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Investigating the Structural Shift in Indonesia's Energy Consumption and its Implications for Sustainable Development and Energy Policy

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ABSTRACT

The path of economic development and the standard of living of households are determined by the availability of energy as a production factor. Patterns of final energy use in Indonesia have exhibited notable structural change between 2010 and 2023. The purpose of this research is to examine the dynamics of the shift in energy consumption from the household sector to the productive sector, specifically, industry and transportation, and its consequences for sustainable development and energy security. The Indonesian Energy Balance (2010-2023) was obtained from Central Bureau of Statistics (BPS), International Energy Agency (IEA), and other relevant publications, which are the sources of secondary data used in the research methodology. Using a time series technique, the analysis compared the pre-, during, and post-COVID-19 pandemic phases to determine the proportion of energy consumption for each sector. To ensure uniformity across energy sources, all data were converted to barrels of oil equivalent (BOE). With average growth rates of 7.66% and 6.11% per year, respectively, the data reveal that the transportation and industrial sectors are the primary drivers of growth in the nation's energy consumption. On the other hand, the household sector saw a notable decline (–1.56), consistent with the switch from biomass to electricity and LPG. There were steady but modest increases in the public, commercial, and agricultural sectors. Although industry and transportation once again drove the post-pandemic recovery, the COVID-19 pandemic turned out to be a turning point that curtailed productive energy use. These results support the notion that Indonesia's energy use is shifting increasingly toward the productive sector as the country's economy becomes more sophisticated and industrialized. However, the Net Zero Emission 2060 target is seriously threatened by the prevalence of fossil fuels in the industrial and transportation sectors. Therefore, to maintain a balance between environmental sustainability, social justice, and growth, future energy policy must prioritize efficiency, diversity, and accelerating the transition to clean energy.

Keywords: Final Energy Consumption, Energy Transition, Productive Sector, COVID-19 Pandemic
JEL Classifications: G21, Q53, Q56, O13, C32

1. INTRODUCTION

Energy is one of the production factors that greatly determines the dynamics of economic development. In developing countries such as Indonesia, energy is not only a technical input in the production process, but also a pillar of household quality of life. Consumption patterns are a crucial indicator that reflects the direction of national development, the level of community welfare, and even the orientation of a country's economic structure (Ahmat et al., 2025). The energy consumption structure of Indonesia underwent a substantial change between 2010 and 2023. While households, particularly those in rural regions, continued to be the primary

consumers of traditional energy sources like biomass over the past decade, the last decade has witnessed a shift toward the productive sectors, especially industry and transportation. This alteration is consistent with both urbanization, which increases the requirement for energy for transportation, and Indonesia's structural economic transformation, which is moving the country away from the primary sector and toward the industrial and service sectors.

Energy is one of the production factors that greatly determines the dynamics of economic development. In developing countries such as Indonesia, energy is not only a technical input in the production process, but also a pillar of household quality of life. The ultimate energy consumption structure of Indonesia underwent a substantial change between 2010 and 2023. While households, particularly those in rural regions, continued to be the primary consumers of traditional energy sources like biomass in the previous 10 years, the last 10 years have witnessed a move toward productive sectors, especially industry and transportation (Budianto et al., 2025; Tan et al., 2023). This change is consistent with both urbanization, which increases the requirement for energy for transportation, and Indonesia's structural economic transformation (Andriansyah et al., 2023), which is moving the country away from the primary sector and toward the industrial and service sectors.

Empirical studies further substantiate this evolution. Indonesia's household energy demand has become less dependent on traditional fuels and more responsive to income and infrastructure development, reinforcing the energy ladder hypothesis (Rasyid and Kristina, 2021; Waleed and Mirza, 2023). Meanwhile, decentralized innovations, such as biogas programs, enhance household energy efficiency and resilience, especially in rural contexts (Bedi et al., 2017). These findings suggest that while household energy use remains a core component of welfare, its relative share in national demand diminishes as access to modern fuels expands. At the same time, Indonesia's productive sectors display rising energy intensity, reflecting their role as drivers of post-industrial growth. The expansion of transportation infrastructure can either promote long-term energy conservation through improved logistics or exacerbate fuel dependency when growth is unmanaged (Tan et al., 2023). Similarly, institutional dimensions, such as corporate sustainability governance, play a pivotal role in ensuring that industrial and transport growth remains aligned with decarbonization and transparency goals (Budianto et al., 2025).

The COVID-19 pandemic in 2020 presented a stress test for these dynamics, revealing the vulnerability of productive energy demand to global shocks, in contrast to the relative stability of household energy consumption. Such evidence underscores the importance of energy resilience, where diversification across sectors and technologies acts as a macroeconomic buffer. The primary objective of this article is to provide a comprehensive analysis of Indonesia's final energy consumption between 2010 and 2023, to identify the main structural and behavioral drivers of these shifts, and to assess their implications for sustainable development and energy security. By integrating empirical data with theoretical and policy perspectives, this study contributes to the growing discourse on how emerging economies can sustain growth while pursuing equitable and low-carbon energy transitions.

2. LITERATURE REVIEW

2.1. Final Energy Consumption

Final energy consumption refers to the energy used directly by end consumers, including both households and the production sector, after undergoing a conversion process from primary energy sources. The fundamental difference between primary energy and final energy lies in their use: primary energy encompasses the production of oil, gas, coal, and renewable energy, whereas final energy represents the energy that is utilized by the community and industry (Iacovoiu et al., 2025; International Energy Agency, 2017). The final energy demand theory emphasizes the role of the energy coefficient per sector. Household energy consumption tends to be elastic with respect to income but relatively inelastic with respect to price, while the industrial and transportation sectors are more influenced by production output and logistics costs (Ghoddusi et al., 2021; Havranek and Kokes, 2015; Sapnken et al., 2025). Changes in consumption patterns in Indonesia from 2010 to 2023 can be analyzed through this sectoral elasticity.

2.2. Energy Transition Theory

Literature on energy transition describes the shift from traditional energy sources (biomass) to modern energy sources (electricity, gas, fuel) as part of economic modernization (Adrian et al., 2023; Resosudarmo et al., 2023). This transition typically coincides with an increase in GDP per capita, urbanization, and industrialization. The theory of energy transition explains the fundamental shift in the way societies generate, distribute, and use energy in line with economic, social, and technological developments (Adrian et al., 2023; Hadasik et al., 2025; Shahzad, 2025). In the long term, energy transition is not only seen as a technical change, but also as part of a structural transformation in a country's development. However, the theory of energy transition also reminds us that this shift is not without challenges. High dependence on fossil fuels in the transportation sector and coal in the industrial sector poses risks to energy security and environmental sustainability (Adrian et al., 2023; Rahko et al., 2025; Yang et al., 2023). Therefore, although the shift in productive energy consumption can support industrialization and economic growth, policy strategies that integrate renewable energy, energy efficiency, and clean technology incentives are still needed so that the energy transition is in line with sustainable development targets and the government's 2060 Net Zero Emission agenda (Khan et al., 2022; (Khan et al., 2022; National Development Planning Agency, 2019).

2.3. Structural Change and Economic Development Theory

The theory of structural change by Kuznets (1966) and Chenery (1971) state that as the economy grows, the contribution of the household sector declines, while that of the productive sectors (industry, transportation, services) increases (Hardt et al., 2021). Energy is a crucial indicator in this transformation as increased productivity necessitates intensified energy consumption. Thus, shifts in energy consumption between sectors reflect the dynamics of Indonesia's economic development. In the Indonesian context, the period from 2010 to 2023 provides clear evidence of this theory. Household energy consumption has gradually declined, not because household energy needs have decreased, but because

of a fuel switch from traditional biomass to more efficient modern energy sources (LPG and electricity). At the same time, the transportation and industrial sectors have experienced rapid growth in line with accelerated urbanization, infrastructure development, and increased demand for goods and services. As a result, the share of national energy consumption has shifted from household-based energy use to productive-based energy use, reflecting the economic transition from a subsistence-based economy to industrialization and global integration.

The theory of structural change explains that energy shift is not only a technical phenomenon, but also an indicator of economic development (Higginson et al., 2014; Muttaqee et al., 2024). When the productive sector becomes the largest energy user, it signifies that energy has become a significant input factor in generating economic value. However, transformation also brings new implications by increasing energy intensity per unit of output, potential dependence on fossil fuels, and challenges in maintaining a balance between economic growth and environmental sustainability (Dietzenbacher et al., 2020; Hardt et al., 2021). Thus, the application of structural change theory in this study allows us to understand energy consumption not only as statistical data but also as a reflection of Indonesia's economic transformation. The shift in energy consumption between sectors is empirical evidence that Indonesia is embarking on a more modern and productive path of development, albeit with sustainability risks and challenges that must be carefully managed.

2.4. Energy Ladder and Fuel Switching Model

In household energy studies, there is a concept known as the energy ladder, whereby households shift from traditional fuels (biomass) to modern energy sources (LPG, electricity) as their income increases (Waleed and Mirza, 2023; Yadav et al., 2021). This shift affects energy consumption patterns on a macro level, as the decline in the dominance of the household sector occurs alongside increased energy use by the industry and transportation sectors. This model is important in the research framework because it provides a conceptual basis that a decrease in household energy consumption does not mean a decrease in energy demand, but rather the result of a shift to more efficient energy sources (Waleed and Mirza, 2023). This also contributes to a shift at the national level, where greater energy consumption in the productive sector signals a structural transformation of the economy.

2.5. Sustainable Development and Energy Security

Within the framework of sustainable development, Hernandez et al., 2022; Higginson et al., 2014; Muttaqee et al., (2024) stated that a shift of energy to the productive sector needs to be viewed from two dimensions. (i) Positive: Continuing economic growth, industrialization, and national productivity. (ii) Negative: Increasing dependence on fossil fuels (fuel oil, coal), which put pressure on the environment and energy security. Therefore, this theory also emphasizes the importance of energy diversification (Henriques et al., 2024) and the integration of renewable energy in the productive sector.

2.6. The Conceptual Framework

Fig. 1 shows the conceptual framework of this study was developed to explain the dynamics of energy use shifts in Indonesia from the household sector to the productive sector during the period 2010-2023. The main proposition is that energy not only serves as a basic household need, but also as an important input in production processes, transportation, and other economic activities that support national growth (Nugraha and Osman, 2017). The energy shift mechanism can be seen from two directions. In the household sector, there has been a shift from biomass (firewood, charcoal) to LPG and electricity, in line with increasing incomes and access to modern energy sources (Bedi et al., 2017). This shift has led to a decline in the contribution of households to the nation's total energy consumption. Conversely, the industrial and transportation sectors are experiencing energy intensification, namely an increase in energy consumption in line with the expansion of production and logistics. This makes the productive sector the main driver of final energy consumption growth in Indonesia.

The result of this mechanism is a shift in energy use, namely a shift in the dominance of energy consumption from the household sector to the productive sector. This shift has dual implications: on the one hand, it supports productivity, industrialization, and economic growth (Nugraha and Osman, 2017), but on the other hand, it increases pressure on energy security and dependence on fossil fuels (Chen and Pitt, 2017). Therefore, this shift must be understood not only as an economic phenomenon but also as a challenge within the framework of sustainable development, which requires the integration of renewable energy.

3. MATERIAL AND METHODS

This paper employs secondary data and a descriptive-analytical methodology. The Ministry of Energy and Mineral Resources, Indonesian Energy Balance 2010-2023, Central Bureau of Statistics (BPS), and International Energy Agency (IEA) are the main statistical sources. To obtain a comprehensive understanding of shifts in the energy demand structure, this study employs a range of complementary analytical procedures to examine the dynamics of Indonesia's final energy use. From 2010 to 2023, the dynamics of Indonesia's final energy consumption are tracked using the trend analysis approach. Growth patterns, variations, and turning points are displayed through the processing of time series data. Finding simulation parameters for energy consumption increase using an empirical model of trends in energy consumption and simple regression.

$$E_t = \alpha + \beta T + \varepsilon_t$$

T = time period (2010, 2011,…, 2023), ε_t = error term, α is an intercept, β is the trend coefficient (average yearly growth rate), and E_t is the final energy consumption in year t (in million Equivalent Barrels of Oil/BOE). Consistently, energy consumption rises when $\beta > 0$ and falls when $\beta < 0$. This approach can be used to assess the growth rates of the household, industrial, and transportation sectors.

The consumption proportion of each sector relative to the overall final energy consumption is calculated to visualize the energy mix structure. The following is the formula:

$$S_{i,t} = \frac{E_{i,t}}{\sum_{j=1}^{n} E_{j,t}} \times 100\%$$

Where $S_{i,t}$ is the share of energy consumption in *i* sector i in year (t); ($E_{i,t}$) = energy consumption in *i* sector of industry (E_1), transportation (E_2), households (E_3), commercial/public (E_4), agriculture(E_5); $\sum_{j=1}^{n} E_{j,t}$ total national final energy consumption (TEC) in *n* number of sectors. These calculations provide a structural overview of energy per year.

Three periods of energy consumption were used to assess the impact of the COVID-19 pandemic: Pre-pandemic (2010-2019), pandemic era (2020-2021), and post-pandemic (2022-2023). The following method was employed to determine each sector's average energy consumption:

$$\bar{E}_{i,P} = \frac{1}{T_P} \sum_{t \in P} E_{i,t}$$

Where T_P is the number of years in *P* period; $E_{i,t}$ is the energy consumption of *i* sector in year *t*, and $E_{i,P}$ is the average energy consumption of *i* sector in *P* period. Additionally, the following method is used to assess changes over time:

$$\Delta \bar{E}_i = \frac{\bar{E}_{i,P2} - \bar{E}_{i,P1}}{E_{i,P1}} \times 100\%$$

With $\Delta \bar{E}_i$ = average change in energy consumption of *i* sector in percentage terms.

The growth simulation of energy consumption, covering the pre-pandemic, pandemic, and post-pandemic periods, was conducted using the growth index method. Here, g_i represents the average annual growth rate in *i* period; and t_i represents the length of the period in years.

$$Index_t = Index_0 \times \prod_{i=1}^{n} (1 + g_i)^{t_i}$$

Oil Barrel Equivalent (BOE or SBM) units are used in this paper's energy analysis as a standard measure to convert several forms of energy into a single, consistent unit. This is required since there are many various sources of energy consumption, each with unique properties and energy contents, including coal, gas, electricity, biomass, and petroleum (HEESI, 2022). Comparisons between sectors and energy sources can be made more reliably by converting all forms of energy into BOE. Since one BOE is conceptually equal to one barrel of crude oil in terms of energy content, BOE or SBM is a commonly used standard unit in both domestic and international energy balances.

4. RESULTS AND DISCUSSION

4.1. Descriptive statistics

The six primary variables used in this research to reflect Indonesia's energy user sectors are: Industry (E1), transportation (E2), households (E3), commercial and public (E4), agriculture (E5), and total national energy consumption (TEC) as a whole. The structural features of the Indonesian economy throughout the study period are reflected in descriptive statistics, which display various consumption variances across sectors.

Table 1 illustrates that the productive sector accounts for the majority of national energy consumption. The industrial sector recorded an average of 227.63 BOE with significant variation, in line with the dynamics of manufacturing production. The transportation sector ranked highest, with an average of 282.06 BOE, with greater fluctuations due to sensitivity to mobility, fuel prices, and infrastructure. Meanwhile, the household sector averaged 139.48 BOE, remaining relatively stable but experiencing a significant shift from biomass to LPG and modern electricity sources. The commercial and public sectors (22.86 BOE) and agriculture (8.66 BOE) displayed smaller and more stable consumption, although both still contributed to the diversification of energy needs.

Total national energy consumption (680.70 BOE) is primarily influenced by the industrial and transportation sectors, which are the largest contributors. This finding confirms a structural shift in Indonesia's energy consumption from the household sector to the productive sector, in line with the literature on energy transition and structural change theory. Thus, energy increasingly plays a role as a productive input that supports industrialization, urbanization, and economic modernization, while also demanding attention to issues of efficiency, sustainability, and energy source diversification.

4.2. Patterns and Dynamics of Final Energy Consumption

Table 2 shows estimated trends result of final energy consumption in Indonesia. The results indicate that energy consumption dynamics in Indonesia during the 2010–2023 period are characterized by significant growth in the productive sectors, particularly transportation and industry. The trend coefficient for

Table 1: Result of descriptive statistics

Variable	Sector	Mean	Min	Max	Standard deviation	Key characteristics
E_1	Industry	227.63	185.20	270.10	26.57	Relatively high variation; influenced by manufacturing cycles
E_2	Transportation	282.06	232.00	334.20	32.80	Highest; highly sensitive to mobility and fuel prices
E_3	Household	139.48	130.90	150.50	6.82	Stable; reflects fuel switching from biomass to LPG/electricity
E_4	Commercial and public services	22.86	20.30	25.30	1.57	Low; gradual and relatively homogeneous growth
E_5	Agriculture	8.66	7.60	9.80	0.73	Smallest share; stable, but increasingly driven by mechanization
TEC	Total final energy consumption	680.70	595.60	773.40	55.33	Dominated by industry and transportation sectors

the transportation sector (β = 7.66) was the highest, indicating a consistent increase in energy consumption in line with increased population mobility, expansion of the transportation network, and dependence on fossil fuels. The industrial sector (β = 6.11) also experienced strong growth, reflecting the role of energy as an essential input in the manufacturing process and the expansion of national industrial capacity. Both confirm that Indonesia's energy consumption is increasingly concentrated in productive sectors that drive economic activity.

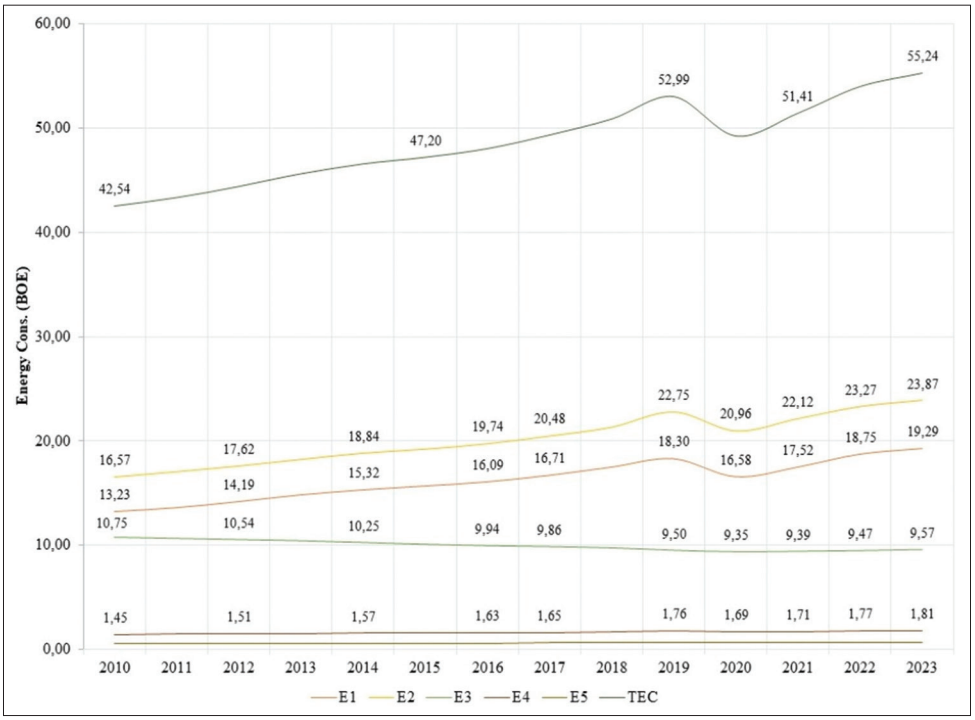
Conversely, the household sector exhibits a downward trend in energy consumption, as indicated by a negative coefficient (β = –1.56). This reflects a shift in consumption patterns from traditional biomass use to more efficient modern LPG and electricity. In other words, although household energy consumption remains significant, its contribution to total national energy consumption has declined. This change is consistent with the energy ladder theory, which posits that households transition from traditional to modern energy sources as their income and access to energy increase.

In addition, the commercial and public sectors (β = 0.37) and the agricultural sector (β = 0.17) exhibit a smaller but stable upward trend, with a very high R^2 value (>0.95), indicating a consistent growth pattern. Energy growth in the commercial sector is closely related to urbanization, expansion of public service infrastructure, and increased urban economic activity. On the other hand, the labor-intensive agricultural sector consumes only a relatively small amount of energy; however, its positive trend reflects the increasing mechanization and energy use in irrigation and post-harvest systems. In aggregate, total national energy consumption (TEC) follows the dynamics of transportation and industry as the largest contributors (Figure 1). The dominance of these two sectors marks a structural shift in Indonesia's energy consumption, from household-based use to the productive sector. This shift is in line with the literature on structural transformation in economic development (Adrian et al., 2023; Resosudarmo et al., 2023), where energy plays an increasingly important role as a productive input to support industrialization, urbanization, and national economic integration.

The results of the estimation highlight a clear structural shift in Indonesia's final energy consumption from household-based use toward productive sectors, particularly transportation and industry. The transportation sector, with the highest growth coefficient (β = 7.66), demonstrates its rising dominance in the energy landscape. Compare with findings from Rasyid (2021), energy demand in Indonesia, and Kanzari (2025) conclusion regarding energy transition and decarbonization in less developed economic countries (Kanzari et al., 2025; Rasyid and Kristina, 2021). This reflects the rapid expansion of mobility, dependence on fossil fuels, and development of transport infrastructure. Similarly, the industrial sector (β = 6.11) confirms the critical role of energy as an essential input for manufacturing growth and national industrialization. These findings support theories of structural change and energy-led development, which posit that as economies mature, energy demand becomes increasingly concentrated in sectors that drive output and productivity.

The household sector shows a declining trend (β = –1.56), indicating an ongoing transition in energy use. While this pattern aligns with the classical energy ladder framework, where rising income and improved infrastructure encourage shifts from traditional biomass to modern fuels such as LPG and electricity, recent studies suggest that the transition is neither fully linear nor uniform. As noted by Yadav et al. (2021), cultural preferences,

Figure 1: Conceptual framework



Source: Central Bureau of statistics/BPS (2025)

cooking traditions, and gender roles often sustain the parallel use of multiple fuels, a behavior known as fuel stacking (Yadav et al., 2021). Similarly, Waleed and Mirza (2023) demonstrate through their Household Energy Transition Index that household energy shifts are multidimensional, shaped by access, education, and spatial disparities rather than income alone (Waleed and Mirza, 2023). Hence, although household energy demand in Indonesia appears to decline in relative terms, this change likely reflects a complex, hybrid transition process rather than a complete substitution. Meanwhile, gradual increases in the commercial ($\beta = 0.37$) and agricultural ($\beta = 0.17$) sectors underscore the diversification of energy use, supporting a broader modernization trajectory grounded in sectoral and social transformation.

From a policy perspective, these dynamics carry significant implications. First, the dominance of transport and industry suggests that energy efficiency measures and low-carbon technologies in these sectors should be prioritized. For transport, this could include expanding mass transit systems, accelerating the adoption of electric vehicles, and rationalizing fuel subsidies. For the industry, promoting energy-efficient machinery, incentivizing the integration of renewable energy, and strengthening industrial energy management standards are essential steps. Second, the decline in household energy consumption relative to the total indicates the success of fuel switching, yet it also highlights the need for continued efforts to ensure affordable and reliable access to modern energy, especially in rural areas. Third, the steady rise in commercial, public, and agricultural energy use suggests the importance of aligning energy policy with urbanization strategies, service sector growth, and agricultural modernization programs (Roslan et al., 2022).

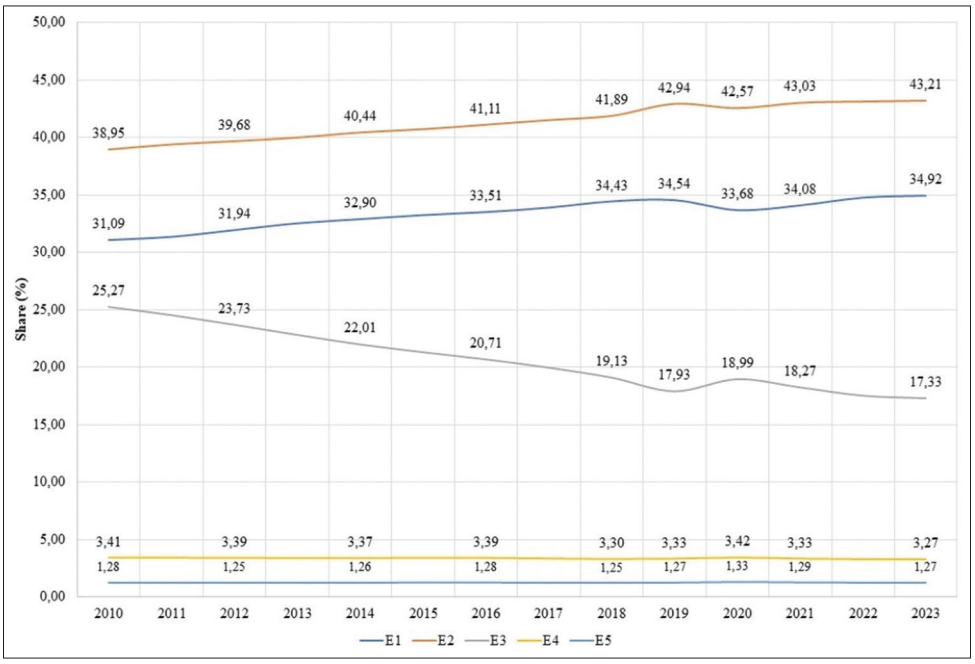
The findings emphasize that Indonesia's energy policy must strike a balance between economic growth, social equity, and environmental sustainability. The rising energy consumption in productive sectors indeed strengthens industrial competitiveness and supports economic expansion (see Fig. 2), yet as highlighted by Chen and Zhang (2025), such growth-driven energy demand risks reinforcing the energy-growth-emission nexus, where economic expansion directly amplifies CO_2 emissions unless structural decoupling occurs (Chen and Zhang, 2025). This underscores the need for complementary climate policies, such as carbon pricing, renewable energy subsidies, and stringent efficiency standards, to realign economic incentives. Meanwhile, Le et al. (2025) provide evidence from OECD countries that research and development (R&D) can play a nonlinear, transformative role: Investments in innovation initially increase energy use but eventually drive significant reductions as technology matures and efficiency gains become dominant.

For Indonesia, this suggests that embedding R&D-driven innovation in industrial and agricultural sectors is key to achieving both productivity and sustainability. At the same time, household energy affordability and inclusiveness remain central to social equity. As Luo and Cao (2025) demonstrate through their model of zero-emission energy resilience, smart energy management systems that integrate distributed storage and renewables can maintain stability and affordability even during grid disruptions (Luo and Cao, 2025). Translating such resilience frameworks to Indonesia's context could reduce vulnerability among low-income households and remote communities. Therefore, Indonesia's energy transition must not only pursue efficiency and competitiveness but also foster adaptive systems that ensure both climate resilience and social justice.

4.3. Shifting Energy Use from Households to Productive Sectors

Figure 3 illustrates the shares of energy consumption. It indicates a steady structural change from 2010 to 2023. The largest energy

Figure 2: Share of energy consumption in Indonesia: Sectoral averages and national trends



Source: Central Bureau of Statistics/BPS (2025)

user has continuously been the transportation sector (E_2), which increased its share from 38.95% in 2010 to 43.21% in 2023. This pattern suggests that national economic mobility is increasingly reliant on energy, particularly fossil fuels. The industrial sector (E_1), on the other hand, saw a consistent increase in its share, rising from 31.09% to 34.92%, demonstrating the importance of energy as a key component of industrialization. In contrast, the household sector (E_3) experienced a significant decline in share from 25.27% in 2010 to 17.33% in 2023. This decline reflects the phenomenon of household fuel switching from traditional biomass to modern energy sources (LPG and electricity), which, in aggregate, reduces the relative burden of households in the national energy structure. The commercial and public sector (E_4) remained relatively stagnant at around 3.3-3.4%, while the agricultural sector (E_5) remained the smallest at around 1.2-1.3%. This pattern confirms the dominance of the productive sectors (transportation and industry) over Indonesia's energy consumption, while also signaling a structural transformation in energy consumption in line with economic growth.

Figure 4 describes annual consumption changes, revealing more fluctuating growth dynamics. During the 2010-2019 period, almost all sectors exhibited growth, with the transportation and industrial sectors growing at the most consistent rate (approximately 3-7% per year). Peak growth occurred in 2019, when transportation rose by 6.81%, industry by 4.53%, and total national energy consumption (TEC) increased by 4.20%. This was in line with the momentum of national economic growth before the pandemic. However, 2020 was a turning point due to the COVID-19 pandemic. Almost all sectors recorded sharp contractions: industry fell by –9.41%, transportation by –7.88%, commercial and public by –4.45%, and total national energy by –7.09%. Only the household sector saw a smaller decline (–1.58%), remaining relatively stable as domestic consumption increased during the mobility restrictions.

Furthermore, regarding the 2021-2023 period, a gradual recovery occurred. Transportation grew again by 5.56% in 2021, followed by 5.20% in 2022, although it slowed to 2.58% in 2023. The industry experienced a similar rebound, with the highest growth of 7.01% in 2022, followed by a decline to 2.90% in 2023. This pattern reflects the strong post-pandemic recovery effect at the beginning but returned to normal as the economy stabilized. The household sector recorded small growth since 2021, although the long-term trend remained downward. The combined effect of the two tables indicates two levels of phenomenon. First, structurally, the transportation and industrial sectors account for a growing portion of energy consumption (Figure 3), supporting the idea that Indonesia's energy is shifting toward productive sectors. Second, external events, such as the pandemic, have a significant impact on energy consumption on a cyclical basis. This has led to a significant decrease in the transportation and industrial sectors, but a comparatively smaller one in the residential sector.

Thus, while exogenous shocks (such as pandemics and global energy prices) impact short-term dynamics, the dominance of productive sectors is a long-term feature of national energy consumption. This circumstance highlights the importance of energy policies that prioritize industry and transportation efficiency, energy source diversity to reduce reliance risk, and household protection to prevent further marginalization during the energy transition. The period from 2010 to 2023 has witnessed a structural transformation in Indonesia's final energy consumption, with a notable shift toward the productive sectors. The data indicate that the share of household energy has declined sharply from 25.27% in 2010 to 17.33% in 2023, in line with the gradual substitution of traditional biomass by more efficient LPG and electricity sources. This transition reflects the success of national

Figure 3: Estimated sectoral shifts in final energy use: Annual percentage changes

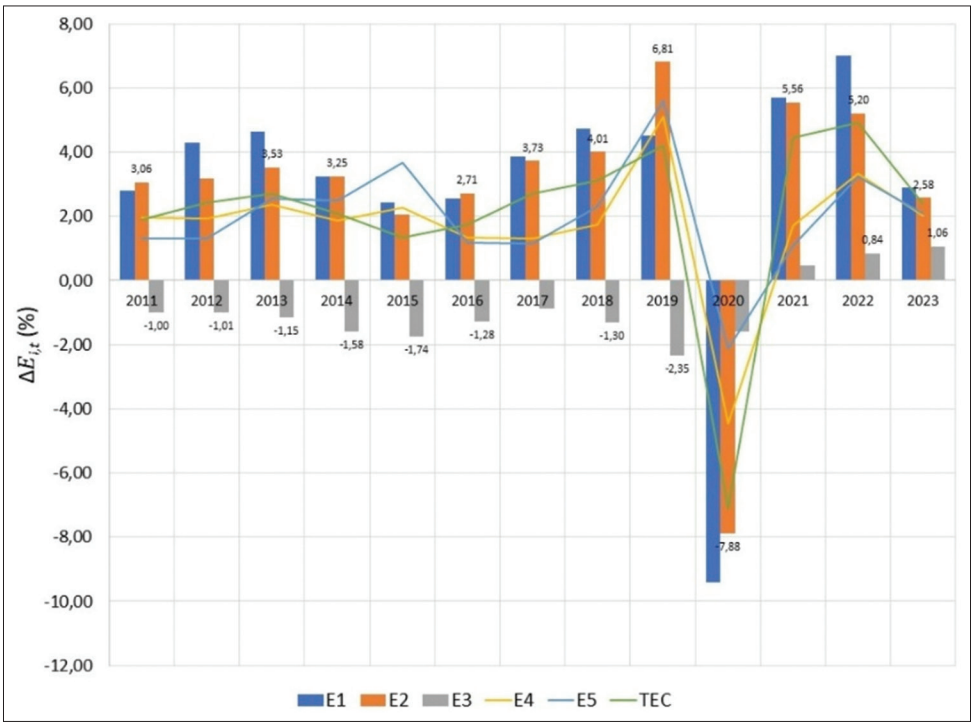


Table 2: Result of estimated trends of final energy consumption in Indonesia for 2010-2023

Variable (sector)	Trend coefficient (β)	Sig.	R^2	Trend direction
E_1 - Industry	+6.11	0.000	0.926	Increasing
E_2 - Transportation	+7.66	0.000	0.955	Increasing (fastest)
E_3 - Household	–1.56	0.000	0.920	Decreasing
E_4 - Commercial and Public	+0.37	0.000	0.952	Increasing (gradual)
E_5 - Agriculture	+0.17	0.000	0.979	Increasing (stable)
TEC - Total energy consumption	– (aggregate of E_1-E_5)	–	–	Follows industry and transport

electrification initiatives and the diffusion of modern energy technologies across both urban and rural areas.

Such findings are consistent with the long-term dynamics identified by Chen and Pitt (2017), who demonstrated that the reduction in household biomass dependence in Indonesia between 1980 and 2002 was primarily driven by income growth and urbanization, yet constrained by unequal access and infrastructure limitations. The continued decline in household energy share after 2010 suggests that many of those structural barriers have been partially overcome through targeted electrification programs and expansion of LPG distribution networks. However, as Cahyani et al. (2022) Notably, disparities persist between urban and rural households not only in access but also in the quality and sufficiency of electricity use. While urban households exhibit patterns of relative efficiency, many rural households still experience energy insufficiency, limited capacity, and low literacy in energy management.

Therefore, the recent downward trend in household energy consumption should not be interpreted solely as evidence of higher efficiency but also as a reflection of uneven sufficiency levels across regions. The observed transformation thus embodies a dual reality: the modernization of energy systems on one hand, and the persistence of socio-spatial inequality on the other. Ensuring that the shift toward productive energy use does not deepen such inequalities requires policies that integrate efficiency with equity, emphasizing inclusive access, affordability, and capacity-building for sustainable household energy transitions.

On the other hand, market share growth was steady in the industrial and transportation sectors. Over the same time span, industry grew from 31.09% to 34.92%, while transportation went from 38.95% to 43.21%. This rise is a result of increased manufacturing activity, population mobility, motor vehicle growth, and the development of logistical infrastructure. These circumstances demonstrate that energy is becoming a vital input to promote national economic integration and industrialization.

This shift is even more apparent when viewed from an annual perspective. During the 2020 pandemic, transportation and industrial consumption experienced major contractions, while household consumption remained relatively stable. However, in the post-pandemic period, consumption recovery was once again driven by the productive sectors, confirming their dominance in the national energy structure. Thus, the shift in Indonesia's energy consumption can be understood as part of a structural change that not only reflects economic modernization but also demands energy policies that emphasize efficiency, diversification, and long-term sustainability.

Table 3: Result of average growth of final energy consumption by sector in Indonesia for 2010-2023

Sector	Pre-Pandemic (2010-2019) (%)	Pandemic (2020) (%)	Post-Pandemic (2021-2023) (%)
Industry (E_1)	+3.8	–9.4	+5.2
Transportation (E_2)	+4.2	–7.9	+4.4
Households (E_3)	–1.3	–1.6	+0.8
Commercial and Public (E_4)	+2.2	–4.5	+2.3
Agriculture (E_5)	+2.0	–2.1	+2.1
Total final energy (TEC)	+3.2	–7.1	+3.9

4.4. Pre- and Post-Pandemic Energy Consumption: Sectoral Perspectives

The dynamics of energy consumption in Indonesia have been significantly impacted by the COVID-19 outbreak. Prior to the pandemic, final energy consumption patterns exhibited a steady and rising growth trend, particularly in the industrial and transportation sectors, which are the primary drivers of the economy. This growth rate was consistent with growing urban, commercial, and public activity, industrialization, and mobility. However, when the pandemic struck in 2020, patterns of energy use underwent drastic changes. National energy consumption declined significantly due to mobility restrictions, a decline in industrial activity, and a decrease in international demand.

The transportation and industrial sectors were the most severely affected, while household energy consumption remained relatively stable as domestic activity increased during lockdown. After the pandemic subsided, energy consumption patterns returned to their normal levels. Productive sectors, particularly transportation and industry, showed a rapid recovery, even approaching pre-pandemic trends. This suggests that the post-pandemic economic recovery is closely tied to the rebound in energy consumption in key sectors that drive growth. The sectoral perspective in comparing pre- and post-pandemic energy consumption is therefore important for understanding the vulnerability and resilience of the national energy system. This analysis not only illustrates the short-term dynamics resulting from the global health crisis but also provides insights into the direction of Indonesia's future energy transition in the face of similar external shocks.

Table 3 illustrates the impact of external shocks and structural factors on Indonesia's final energy consumption patterns between 2010 and 2023. Nearly every sector experienced significant growth during the pre-pandemic period (2010-2019), with industry (+3.8%) and transportation (+4.2%) driving most of the country's energy consumption. This aligns with development literature that

highlights energy's role as a productive input for the growth of industry and mobility. The household sector, which shifted from traditional biomass to more efficient contemporary energy sources, was an outlier, with an average negative growth rate of −1.3%. The COVID-19 pandemic in 2020 marked a significant turning point. Nearly all sectors experienced contraction, particularly industry (−9.4%) and transportation (−7.9%), in line with declining manufacturing and distribution activities, as well as mobility restrictions. This contraction underscored the vulnerability of productive sectors to external shocks. Meanwhile, the household sector declined only slightly (−1.6%), demonstrating relatively better resilience as domestic activities increased during the period of social restrictions.

Entering the post-pandemic phase (2021-2023), national energy consumption recovered. The average growth in industry (+5.2%) and transportation (+4.4%) reflected the rapid recovery of productive economic activity, confirming that these sectors continue to dominate the long-term trend. The household sector turned positive (+0.8%), although the increase was more moderate, in line with the normalization of domestic consumption. Commercial and public (+2.3%) and agriculture (+2.1%) recorded stable growth, confirming that although their share is relatively small, these sectors still play a role in diversifying energy consumption. These findings highlight three important points. First, Indonesia's long-term energy consumption is shifting from households to the productive sector, in line with the theory of structural change. Second, the transportation and industrial sectors are highly sensitive to external crises, making energy efficiency and diversification policies essential. Third, the post-pandemic recovery shows the potential for accelerating the energy transition, particularly through the electrification of transportation, the strengthening of clean energy-based industries, and increased access to modern energy for households and the agricultural sector.

4.5. Discussion

The results of the analysis of Indonesia's final energy consumption trends show a consistent structural shift alongside significant vulnerability to external shocks. In the pre-pandemic period, the transportation and industrial sectors emerged as the primary drivers of energy consumption growth, with average annual increases of 4.2% and 3.8%, respectively. This pattern aligns with the theory of structural change, which posits that as industrialization and urbanization advance, economic activity becomes increasingly concentrated in productive sectors characterized by high energy intensity. However, such a transformation also exposes the economy to global energy price fluctuations and supply disruptions—an issue that underscores Indonesia's vulnerability to external shocks and its need for greater technological resilience.

Conversely, the household sector experienced negative growth (−1.3%), reflecting a long-term energy transition trajectory in which households gradually shift from traditional biomass to more efficient modern fuels, such as LPG and electricity. This finding extends the evidence presented by Chen and Pitt (2017), who identified similar substitution patterns during 1980-2002, but also warned that unequal access and price distortions could slow the transition (Chen and Pitt, 2017). The post-2010 decline in household energy consumption suggests that many of these structural barriers have eased through the national electrification program and the widespread adoption of LPG. Yet, as Cahyani et al. (2022) reveal, the transformation remains uneven: urban households have achieved relative efficiency, while rural communities often face energy insufficiency due to limited power capacity, affordability constraints, and low energy literacy (Cahyani et al., 2022).

Moreover, the ongoing transformation in sectoral energy use must be viewed within the broader context of technological and policy adaptation. Evidence from Le et al. (2025) (Le et al., 2025) indicates that investment in energy-related research and development (R&D) can initially increase energy intensity but ultimately lead to substantial reductions as innovation drives efficiency and low-carbon transitions. For Indonesia, this implies that sustaining structural change requires embedding innovation into industrial policy and fostering R&D-led efficiency improvements rather than relying solely on consumption-side adjustments. As emphasized by Shahzad (2025), clean energy transitions in emerging economies depend critically on the synergy between green innovation and financial development, which together enhance energy efficiency and reduce carbon intensity in production systems. The study highlights that economies with stronger financial intermediation and targeted R&D incentives are more capable of transforming industrial structures toward low-emission growth pathways (Shahzad, 2025). This implies that Indonesia's long-term energy transition should not only promote efficiency at the household or demand side but also institutionalize mechanisms for green technology financing and innovation diffusion within industrial sectors.

In line with this view, Mandasari and Luckstead (2025) demonstrate that export-oriented, agri-based manufacturing in Indonesia exhibits higher CO_2 productivity compared to non-exporting firms, suggesting that exposure to international markets drives technological upgrading and improved environmental performance. Their findings suggest that trade competitiveness can reinforce sustainability if innovation and resource efficiency are integrated into industrial strategy (Mandasari and Luckstead, 2025). Therefore, structural transformation in Indonesia's energy economy must be anchored in innovation-oriented industrial policy, linking R&D incentives, financial access, and export competitiveness to achieve enduring efficiency gains across sectors.

Thus, Indonesia's energy transition narrative captures a dual reality: A steady modernization of the energy structure driven by industrial growth and household efficiency yet coupled with systemic vulnerabilities arising from external dependence and domestic inequality. Achieving sustainable and inclusive energy transformation will therefore depend on policies that integrate technological innovation, resilience building, and social equity across all sectors of the economy.

The COVID-19 pandemic crisis in 2020 provided clear evidence of how external factors can disrupt national energy consumption patterns. The sharp decline in the industrial sector (−9.4%) and transportation sector (−7.9%) reflects the vulnerability of these two

sectors to global shocks, both in terms of production and mobility. However, the household sector was relatively more resilient, declining by only −1.6%, which shows that household energy functions as a more stable basic need compared to productive energy. This reinforces the concept of energy resilience, where diversification of energy use across sectors can serve as a buffer against macroeconomic shocks.

As highlighted by Tan et al. (2023), transportation infrastructure can either amplify or mitigate such vulnerabilities depending on its efficiency and adaptability. Well-integrated, low-emission transport systems improve long-term energy conservation and resilience to crises, while poorly managed expansion increases fuel dependency (Tan et al., 2023). Meanwhile, Budianto et al. (2025) emphasize that corporate governance also plays a vital role in sustaining energy resilience—firms with stronger sustainability committees and transparent carbon reporting tend to adapt better to external disruptions through efficiency-oriented practices (Budianto et al., 2025). These findings suggest that post-pandemic recovery in Indonesia should not only restore energy demand but also embed green infrastructure planning and corporate sustainability governance as core instruments for building systemic resilience.

Empirical evidence from Rasyid and Kristina (2021) supports this observation, showing that household demand for energy in Indonesia tends to be relatively inelastic to short-term economic disturbances. Energy sources such as LPG and electricity remain essential, even when income and employment fluctuate. Meanwhile, Bedi et al. (2017) demonstrate that community-based innovations—such as household biogas programs—can further enhance this resilience by reducing dependence on commercial fuels and stabilizing expenditures during crisis periods. Such localized technologies create a safety net for rural households when broader energy supply chains are disrupted (Bedi et al., 2017). However, the results of Neto-Bradley et al. (2021) show that fuel flexibility, or energy stacking, also affects family energy consumption resilience (Neto-Bradley et al., 2021). Households often employ a variety of fuels to deal with shortages and price swings during uncertain times, particularly in metropolitan areas with low incomes. This behavioral flexibility reduces the likelihood of energy insecurity, emphasizing the importance of national policy in guaranteeing a variety of reasonably priced energy sources.

In this light, Indonesia's relatively stable household energy demand during the pandemic illustrates both economic necessity and adaptive capacity. Strengthening this resilience in the future will require expanding access to decentralized energy technologies, improving energy governance at the local level, and embedding social protection mechanisms into energy policy, so that the household sector remains a stabilizing force amid systemic shocks. Following the pandemic, energy consumption growth rates rebounded to positive territory, surpassing those of the previous period in the industrial (+5.2%) and transportation (+4.4%) sectors. This recovery indicates a rebound effect in energy demand, triggered by accelerated mobility, industrial revival, and economic policy stimulus. Meanwhile, households (+0.8%), commercial and public (+2.3%), and agriculture (+2.1%) show a more moderate but consistent recovery pattern. These findings reinforce that in the long term, Indonesia's energy consumption is increasingly dominated by the productive sector, although other sectors continue to contribute to the national energy diversification framework.

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5. CONCLUSION

The analysis of Indonesia's final energy consumption from 2010 to 2023 demonstrates a clear structural transformation. Productive sectors, particularly transport and industry, have emerged as the dominant drivers of energy demand, while household consumption has declined due to the transition from traditional fuels to LPG and electricity. The pandemic served as a stress test, temporarily suppressing demand across all sectors; yet, transport and industry rebounded strongly, confirming their cyclical yet resilient nature. In contrast, household demand followed a steady structural decline, reflecting efficiency improvements rather than cyclical effects. When these findings are placed alongside Indonesia's Net Zero Emissions (NZE) Roadmap 2060, the alignment becomes evident.

The roadmap identifies transport and industry as key areas for decarbonization, setting ambitious targets for emission reduction through electrification, expansion of renewable energy sources, fuel economy standards, industrial process innovations, and the development of carbon capture technologies. Without significant policy interventions, the growth trajectories observed in the simulation risk locking Indonesia into a high-carbon pathway, undermining its climate commitments (Utomo et al., 2025). Meanwhile, the household sector, though less significant in aggregate demand, remains important for ensuring equitable access to modern energy services. Here are some recommendations derived from the study's analysis and conclusions, which include the following:

1. Targeted decarbonization in transport and industry - Policies should prioritize efficiency improvements and low-carbon technologies in transportation and industry, given their significant role in driving demand growth. Measures such as the deployment of electric vehicles, investment in public transport, industrial fuel substitution, and stricter efficiency standards are critical.
2. Acceleration of renewable energy deployment - To ensure that growing energy demand does not translate into higher emissions, Indonesia must expand renewable energy capacity

beyond current targets. This includes scaling up solar, wind, bioenergy, and hydropower to meet the needs of industrial and transportation electrification.

3. Household energy transition and equity - Although household demand is declining, continued support for clean cooking programs, rural electrification, and affordability schemes are vital to prevent disparities in energy access and ensure an inclusive energy transition.
4. Resilience against external shocks - The pandemic revealed the vulnerability of transport and industry to sudden disruptions. Strengthening domestic supply chains, diversifying energy sources, and developing adaptive policies will improve resilience against future crises.
5. Integration of empirical monitoring with policy targets - Continuous monitoring of energy demand and emissions by sector should be integrated with NZE targets. Scenario-based forecasting, supported by econometric and decomposition analysis, can guide policy adjustments in line with actual consumption patterns.

Several strategic implications might be inferred from a policy standpoint. First, stronger energy efficiency regulations are necessary due to the significant share of energy use held by the transportation and industrial sectors. Reducing reliance on fossil fuels in transportation requires implementing car electrification techniques, bolstering mass transit, and enhancing fuel subsidy management. In the industrial sector, incentives for integrating renewable energy, enforcing industrial energy standards, and adopting energy-efficient technologies may help strike a balance between energy demands and decarbonization goals, as aligned with Budianto et al. (2025) and Utomo et al. (2025). Second, the pattern of decline in household energy consumption suggests that the transition to modern energy is underway; however, it also poses challenges in terms of equity. Reliable, affordable, and equitable access to energy must remain a priority so that low-income households are not left behind in the energy transition process. Rural electrification programs, targeted subsidies for LPG and electricity, and the development of small-scale renewable energy can strengthen energy justice.

Third, the relatively rapid post-pandemic recovery also shows that energy consumption is closely linked to the economic cycle. This reinforces the need to integrate energy policy with long-term economic development strategies. With Indonesia's commitment to the 2060 Net Zero Emissions target, the energy transition needs to be directed towards strengthening the competitiveness of the productive sector while ensuring environmental sustainability. Carbon trading policies, bioenergy development, and investment in clean energy infrastructure are important instruments to support this transformation. This discussion confirms that Indonesia's energy consumption not only reflects sectoral demand dynamics but also reflects the direction of national economic development. Thus, energy policies that are integrated with the agenda of industrialization, agriculture and food security, urbanization, and environmental sustainability are essential for achieving energy security and economic independence for Indonesia in the future.

REFERENCES

Adrian, M.M., Purnomo, E.P., Enrici, A., Khairunnisa, T. (2023b), Energy transition towards renewable energy in Indonesia. Heritage and Sustainable Development, 5(1), 107-118.

Andriansyah, Nurwanda, A., Rifai, B. (2023), Structural change and regional economic growth in Indonesia. Bulletin of Indonesian Economic Studies, 59(1), 1914320.

Ahmat, N., Christopher, S., Saputra, J., Sukemi, M. N., Nawawi, M. N. (2025), The impact of energy consumption, economic growth, and non-renewable energy on carbon dioxide emission in Malaysia. International Journal of Energy Economics and Policy, 15(1), 143-152.

Bedi, A.S., Sparrow, R., Tasciotti, L. (2017), The impact of a household biogas programme on energy use and expenditure in East Java. Energy Economics, 68, 66-76.

Budianto, Setiawan, D., Widarjo, W., Arifin, T. (2025), Influence of corporate sustainability committees, environmental performance, and environmental costs on carbon disclosure in energy, mining, and transportation companies in Indonesia. Journal of Asian Energy Studies, 9, 91-110.

Cahyani, A.D., Nachrowi, N.D., Hartono, D., Widyawati, D. (2022), Between insufficiency and efficiency: Unraveling households' electricity usage characteristics of urban and rural Indonesia. Energy for Sustainable Development, 69, 103-117.

Chen, J.J., Pitt, M.M. (2017), Sources of change in the demand for energy by Indonesian households: 1980–2002. Energy Economics, 61, 147-161.

Chen, Q., Zhang, E. (2025), Economic growth, energy consumption and CO_2 emissions: A replication. Energy Economics, 147, 108538.

Chenery, H.B. (1971), Growth and structural change. Finance and Development, 8(3), 16-24

Dietzenbacher, E., Kulionis, V., Capurro, F. (2020), Measuring the effects of energy transition: A structural decomposition analysis of the change in renewable energy use between 2000 and 2014. Applied Energy, 258, 114040.

Ghoddusi, H., Rodivilov, A., Roy, M. (2021), Income elasticity of demand versus consumption: Implications for energy policy analysis. Energy Economics, 95, 105009.

Hadasik, B., Kubiczek, J., Ryczko, A., Krawczyńska, D., Przedworska, K. (2025), From coal to clean energy: Economic and environmental determinants of household energy transition in Poland. Energy Economics, 148, 108697.

Hardt, L., Barrett, J., Taylor, P.G., Foxon, T.J. (2021), What structural change is needed for a post-growth economy: A framework of analysis and empirical evidence. Ecological Economics, 179, 106845.

Havranek, T., Kokes, O. (2015), Income elasticity of gasoline demand: A meta-analysis. Energy Economics, 47, 004.

HEESI. (2022), Handbook of Energy and Economic Statistics of Indonesia. Jakarta: Ministry of Energy and Mineral Resources Republic of Indonesia.

Henriques, S.T., Sharp, P., Tsoukli, X., Vedel, C. (2024), Adaptability, diversification, and energy shocks: A firm level productivity analysis. Energy Economics, 139, 107887.

Hernandez, M., Bhagavatula, K., Cibi, S., Ravichandran, K, Krishnan, S., Malaviya, S., Jairaj, B. (2022), Shifting Household Energy Use in Bangalore, India: Using Behaviorally Informed Energy Reports. Washington, D.C: World Resources Institute.

Higginson, S., Thomson, M., Bhamra, T. (2014), "For the times they are a-changing": The impact of shifting energy-use practices in time and space. Local Environment, 19(5), 802459.

Iacovoiu, V., Panait, M., Stancu, A., Iacob, Ștefan. (2025), Driving factors of final energy consumption in the European Union: A comprehensive

analysis. Energies, 18(7), 1703.
International Energy Agency. (2017), World Energy Statistics 2017. France: IEA.
Kanzari, E., Fazio, G., Fricano, S., Cardinale, R. (2025), Energy reserve dynamics: Integrating renewable energy for energy security and sustainability in lesser-developed economies. Energy Economics, 150, 108882.
Khan, I., Zakari, A., Zhang, J., Dagar, V., Singh, S. (2022), A study of trilemma energy balance, clean energy transitions, and economic expansion in the midst of environmental sustainability: New insights from three trilemma leadership. Energy, 248, 123619.
Kuznets, S., Murphy, J.T. (1966), Modern economic growth: Rate, structure, and spread (Vol. 2). New Haven: Yale University Press.
National Development Planning Agency (2019), Low Carbon Development: A Paradigm Shift Towards a Green Economy in Indonesia. 1-24, Ministry of National Development Planning. Available from: https://lcdi-indonesia.id/wp-content/uploads/2022/03/Low-Carbon-Development-A-Paradigm-Shift-Towards-a-Green-Economy-in-Indonesia-Policymakers-Summary-2019.pdf
Le, H.C., Bhattacharya, M., Smyth, R., Zhang, X. (2025), The impact of R&D on energy consumption: Evidence from nonlinear semi-parametric estimations for selected OECD countries. Energy Economics, 2025, 108708.
Luo, H., Cao, S. (2025), Energy resilience enhancement against grid outages for a zero-emission hotel building via optimal energy management of onshore and offshore energy storages. Energy Nexus, 18, 100431.
Mandasari, P., Luckstead, J. (2025), Examining the nexus between exporting status and CO_2 productivity in Indonesian agri-based manufacturing. Energy Economics, 143, 108215.
Muttaqee, M., Stelmach, G., Zanocco, C., Flora, J., Rajagopal, R., Boudet, H.S. (2024), Time of use pricing and likelihood of shifting energy activities, strategies, and timing. Energy Policy, 187, 114019.
Neto-Bradley, A.P., Rangarajan, R., Choudhary, R., Bazaz, A.B. (2021), Energy transition pathways amongst low-income urban households: A mixed method clustering approach. MethodsX, 8, 101491.
Nugraha, T.A., Osman, H.N. (2017), The energy-economic Growth Nexus in Indonesia. Journal of Business Management and Accounting, 7(2), 61-75.
Rahko, J., Onifade, S.T., Alola, A.A. (2025), How harmful are fossil fuel subsidies to the diffusion of low-carbon energy technologies? Energy Economics, 147, 108547.
Rasyid, M., Kristina, A. (2021), Estimation of demand system for household energy consumption: Empirical evidence from Indonesia. International Journal of Energy Economics and Policy, 11(6), 289-295.
Resosudarmo, B.P., Rezki, J.F., Effendi, Y. (2023), Prospects of energy transition in Indonesia. Bulletin of Indonesian Economic Studies, 59(2), 2238336.
Roslan, F., Gherghina, Ș.C., Saputra, J., Mata, M.N., Zali, F.D.M., and Martins, J.M. (2022), A panel data approach towards the effectiveness of energy policies in fostering the implementation of solar photovoltaic technology: Empirical evidence for Asia-Pacific. Energies, 15(10), 3775.
Sapnken, F.E., Nna Nna, P.T., Stevy Sama, J.M., Ewodo-Amougou, M.R., Tamba, J.G. (2025), A disaggregated analysis of energy demand in Cameroon: Determinants, elasticities, and policy implications. Energy Strategy Reviews, 60, 101799.
Shahzad, U. (2025), Achieving clean energy transitions: How green innovation and financial development shape energy usage. Energy Economics, 150, 108851.
Tan, R., Cui, L., Meng, X., Xu, M. (2023), Towards energy conservation by constructing more transportation infrastructure? An endogenous stochastic frontier analysis framework. Journal of Environmental Management, 346, 118992.
Utomo, D.P., Subrata, M.E., Dhelika, R. (2025), Decarbonization roadmap and energy system scenarios for Southern Sulawesi system: Response to demand growth from smelters sector. Journal of Asian Energy Studies, 9, 149-171.
Waleed, K., Mirza, F.M. (2023), Examining fuel choice patterns through household energy transition index: An alternative to traditional energy ladder and stacking models. Environment, Development and Sustainability, 25(7), 6449-6501.
Yadav, P., Davies, P.J., Asumadu-Sarkodie, S. (2021), Fuel choice and tradition: Why fuel stacking and the energy ladder are out of step? Solar Energy, 214, 077.
Yang, Y., Xia, S., Qian, X. (2023), Geopolitics of the energy transition. Journal of Geographical Sciences, 33(4), 2101-2102.