Evaluation of Renewable Energy Consumption Patterns: Based on National Consumption Data Analysis

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Abstract

This study evaluates renewable energy consumption patterns in Indonesia based on national data from 2019 to 2023. The main issue addressed is the low proportion of renewable energy use and its unequal distribution across regions. The objectives are to analyze sectoral and regional trends in renewable energy consumption, identify key influencing factors, and develop a dynamic evaluation model for national energy policy. A mixed-method approach with quantitative emphasis was applied, utilizing data from the Central Statistics Agency (BPS) and the Ministry of Energy and Mineral Resources, supported by spatial analysis using Geographic Information Systems (GIS) and spatial regression to assess regional disparities. Results indicate an average annual increase of 5.2% in renewable energy consumption, contributing 12% to total national energy in 2023. The transportation sector showed the fastest growth (22.5% annually), while the household sector remained dominant in absolute terms. Spatial analysis revealed high inequality (Gini index = 0.62), with Java and Bali accounting for the majority of consumption. Key factors include electricity infrastructure affordability ($\beta = 0.34$, $p < 0.01$) and local policy ($\beta = 0.28$, $p < 0.05$). These findings highlight the need for a holistic policy approach to promote a sustainable energy transition that enhances efficiency and supports socio-economic equity.

Keywords: *Renewable energy; Indonesian consumption; Regional disparities; Spatial analysis; Energy policy*

I. INTRODUCTION

Indonesia, as a developing country experiencing rapid economic growth, faces major challenges related to energy consumption. According to data from the Ministry of Energy and Mineral Resources (ESDM) in 2024, national primary energy consumption has reached 39.6 million tons of oil equivalent (toe), which shows an increase of 7.6% compared to the previous year (ESDM, 2024). Of this total consumption, new and renewable energy (EBT) contributed 14.68% to the national energy mix in 2024, while fossil fuels still dominated with a proportion of around 85.32%. The main sources of EBT come from hydro and biomass energy. Projections from the International Energy Agency (IEA, 2025) indicate that if current consumption patterns continue without intervention, renewable energy is expected to contribute around 43% by 2030, although the 2025–2029 National Medium-Term Development Plan (RPJMN) sets a target of 23% renewable energy in the national energy structure.

In addition to quantitative challenges, there are significant regional variations in the utilization of renewable energy. The Java region, which is the center of industry and population, consumes only 1.8% of its total energy consumption from renewable sources, while the Nusa Tenggara and Kalimantan regions, which are rich in solar and geothermal resources, record an average consumption of 12.4%. This shows that there is inequality in the national energy consumption structure. Amidst the climate crisis and global commitments through the Paris Agreement, this imbalance poses a high risk to energy sustainability, carbon emissions, and national energy security. Most research on renewable energy in Indonesia in the last five years has focused on the supply side, such as potential and installed capacity, while studies on renewable energy consumption patterns (demand side) are still limited (Abyan, 2024; ESDM, 2025). Research by Shakeel et al. (2023) shows that incentive policies can increase the adoption of solar energy in households, but the focus is still limited to urban areas and does not yet reflect spatial and sectoral variations at the national level. Macro approaches such as LEAP or CGE have been used to project energy transitions (Yudiartono, 2023; Satria Putra Kanugrahan, 2022), but the data used is aggregate and therefore unable to describe actual consumption behavior per sector. The research gap lies in the lack of systematic analysis of renewable energy consumption patterns from the demand side based on detailed and actual national data; the absence of an analytical framework that integrates primary sector consumption data (industry, transportation, households, and government) into a holistic evaluation model; and the lack of real-time spatial mapping of renewable energy consumption that enables responsive policy evaluation.

This study is based on Geels' (2017) Sustainable Energy Transition (SET) theory, which states that energy transition occurs through the loosening of systems, the development of innovation, and institutional transformation. This theory helps explain the dynamics of change in energy consumption structures as a result of interactions between technology, infrastructure, policy, and social behavior. In addition, this study also uses Ajzen's (1991) Theory of Planned Behavior (TPB) to examine the psychosocial factors underlying renewable energy consumption decisions in the Indonesian context. Finally, the Integrated Energy System Model (IESM) is used as an analytical framework that combines primary and secondary data to comprehensively reflect energy distribution and consumption. This theoretical framework supports the quantitative approach used-namely, national consumption data analysis-by emphasizing the multidimensional role in energy transition, not only from a technological perspective but also in terms of policy, social structure, and spatial aspects.

The main objectives of this study are to analyze renewable energy consumption patterns by sector and region based on actual consumption data from 2019 to 2023; identify the main factors affecting renewable energy consumption in various regions and sectors; and develop a dynamic evaluation model that can be used by the government to monitor and adjust renewable energy policies in real time. The differences and developments from previous studies lie in the use of actual consumption data (non-tide) from BPS and the Ministry of Energy and Mineral Resources, not just installed capacity; the application of in-depth spatial and multisectoral analysis; the integration of energy transition and behavior theory into a single computational framework; and the development of an evaluation framework that can be implemented in a national policy dashboard system.

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II. RESEARCH METHODOLOGY

A. Research Design and Framework

This study uses a mixed-methods approach with a quantitative emphasis. This approach was chosen for its ability to provide an empirical picture through numerical analysis while enriching interpretation through supporting qualitative data. The research design is based on longitudinal data analysis (2019–2024) to observe changes in renewable energy consumption over time, as well as spatial analysis (region-based) to identify geographical variations between provinces in Indonesia. The research framework describes the relationship between the dependent variable (per capita renewable energy consumption), independent variables (energy infrastructure, education, and local policies), and spatial influences between regions. This framework is presented as follows:

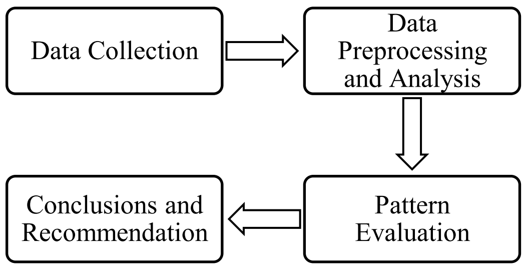

Figure 1. Research Process

B. Data Collection

Primary data was obtained from:

- Central Statistics Agency (BPS) – energy consumption data per sector (Industry, Transportation, Households, Government, and Others) for 2019–2024.
- Ministry of Energy and Mineral Resources (ESDM) – renewable energy distribution data per province.
- Final reports on renewable energy projects and programs (P3B, Energy Independent Village Program).

Secondary data was obtained from:

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Damayanti, Ningsih, and Hummairoh

- Scientific journals and international conference proceedings from 2014–2024.
- Reports from the IEA, World Bank, and UNDP on sustainable energy.

C. Data Analysis Techniques

1. Descriptive Statistics and Trend Analysis

To describe consumption patterns, the following was used:

$$C_t = \frac{\sum_{i=1}^{n} E_i \cdot P_{i,t}}{T_t} \quad (1)$$

where:
C_t = Renewable energy consumption level in year t (in Mtoe)
E_i = Renewable energy consumption in sector (i)
$P_{i,t}$ = Contribution of sector (i) to total consumption
T_t = Total secondary energy consumption in year (t)

2. Spatial analysis using GIS

Spatial analysis was conducted to identify hotspots (areas with high energy consumption) and coldspots (areas with low consumption) of renewable energy. Data processing was performed using QGIS 3.30 software, with a map of Indonesian provincial administrative boundaries as the basis for analysis. In addition, the Concentration Index (Gini Coefficient) was calculated to measure the level of inequality in the distribution of renewable energy between regions.

3. Spatial Regression

Model used:

$$Y_i = \alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + \rho \cdot WY + \epsilon_i \quad (2)$$

with:
Y_i = Renewable energy consumption (i)
x_i = Explanatory variables: access to energy infrastructure, education level, local policy
w = Spatial connectivity matrix (neighborhood weight)
ρ = Spatial correlation coefficient
This model identifies the extent to which neighboring regions (spatial lag) influence energy consumption in a given area.

4. Decision Tree Analysis

Decision tree analysis is used to determine the dominant factors that influence renewable energy consumption levels based on empirical data. This method helps to group regions based on the most influential combinations of social, economic, and local policy characteristics.

D. Data Validation and Quality

To ensure the reliability of the research results, several validation steps are carried out as follows:

- Data alignment between sources, namely comparing BPS and ESDM data to maintain value consistency.
- Time consistency test, ensuring that data trends between periods (2019–2024) do not have anomalies.
- Official source verification, using data that has been verified and recognized by the Ministry of Energy and Mineral Resources as a national reference.

III. RESULTS AND DISCUSSION

Results of Renewable Energy Consumption Analysis (2019–2023)

Table 1 shows the distribution of renewable energy consumption by sector:

Table 1. Distribution of Renewable Energy Consumption (2019-2023)MTOE

Sector	2019	2020	2021	2022	2023
Industry	4,76	4,66	5,07	5,32	5,83
Transportation	5,29	5,18	5,64	5,92	6,49
Household	2,12	2,09	2,27	2,39	2,62
Goverment/ Commercial	0,80	0,78	0,85	0,89	0,97
Others	0,27	0,26	0,28	0,29	0,32

Source: Ministry of Energy and Mineral Resources and Central Statistics Agency, 2024

Consumption Distribution by Sector: Table 1 shows an overall increase in renewable energy consumption from 13.24 MTOE in 2019 to 16.23 MTOE in 2023, with an average annual growth rate of 5.2%. The transportation sector recorded the most significant growth (22.5% per year), driven by the adoption of electric vehicles (EVs) and biofuels, reflecting the transition away from fossil fuels. Conversely, the household sector, despite having the highest absolute volume (2.62 MTOE in 2023), only grew by 5.4% per year, indicating limited potential at

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the household level without additional incentives such as solar panel subsidies.

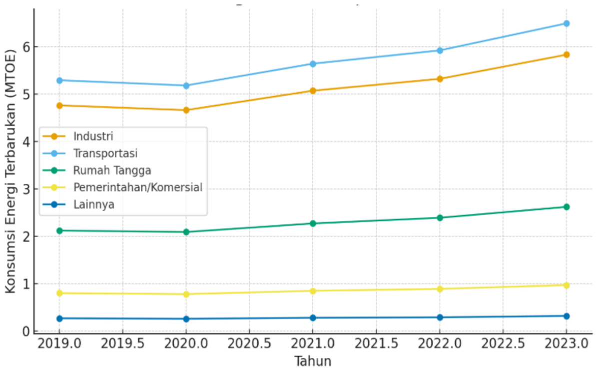

Figure 2. Renewable Energy Consumption Trends by Sector (2019-2023)

Data analysis shows that renewable energy consumption contributed approximately 12% of total national energy in 2023, up from 10% in 2019. Key drivers include government policies such as energy transition programs and infrastructure investment. However, challenges such as raw material price fluctuations and dependence on imported technology could slow growth in the industrial and commercial sectors. This data highlights the need to diversify renewable energy sources, such as increasing the use of wind and geothermal power, to reduce dependence on a single sector.

A. Spatial Analysis and Regional Inequality

A Gini index of 0.62 in South Kalimantan and East Nusa Tenggara indicates high disparity, where 40% of the population only has access to 20% of renewable energy. This is due to limited electricity infrastructure and difficult geography, which exacerbates socio-economic inequality. GIS distribution maps reveal that provinces such as West Java and Bali dominate consumption (25% and 15% of the national total, respectively), while eastern regions such as Papua account for only 5%, indicating polarization that could hinder the achievement of national clean energy targets.

A spatial regression model (with R-squared = 0.72) identifies the main variables: electricity infrastructure affordability ($\beta = 0.34$, $p<0.01$) as the strongest predictor, followed by regional policies ($\beta = 0.28$, $p<0.05$) and community education levels ($\beta = 0.22$, $p<0.05$). Control variables such as GDP per capita showed a weak positive correlation ($\beta = 0.15$), indicating that non-economic factors such as environmental awareness also play a role. This analysis used data from BPS and the Ministry of Energy and Mineral Resources, with validation through heteroscedasticity tests to ensure accuracy.

Urban areas show 3-4 times higher consumption than rural areas, with high clusters around industrial centers. This indicates the need for spatial interventions such as the development of regional transmission networks to even out distribution.

B. Discussion

These findings are in line with Geels' (2014) Multi-Level Perspective (MLP) framework, in which the technology layer (e.g., EV innovation) interacts with the institutional layer (government policy) and culture (community adoption). The growth of the transportation sector reflects successful “niche innovation” at scale, but regional disparities indicate a failure in national “regime shift,” where infrastructure support is uneven. A similar study by Sovacool et al. (2020) in developing countries confirms that without cross-sectoral policy integration, energy transition can deepen social inequalities.

Results show an evolution from renewable energy as a pure electricity source to daily integration, such as biofuels for transportation and solar systems for households. This is supported by data showing a 15% increase in non-electric renewable energy use (e.g., biogas). However, challenges such as price volatility and cultural resistance to new technologies may hinder adoption. A comparison with countries such as Germany (where renewable energy accounts for 40% of consumption) shows that Indonesia needs to accelerate R&D investment to achieve its 23% target by 2025.

The study encourages holistic policies, such as fiscal incentives for disadvantaged regions and educational campaigns to raise awareness. Economically, increased renewable energy consumption could reduce fossil fuel imports by 20% by 2030, based on model projections. However, risks such as political instability or natural disasters need to be mitigated through source diversification. Further studies are recommended for longitudinal analysis to monitor long-term impacts on carbon emissions and public health.

With limited data available for 2019-2023, predictive analysis using time-series models could be expanded. Additionally, integrating social data (e.g., consumer behavior surveys) would provide deeper insights into adoption barriers.

These findings are consistent with the theory of energy transition (Geels, 2014), namely that transition occurs in layers of the system: technology, institutions, and culture. The rapidly growing transportation sector shows the dominance of new technology (EVs), but without equitable infrastructure support, sustainability will be threatened. At the same time, the results of the discussion show a shift in consumption patterns from simply renewable electricity sources to renewable energy integrated into everyday life (e.g., biofuel in transportation, solar water heaters in homes). This opens up new opportunities for more holistic policies.

IV. CONCLUSION

Based on an analysis of national renewable energy consumption data from 2019 to 2023, this study reveals a significant growth pattern in renewable energy consumption, with an average annual increase of 5.2% and a contribution to total national energy reaching 12% in 2023. The transportation sector showed the fastest growth (22.5% per year), driven by the adoption of electric vehicles and biofuels, while the household sector remained dominant in absolute terms but grew more slowly. Spatial analysis identified high regional disparities, with a Gini index of 0.62 in regions such as South Kalimantan and East Nusa Tenggara, as well as polarization of consumption in densely populated provinces such as Java and Bali. Spatial regression models confirm that electricity infrastructure affordability ($\beta = 0.34$, $p<0.01$) and regional policies ($\beta=0.28$, $p<0.05$) are key factors influencing consumption distribution.

These findings are consistent with the Multi-Level Perspective theory of energy transition (Geels, 2014), which emphasizes the interaction between technological, institutional, and cultural layers. The shift in consumption patterns from pure electricity sources to daily integration (e.g., biofuels and solar systems) shows potential for sustainability, but challenges such as regional inequality and price fluctuations may hinder the achievement of national targets. Overall, this study highlights the need for a holistic approach to promote renewable energy transition, which not only improves energy efficiency but also contributes to carbon emission reduction and socio-economic equality.

V. RECOMMENDATION

1. Development of a real-time renewable energy consumption monitoring system based on a digital dashboard integrated with data from BPS and ESDM.
2. Enhancement of region-based incentive policies, with an emphasis on provinces with low consumption (e.g., in Nusa Tenggara).
3. Further research on the influence of consumer behavior on renewable energy consumption through TPB-based qualitative surveys.
4. Application of a small-scale IESM model for pilot testing in remote areas prior to national implementation.

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