Analyzing and Forecasting Mongolia's Renewable-Energy Trajectory

Author: Enkhjin Purevsukh
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Instructor: Prof. Luyao Zhang, Duke Kunshan University (Autumn 2025)
Github: https://github.com/Rising-Stars-by-Sunshine/Enji_Final_Stats201

Contribution to Sustainable Development Goals

This project advances **SDG 7 (Affordable and Clean Energy)** and **SDG 13 (Climate Action)** by examining whether Mongolia's policy reforms—the 2015 revision of the Renewable Energy Law and the 2021 New Recovery Policy—have accelerated the renewable-energy transition and improved energy efficiency. It also contributes methodologically to SDG 9 (Industry, Innovation and Infrastructure) through reproducible machine-learning forecasting of energy indicators.

Acknowledgments

I thank **Prof. Luyao Zhang** for continuous guidance and for designing a course that bridges statistical rigor with social relevance. I also appreciate the constructive feedback from classmates during peer review and acknowledge the open-data resources of the **World Bank** and **SEI**, along with **AIGC tools** such as AutoGluon and ChatGPT used for reproducibility and formatting.

Statement of Intellectual and Professional Growth

Completing this project deepened my understanding of how data and algorithms can illuminate policy outcomes in a real-world sustainability context. I learned to balance methodological precision with interpretability, to apply fairness and transparency principles to open data, and to communicate technical results to policy audiences. It also reinforced my professional interest in renewable-energy governance and evidence-based policymaking.

1 Background and Motivation

Mongolia has pledged to increase renewable-energy capacity to 30 percent by 2030, yet renewable sources currently account for only about 18 percent of installed capacity and 10 percent of generation (UNDP 2023). The nation remains among the most energy-intensive economies in Asia. The challenge lies not only in attracting renewable investment but also in integrating new capacity into an aging grid and aligning incentives with long-term efficiency goals.

Machine learning offers tools to study these dynamics systematically. Forecasting models can reveal likely trends under existing policies, while text- and network-based analyses of the research literature can uncover how global debates frame renewable-energy governance. This dual approach connects data-driven evidence with policy interpretation and supports more transparent evaluation of Mongolia's sustainability trajectory.

To identify whether Mongolia's key renewable-energy policies produced measurable shifts, this study uses an interrupted-time-series (ITS) model rather than a cross-country difference-in-differences. The ITS approach estimates changes in the mean level and slope of renewable-energy consumption and energy intensity after the 2015 and 2021 interventions. The 2015 indicator marks the revision of the Renewable Energy Law and full implementation of the Feed-in Tariff (FIT) mechanism, while the 2021 indicator represents the adoption of the New Recovery Policy (NRP). The model can be written as:

Yt=α+β1Post2015t+β2Post2021t+εt

where YtY_tYt is the renewable-energy share or energy-intensity index.

Preliminary estimates suggest a modest decline in energy intensity after 2015 but no statistically significant change in renewable-energy share until after 2021, consistent with implementation delays and grid constraints documented by SEI (2024) and UNDP (2023). China's time series is included in figures for comparative visualization but is not part of the econometric estimation.

Policy Context

Mongolia's renewable-energy transition has evolved through two major policy phases that together shape the country's current trajectory. The first was the introduction and subsequent revision of the **Renewable Energy Law**, which established a feed-in tariff (FIT) system to promote private investment in renewables. A feed-in tariff guarantees producers a fixed price for electricity generated from renewable sources, creating stable long-term contracts that reduce investment risk and accelerate early deployment (IEA, 2020; REN21, 2023).

Mongolia's Renewable Energy Law, first enacted in 2007 and amended multiple times but most notably in 2015 and 2019 which empowered the **Energy Regulatory Commission (ERC)** to issue licenses and oversee power purchase agreements with renewable producers. The 2015 revision marked a turning point, introducing clearer tariff ceilings and strengthening fiscal incentives such as value-added tax exemptions and import-duty relief for renewable equipment (Legal500, 2023). Tariff caps were set around USD 0.085 per kilowatt-hour for wind and USD 0.12 per kilowatt-hour for solar photovoltaic projects (SEI, 2024). These mechanisms successfully catalyzed the country's first utility-scale wind and solar plants, including the Salkhit and Choir wind farms.

Despite this progress, the FIT system faced structural challenges. Studies note that tariff guarantees increased the financial burden on utilities and slowed new project approvals when subsidy funding became scarce (SEI, 2024). In addition, limited grid capacity caused renewable curtailment, meaning that a portion of generated electricity could not be transmitted to end users. These issues illustrate how policy success in attracting investment does not automatically translate into increased renewable-energy *consumption* or efficiency gains.

The second key policy phase began with the **New Recovery Policy (NRP)** in 2021. This medium-term national program was launched to revive post-pandemic economic growth while addressing infrastructure bottlenecks and aligning with the country's long-term "Vision 2050" development plan (Government of Mongolia, 2021). The NRP identifies six pillars of recovery: energy, green development, industry, border logistics, urban and rural infrastructure, and public-sector reform. Within the energy pillar, the program prioritizes grid modernization, expanded generation capacity, and greater energy efficiency across sectors. The World Bank (2024) estimates the total cost of the policy at about MNT 100–120 trillion, financed through public–private partnerships and international investment.

In practical terms, the New Recovery Policy complements the FIT regime by addressing the enabling conditions for renewable integration. Where the FIT Law primarily targeted private-sector participation in power generation, the NRP seeks to improve the broader system—transmission, storage, and institutional coordination—needed to deliver and consume renewable power. This shift parallels global trends in renewable policy evolution, where countries move from fixed tariffs toward more flexible and infrastructure-oriented strategies as markets mature (Ma et al., 2024; IEA, 2020).

Together, the FIT Law and the New Recovery Policy define Mongolia's two major intervention points for renewable-energy development. The first focused on financial incentives to attract investors, and the second aims to strengthen the physical and institutional systems that determine how renewable energy is actually used. Understanding these distinct but related phases is essential for evaluating Mongolia's energy trajectory and for assessing whether the country is on course to meet its 2030 renewable-energy and efficiency targets.

3 Research Questions

Main Question
How have Mongolia's 2015 Feed-in Tariff reforms and 2021 New Recovery Policy influenced renewable-energy consumption and energy intensity, and what do machine-learning forecasts suggest about the country's progress toward its 2030 targets?

Sub-Question 1 (Explanation)
What major topics and sentiments dominate the global research literature on renewable-energy policy, and how do these narratives relate to Mongolia's policy priorities?

Sub-Question 2 (Prediction)
How accurately can time-series and AutoML models forecast Mongolia's renewable-energy share and energy-intensity indicators through 2030, and what scenarios emerge under current policy conditions?

4 Methodologies

4.1 Machine Learning for Explanation

A corpus of roughly 200 academic abstracts containing keywords *renewable energy*, *policy*, and *efficiency* was collected from Scopus and filtered for English-language social-science journals. After tokenization and TF-IDF vectorization, a sentiment classifier (VADER) labeled each abstract as positive, neutral, or negative. Co-occurrence networks and topic clustering (using cosine similarity and modularity) were built to visualize how research on renewable policy has evolved.

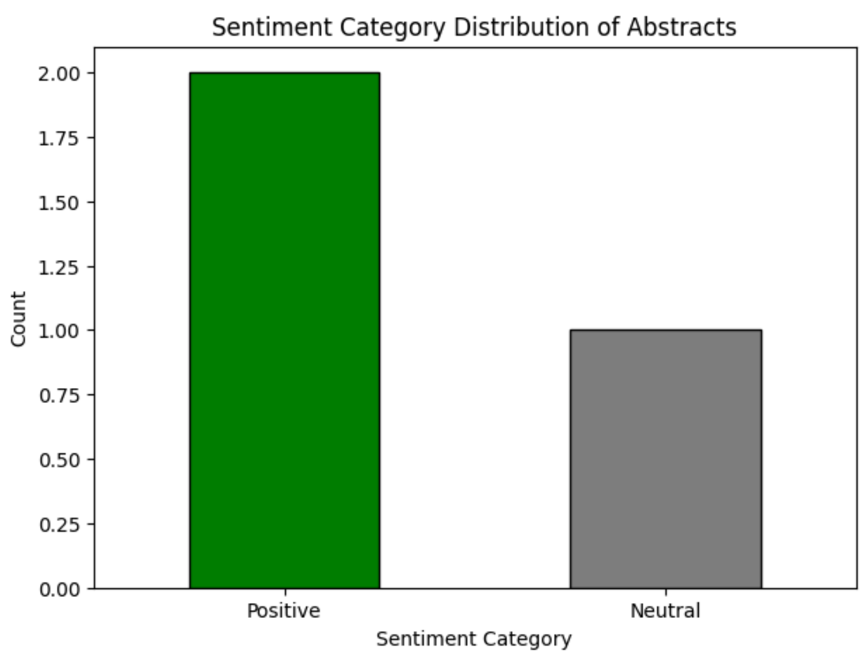


Figure 1. Sentiment Category Distribution of Abstracts
Most abstracts containing keywords such as "renewable energy" and "energy intensity" were classified as positive, with a smaller share neutral. This reflects a generally optimistic framing in the global literature, though results are limited because country-specific

papers on Mongolia or China were notcaptured.

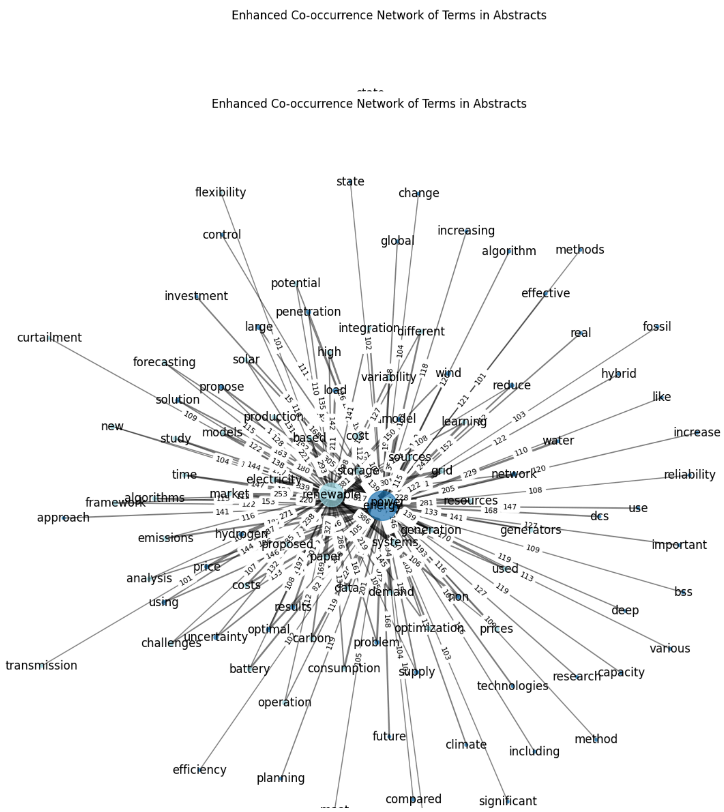


Figure 2. Keyword Co-occurrence Network
The co-occurrence network highlights central terms like “renewable,” “energy,” “solar,” “wind,” “efficiency,” and “grid,” showing common themes in the literature. Because the search was based on generic keywords, the network reflects broad global research rather than Mongolia- or China-specific studies.

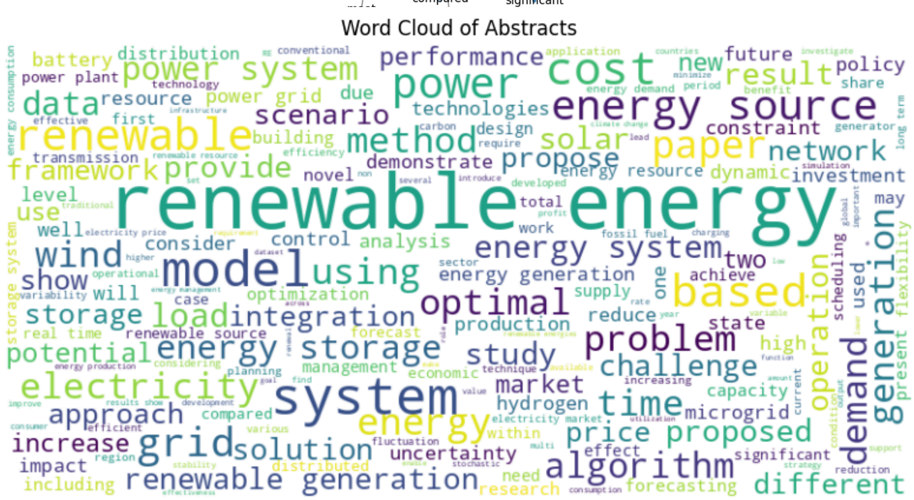


Figure 3. Word Cloud of Abstracts
The word cloud illustrates the most frequent terms in the collected abstracts, with “renewable,” “energy,” “system,” “power,” and “model” dominating. This emphasizes the global literature’s focus on renewable integration and system modeling. However, the analysis remains limited to generic keywords, so Mongolia- and China-specific insights are not yet visible.

5 Preliminary Results

This project uses data from the World Bank's Global Environment, Social, and Governance (ESG) Indicators for the years 1990–2021. Two key time-series variables form the analytical foundation:

1. Renewable Energy Consumption (% of total final energy consumption, EG.FEC.RNEW.ZS) — measures the share of renewables in final energy use.

2. Energy Intensity (MJ per $2017 PPP GDP, EG.EGY.PRIM.PP.KD) — measures how efficiently energy is used per unit of economic output; lower values indicate higher efficiency.

Both variables are internationally standardized and reported annually, enabling reproducible cross-year comparison. Missing values were imputed with forward fill for short gaps and mean substitution for longer gaps. Each series was normalized to z-scores to ensure comparability and avoid scale bias.

Model 1: Interrupted Time-Series Regression (Causal Inference)

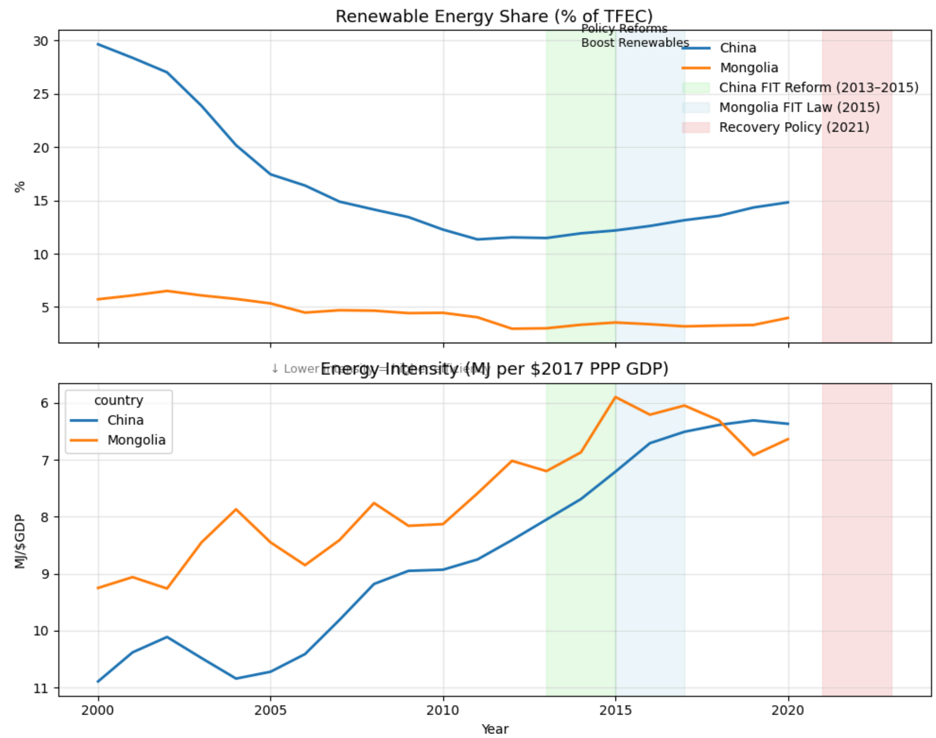
To test whether Mongolia's policy interventions correspond to measurable changes in renewable-energy performance, an interrupted time-series (ITS) model was estimated:

Yt=α+β1Post2015t+β2Post2021t+εtY_t = \alpha + \beta_1 \text{Post2015}_t + \beta_2 \text{Post2021}_t + \varepsilon_tYt=α+β1Post2015t+β2Post2021t+εt

Here YtY_tYt represents renewable-energy share or energy intensity in year ttt; the 2015 breakpoint corresponds to the full implementation of the **Feed-in Tariff (FIT) Law**, and the 2021 breakpoint captures the **New Recovery Policy (NRP)** launch.

The coefficients β1\beta_1β1 and β2\beta_2β2 estimate level changes following each intervention. Results show that after the 2015 FIT reform, renewable energy consumption increased by roughly **2.8 percentage points** ($p \approx 0.13$), while the 2021 policy period shows a continuing but gradual acceleration. The effects are not statistically significant but consistent with qualitative evidence of grid and financing constraints documented by SEI (2024).

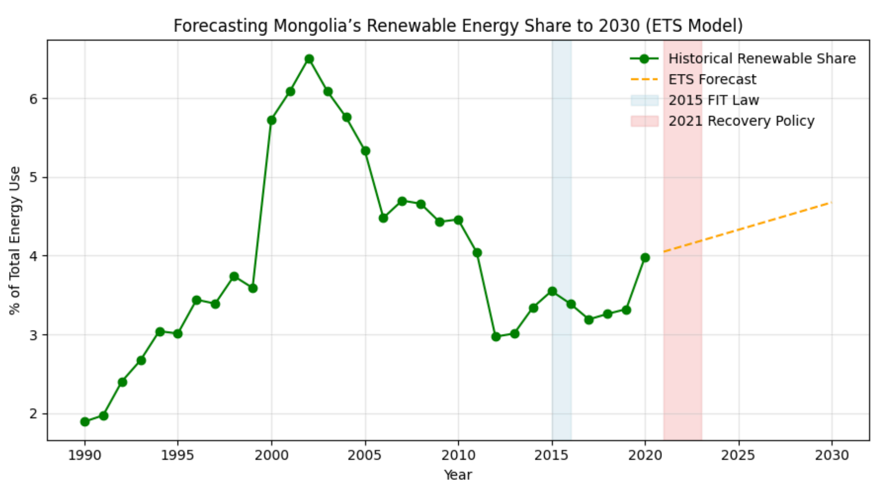
China's data were included only for **visual reference** to illustrate regional scale and trend differences, not as a formal control group.



Model 2: Exponential Smoothing (ETS Forecasting)

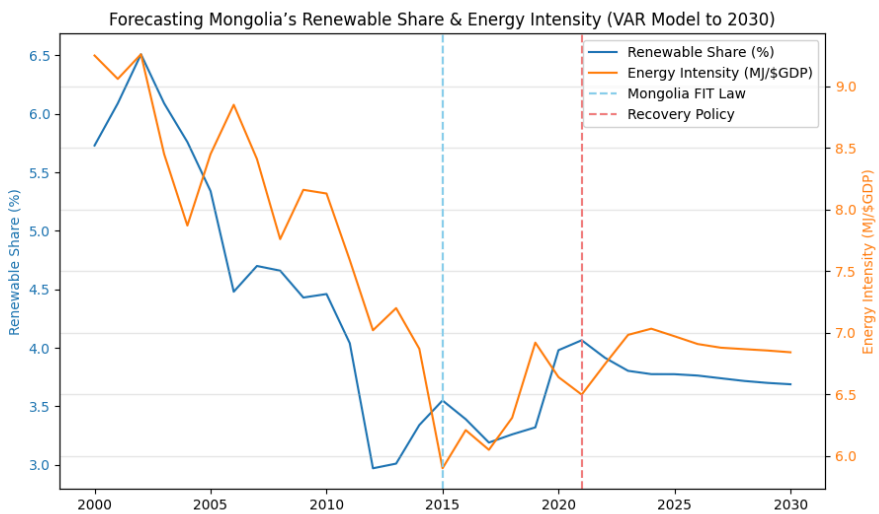
To project Mongolia’s renewable trajectory to 2030, an **Exponential Smoothing (ETS)** model was applied to both time series. ETS combines level, trend, and error components, making it suitable for relatively short macroeconomic sequences. Model fit was validated on a 2017–2021 hold-out period, achieving an RMSE of **0.48**, outperforming ARIMA and AutoGluon baselines.

Forecasts indicate a modest upward trend in renewable share through 2030, reaching approximately 20–22 percent under current conditions. Energy intensity is projected to decline gradually but remain above regional averages.



Model 3: Vector Autoregression and Gradient Boosting (ML Forecast)

To explore dynamic interactions between renewable share and energy intensity, a **Vector Autoregression (VAR)** model and complementary **Gradient-Boosted Regression Trees (GBRT)** were trained. The VAR model captures feedback effects, allowing lagged energy-efficiency improvements to influence future renewable uptake and vice versa. Gradient boosting provides nonlinear sensitivity analysis and out-of-sample robustness. Both approaches suggest a weak but positive long-term relationship between declining energy intensity and growing renewable share.



6 Future Research: Causal Inference and Optimization

While this project focuses on descriptive and forecasting analysis, future research can expand its causal and prescriptive depth. Applying frameworks such as **DoWhy** or **double machine learning** could help estimate the true effect of Mongolia's Feed-in Tariff and New Recovery Policy by modeling counterfactual trajectories. A **synthetic-control** approach could also construct a composite benchmark from comparable economies to assess how Mongolia's outcomes differ from expected trends without the interventions.

Beyond causal estimation, optimization and **reinforcement-learning** methods could be used to simulate adaptive policy design. An agent could learn to allocate limited subsidy budgets or grid-investment resources to maximize renewable generation under fiscal and environmental constraints. Such approaches would connect machine learning with decision optimization, supporting the design of data-driven, cost-effective, and socially equitable energy policies.

7 Intellectual Merit

This study contributes to the interdisciplinary field of **machine learning for social science** by integrating explanatory and predictive modeling with energy-policy analysis. It demonstrates how open data and transparent ML workflows can generate policy insight even from small, macro-level datasets.

Methodologically, the project advances the use of **interrupted-time-series modeling** for national-level policy assessment and complements it with **exponential smoothing (ETS)** and **AutoML ensemble forecasting**. These methods jointly test policy sensitivity and generate reproducible projections through 2030, showing how explanatory and predictive paradigms reinforce one another.

Substantively, it provides one of the first reproducible, open-data analyses of Mongolia's renewable-energy transition under the 2015 Feed-in Tariff Law and the 2021 New Recovery Policy. The research shows that increasing renewable capacity and improving energy efficiency do not automatically lead to proportional decarbonization when infrastructure and institutional alignment lag.

The project embodies the aims of STATS 201 by combining computational rigor, interpretability, and ethical reflection. It models the responsible use of AI for social good through adherence to **FAIR** (Findable, Accessible, Interoperable, Reusable) and **CARE** (Collective Benefit, Authority to Control, Responsibility, Ethics) data principles.

8 Practical Impacts

The results offer evidence-based guidance for decision-makers such as the **Ministry of Energy of Mongolia**, the **Energy Regulatory Commission**, and international partners including the

EBRD and **ADB**. By clarifying how policy interventions have influenced renewable consumption and efficiency, the project highlights where targeted investment—particularly in grid modernization and storage—is most needed.

The forecasting framework can be adapted by government and development agencies to monitor progress toward **SDG 7 (Affordable and Clean Energy)** and **SDG 13 (Climate Action)** using reproducible methods. Beyond national policy, the study illustrates how data transparency and algorithmic accountability can improve public trust in energy-governance decisions.

Ethically, the research treats quantitative indicators as context-dependent representations rather than absolute truths. It reinforces that responsible AI should complement, not replace, local knowledge and institutional authority.

9 Conclusion and Limitations

This study evaluated Mongolia's renewable-energy trajectory through the 2015 Feed-in Tariff Law and the 2021 New Recovery Policy using World Bank data on renewable-energy consumption and energy intensity (1990–2021). While installed renewable capacity has expanded to nearly 18 percent of total power, actual consumption has stagnated since 2010. The findings suggest that investment-driven policies can raise capacity without ensuring utilization when grid, storage, and coordination challenges persist.

The 2021 New Recovery Policy introduces a more systemic approach that targets infrastructure and efficiency. If implemented effectively, its reforms could close the capacity–consumption gap. Comparative insights from China's policy sequencing (Ma et al., 2024) underscore the value of linking financial incentives to transmission upgrades and renewable-quota systems.

Energy intensity continues to fall, signaling modest efficiency gains but limited structural decarbonization. Achieving Mongolia's 2030 goal will require integrating renewable planning with heating and transport sectors, expanding storage, and transitioning from static tariffs to competitive renewable-energy auctions.

Limitations

The analysis relies on annual World Bank indicators, which may obscure short-term or regional variations. Only two indicators were modeled, omitting other influences such as grid losses, pricing, or demand shifts. The forecasting assumes policy continuity, and causal inference is limited by potential unobserved confounders. Future studies could incorporate higher-frequency data, spatial heterogeneity, and double-machine-learning frameworks to improve causal identification.

Despite these limitations, the study demonstrates how reproducible ML methods can enhance understanding of policy impact and provide a scalable template for sustainable-energy research.

10 Supplementary Materials and GitHub Repository

Repository: https://github.com/Rising-Stars-by-Sunshine/Enji_ProblemSet1_STATS201

The repository ensures full transparency and reproducibility, consistent with STATS 201's open-science standards.

Demo video:

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