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MONGOLIA'S ENERGY TRANSITION: BETWEEN CLIMATE GOALS AND COAL LEGACY

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Abstract

Mongolia is at a critical juncture in its energy transition, seeking to reconcile ambitious climate targets with its historical reliance on coal. Coal currently accounts for the majority of electricity generation and industrial energy consumption, making the transformation of the energy system both urgent and complex. This study provides a comprehensive analysis of Mongolia's energy transition, focusing on the potential of renewable energy, the structure of the energy balance, and technological barriers to low-carbon energy deployment. Using a mixed-methods approach that combines energy statistics and analysis of national energy strategies, the study identifies key drivers and constraints for the adoption of solar, wind, and other renewable energy sources. The results indicate that Mongolia has substantial renewable energy potential, particularly in wind and solar; however, the existing coal infrastructure, limited grid capacity, and financial barriers slow the transition. The study demonstrates that effective integration of renewables into the energy system requires grid modernization, optimization of energy flows, and deployment of energy storage technologies. The findings highlight that a successful energy transition in Mongolia could simultaneously achieve low-carbon development and enhance the country's energy resilience. The practical significance of this research lies in providing evidence-based recommendations for government policy on renewable energy deployment, energy infrastructure modernization, and social equity in the transition process, contributing to a sustainable, environmentally safe, and socially responsible development of Mongolia's energy sector.

Keywords: renewable energy, energy transition, energy sector, energy system transformation, coal-based generation, clean energy

Introduction

Current global trends in energy development demonstrate that the transition to a low-carbon economy is not only an environmental imperative but also a strategic requirement for sustainable socio-economic growth. For Mongolia, this challenge is particularly complex due to the structural dependence of the national energy system on coal, which remains the primary resource for electricity and heat production. While this model ensures the country's energy stability, it simultaneously generates significant environmental and social risks that require urgent attention (Sumiya, E. et al., 2023).

Air quality and public health issues are especially acute in Mongolia, exacerbated by the cold climate (Ma S. et al., 2025) and the high urban population density, making pollution a national concern (Nyam-Osor, N. et al., 2024). Air monitoring data indicate that high pollution levels, primarily caused by coal combustion in thermal power plants and household stoves, correlate with increased respiratory diseases, premature mortality, pregnancy complications, and higher cardiovascular risk (Choi, S., Munkhsaikhan, Z., & Oh, J., 2022). Vulnerable groups include children, the elderly, and residents of traditional yurt settlements, where the use of low-quality coal during winter is essential for survival (Dickinson-Craig, E., 2023).

Thus, Mongolia's coal-based energy model produces a broad spectrum of negative externalities that constrain socio-economic development, increase healthcare system costs, and reduce overall quality of life (Lee H. et al., 2024). A just energy transition for Mongolia, therefore, involves not only a technical shift to renewables but also a comprehensive transformation aimed at protecting public health (Jia H. et al., 2024). This is particularly relevant given the country's exceptionally high potential for solar and wind energy, which could significantly reduce dependence on coal.

In this context, long-term strategic planning is especially important. Mongolia aims to achieve 30% renewable energy capacity by 2030, reflecting the country's commitment to a low-carbon economy, as outlined in the Vision 2050 Strategy (Vision 2050). This goal is feasible because Mongolia's renewable energy potential is estimated at 2,600 GW, including wind and solar energy (Assessment & Status Report, 2024), more than 1,000 times the country's current installed electricity capacity of 1.6 GW (Solar, 2024). Unfortunately, by the end of 2024, electricity generation from renewables accounted for only about 9% of the total (6.2% wind, 2.3% solar, 0.5% hydro), well below the estimated global average of 30% for 2024. This underscores the need to strengthen development and investment in the sector (Solar, 2024; Assessment & Status Report, 2024).

Despite Mongolia's exceptionally high technical potential for renewables, its deployment remains limited due to a complex set of interrelated structural barriers (Ganbat K., 2025). Chief among these is infrastructural insufficiency: the national electricity system was historically designed to meet the needs of centralized thermal generation and is characterized by low flexibility, insufficient interregional transmission capacity, and vulnerability to seasonal fluctuations (Sarnai B. and Shobhakar D., 2023). The absence of modern energy storage systems and low levels of digitalization in dispatch management restrict the integration of significant shares of variable solar and wind generation (Nergui O. et al., 2025).

Literature Review

A review of the literature indicates that the issues of energy transition and the interrelationship between economic development and CO_2 emissions have attracted significant scholarly attention for decades. Early studies primarily focused on quantitative analyses of correlations between economic growth, fossil fuel consumption, and CO_2 emissions, using simple statistical and regression models (Grossman & Krueger, 1991; Shafik & Bandyopadhyay, 1992). Later research expanded the focus to include structural and technological aspects of the energy sector, the efficiency of renewable energy deployment, and the nonlinear interactions between economic development and environmental impacts (Sadorsky, 2012; Apergis & Payne, 2010).

Contemporary studies increasingly emphasize the environmental and social consequences of coal-based generation in low-industrialized countries, which aim to simultaneously address socio-economic development challenges and entrenched carbon dependence. Mongolia is among the leading countries in this regard (Plotkin J. et al., 2023; Levchenko S., 2023; Ma S. et al., 2025; Khan I. et al., 2025).

Specifically, the NewClimate Institute report highlights the impact of coal-fired thermal power plants on public health in Mongolia, estimating that the introduction of new coal generation capacity could result in over 1,600 premature deaths by 2050 if planned coal plant construction proceeds (The important health, 2020). Similarly, the Asian Development Bank (ADB) notes that the highest air pollution in Ulaanbaatar is associated with coal use in household "ger" districts. Even after replacing rudimentary coal stoves with briquettes, pollution levels remain above WHO safe standards (Cardascia S., Cowlin S., 2022).

The OECD, in its report *"Towards a Renewable Hydrogen Strategy for Mongolia,"* emphasizes that the country's coal-based energy sector constitutes a major barrier to environmentally sustainable development while simultaneously outlining strategies for renewable energy deployment (OECD). The UNDP Mongolia reports stress the need to transition to "clean" energy, taking into account public health, social equity, and human development (UNDP). Within the *Just Energy Transition* program, UNDP collaborates with the Mongolian government to reduce coal dependence, modernize infrastructure, and increase renewable energy investment (UNDP).

Scholarly research also underlines the necessity of decarbonizing Mongolia's energy system. Guo S., He R., Bayaraa M., and Li J. (2020) provide a comprehensive long-term analysis of Mongolia's greenhouse gas emissions and identify key drivers, offering policymakers valuable insights for implementing sector-specific measures. Liu X., Yu J., et al. (2025) highlight the urgency of accelerating renewable energy deployment to address energy poverty among nomadic herders and meet basic energy needs. Balgansuren O. and Arunotai N. (2025) focus on energy poverty issues in Ulaanbaatar's ger districts, while Battulga S. and Dhakal S. (2024) emphasize stakeholder engagement in achieving sustainable electricity supply. Nergui, Paisiripas, and Jargalsaikhan (2025) analyses the combined use of solar and wind generation, energy storage systems, and small modular reactors (SMRs) as a pathway toward energy stability and emissions reduction.

Thus, the literature demonstrates significant scholarly attention to the interconnection between economic development, energy structure, and CO_2 emissions, as well as the role of renewable energy in global decarburization (Farzaneh H. et al., 2022). However, despite important empirical and policy research, the specifics of Mongolia's energy system—particularly the impact of its coal legacy on the pace and effectiveness of the country's energy transition—remain insufficiently explored, highlighting the relevance of this study.

The aim of this study is to assess Mongolia's current energy transition, its potential for renewable energy development, and the influence of the country's coal legacy on achieving climate goals.

Based on this aim, the main objectives of the study are:

- To analyze the current structure of Mongolia's energy system;
- To evaluate the progress of the country's energy transition in recent years;
- To identify possible pathways for low-carbon energy development, enabling the integration of renewable energy sources and advancing the country toward its climate targets.
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Research Methods

The study employs a comprehensive mixed-methods approach, combining quantitative and qualitative analyses of Mongolia's energy system. Statistical data on the energy balance and electricity consumption, structural indicators of generation and coal dependence, and assessments of renewable

energy potential, particularly solar and wind, were utilized. The analysis drew on energy and strategic documents, national renewable energy development plans, and international reports on energy transition and decarburization.

System analysis was applied to assess grid conditions, the potential for renewable energy integration, and the need for energy storage technologies. Additionally, a comparative analysis of possible energy transition trajectories was conducted, evaluating risks and identifying opportunities to optimize energy flows while considering the coal legacy and the country's climate commitments. This broad methodological approach provided a holistic picture of renewable energy potential, identified key transition barriers, and formulated evidence-based recommendations to accelerate Mongolia's low-carbon energy transformation.

Results

Mongolia's energy system is characterized by a high dependence on coal, which dominates electricity generation and industrial energy consumption. This structure results in significant greenhouse gas emissions, environmental pollution, and low generation and transmission efficiency. The country's energy infrastructure is outdated, transmission networks are underdeveloped, and a reliable energy supply for remote regions remains a challenge. These factors complicate the modernization of the energy sector and present substantial barriers to transitioning toward a more sustainable and low-carbon energy system.

As a result, Mongolia, despite its small population, ranks 17th globally in per capita CO_2 emissions—11.2 tons per person in 2022—primarily because 91% of energy supply comes from thermal power plants, small boiler houses, and household stoves in nomadic areas (Battulga S. & Dhakal S., 2024). During winter, this leads to pollution levels exceeding WHO standards by up to eight times (World Bank Group, 2024).

Due to Mongolia's reliance on fossil fuels and economic growth, CO_2 emissions from the energy sector have increased by 59.6% over the past decade (Advancing carbon market, 2025).

Table 1 – Different Measures of Mongolia's Carbon Footprint (World Bank Group, 2024)

Country	GHG emissions per capita (tCO2 e per capita	Carbon intensity (tCO2 e per US$ million of GDP)	Total GHG emissions (MtCO2 e)	Annual GHG emissions growth rate (% between 2010 and -2021)
China	9,1	721	12,792	2,2
Indonesia	5,4	1,252	1,485	0,4
Kazakhstan	16,8	1,665	318	0,1
Mongolia	23,7	5,224	79	3,0
Singapore	12,4	170	67	14
Thailand	6,4	888	449	2,2

According to the WHO guidelines, the annual mean concentration of fine particulate matter (PM2.5) should not exceed 5 μg/m³. In Mongolia, however, this value reaches 41 μg/m³ (World Health Organization, 2023). Air pollution from coal-based electricity generation causes approximately 2,839 deaths annually and results in economic losses of 905 billion MNT, equivalent to 2.4% of the country's GDP (UNDP, 2024). Additionally, coal-based household stoves contribute to up to 4,300 deaths per year and economic losses of 3.9 trillion MNT, representing around 7.6% of GDP (Sainnokhoi T. et al., 2024; Sainnokhoi T., 2024; UNDP, 2024).

In Ulaanbaatar, air pollution is linked to high rates of bronchial asthma, chronic bronchitis, and ischemic heart disease (Asian Development Bank, 2022; Bayart N. et al., 2024). Vulnerable populations include children, the elderly, and individuals with weakened immune systems (Woolley K. E. et al., 2022; Dai Z., Woolley K., 2025). According to studies conducted by the National Institute of Public Health of Mongolia over the past five years, the incidence of respiratory infections among children in Ulaanbaatar has increased by 40% (Otgonbyamba O. et al., 2023).

World Bank research indicates that electrifying heating systems in ger districts through renewable energy development could reduce PM2.5 concentrations by up to 120 μg/m³, potentially decreasing annual DALY burdens and mortality by up to 40% (World Bank Group, 2024). Furthermore, under Mongolia's Nationally Determined Contribution (NDC) within the framework of the Paris Agreement, the country has committed to green economic objectives, positioning sustainable development as a cornerstone of its *Vision 2050*, ratified by Parliament (Resolution No. 52, adopted May 13, 2020) — aiming to reduce greenhouse gas emissions by 22.7% by 2030 compared to the baseline year 1990 (Figure 1).

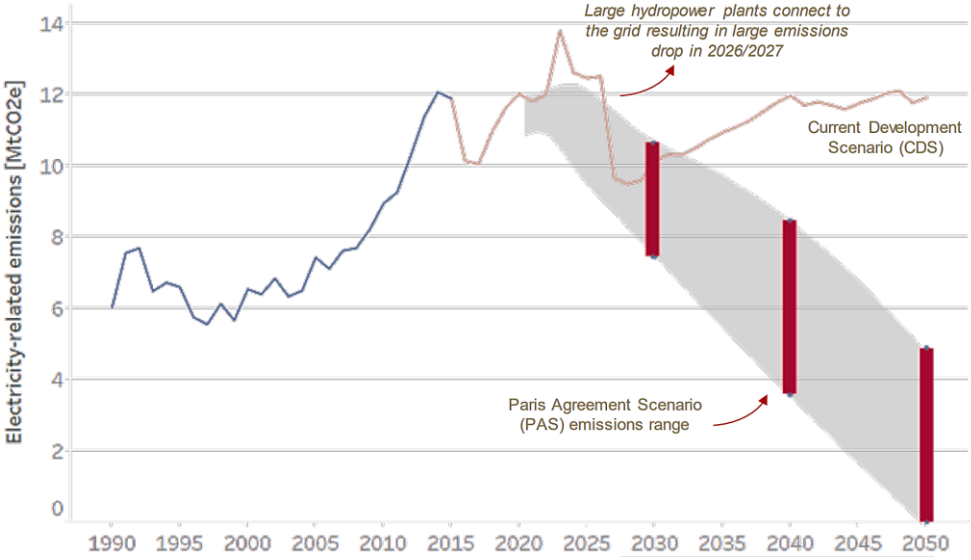

Figure 1: Emission pathways for the Mongolian electricity supply sector considered "Paris Agreement-compatible" (first estimate), informing the selection of emission ranges in 2030, 2040, and 2050 (World Bank Group, 2024)

However, the transition from fossil fuels to renewable energy is challenging, particularly for a country with significant fossil fuel reserves (Gansukh Z., 2021) and a coal-based electricity share of approximately 91% (Table 2).

Table 2 – Dynamics of Mongolia's Energy Infrastructure Structure, 2018–2024 (Assessment, 2024)

Indicators	2018	2019	2020	2021	2022	2023	2024
Combined heat and power plants, coal-based (MW)	1110 (85,1%)	1145 (83,9%)	1234 (81,5%)	1269 (81,9%)	1269 (81,1%)	1411 (87,0%)	1645 (91%)
RE Sources (MW)	216,4 (16,6%)	214,2 (17,7%)	271,2 (18,3%)	271,2 (17,5%)	286,8 (18,3%)	202,8 (12,5%)	153,7 (8,5%)

Diesel stations (MW)	2,3 (0,2%)	2,3 (0,2%)	2,3 (0,2%)	8,6 (0,6%)	8,6 (0,5%)	8,1 (0,5%)	9,0 (0,5%)
Total (MW)	1318,7	1361,5	1507,5	1548,88,	1564,4	1622	1808

The structure of electricity generation in Mongolia during 2018–2024 has been highly inertial: coal-fired thermal power plants continue to carry the bulk of the load. Renewable energy capacities, however, are gradually increasing (Table 3), primarily due to newly constructed solar power plants in Mongolia's southern region, particularly in Umnugobi (Assessment, 2024).

Table 3 – Dynamics of Electricity Generation Structure in Mongolia, 2018–2024 (Assessment, 2024)

Indicators	2018	2019	2020	2021	2022	2023	2024
CHPз	6,152.4	6,346.6	6,493.6	7,109.6	7,428.5	7,743.5	7956,9
Diesel energy generation	3.7	3.0	2.7	1.1	1.2	1,2	1,2
Solar energy generation	51.5	109.0	108.9	156.9	178.7	187,2	191,2
Hydropower generation	78.2	85.4	83.3	83.1	61.7	62,3	70,0
Wind power generation	339.0	459.3	457.2	563.0	508.5	534,5	535,4
Total generation	6,624.8	7,003.3	7,145.7	7,913.6	8,178.6	8,528.7	8754,7
Imported (from Russia and China)	1,683.6	1,715.8	1,705.6	1,861.9	2,161.5	2447,6	2863,4

In 2024, Mongolia’s total electricity generation reached 8,754.7 million kWh, an increase of 226.4 million kWh, or 2.7%, from the previous year. Of the total electricity produced, 90.6% came from thermal power plants, 8.3% from solar and wind sources, 0.8% from hydropower, and 0.001% from diesel power plants. Electricity imports amounted to 2,863.4 million kWh, an increase of 416.6 million kWh, or 17%, compared to the previous year (Energy Regulatory Commission, 2024).

Consequently, the contribution of renewable energy to the overall energy balance is increasing slowly and does not yet provide a substantial alternative to conventional generation. This reflects the lack of interregional transmission lines, modernized grid management systems, gaps in national policy, insufficient economic incentives, and the absence of comprehensive mechanisms to support investors. These challenges pose risks not only to meeting national climate goals but also to energy supply stability, economic efficiency, and environmental security. As Table 3 indicates, the share of electricity imports from Russia and China continues to rise.

The implementation of Mongolia’s energy transition, therefore, requires a systemic approach that accounts for the country’s technical, economic, and political characteristics. The existing electricity grid infrastructure is outdated and underdeveloped, particularly in remote regions, limiting the integration of renewable energy. Gradual modernization and reconstruction of the grid are necessary to enable the safe incorporation of solar, wind, and other renewable sources into the centralized system without risking instability.

Simultaneously, it is crucial to decommission ageing coal-fired power plants and replace them with high-efficiency cogeneration units and hybrid solutions that combine renewables with conventional generation, thereby reducing emissions and improving energy efficiency. The integration of renewables should also be accompanied by energy storage systems and digital energy flow management platforms to balance production and consumption amid variable resources and geographically dispersed demand.

On the political and economic fronts, it is essential to implement transparent, incentive-based mechanisms to attract investment in renewable energy, including tariff incentives, tax benefits, and support for international financing. All these measures must align with Mongolia's international climate commitments, including its national emission-reduction plans and the goal of achieving carbon neutrality. Such an approach will not only mitigate environmental risks but also ensure a stable energy supply, economic resilience, and social acceptability during the transition to renewable energy.

Conclusions

The analysis of the current state of Mongolia's energy sector has shown that the country remains heavily dependent on coal-fired generation, which dominates electricity production and supplies most industrial consumption. This energy structure results in high greenhouse gas emissions, low resource-use efficiency, and limited energy autonomy, creating significant economic, environmental, and social challenges. The current level of renewable energy development does not yet provide a substantial replacement for conventional sources nor contribute significantly to reducing the carbon footprint.

Addressing these challenges requires a systemic approach that includes infrastructure modernization, the development of energy storage technologies, and digital platforms for energy flow management. Decommissioning outdated coal-fired power plants and gradually integrating renewable energy sources will help reduce CO_2 emissions, improve air quality, and enhance the reliability of energy supply.

Equally important is improving political and financial instruments, including establishing transparent tariff mechanisms, providing tax incentives and state grants, and attracting private and international investment in renewable energy.

The implementation of these measures will enable Mongolia to gradually transition to a low-carbon energy system, increase the share of renewable energy in electricity generation, strengthen energy security and economic stability, and promote the development of a green economy with new employment opportunities in the renewable energy sector. Such a comprehensive approach will ensure the simultaneous fulfilment of national climate commitments and support the country's sustainable development.

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Резюме

ЭНЕРГЕТИЧЕСКИЙ ПЕРЕХОД МОНГОЛИИ: МЕЖДУ КЛИМАТИЧЕСКИМИ ЦЕЛЬЮ И УГОЛЬНЫМ НАСЛЕДИЕМ

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Монголия находится на критическом этапе своего энергетического перехода, стремясь согласовать амбициозные климатические цели со своей исторической зависимостью от угля. В настоящее время уголь составляет большую часть производства электроэнергии и промышленного энергопотребления, что делает трансформацию энергетической системы одновременно неотложной и сложной. В данном исследовании представлен всесторонний анализ энергетического перехода Монголии, с акцентом на потенциал возобновляемой энергии, структуру энергетического баланса и технологические барьеры на пути внедрения низкоуглеродной энергетики. В исследовании, использующем смешанный подход, сочетающий энергетическую статистику и анализ национальных энергетических стратегий, определены ключевые факторы и ограничения для внедрения солнечной, ветровой и других возобновляемых источников энергии. Результаты показывают, что Монголия обладает значительным потенциалом возобновляемой энергетики, особенно ветровой и солнечной; однако существующая угольная инфраструктура, ограниченная пропускная способность сети и финансовые барьеры замедляют переход. Исследование демонстрирует, что эффективная интеграция возобновляемых источников энергии в энергетическую систему требует модернизации сети, оптимизации энергетических потоков и внедрения технологий хранения энергии. Полученные результаты подчеркивают, что успешный энергетический переход в Монголии может одновременно обеспечить низкоуглеродное развитие и повысить энергетическую устойчивость страны. Практическая значимость данного исследования заключается в предоставлении основанных на фактических данных рекомендаций для государственной политики в области внедрения возобновляемых источников энергии, модернизации энергетической инфраструктуры и социальной справедливости в процессе перехода, способствуя устойчивому, экологически безопасному и социально ответственному развитию энергетического сектора Монголии.

Ключевые слова: возобновляемая энергия, энергетический переход, энергетический сектор, трансформация энергетической системы, угольная генерация, чистая энергия