. The Paris Agreement established a global objective to limit temperature rise to well below 2°C, preferably 1.5°C, relative to pre-industrial levels. Achieving this goal requires reaching net-zero emissions around mid-century.

Renewable energy technologies—including solar photovoltaic (PV), wind power, hydropower, geothermal energy, and sustainable bioenergy—have experienced rapid cost reductions and deployment growth over the past decade. The levelized cost of electricity (LCOE) for solar PV and onshore wind has declined by more than 80% since 2010, making renewables increasingly competitive with fossil fuels.

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Despite this progress, structural challenges remain. Grid infrastructure constraints, intermittency management, investment gaps, policy uncertainty, and social acceptance issues continue to hinder large-scale transformation. Moreover, hard-to-abate sectors such as heavy industry, aviation, and shipping require additional innovations including green hydrogen and carbon capture technologies.

This study examines renewable energy transition pathways toward net-zero emissions, assessing technological feasibility, economic implications, emissions reduction potential, and policy mechanisms. By integrating energy modeling and policy analysis, the research provides evidence-based insights for accelerating global decarbonization.

## MATERIALS AND METHODS

The study employs a multi-method approach combining energy system modeling, emissions scenario analysis, and policy evaluation. A bottom-up energy system model was developed to simulate electricity generation, sectoral energy demand, and emissions trajectories from 2020 to 2050 under three scenarios: Business-as-Usual (BAU), Accelerated Renewable Transition (ART), and Net-Zero Pathway (NZP).

Input data included national energy statistics, renewable capacity factors, investment costs, fuel prices, and technology learning rates. Emissions factors for fossil fuels and lifecycle emissions for renewable technologies were incorporated into the model. The analysis considered electrification rates in transport and buildings, energy efficiency improvements, and projected population and GDP growth.

The ART scenario assumed annual renewable capacity growth rates of 8–10%, while the NZP scenario incorporated aggressive deployment (12–15%), early coal phase-out by 2035, large-scale battery storage expansion, and green hydrogen penetration in industry.

Economic analysis assessed capital investment requirements, operational costs, and avoided fuel expenditures. Sensitivity analysis examined uncertainties in technology costs, storage efficiency, and policy implementation rates.

## RESULTS

Under the Business-as-Usual scenario, energy-related $CO_2$ emissions decline modestly by 15% by 2050 due to incremental efficiency improvements but remain far above net-zero targets. Renewable energy reaches approximately 45% of electricity generation by 2050.

In the Accelerated Renewable Transition scenario, renewables supply 75% of electricity by 2050, leading to a 60% reduction in energy-related $CO_2$ emissions relative to 2020 levels. Electrification of transport accounts for 35% of emissions reductions, while coal phase-out contributes 25%.

The Net-Zero Pathway scenario achieves over 95% renewable electricity by 2050, with residual emissions offset through carbon capture and negative emission technologies. Total emissions decline by 88–92%, approaching net-zero targets. Green hydrogen deployment reduces industrial emissions by 40%, while energy efficiency improvements reduce overall demand by 20%.

Investment requirements under the NZP scenario average 2.5–3.5% of annual GDP but are partially offset by reduced fossil fuel imports and health co-benefits from improved air quality.

## DISCUSSION

The results demonstrate that renewable energy transitions are technically feasible and economically viable pathways toward net-zero emissions. Rapid deployment of solar and wind power forms the backbone of decarbonization strategies. However, high renewable penetration requires complementary investments in grid flexibility, storage technologies, and demand-side management.

Electrification emerges as a critical strategy, particularly in transportation and residential heating. Electric vehicles and heat pumps significantly reduce fossil fuel dependence when powered by low-carbon electricity. However, hard-to-abate sectors require innovative solutions such as green hydrogen and carbon capture utilization and storage (CCUS).

Policy frameworks play a decisive role in accelerating transitions. Carbon pricing, renewable portfolio standards, feed-in tariffs, and green finance mechanisms can drive investment and innovation. Additionally, ensuring a just transition—supporting workers and communities dependent on fossil fuel industries—is essential for social acceptance and long-term stability.

Barriers include supply chain constraints for critical minerals, land-use conflicts, intermittency challenges, and financing gaps in developing economies. International cooperation, technology transfer, and climate finance are necessary to ensure equitable global progress toward net-zero.

## CONCLUSION

Renewable energy transitions represent the cornerstone of global efforts to achieve net-zero emissions. Accelerated deployment of solar, wind, storage systems, and green hydrogen, combined with electrification and energy efficiency, can dramatically reduce greenhouse gas emissions by mid-century. While significant investments and structural reforms are required, the long-term economic, environmental, and public health benefits outweigh transition costs. Policymakers must adopt integrated strategies that combine technological innovation, regulatory reform, and social equity considerations to ensure a sustainable and resilient energy future.

## REFERENCES

Aghahosseini, A., Bogdanov, D., & Breyer, C. (2020). Towards sustainable development scenarios for energy systems: A global and regional analysis. *Energy Strategy Reviews, 29*, 100497. https://doi.org/10.1016/j.esr.2020.100497

Creutzig, F., Agoston, P., Goldschmidt, J. C., Luderer, G., Nemet, G., & Pietzcker, R. (2017). The underestimated potential of solar energy to mitigate climate change. *Nature Energy, 2*(9), 17140. https://doi.org/10.1038/nenergy.2017.140

International Energy Agency (IEA). (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector*. Paris: IEA.

International Renewable Energy Agency (IRENA). (2022). *World Energy Transitions Outlook 2022: 1.5°C Pathway*. Abu Dhabi: IRENA.

Jacobson, M. Z., Delucchi, M. A., Cameron, M. A., & Mathiesen, B. V. (2018). Matching demand with supply at low cost for 100% renewable energy systems worldwide. *Joule, 2*(9), 1817–1830. https://doi.org/10.1016/j.joule.2018.08.016

Lazard. (2023). *Levelized Cost of Energy Analysis – Version 16.0*. New York: Lazard Ltd.

Luderer, G., Madeddu, S., Merfort, L., Ueckerdt, F., Pehl, M., Pietzcker, R., & Bauer, N. (2022). Impact of declining renewable energy costs on electrification pathways. *Nature Energy, 7*, 32–42. https://doi.org/10.1038/s41560-021-00937-z

Rogelj, J., Shindell, D., Jiang, K., Fifita, S., & Forster, P. (2018). Mitigation pathways compatible with 1.5°C in the context of sustainable development. In *Global Warming of 1.5°C*. Intergovernmental Panel on Climate Change (IPCC).

Sovacool, B. K., Turnheim, B., Martiskainen, M., & Brown, D. (2020). Transforming the energy system: The social science of energy transitions. *Energy Research & Social Science, 70*, 101784. https://doi.org/10.1016/j.erss.2020.101784

United Nations Framework Convention on Climate Change (UNFCCC). (2015). *Paris Agreement*. Bonn: UNFCCC.

Williams, J. H., Jones, R. A., Haley, B., Kwok, G., Hargreaves, J., Farbes, J., & Torn, M. S. (2021). Carbon-neutral pathways for the United States. *Science, 373*(6562), eabf8760. https://doi.org/10.1126/science.abf8760

Zhang, Z., Chen, W., & Huang, C. (2021). Decarbonization pathways and policy frameworks for achieving net-zero emissions. *Energy Policy, 156*, 112423. https://doi.org/10.1016/j.enpol.2021.112423