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ENERGY POLICY IN INDONESIA: A COMPREHENSIVE REVIEW OF ENERGY POLICY IN INDONESIA FOR A LOW-CARBON FUTURE

Ibham Veza[1,2,*], Raditya Yudha Wiranegara[3], Ihwan Ghazali[4], Andy Tirta[5]

[1]Department of Mechanical Engineering, Faculty of Engineering, Universitas Bung Karno, Jl. Kimia No. 20. Menteng, Jakarta 10320, Indonesia ibham@vezas.org
[2]Centre for Renewable Energy System Modeling & Policy Review, Aras Energy Consulting, Jl. HR Rasuna Said Kav. C-5, Setia Budi, Jakarta Selatan 12920, Indonesia
[3]IESR (Institute for Essential Services Reform), Jl. Tebet Timur Raya No. 48B Jakarta Selatan 12820 Indonesia raditya@iesr.or.id
[4]Fakulti Teknologi dan Kejuruteraan Industri dan Pembuatan Universiti Teknikal Malaysia Melaka, Malaysia ihwan@utem.edu.my
[5]Graduate School of Renewable Energy, Darma Persada University, Jl. Radin Inten 2, Pondok Kelapa, East Jakarta, 13450, Indonesia andy.tirta@pasca.unsada.ac.id

*Corresponding author: Ibham Veza (ibham@vezas.org)

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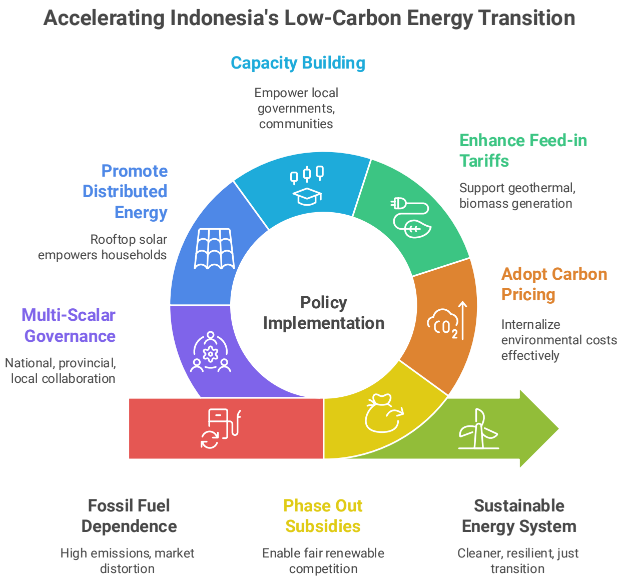
GRAPHICAL ABSTRACT



HIGHLIGHTS

- Provides a comprehensive framework for Indonesia's low-carbon energy transition.
- Integrates governance, finance, and technology in renewable energy policy.
- Examines solar, biomass, geothermal, and biofuel potentials with clear pathways.
- Connects technical modeling to practical, multi-level policy actions.
- Offers lessons applicable to other emerging economies moving to clean energy.

ABSTRACT

Energy policy in Indonesia is becoming increasingly central to the country's efforts to pursue low-carbon development, economic resilience, and long-term sustainability. As global and domestic pressures intensify, energy policy in Indonesia must respond to rising energy demand, shifting technology costs, and the urgent need to reduce emissions while maintaining affordability and security. This study provides an integrated analysis of how energy policy in Indonesia shapes the national energy transition, focusing on regulatory structures, institutional dynamics, and the interaction among key stakeholders across multiple governance levels. Despite notable progress, energy policy in Indonesia continues to face persistent challenges, including fossil-fuel subsidy dependence, uneven regional implementation, and limited financial support for renewable energy development. These constraints reflect structural gaps in how energy policy in Indonesia balances economic growth with environmental commitments. The analysis highlights solar, biomass, geothermal, and emerging technologies as major opportunities that can be unlocked through stronger and more coherent energy policy in Indonesia. By examining the political economy underpinning current regulations, this paper demonstrates that energy policy in Indonesia must evolve toward transparent incentive frameworks, streamlined permitting, and more predictable investment environments. The success of energy policy in Indonesia also depends on empowering local governments, improving institutional coordination, and ensuring that marginalized communities benefit from the transition. Furthermore, this study shows that distributed energy solutions can advance social equity when supported by inclusive and community-oriented energy policy in Indonesia. Ultimately, the findings illustrate that achieving national climate targets requires aligning energy policy in Indonesia with long-term planning documents, strengthening cross-sectoral coherence, and accelerating renewable energy deployment. Energy efficiency, carbon pricing, technology innovation, and capacity building must be embedded directly into future energy policy in Indonesia. By addressing governance, financing, and technological barriers, energy policy in Indonesia can play a transformative role in guiding the country toward a just, resilient, and sustainable energy future. The insights presented here offer a comprehensive foundation for scholars, policymakers, and practitioners seeking to understand and improve the direction of energy policy in Indonesia.

Keywords: Energy transition; Renewable energy policy; Low-carbon development; Indonesian energy policy; Stakeholder engagement; Low carbon policy

1. Journey to Achieve SDG 7: Challenges, Policies, and the Future of Energy Justice and Transition in Indonesia

As countries begin incorporating the Sustainable Development Goals (SDGs) into their national development strategies, it is crucial to review existing policies to ensure that the goals are within reach by 2030 [1]. Santika, et al. [2] evaluates Indonesia's energy policy in terms of its effectiveness in promoting universal energy access, increasing the deployment of renewable energy, and enhancing energy efficiency. Relevant laws and regulations were analyzed to assess their contribution toward achieving Indonesia's energy-related SDG targets. The findings indicate that supplying electricity to the remaining 1.1 million households in the outermost and least developed regions of the archipelago poses significant challenges. However, with sufficient annual budget allocation, Indonesia is still on course to achieve full residential electrification by 2030. On the other hand, the country may struggle to ensure access to clean cooking fuels and technology for all by 2030. Current policies, which focus heavily on gas for cooking, are likely to be ineffective for households still reliant on solid biomass, many of whom live in poverty. Similarly, the existing policy framework is inadequate to achieve the renewable energy target. Additionally, the evaluation of energy efficiency policies reveals that sectoral energy use is influenced by various factors and regulations not primarily aimed at improving energy efficiency.

Countries worldwide are increasingly committed to achieving universal electrification in line with Sustainable Development Goal 7. Indonesia is one of these nations, striving to reduce energy poverty, recognizing that about 25 million people still lack access to electricity. Setyowati [3] looks at Indonesia's efforts to achieve energy justice by using private finance for renewable energy projects in rural areas. It specifically examines how well the country has addressed energy justice issues and their social consequences. Through interviews and document analysis, the study reveals that Indonesia's approach to energy justice mainly focuses on ensuring accessibility and affordability. However, important aspects of energy justice, such as procedural justice and recognition, have been overlooked. This limited approach has led to policies that prioritize large-scale, on-grid solutions, leaving fewer financial options for small, distributed renewable energy projects. It also worsens spatial inequality and marginalizes energy-poor communities from participating in energy-related decisions. To achieve a more comprehensive vision of energy justice, policies must address all aspects of justice and promote diverse financial solutions to tackle energy poverty.

The increasing pressure on the government to transition to renewable energy sources as alternatives to fossil fuels has led to a focus on exploring alternative energy options. There are a few estimates on the renewable energy potential in Indonesia. Indonesian Ministry of Energy and Mineral Resources (MEMR) initially estimated that Indonesia has about 443 GW of renewable energy technical potential, with sources ranging from solar energy to tidal [4]. In 2021, using a GIS approach whilst considering the land-use restriction and the cycle of selected feedstock availability, IESR, an energy and environmental think-tank based in Jakarta, proposed an alternative estimate of the potential by offering a staggering 7,879.43 GW [5]. Immediately after that, the ministry then improved its methodology, prompting an update to its official estimate on the potential. It is now standing at 3,643 GW [6]. Of these estimates, solar energy has consistently been the largest source of renewable energy resources, ranging from 207 GW to 7,714.6 GW. Wind comes in second with potential ranging from 88 GW to 154.9

GW. Following these resources, there is quite a variation in the order of the potential estimate, as indicated in Table 1.

Table 1. Renewable energy technical potential in Indonesia [4-6].

Sources	MEMR_2017 (in GW)	IESR (in GW)	MEMR_2021 (in GW)
Solar	207	7,714.6	3,294.4
Wind	-	88 - 106[1]	154.9[2]
Hydro	75	28.1[3]	95[4]
Bioenergy	102	30.73[5]	56.9[6]
Geothermal	29	23.9	-
Tidal	17.9	-	17.9

A significant research gap in Indonesia's policy landscape is the limited discussion regarding its energy planning. Rahman, et al. [7] tackles the issue by using a political economy perspective to explore the country's energy mix and supply security until 2050. Through a thorough review, it raises three main questions about the ongoing dependence on oil and the potential shift towards renewable energy sources. A situation analysis examines Indonesia's role in the global oil supply politics, its domestic logistics, ongoing oil subsidies, and its stance on fossil fuel emissions and renewable energy. The analysis identifies shortcomings, including a heavy reliance on fossil fuels, particularly oil imports; the scale of oil subsidies; the absence of strategic oil reserves; a lack of focus on emissions; and conflicting policies regarding renewable energy. The article concludes by outlining a research agenda aimed at facilitating Indonesia's transition in energy mix and security by 2050. Figure 1 illustrates the interaction between the ecosystem (sources) and the economy (stocks) within the energy cycle framework of a steady-state economy, highlighting the concepts of depletion, production, emission, depreciation, throughput (cost), and service (income).

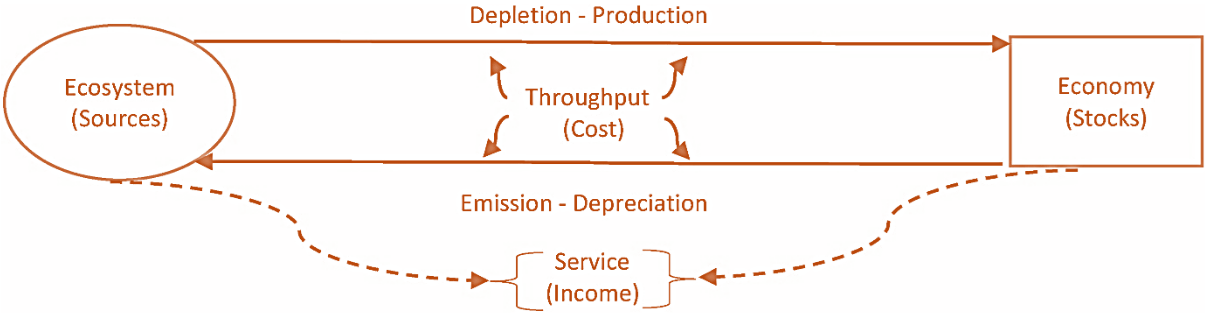


Figure 1. The energy cycle conceptualized from the steady-state economy perspective, adapted from [7].

The shift to low-carbon energy requires coordinated policies, institutions, and stakeholders at various levels of governance. Indonesia's goal of moving towards low-carbon energy is influenced by changes in environmental governance due to

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[1]Estimated for onshore with low end measured at 100 m hub height & high end measured at 50 m hub height
[2]Estimated for both onshore and offshore
[3]Estimated for micro and mini scales with capacity < 10 MW
[4]Estimated for run-off river and reservoir/dam
[5]Estimated for biomass-type with feedstock coming from crop wastes and wooden biomass
[6]Estimated for municipal and industrial wastes

decentralization. Setyowati and Quist [8] explores how national and provincial actors interact as they negotiate future energy plans and identifies specific contextual factors that affect the results. It also looks into how the regulatory framework and institutional arrangements for energy transition planning can create both barriers and opportunities for renewable energy initiatives. The research is based on interviews with stakeholders at both national and local levels, along with an analysis of policy documents, studies, and relevant reports. The findings indicate that there are emerging opportunities for local actions within restrictive regulatory and institutional frameworks during the development of regional energy plans. However, the capacity of local actors to take advantage of these opportunities is influenced by various factors, including political leadership, civil society involvement, political economic structures, and power dynamics. The insights gained from Indonesia offer broader implications for understanding the complex dynamics of energy transitions and provide valuable policy suggestions for involving local actors in the transition process. Figure 2 depicts the complex institutional framework involving national and subnational government agencies and stakeholders in shaping Indonesia's energy transition planning and implementation. Figure 3 illustrates the projected shares of oil, gas, coal, and renewable energy in the energy mix (Bali and South Kalimantan) for the years 2015, 2025, 2025, and 2050, highlighting both national and regional disparities in energy transition strategies.

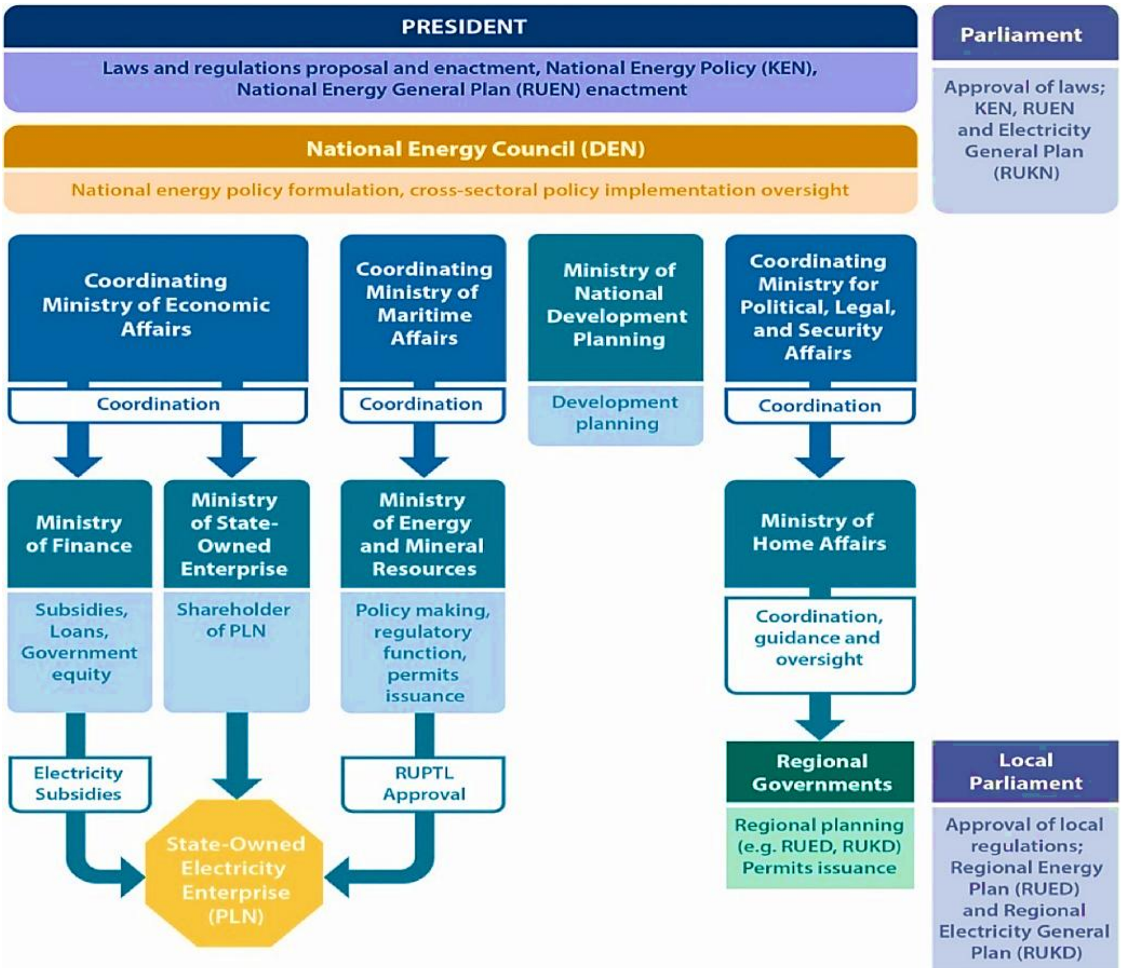


Figure 2. Multi-scalar institutional arrangements for energy planning and implementation in Indonesia, highlighting the roles of national and local state institutions in achieving energy transition targets, adapted from [8].

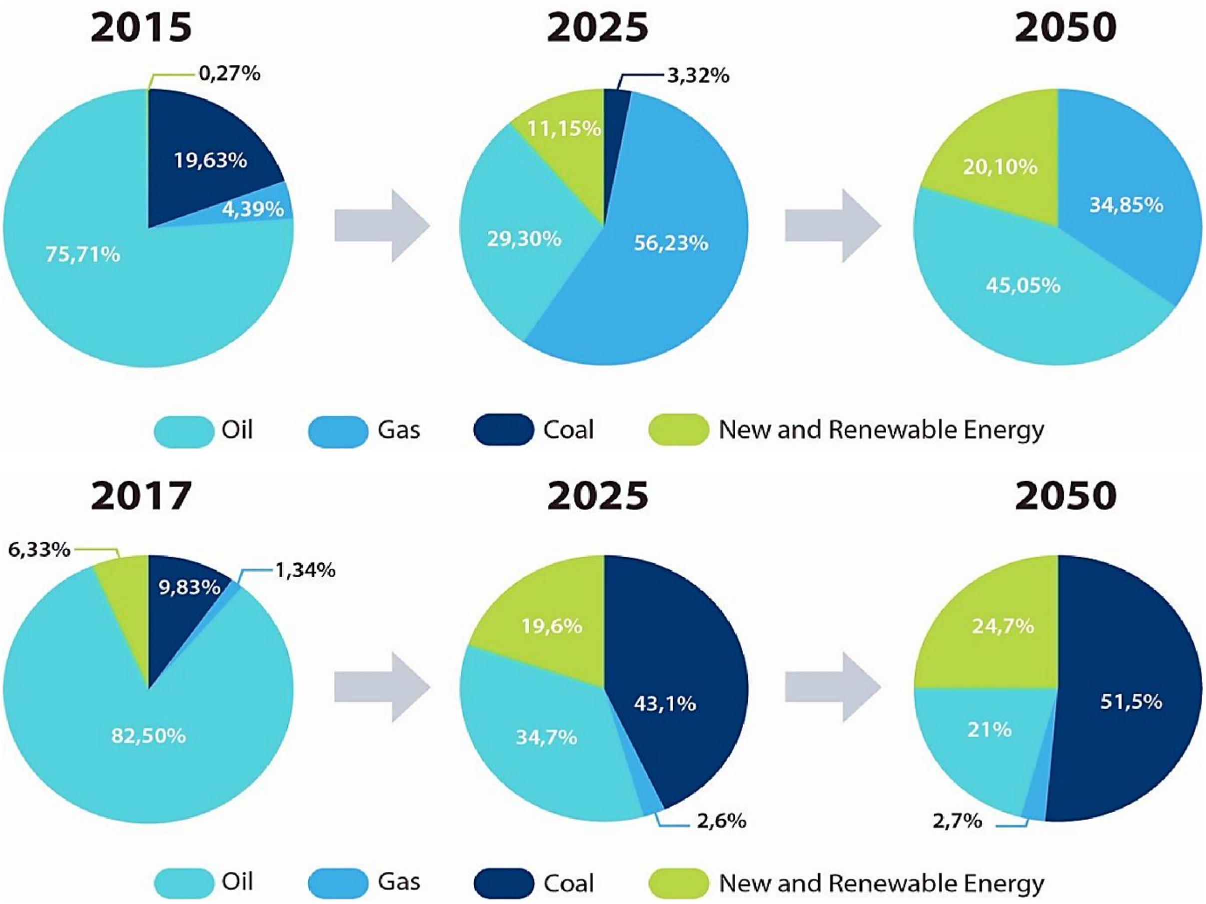


Figure 3. Projected energy mix scenarios for Bali (top), and South Kalimantan (bottom) showing the evolving shares of oil, gas, coal, and new and renewable energy sources up to 2050, and highlighting the regional disparities and challenges in achieving a balanced and secure energy transition, adapted from [8].

2. Indonesia's Solar, Bioenergy, and Geothermal Potential: Policy Challenges and Pathways for SDG-Aligned Energy Transition

Energy plays a crucial role in achieving the Sustainable Development Goals (SDGs), which aim to eliminate poverty and hunger, enhance human well-being, and protect the environment. As countries integrate SDGs into their development plans, energy consumption is expected to rise, making it essential to reassess energy planning. Santika, et al. [9] aims to forecast Indonesia's additional energy needs under SDG implementation compared to business as usual (BAU) and current policy (CP) scenarios. By considering the inclusion of all SDG targets in Indonesia's national development plan, the study calculates the extra energy demand for each target by 2030. The findings reveal that 18 out of 169 SDG targets in Indonesia will require more energy. Overall, more energy will be necessary to achieve these targets compared to the BAU scenario. However, the full implementation of current energy policies is projected to meet the additional energy demands under the SDG scenario. Figure 4 presents a flowchart illustrating the methodology for estimating energy demand in Indonesia by comparing the business as usual (BAU), SDG-driven, and current policy (CP) scenarios using sectoral fuel data, growth rates, and target gaps.

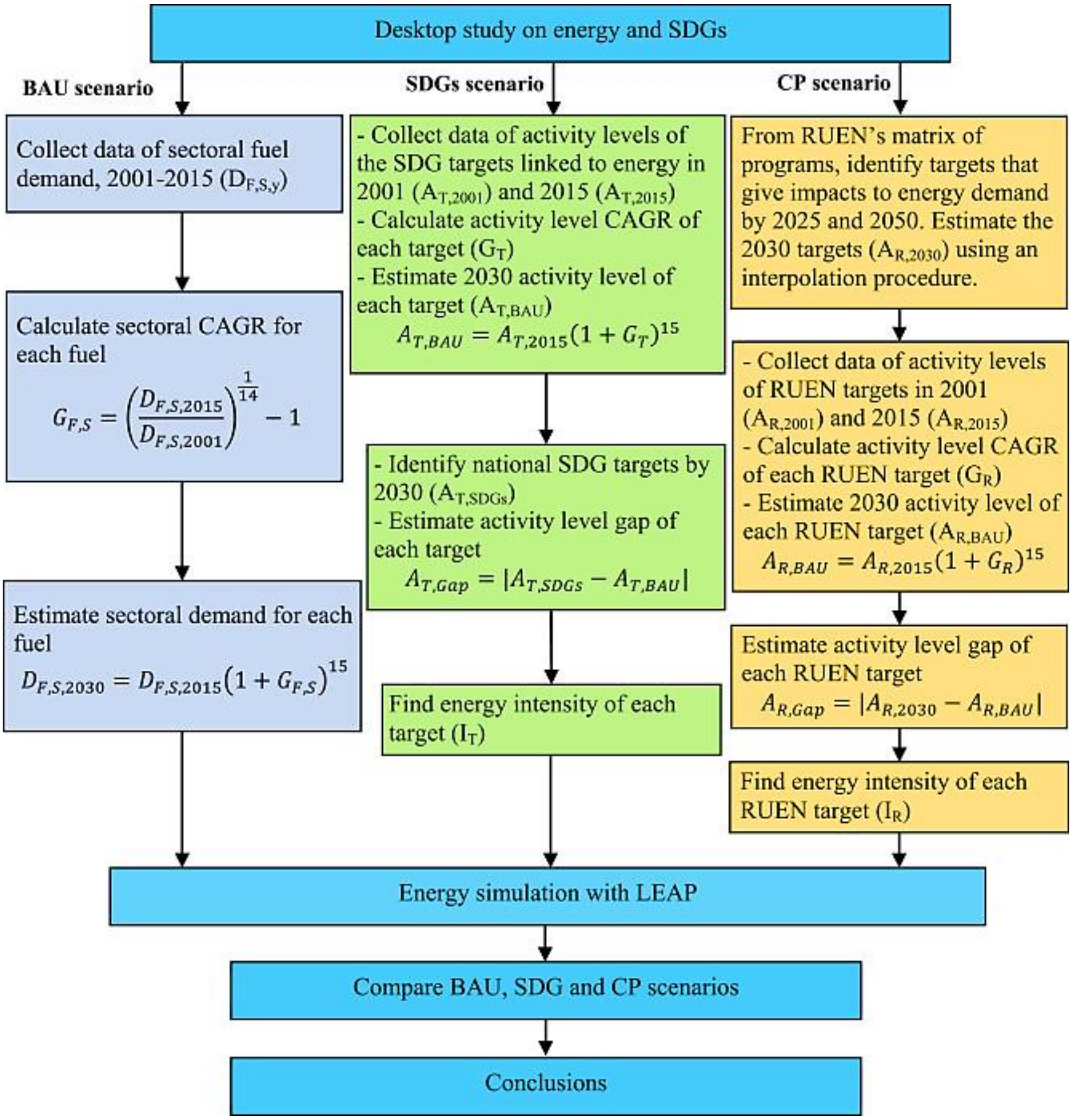


Figure 4. Flowchart of the methodology for estimating Indonesia's energy demand under BAU, SDGs, and CP scenarios, highlighting data collection, growth rate estimation, gap analysis, and simulation with the LEAP model, adapted from [9].

The Indonesian government is integrating Low-Carbon Development (LCD) into its National Medium-Term Development Plan for 2020–2024. In the future, the energy sector may become the largest source of carbon emissions unless the government takes steps to remove obstacles to the growth of renewable energy. Literature identifies four main barriers to LCD: socio-cultural, economic, technological, and governance-related. Sambodo, et al. [10] aims to explore these barriers and determine which are the most significant. Using a mixed-methods approach, both qualitative and quantitative data were collected during fieldwork in the provinces of DKI Jakarta, Bali, West Nusa Tenggara, and Bangka Belitung. The Partial Least Square – Structural Equation Modeling (PLS-SEM) technique was applied to assess the direction and strength of relationships, while qualitative data provided further insights into provincial contexts. The findings suggest that technological and governance barriers have a significant and negative impact on LCD, with governance emerging as the most critical challenge. The study highlights the need for strong collaboration between central and local governments to effectively implement LCD. A shared vision, equal responsibilities, clear governance roles, and the development of fiscal tools are essential to ensure coherence and continuity in renewable energy development programs.

Indonesia has significant solar energy potential, with an estimated capacity of 3.295 GW due to its location on the equator [11]. Despite this, solar energy development remains low. According to the latest MEMR data in November 2024, the generating capacity from solar is at 761.31 MW, ~0.02% of the total potential [12]. 244 MW comes from the ground-mounted utility scale and another 193.01 MW is from the floating one. Rooftop PV contributes to 324.30 MW. Developing a large-scale grid-connected photovoltaic (PV) system presents a great opportunity to enhance solar energy utilization, but the government currently lacks the investment needed for such a project. A more viable alternative is the adoption of distributed PV systems, like rooftop PV for households. Policies such as net metering and net billing have been introduced to encourage the adoption of household rooftop PV systems, though their effectiveness has not been fully evaluated. Hidayatno, et al. [13] aims to assess the effectiveness of these two policy tools by analyzing the dynamic complexities of rooftop PV adoption using a system dynamics approach and policy analysis framework. The results show that net metering is more effective than net billing in promoting rooftop PV adoption. The study also highlights the need for a systems perspective to better understand the complexities of solar energy development and to improve energy policy evaluation.

In 2018, the Indonesian government introduced the Rooftop Photovoltaic Solar Systems (RPVSS) policy, which allows customers of the State Electricity Company (PLN) to generate their own electricity using solar photovoltaic (PV) systems and sell any excess electricity to the national grid at 65% of the full retail price. This policy aims to boost the share of renewable energy in the national energy mix to 23% by 2025. The adoption of PV systems by customers depends on their perceptions of the technology and its benefits, as well as overall trust in the product. Setyawati [14] examines public acceptance of the RPVSS policy from various viewpoints. An online survey of 987 PLN customers revealed concerns about adopting PV systems, including high upfront costs, a long return on investment period, and a lack of information. Additionally, institutional challenges were identified, such as PLN's limited involvement and the absence of government financial support. Interviews with government officials, private sector representatives, and energy experts pointed to the export rate for electricity sent to the grid as a key barrier to attracting potential users. The findings offer valuable recommendations for policymakers to improve the implementation of the policy and promote greater solar energy use. Figure 5 shows the operational flow of an on-grid solar PV electricity system under Indonesia’s RPVSS policy, illustrating the interaction between solar panels, grid components, and customer usage and export.

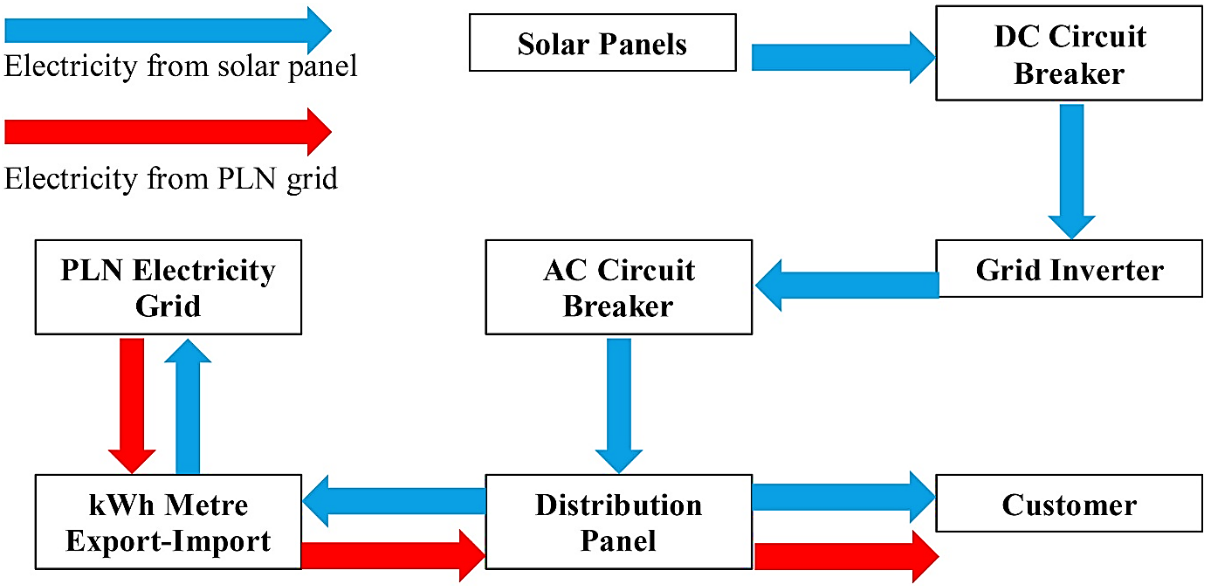


Figure 5. Operational schematic of an on-grid solar PV electricity system in Indonesia, illustrating the interaction of solar panels, grid inverters, AC/DC circuit breakers, kWh meters, and the national PLN grid for energy flow and export-import operations, adapted from [14].

In its flagship report on solar energy outlook, IESR examines at the adoption rate of solar rooftop in Indonesia [15]. The historical record is available in Figure 6. Between 2018-2021, the enactment of the Ministerial Regulation Permen ESDM 49/2018 has provided a legal basis for rooftop PV deployment. The implementation of the 65% net-metering scheme and the revision for capacity charge for industrial customers has prompted a rapid growth of a cumulative 138% per annum. Further adoption has been promoted through a partnership with the UNDP Sustainable Energy Fund (SEF). However, a limitation was put in place through the enactment of Ministerial Regulation Permen ESDM 26/2021. Capacity was limited to 10-15%, hence driving the growth of rooftop PV down to 41% between 2021-2023. The impacts of such a limitation are mostly apparent for residential customer, growing by merely 17%, a significant drop from 92% prior to 2021. The fiasco in the capacity limitation was ended with the enactment of the Ministerial Regulation Permen ESDM 2/2024, abolishing the electricity export (net metering) and imposing the quota system to address PLN's concerns on system stability and grid congestion. Despite the seemingly unfavourable policy, the rooftop adoption rate is still particularly growing in the business and industrial customers. The industrial customers saw an addition of 104 MW as per July 2024.

In Indonesia, biomass is recognized for its significant potential as a renewable energy source. However, there are several obstacles to the application and development of biomass-based energy. One major issue is the competing use of biomass resources, such as crude palm oil (CPO) converted to stearin, which serves as a biofuel feedstock. Outside of the biodiesel sector, stearin is also needed by large industries, including oleochemicals, food, and cosmetics, leading to competition and conflicts of interest among these sectors. Additionally, challenges such as frequent forest fires and illegal logging continue to threaten biomass sources.

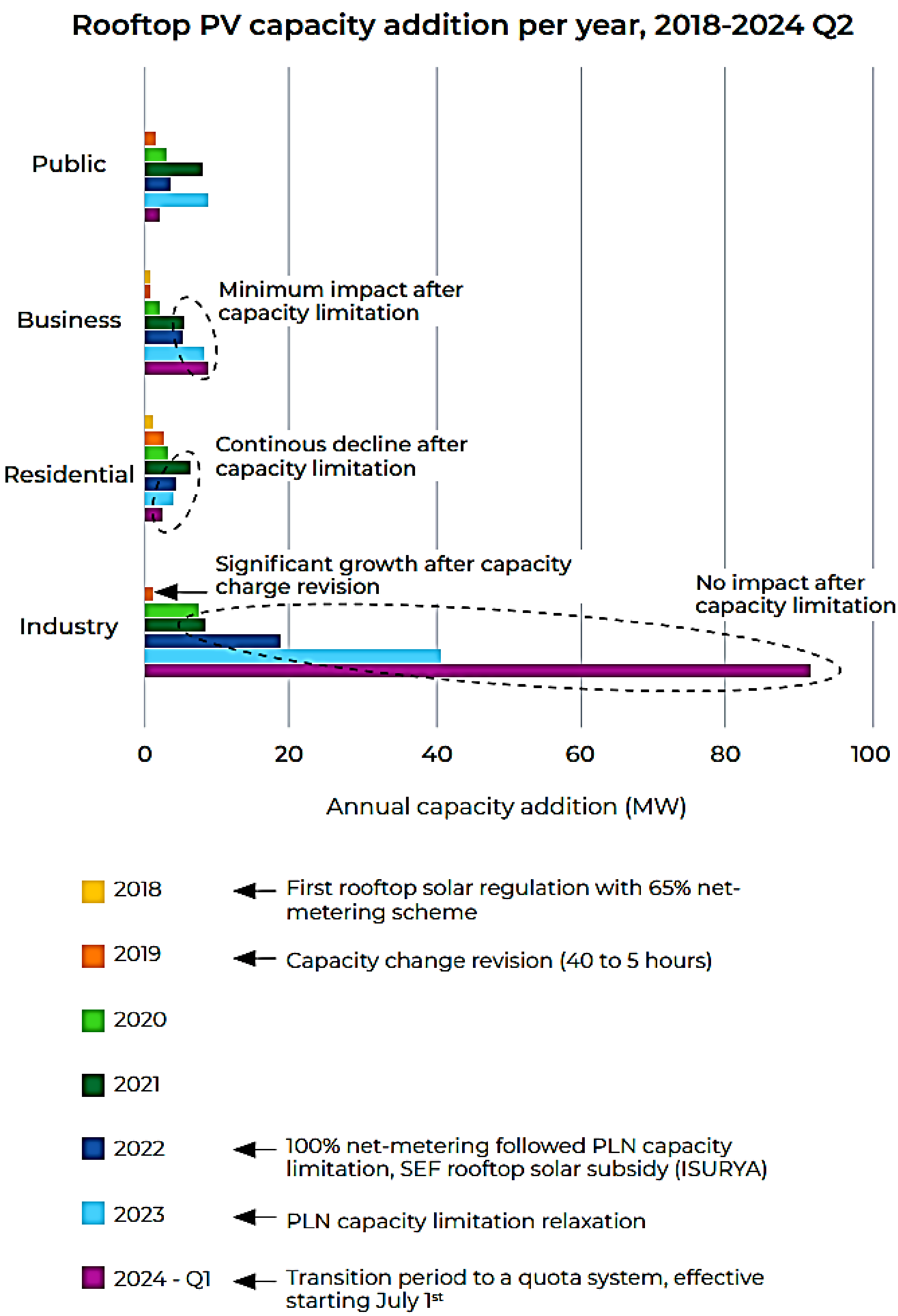


Figure 6. Rooftop PV addition between 2018 & 2024 Q2, adapted from [15].

The Covid-19 pandemic has also affected the global economy, causing a drop in energy demand, delaying the prioritization of renewable energy, and jeopardizing the achievement of the national energy mix target. Yana, et al. [16] aims to provide a better understanding of the implementation, limitations, challenges, and regulations related to converting biomass into renewable energy and meeting the 2025 energy mix goal. Figure 7 illustrates how various agricultural residues, such as palm oil waste, sugarcane bagasse, coconut shells, corn stalks, and rice straw, contribute to the Indonesia's potential for bioenergy and sustainable material applications.

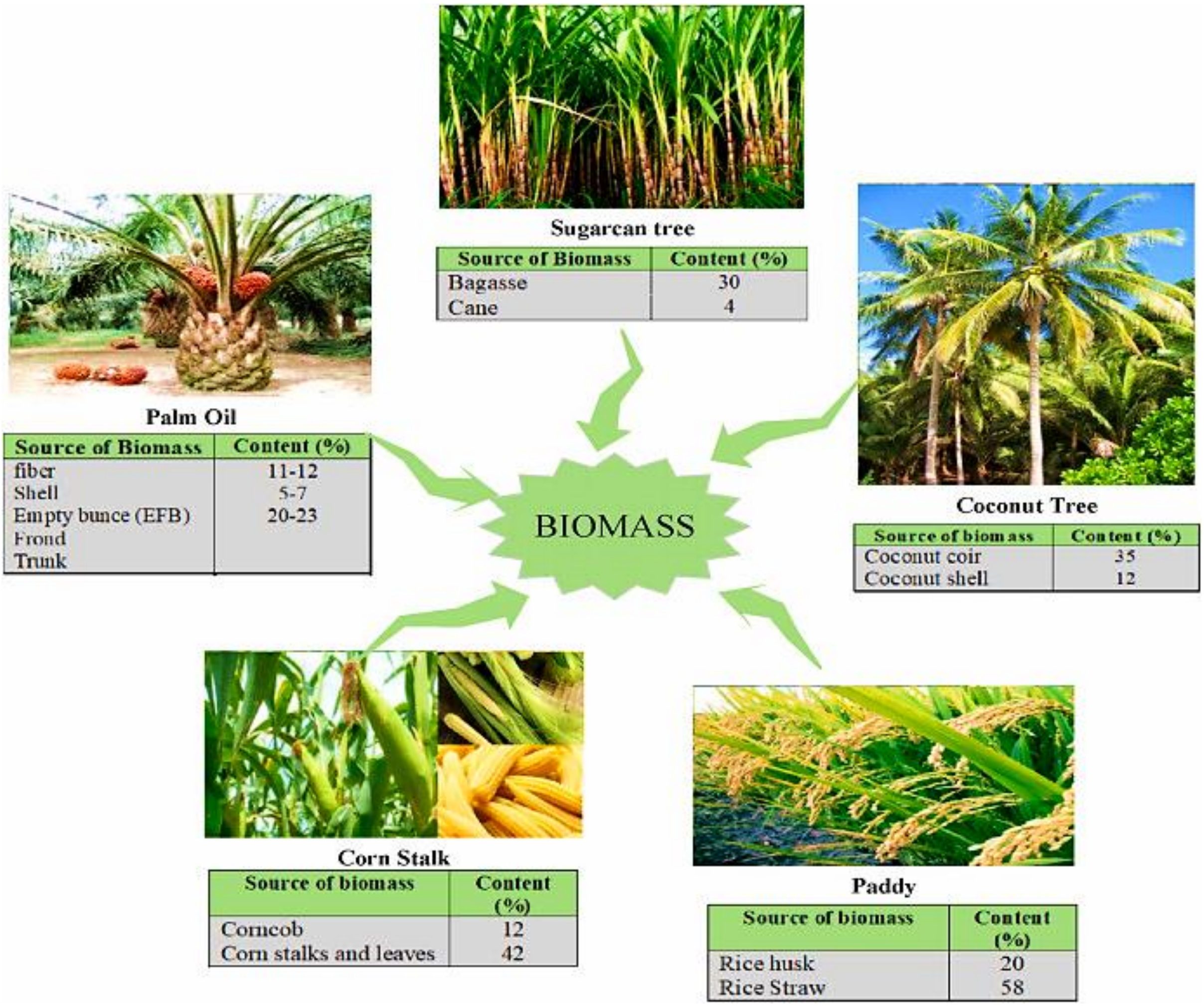


Figure 7. Biomass sources in Indonesia, adapted from [16].

Global concerns about carbon emissions from fossil fuel usage are significant. To promote sustainable energy in the future, efforts are being made to develop wood pellets as a renewable energy source. The Indonesian government is also focused on enhancing renewable energy technology to provide electricity for its industries and residents. However, the growth of wood pellets as a renewable energy option in Indonesia faces several challenges and competing sources. Previous studies have identified four main barriers to low-carbon development: sociocultural, economic, technological, and governmental. Rimantho, et al. [17] aims to identify these inhibiting factors and determine the most effective strategies for advancing wood pellets as a renewable energy source. To achieve this, the researchers employed Interpretive Structural Modeling (ISM) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to find the best development strategy for wood pellets in Indonesia.

Furthermore, key informants were recruited to help identify factors and evaluate alternatives. The ISM analysis revealed that the sub-factors of Raw Materials (D11) and Standard Products (D6) are crucial for the development of wood pellets as renewable energy in Indonesia. Additionally, the TOPSIS analysis indicated that Alternative A1 (Government Incentives), with a score of 0.825, represents the most favorable option.

However, further evaluation of the studies is necessary to achieve more precise conclusions. Figure 8 presents a 15-level hierarchical structure of factors influencing the growth of wood pellets in Indonesia, identifying key elements such as raw materials and standard products, while mapping their interconnectedness.

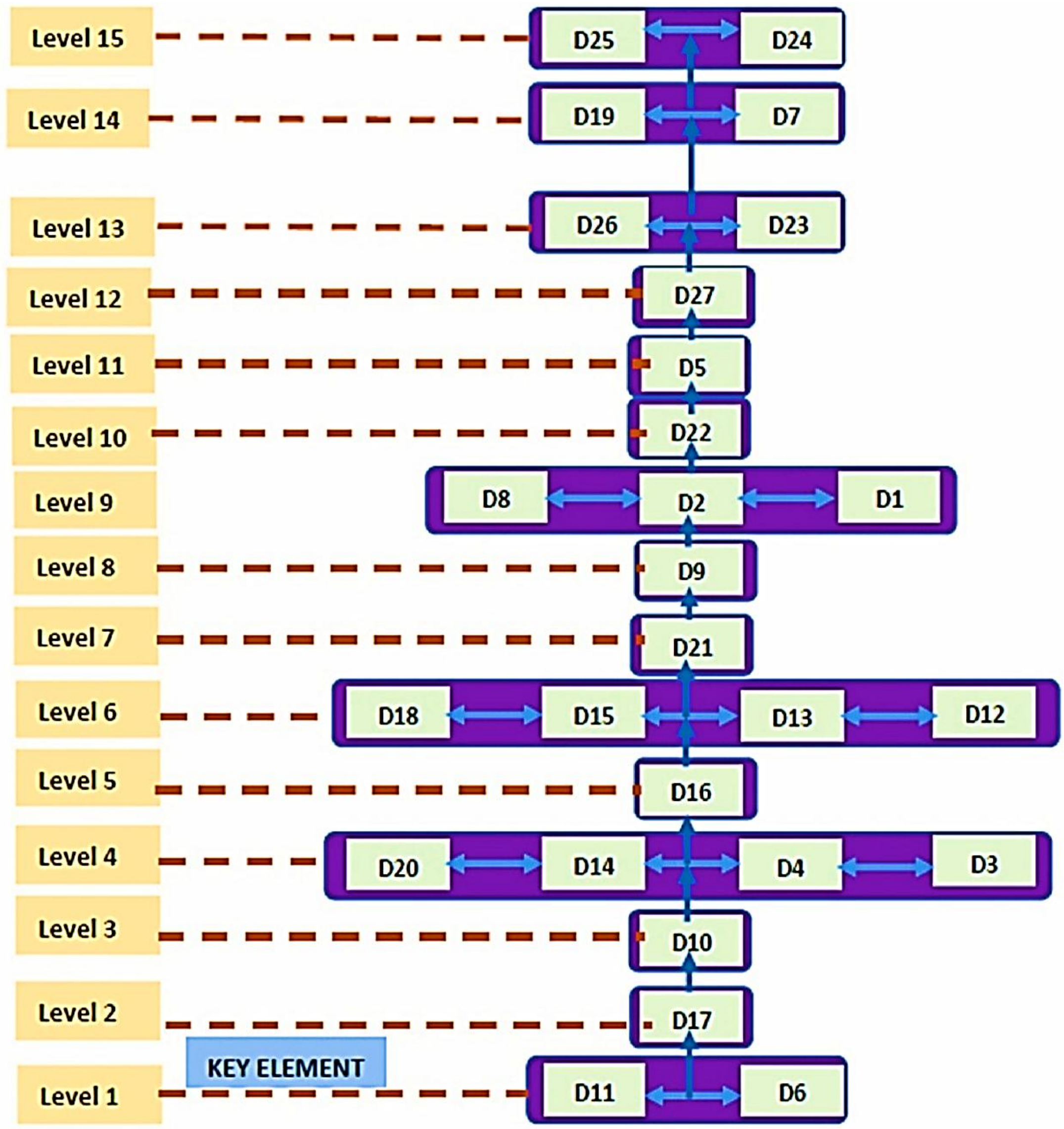


Figure 8. Hierarchical structure of factors affecting the development of wood pellets as a renewable energy source in Indonesia, with key sub-factors at lower levels and other influencing factors across the hierarchy, adapted from [17].

Geothermal energy is crucial for sustainably addressing Indonesia's energy needs, with an estimated potential of 24 GW of electricity. According to the current RUEN, i.e. Perpres 22/2017, the government has set targets for geothermal energy to contribute 7,241.5 MW to the national energy mix by 2025 and 17,546 MW by 2050. However, the utilization has only reached 2,597.51 MW as per November 2024 [12]. To fully utilize the entire potential and meet the target will require substantial investment. To encourage private sector investment in geothermal energy, the government introduced a feed-in tariff (FIT) system, though it has been significantly modified over a short period.

Additionally, the implementation of FIT is challenged by bureaucratic, social, and technical issues. As a result, the effectiveness of FIT in promoting geothermal development in Indonesia needs further investigation. Setiawan, et al. [18] assesses the impact of various FIT schemes on the government's geothermal targets, using a policy analysis framework and system dynamics modeling to understand the interaction of FIT policies with other key factors. The results suggest that streamlined bureaucracy and public support are essential, and to boost geothermal development, FIT should be set at a minimum of 11 cents US$/kWh, alongside technical innovations and government-supported exploration activities. Figure 9 presents a detailed causal loop diagram (CLD) mapping out the interconnected variables and feedback loops involved in geothermal development in Indonesia, including social, technical, economic, and regulatory factors.

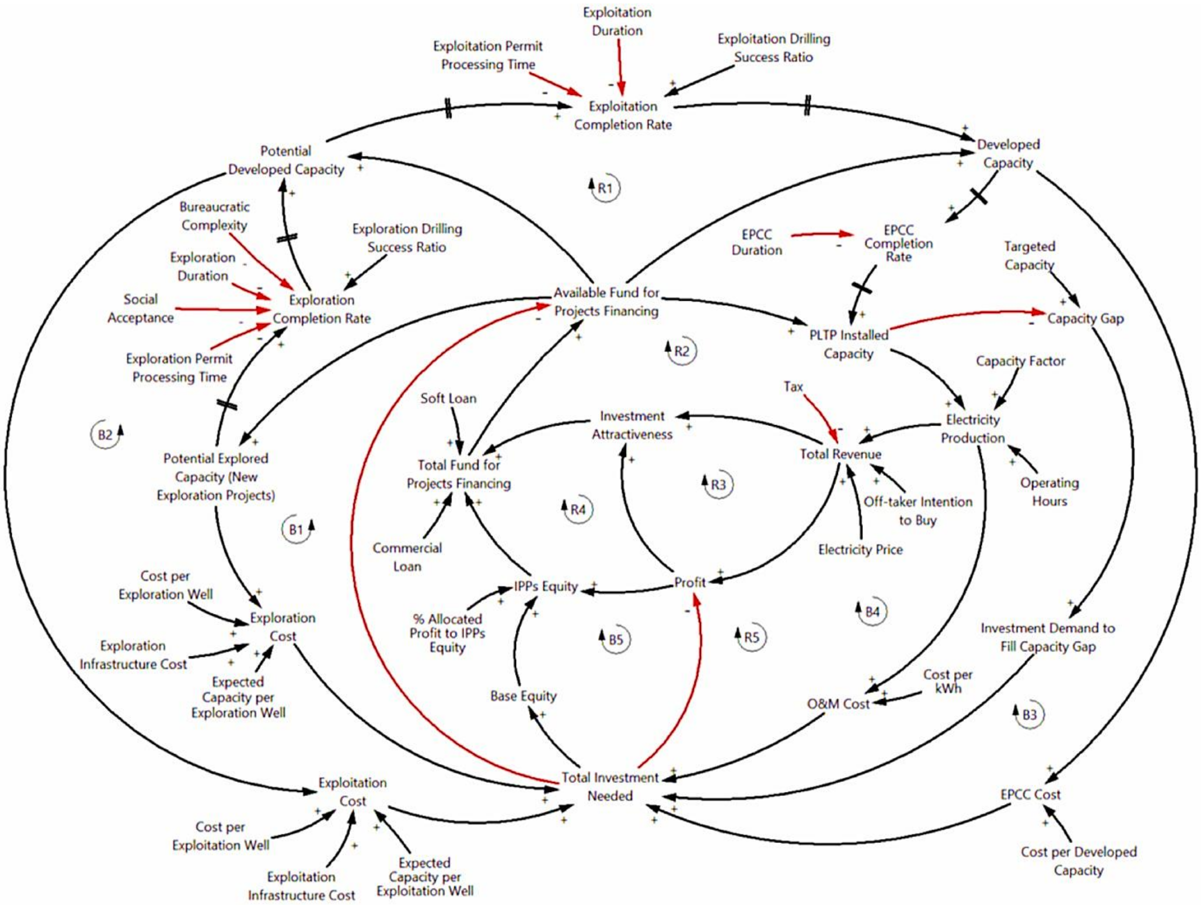


Figure 9. Causal loop diagram of geothermal development in Indonesia, illustrating the complex interplay between geological, social, bureaucratic, and financial factors that influence investment, exploration, and installed capacity outcomes in the geothermal sector, adapted from [18].

3. Path to Carbon Emission Reduction: Policies and Community Renewable Energy in Indonesia

Reducing emissions and improving environmental quality have become global priorities for sustainable development and addressing the adverse effects of global warming and climate change. However, research on emission reduction using econometric methods remains limited.

Raihan, et al. [19] examines how economic growth, fossil fuel energy consumption, renewable energy use, technological innovation, agricultural productivity, and forested areas contribute to reducing carbon dioxide emissions in Indonesia. Using time series data from 1990 to 2020 and applying the Dynamic Ordinary Least Squares method, the study reveals that a 1% increase in economic growth and fossil fuel consumption raises carbon emissions by 0.36% and 0.67%, respectively. Conversely, a 1% rise in renewable energy use, technological innovation, agricultural productivity, and forested areas can decrease emissions by 0.11%, 0.07%, 0.24%, and 2.87%, respectively, in the long term. The article suggests policies focused on promoting a low-carbon economy, renewable energy use, technological innovation funding, climate-smart agriculture, and sustainable forest management to reduce emissions and ensure environmental sustainability in Indonesia.

Greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), pose a significant threat to the environment, economy, and human health. Raihan, et al. [20] presents the findings of an empirical study that examines how economic growth, renewable energy usage, technological advancement, and forest cover in Indonesia can help reduce CO_2 emissions. The study applied the Dynamic Ordinary Least Squares (DOLS) method to analyze time series data from 1990 to 2020. The results indicate that CO_2 emissions in Indonesia are expected to rise by 1.17% for every 1% increase in economic growth. In contrast, a 1% increase in renewable energy usage is associated with a 1.40% decrease in CO_2 emissions, while technological innovation contributes to a 0.17% decrease, and an increase in forest cover is linked to a 3.94% reduction in CO_2 emissions.

The above findings remained consistent even when using alternative estimation methods like fully modified ordinary least squares (FMOLS) and canonical cointegrating regression (CCR). Additionally, the study utilized the pairwise Granger causality test to examine the causal relationships among the variables. The article offers policy recommendations for enhancing environmental sustainability in Indonesia through the reduction of carbon emissions, focusing on a low-carbon economy, promoting renewable energy, funding technological advancements, and ensuring the ecological health of Indonesia's forests.

Over the past decade, the Indonesian government has sought to boost modern energy consumption through the Liquid Petroleum Gas (LPG) conversion program and the establishment of various power plants. These initiatives aimed to enhance access to modern energy. Hartono, et al. [21] examines these government projects by evaluating both the accessibility and affordability of modern energy consumption in urban and rural areas, as well as among households with different income levels. The study used descriptive statistics to measure changes in energy access across various household categories and assessed the energy burden for each category. It confirmed the significant influence of access and income on energy expenditures through multiple regression analysis.

The above findings indicated that access to modern energy improved significantly for all household categories, although rural and low-income households still require further enhancements. Moreover, there was no evidence of energy poverty among low-income households. The study also identified modern energy access, income, and the education level of the household head as key factors influencing energy spending, particularly for low-income and rural households. Therefore, if the government aims to improve energy consumption, households are likely to embrace modern energy if it is available. However, education and financial capability will also play crucial roles in determining the level of energy consumption.

Community-based renewable electricity projects are increasingly seen as an effective way to reduce energy poverty in rural areas by promoting fair and inclusive outcomes. However, there has been limited research into the socio-political dynamics of these initiatives and their ability to address energy injustices in the Global South. Fathoni, et al. [22] examines two case studies from Sumba Island in Eastern Indonesia to critically analyze how the micro-politics involved in planning and implementing community-based renewable projects affect their implications for energy justice. By applying a contextual analysis of energy justice, the study highlights how specific socio-historical factors contribute to ongoing energy injustices in a postcolonial context like Sumba Island. The authors argue that the ongoing apolitical perspective on community-based energy access risks reinforcing exclusions and inequalities in rural energy supply. To effectively tackle energy injustices, it is crucial to move away from the centralized approach that still dominates the development of community-based renewables in Indonesia and similar regions.

4. Indonesian Low-Carbon Energy Future: Challenges, Solutions, and Opportunities in Renewable Energy and Emissions Reduction

As Southeast Asia's largest economy, Indonesia is among the top countries globally in terms of planned expansion of coal-fired power plants. Despite significant reductions in costs for key renewable energy sources like solar PV and wind power over recent decades, their impact on Indonesia's power sector planning remains minimal. To evaluate the potential of renewable energy in this sector, a cost-optimization model for power generation was developed.

Ordonez, et al. [23] analyzed four different scenarios that consider both a slow and rapid decline in renewable energy costs, with and without carbon pricing. This analysis looks at capacity expansion, electricity generation, CO_2 emissions, and total system costs up to 2040. Their findings are compared with Indonesia's latest utility power expansion plans (RUPTL) and its energy master plan (RUEN). The results indicate that the official power sector development plans would lead to higher electricity generation costs due to overcapacity and a failure to adopt future low-cost technologies, particularly solar PV.

Implementing carbon pricing as low as $5 per ton of CO_2 could render coal an economically unfeasible option and promote the use of biomass and geothermal power plants. With rapidly falling renewable energy costs, solar PV is expected to become competitive with coal by the mid-2020s to 2030s, even without carbon pricing. However, wind power is likely to remain uncompetitive throughout the forecast period due to insufficient wind resources.

Overall, the findings suggest that Indonesia's power sector planning could be significantly enhanced for better cost-effectiveness and climate protection. Figure 10 presents the levelized cost of electricity (LCOE) breakdowns for solar PV and coal in Indonesia for 2018, 2025, and 2040 under various scenarios, highlighting the impact of financing, operation, and carbon costs on technology competitiveness. Figure 11 illustrates the hourly power generation profiles for different policy scenarios in the Java-Bali region on a typical dry season day in 2040, highlighting the impact of variable solar PV generation on the ramping requirements of other energy sources.

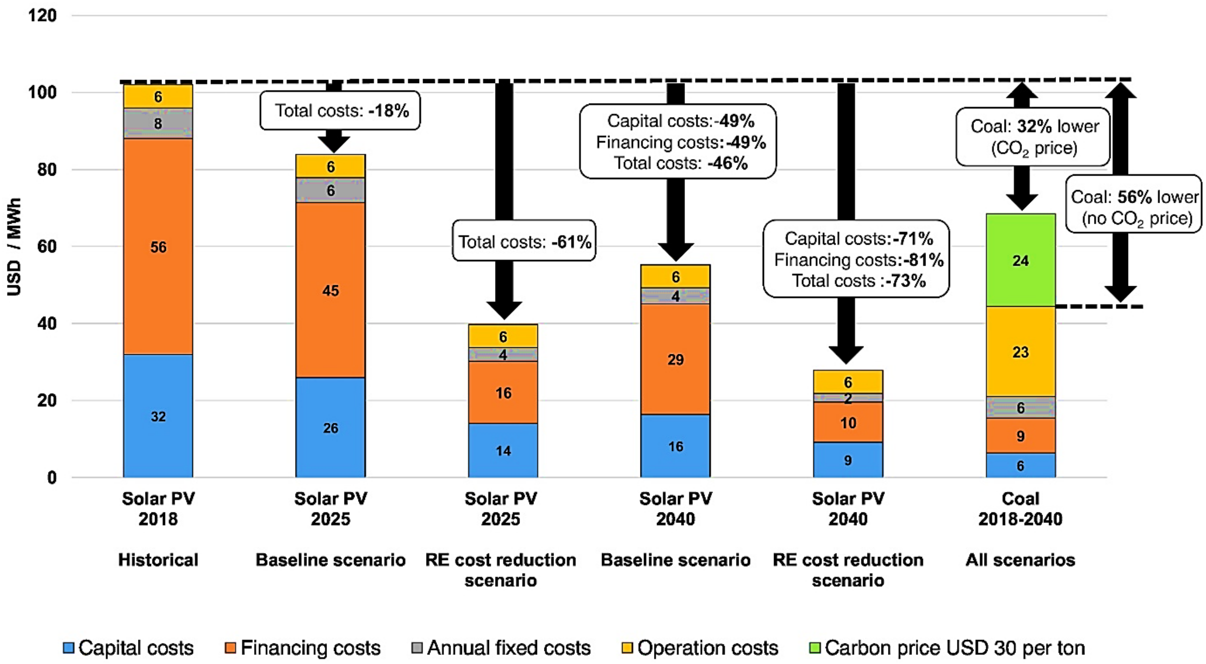


Figure 10. LCOE composition of solar PV (for 2018, 2025, and 2040) and coal (for all scenarios and years) in Indonesia, adapted from [23].

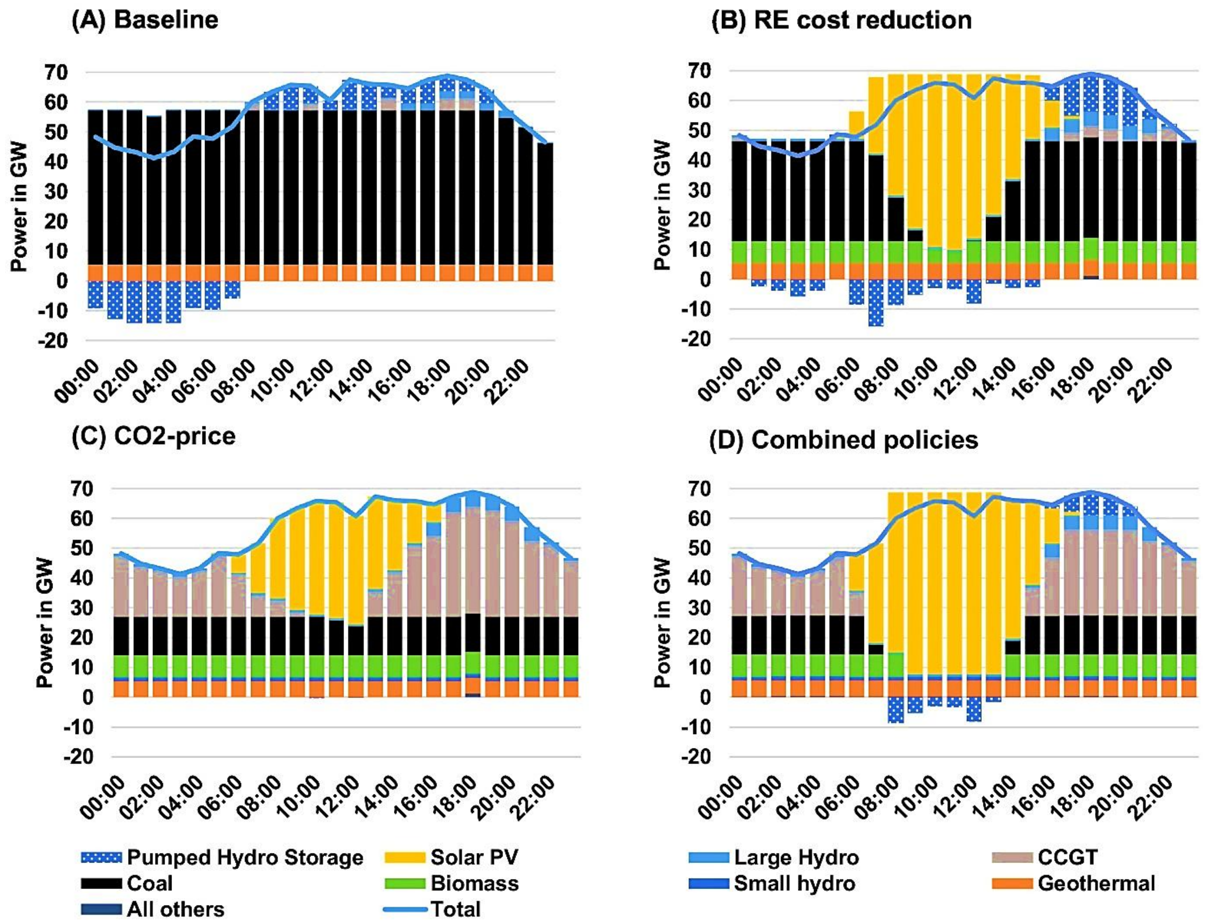


Figure 11. Hourly power generation profiles in the Java-Bali region on a typical dry season day in 2040 for (A) Baseline, (B) RE cost reduction, (C) CO_2-price, and (D) Combined policies scenarios, adapted from [23].

Biomass residue is a key focus for green energy development in Indonesia, as outlined in Government Regulation No. 79 of 2014 on national energy progress. Evaluating residual resources is crucial to demonstrate their availability and help achieve the goal of having biofuels contribute over 5% of the energy supply by 2025. Rhofita, et al. [24] presents a method for assessing energy production from biomass residue, which is essential for its development. The study utilized statistical data and field observations to estimate the total availability of these residues. To calculate the energy potential, minimum and maximum parameters, such as the residue-to-product ratio, moisture content, and heating value, were gathered from existing literature. The analysis of power potential was conducted through three scenarios based on conversion efficiency—low, medium, and high—to provide a thorough assessment. The proposed methods indicate that annual biomass residue production from agricultural and forestry sources could reach approximately 155,271 and 2,554 tonnes, respectively. This could generate an energy potential of around 1,261 PJ, which accounts for 22.12% of national energy consumption.

Considering the high sustainability potential of biomass residue supply and use, strategic factors in government regulation, greenhouse gas emissions, land-use change, and conversion technologies were identified to support the valorization of these residues in planning, organizing, and operational activities. Overcoming challenges and barriers will require integrated collaboration and synergy among policymakers, entrepreneurs, academics, and communities to ensure the sustainability of green energy production in the future. Additionally, an evaluation of environmental, economic, and social factors will serve as a framework to enhance both the quality and quantity of production processes. Figure 12 presents a Sankey diagram illustrating the annual average power potential from various agricultural residues in Indonesia under three scenarios with different conversion efficiencies (20%, 30%, and 40%), highlighting the major contribution of straw, stalk, and husk residues.

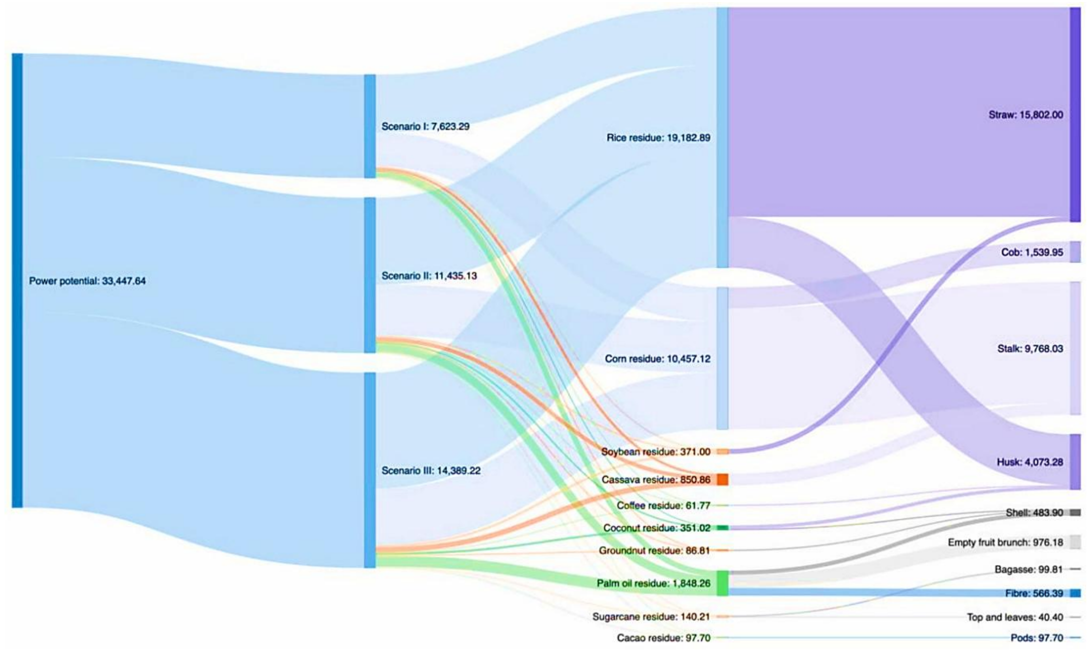


Figure 12. Sankey diagram of the annual average power potential from agricultural residues in Indonesia, showing contributions of different residues under three scenarios of efficiency conversion factors (20%, 30%, and 40%), adapted from [24].

Indonesia is the fourth most populous country globally, following China, India, and the USA, and stands as one of the largest energy consumers in Southeast Asia. Due to the sharp rise in energy demand and the depletion of fossil fuel resources, Indonesia has been a net importer of oil since 2004. In response to this issue, a policy promoting the use of biodiesel as an alternative to fossil fuels was introduced in 2006. Beginning in 2020, the Indonesian government launched the mandatory biodiesel program known as B30, positioning Indonesia as the leading country in biodiesel implementation worldwide.

However, there has been insufficient in-depth research on the current status of Indonesia's palm biodiesel. Farobie and Hartulistiyoso [25] seeks to provide a comprehensive review of the current situation and challenges related to biodiesel implementation in Indonesia. It discusses Indonesia's energy policy, the current state of palm biodiesel, and the potential of biodiesel resources, alongside techno-economic and socio-political factors. The analysis indicates that the mandatory biodiesel policy significantly affects economic and social aspects. It is estimated that this program will create around 10,182 jobs in the biodiesel sector and save approximately US$4.46 billion in foreign exchange by 2030. Additionally, the study highlights key challenges faced in implementing palm oil biodiesel production and suggests several feasible solutions to address these issues.

Crude palm oil (CPO)-based biodiesel is a key product for Indonesia, as part of the Government of Indonesia's (GoI) biofuel strategy aimed at enhancing energy security, reducing the trade balance deficit, lowering subsidies, and decreasing emissions. Indonesia's biodiesel policy has been quite ambitious; by the end of 2019, the blending ratio reached 30% fatty acid methyl ester (FAME) and 70% diesel, referred to as B30. The government views this policy as advantageous due to the anticipated savings on diesel imports. However, it does not consider the potential losses in exports that could result from opportunity costs related to foreign exchange. Additionally, the broader macroeconomic effects of the biodiesel policy have not been thoroughly examined.

Using available input and output data, projected balance sheets for CPO and biodiesel were created for the years 2020 to 2030, based on four different biodiesel blending scenarios. Halimatussadiah, et al. [26] assessed the impact of each scenario on trade balance, subsidies, and land expansion. The findings revealed that: (1) although the biodiesel policy reduces diesel imports, the potential loss of CPO exports surpasses the savings from imports, (2) the effect of the biodiesel policy on subsidies is largely influenced by the subsidy rates for FAME and diesel, and (3) to support the ambitious biodiesel policy, an expansion of productive oil palm plantation land by 48% to 76% is unavoidable.

In conclusion, the findings suggest that more aggressive policies could lead to increased macroeconomic and environmental risks. Therefore, the GoI should create a clear roadmap for optimal biodiesel blending levels to achieve energy security along with favorable economic and environmental outcomes. Figure 13 shows an analytical framework for the link between crude palm oil (CPO) production and biodiesel production in Indonesia, using balance sheets to track the flow and stock of CPO and biodiesel to support ex-ante policy analysis.

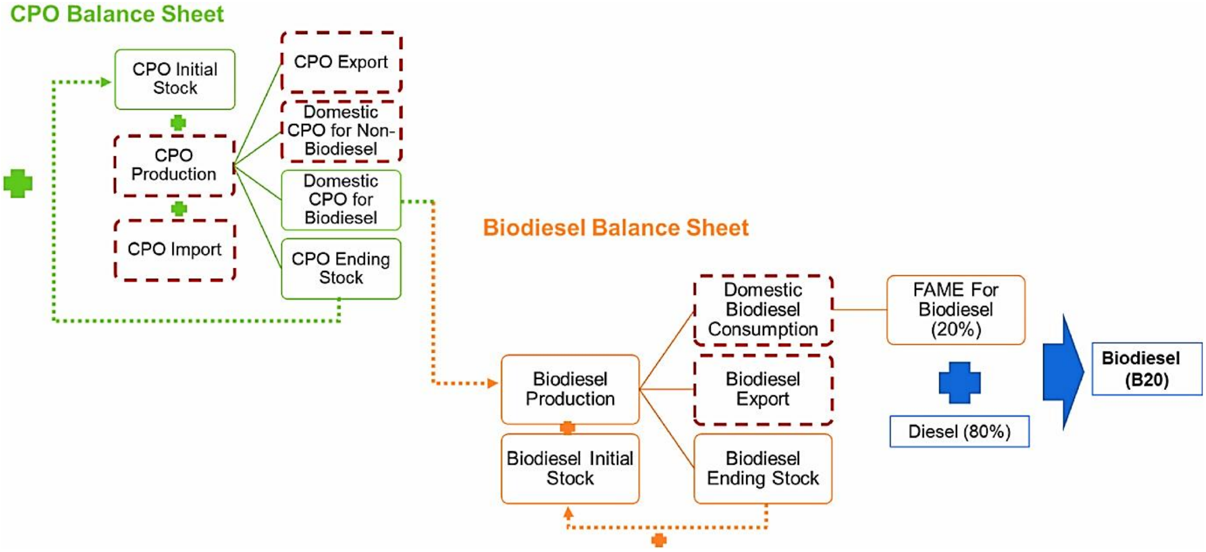


Figure 13. Analytical framework depicting the balance sheets of crude palm oil (CPO) and biodiesel in Indonesia, illustrating the relationships and data flows required for the ex-ante analysis of policy scenarios on trade balance, subsidies, and land use expansion, adapted from [26].

5. Energy Transition in Indonesia: COVID-19 Impacts and Decarbonization Challenges to 2050

Although the pandemic has had a detrimental impact on the economy, it has also contributed to a reduction in emissions from energy consumption, aligning with the goals of the Paris Agreement, particularly for high-emitting nations like Indonesia. However, the policy responses to COVID-19 risk reversing emissions back to pre-pandemic levels. To create an effective policy that balances economic and environmental factors, Hartono, et al. [27] employs a computable general equilibrium model to evaluate how COVID-19 and associated stimulus policies will influence macroeconomic indicators, energy consumption, and emissions on both national and regional scales. The findings indicate that, in the short term, macroeconomic indicators tend to perform worse under the current stimulus policy compared to the long term. Refined petroleum energy consumption experienced the most significant decline, followed by coal-based energy use and overall electricity demand. The reduction in emissions mirrored the decrease in gross domestic product. The Sulawesi region faced the largest drop in refined petroleum energy consumption, while the Java-Bali and Sumatra regions saw the most significant reductions in coal-based energy consumption and emissions. If COVID-19 serves as a catalyst for more environmentally friendly economic development, improved policies are essential for addressing recovery efforts. Simply reverting to pre-pandemic practices will not yield lasting environmental benefits. This study suggests policy measures for economic recovery and environmental enhancement, advocating for the promotion of low-carbon technologies, a transition to clean energy, improved energy efficiency, and sustainable development to prevent a rebound effect in energy consumption and carbon emissions. Additionally, better coordination between central and local governments is necessary to establish fiscal policies that favor low-carbon pathways.

The COVID-19 pandemic has provided an opportunity to accelerate the global energy transition, and Indonesia is among the countries that should seize this chance.

Sumarno, et al. [28] examines the failures of Indonesia's energy subsidy policies using the JUST Framework. The goal of the article is to offer insights into how these policy failures have impeded Indonesia's energy transition, emphasizing the urgency of policy reform. Through quantitative, qualitative, and comparative analyses, the paper assesses Indonesia's energy policy shortcomings, focusing on different strategies for reforming its energy subsidies. For the comparative analysis, countries are categorized as OECD and Non-OECD. The findings indicate that, despite efforts by the Indonesian Government to reform fossil fuel subsidies and advance renewable energy development, Indonesia lags behind similar countries like France, Spain, and Brazil. Additionally, the study shows that higher fossil fuel subsidies hinder renewable energy progress and slow the energy transition. Therefore, the most effective fossil fuel subsidy reform should involve balanced energy regulations, as suggested by the day-watchman approach. Figure 14 provides a visual timeline of fossil fuel subsidy reforms in Indonesia from 2005 to 2021, showing key policy changes, price adjustments, and LPG re-targeting efforts.

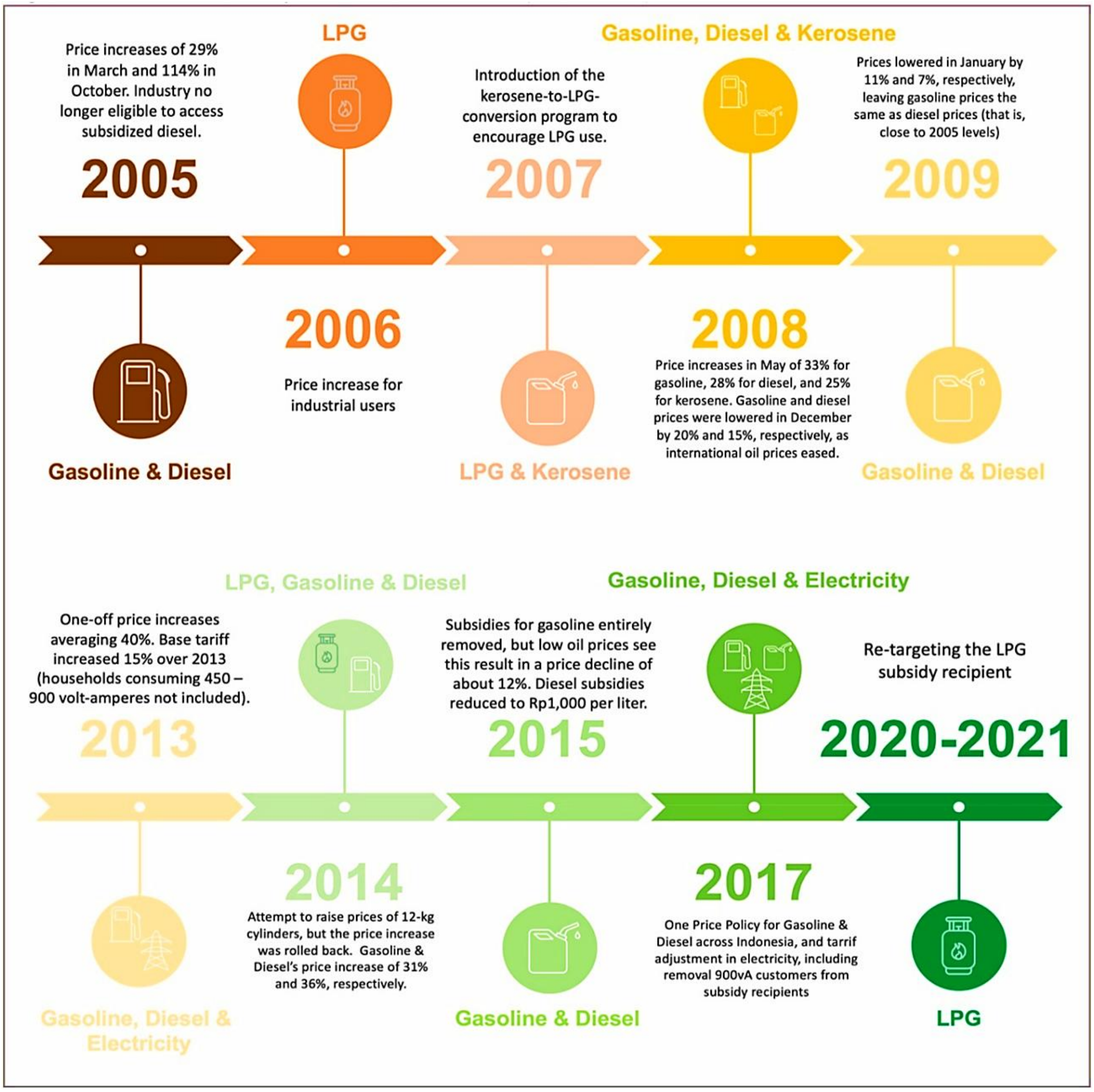


Figure 14. Fossil fuel subsidy reforms in Indonesia between 2005 and 2021, highlighting policy changes, energy price adjustments, and efforts to improve subsidy targeting for fairer and more effective energy transition outcomes, adapted from [28].

National oil companies (NOCs) have long been recognized as key players in financing and delivering fuel subsidies, which hold significant political value. However, the situation becomes more complex when oil reserves start depleting. While fiscal pressures are likely to rise, there is evidence that countries with NOCs, even as net importers, are more likely to maintain subsidies compared to those without NOCs. A critical question for countries going through this transition is how the role of NOCs within the subsidy regime changes as the traditional logic weakens. Ichsan, et al. [29] explores these issues through a case study of Indonesia, which became a net oil importer in the early 2000s. Despite a series of partial fuel subsidy reforms, subsidies remain, and the NOC continues to play a central role in their administration. The study finds that some functions of the NOC, such as concealing the fiscal burden of subsidies, have diminished. However, political factors and institutional inertia have so far prevented the elimination of subsidies, despite growing fiscal pressure. Although fundamental reform is unlikely in the near future, separating the NOC's upstream and downstream operations and revising its governance could facilitate future reforms.

One of Indonesia's key challenges up to 2050 is reducing its reliance on fossil fuels and decarbonizing its energy system. Rahman, et al. [30] uses a systems approach to explore future pathways, suggesting a shift from oil-based fuels to electricity for cooking and transportation. Currently, electricity in Indonesia is primarily generated from gas and coal. The cost competitiveness of renewable energy is crucial for any adjustment in the country's total primary energy supply (TPES). Causal loop diagrams (CLDs) are used to examine variables in the energy system, focusing on three key aspects: constraints (the energy trilemma), resource availability (physical and human resources), and regulatory frameworks. Indonesia's energy market is dominated by state-owned enterprises and subsidies for consumers. This study also considers the role of private companies in fostering competition among renewable energy providers, leading to more competitive pricing. The findings indicate that, regardless of TPES composition over the next 30 years, fossil fuels will continue to play a major role, making carbon capture storage (CCS) technology essential in complementing the promotion of renewable energy. Figure 15 depicts a causal loop diagram (CLD) showing the interconnected dynamics of Indonesia's oil supply security system, capturing relationships among domestic extraction, imports, consumption, conversion technologies, and external drivers like geopolitical risk and economic growth.

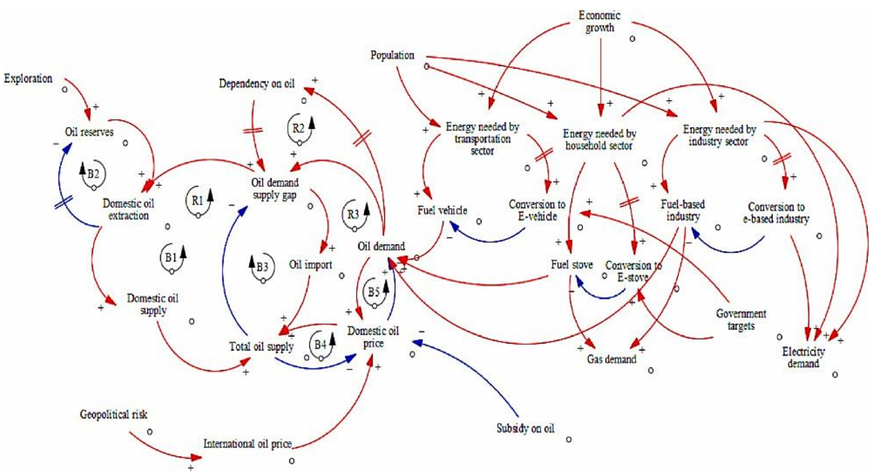


Figure 15. The dynamics influencing the security of Indonesia's oil supply, showing positive (red) and negative (blue) feedback loops connecting oil reserves, demand, imports, conversion strategies, and policy interventions, adapted from [30].

The dominance of private vehicles in Indonesia's transport sector has resulted in substantial energy demand from oil and related externalities. In 2018, the Indonesian government introduced an industrial roadmap to boost the sustainability of the automotive sector, aligning it with national energy policies and CO2 reduction targets. Chandra Setiawan, et al. [31] presents a model to project oil demand, CO2 emissions, and assess the impacts of proposed policy initiatives using the Activity, Mode Share, Intensity, and Fuel Choice (ASIF) framework. The findings indicate that improvements in vehicle fuel efficiency and the adoption of alternative fuels, such as bioethanol, biodiesel, and electricity, could reduce oil demand and CO2 emissions by 30.8% and 33.2%, respectively, compared to a business-as-usual (BAU) scenario by 2030. The largest contribution comes from biofuel blending policies, with bioethanol (E-10) and biodiesel (B-50) reducing oil demand by 5.44% and 10.30%, respectively.

Policies promoting electric vehicles and improvements in new vehicle fuel economy account for a combined 10.38% reduction, while the mandatory use of compressed natural gas (CNG) contributes only 0.98%. Additionally, the end-of-life vehicle (ELV) retirement policy could reduce emissions by 3.49%. These results suggest that the roadmap should be revised to include specific biofuel blending ratios and new vehicle fuel economy targets, alongside a phased implementation plan that allows the industry adequate time to adapt. Figure 16 presents the Indonesian automotive industry roadmap from 1970 to 2035, outlining the progression of product, technology, industrial, and energy-environment developments alongside fiscal policy, aligning with national energy and environmental targets. Additionally, Figure 17 shows the calculated oil consumption reduction potential from various policy initiatives in Indonesia up to 2030, including the introduction of HEVs, BEVs, market shifting from a CO_2 tax, fuel efficiency improvements, end-of-life vehicle (ELV) regulations, commercial vehicle CNG adoption, B50 biodiesel blending, and E10 blended gasoline, alongside the cumulative oil reduction impact relative to the national energy mix target.

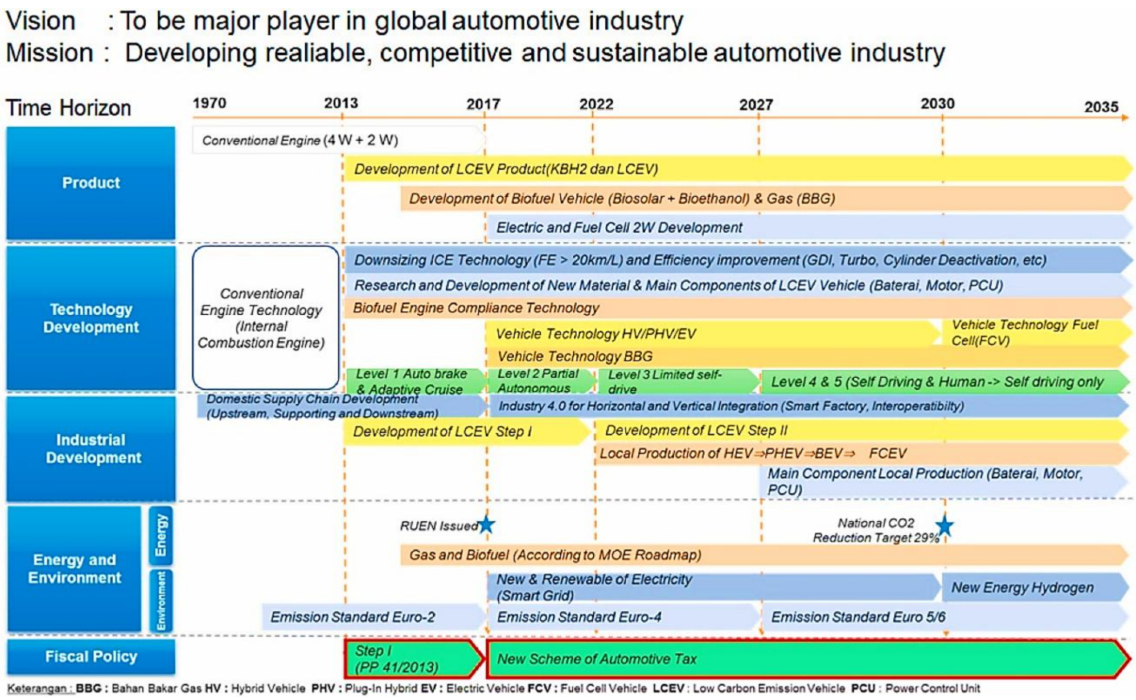


Figure 16. Indonesian automotive industry roadmap (1970–2035), highlighting key developments in products, technology improvements, industrial advancements, energy-environmental actions, and fiscal policy initiatives, adapted from [31].

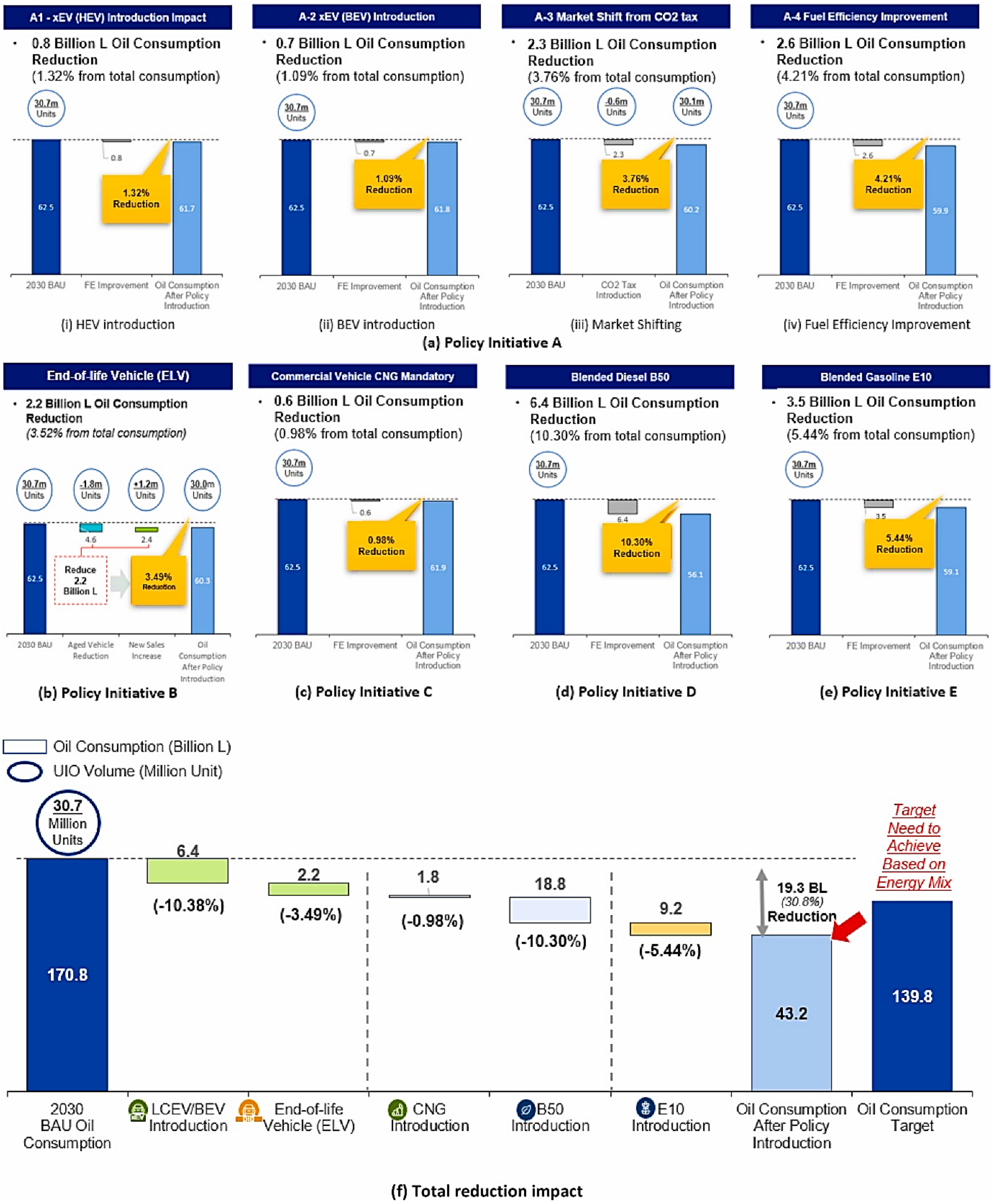


Figure 17. Simulation results of Indonesia's policy initiatives for reducing oil consumption by 2030, covering (a) introduction of xEV (HEV, BEV, market shifting, and fuel efficiency improvement), (b) end-of-life vehicle policy, (c) commercial vehicle CNG adoption, (d) B50 blended diesel, (e) E10 blended gasoline, and (f) total oil reduction impact showing a 30.96% reduction relative to the target set by the national energy mix, adapted from [31].

Java-Bali, Indonesia's largest power system, is a significant source of CO_2 emissions. In response, the Indonesian government has committed to reducing emissions by introducing two key policies: a new renewable energy target and a coal phase-out plan. However, no research has yet explored the energy-carbon-economic relationship in Indonesia, specifically analyzing how these policies will impact CO2 reduction. Sarjiya, et al. [32] examines the economic effects of the energy-carbon nexus in the Java-Bali system and evaluates feasible strategies to support these policies. OSeMOSYS modeling was employed to assess multiple emission reduction scenarios.

The results suggest that policies regulating carbon limits and taxes for power generation companies are essential. A carbon cap of 10,087 million tons with a tax of 67 USD/ton, and a lower cap of 8,482 million tons with a tax of 77 USD/ton, are required to achieve the renewable energy target and coal phase-out plan. Additionally, nuclear energy and liquefied natural gas (LNG) are vital for supporting these initiatives. Thus, the government must promptly decide to incorporate nuclear energy into the system and ensure an affordable and sufficient LNG supply. Moreover, alternative solutions, such as interconnections with other islands rich in renewable energy, should be explored to meet future energy demands and successfully execute the coal phase-out plan. Figure 18 presents a map of Indonesia showing regional differences in renewable energy (NRE) potential, electricity demand, population, and economic growth, highlighting the importance of targeted energy and emission reduction strategies across major island regions.

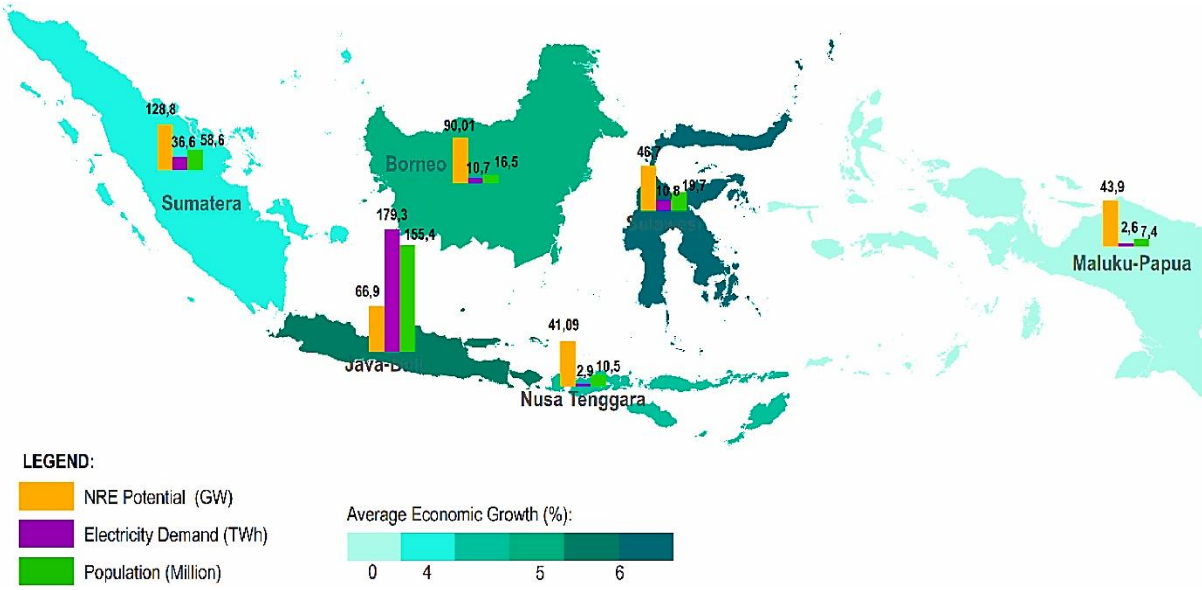


Figure 18. Comparison of NRE potential (GW), electricity demand (TWh), and population (million) in major regions of Indonesia, alongside average economic growth, illustrating the need for region-specific emission reduction policies and the importance of the Java-Bali power system in achieving NRE and coal phase-out targets, adapted from [32].

Adha, et al. [33] aims to estimate the rebound effect across the Indonesian economy by analyzing the factors influencing household energy demand. Determining the rebound effect's magnitude is critical for the government’s energy efficiency initiatives and carbon emission reduction programs. The study employs a two-step analysis using panel data from all Indonesian provinces between 2002 and 2018. The Input Demand Function from the Stochastic Frontier Analysis is applied to measure residential energy efficiency. In the second step, a dynamic panel data model is used to estimate the economy-wide rebound effect.

The model shows that the short-term and long-term rebound effects are 87.2% and -45.5%, respectively. This indicates that a 1% improvement in household energy efficiency leads to a 0.13% reduction in energy use in the short term and a 1.45% reduction in the long term. Additionally, the study finds that a backfire effect occurs in provinces with high energy efficiency, supporting claims that improved energy efficiency can sometimes increase energy consumption. Therefore, energy efficiency programs should continue, but they must be supported by technological innovations and improvements in housing policies.

Energy Service Companies (ESCos) play a vital role in assisting energy users, including businesses, industries, and the commercial sector, in enhancing equipment efficiency through energy services, such as energy performance and credit risk management. ESCos have been effectively implemented to promote energy efficiency (EE) in many European nations and developed countries like the USA, Canada, and Japan. However, the implementation of ESCos needs to be improved in developing nations. This raises concerns about the potential barriers to utilizing ESCos for energy efficiency programs in these countries. To effectively implement and operate ESCos in developing countries such as Indonesia, it is essential to study and understand the opportunities and challenges involved in executing energy efficiency programs.

Nurcahyanto, et al. [34] aims to assess the strengths, weaknesses, opportunities, and threats related to the growth of energy service companies in Indonesia. This assessment is conducted by surveying key stakeholders in the industry, financial institutions, and policymakers to identify important factors, such as regulatory, financial, and awareness issues that influence decision-making. The research findings indicate that strong policy regulations and financial incentives can significantly enhance the development of ESCos by creating substantial investment opportunities for energy efficiency projects in Indonesia. Figure 19 presents the AHP-SWOT construction matrix used for prioritizing factors influencing the implementation of ESCos in Indonesia, including the relative weights of strengths, weaknesses, opportunities, and threats across stakeholders.

Dwi Cahyani, et al. [35] highlights inequality issues in modern residential energy consumption from both income and spatial perspectives, focusing on Indonesia. Energy inequality is analyzed from the standpoint of energy justice, considering both distribution and recognition. The study uses qualitative analysis methods, including Theil’s index, the Gini coefficient, and the mixed-Gini index. The findings show that overall energy usage inequalities have decreased, both in terms of spatial and income levels, except in urban areas.

However, certain groups, particularly residents in rural and remote areas, as well as those in eastern Indonesia, remain vulnerable to energy poverty. To address this, the government should focus on enhancing the stability of the electricity grid, continuing the energy-saving solar lighting (LTSHE) program, and encouraging small-scale decentralized technologies. Improvements in LPG distribution and the development of programs like affordable clean stoves are essential for providing access to clean cooking fuel for underserved populations.

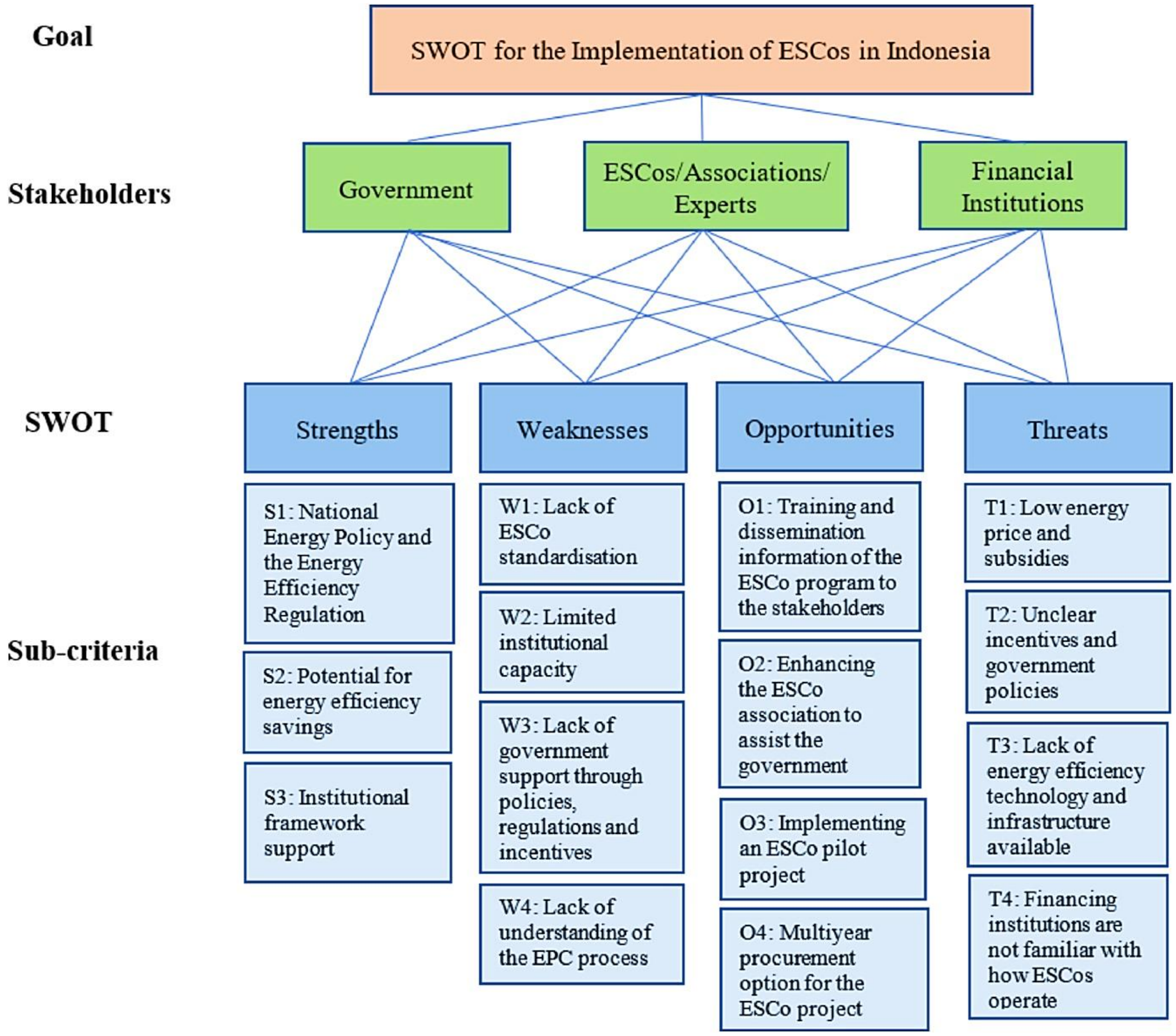
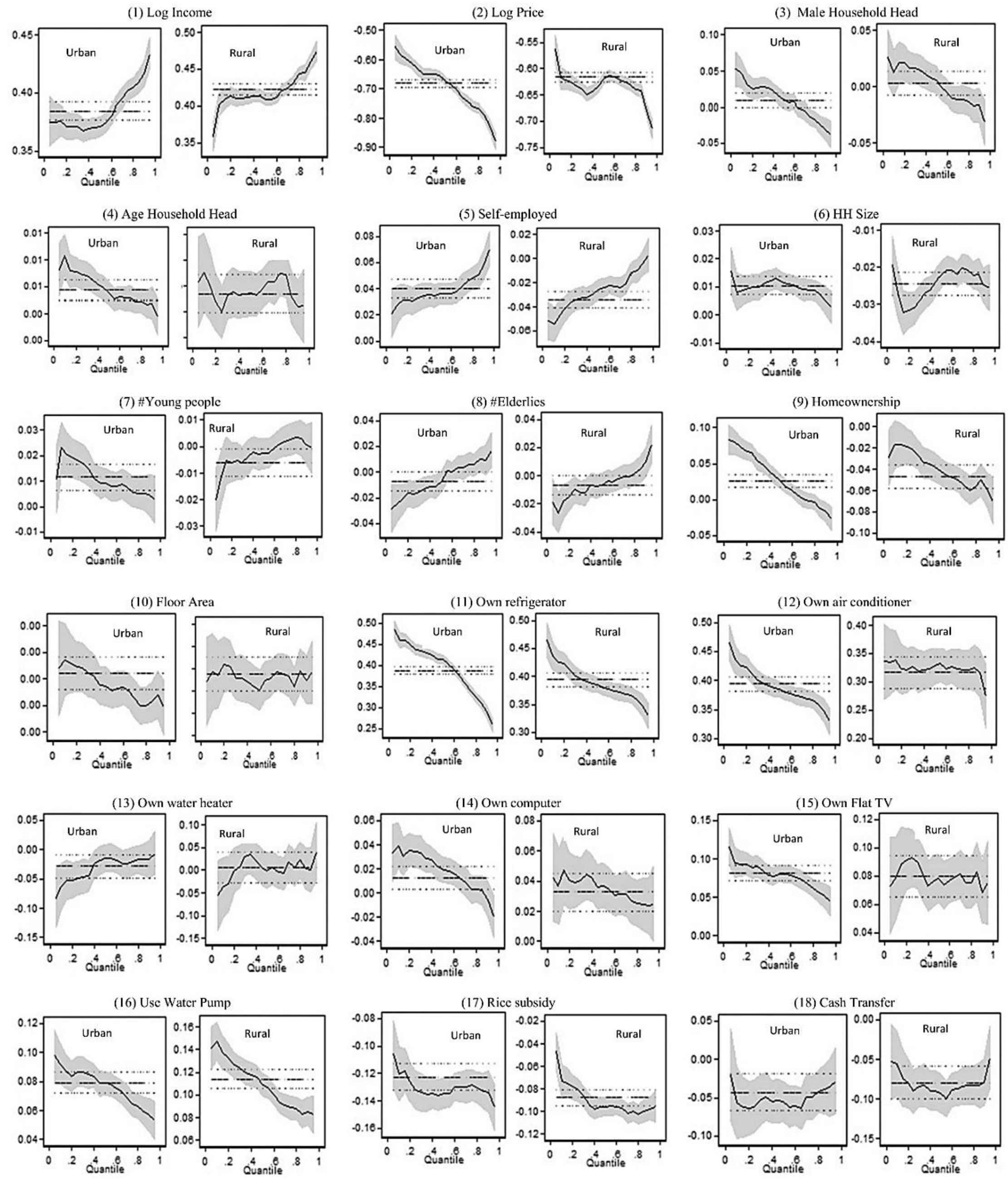


Figure 19. Analytic Hierarchy Process (AHP)-SWOT construction matrix for implementing ESCos in Indonesia, highlighting the priority ranking process of SWOT factors and the incorporation of stakeholder perspectives using pairwise comparisons and scaling factors, adapted from [34].

Indonesia has pledged to achieve Sustainable Development Goal 7, which focuses on ensuring access to affordable, reliable, sustainable, and modern energy for all. The government has worked to improve electricity access through initiatives like the fast-track program for coal-fired power plants and electricity subsidies for low-income households. However, energy efficiency remains a significant challenge due to the country's reliance on coal-powered plants. Cahyani, et al. [36] examines the balance between electricity insufficiency and efficiency by analyzing factors contributing to electricity consumption inequality using quantile regression in both urban and rural areas. The findings indicate that many Indonesian households still face energy insufficiency. Vulnerable households at risk of energy poverty include low-income families, particularly female-headed households in urban areas, households led by non-educated individuals, renters in urban areas, the elderly, and self-employed people in rural areas. Conversely, energy efficiency efforts should target high-consumption households, typically self-employed individuals in urban areas, those with university-level education, and homes with 2200 VA power outlets or more. Notably, only 1% of households are productive users of electricity. To address these challenges, the government should implement affirmative actions to improve access to affordable energy for energy-poor households while promoting sustainable energy development to ensure future generations have access to clean energy. This approach should be integrated into the national energy plan to boost both the electrification ratio and energy consumption.

Figure 20 illustrates marginal effects of multiple socioeconomic and demographic variables on household electricity usage across different quantiles (from 0 to 1) in urban and rural areas of Indonesia. Each plot shows the estimated conditional effect of a specific explanatory variable (like income, household size, appliance ownership, etc.) on electricity usage at each quantile, with shaded areas representing confidence intervals. The results show that the effects vary significantly across quantiles, indicating heterogeneous impacts of these variables on household electricity consumption distribution.



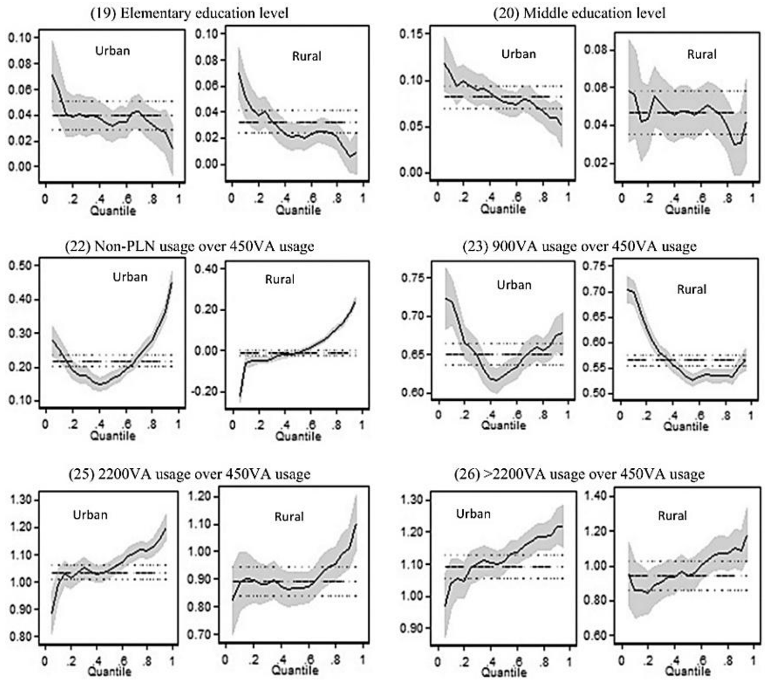


Figure 20. Marginal effects of various socioeconomic and demographic variables on household electricity usage across different quantiles in urban and rural areas. The solid lines indicate estimated effects, while shaded areas denote 95% confidence intervals, highlighting the varying impact of explanatory variables across the electricity usage distribution, adapted from [36].

Some low- and middle-income countries are transitioning to coal-based electricity systems to balance the challenges of energy security, equity, and sustainability. Foreign entities have played a significant role in overcoming obstacles to energy transitions, influencing their pace and direction. However, existing research on the geography and timing of these transitions offers limited insights into how various dimensions and layers, along with domestic and foreign actors, interact and support one another during the shift to a coal-based electricity supply system. To address this gap, Mori [37] presents robust evidence supporting the concept of complementarities within the electricity supply system, making it feasible for empirical analysis. The case study of Indonesia reveals that the transition is accelerated by the collaboration between foreign investors and domestic stakeholders, which helps to tackle multiple complementarity bottlenecks collectively. China, in particular, stands out as a major foreign investor in coal power, providing both tangible and intangible resources to resolve these bottlenecks during a crisis. Moreover, it offers more favorable terms to domestic actors, who wield influence to shape decisions and political objectives in their favor.

6. Indonesia's Pathways to 100% Renewable Energy: Government Plans and Alternative Transition Pathways to 2050

Indonesia’s future energy direction is guided by the National Energy Policy (KEN), regulated under Government Regulation PP 79/2014. The regulation outlines the country’s national-level long-term vision for its energy sector, whilst providing a series of milestones on the projection of the energy supply and demand. Enacted in 2014, the KEN is being revised to account for the latest development and government direction, for instance, the 8% target for economic growth in 2029. A direct derivative of the regulation, the National Energy General Planning (RUEN), was issued through Presidential Regulation Perpres 22/2017 to provide detailed strategies on the activity level. Similar to the KEN, the RUEN is in the process of being updated. Apart from these regulations is another regulation that governs the sectoral pathway produced at the ministerial level. The National Electricity Development Plan (RUKN) by the Ministry of Energy and Mineral Resources (MEMR) specifically describes the pathways for the entire electricity sector, both on-grid and off-grid. The RUKN 2025-2060 (RUKN), which effectively replaces the RUKN 2019-2038, sets the roadmap for Indonesia to achieve its net-zero emissions target in 2060.

Aligned with government direction on achieving the 8% economic growth, the RUKN projects a staggering 5,038 kWh per capita of electricity demand in 2060. Most of the demand is expected to be driven by the industrial sector at 43%, followed by households at 28%, commercial at 13%, transportation at 11%, and the public sector at 5% [38]. Another projection in the document includes the green hydrogen production, increasing the electricity demand further to 6,027 kWh per capita by 2060. To meet these demand projections, the document projects a capacity expansion on the supply side of 443 GW by 2060. 63.6% of the capacity is supplied from renewables, see Figure 21. The document does not consider retirement for all fossil-based assets, including coal-fired power plants (CFPPs). These assets will still be allowed to operate until the end of their economic lifetime. Once that happens, these assets will be retrofitted to run on 100% ammonia/hydrogen and biomass co-firing, complemented with CCS/CCUS technology. Due to the implementation of Presidential Regulation Perpres 112/2022, no new CFPPs, both for the on-grid and off-grid (captive), are enlisted beyond 2030. Nuclear, which contributes to 7.9% of the generating capacity in 2060, will come online in 2033.

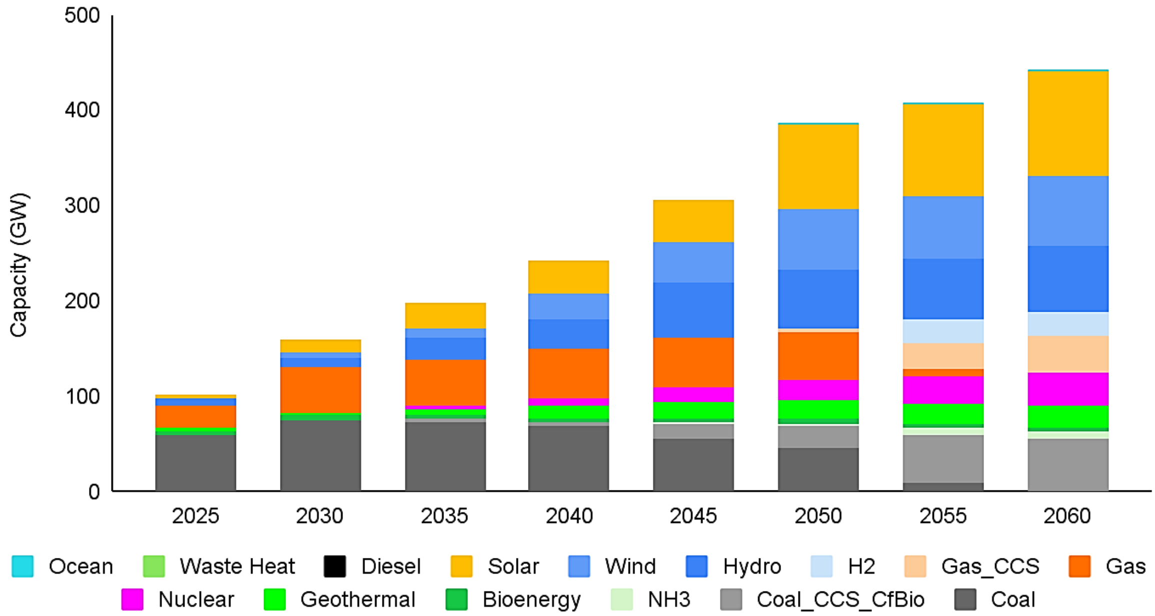


Figure 21. RUKN 2025-2060 capacity projection, adapted from [38].

The Indonesian power sector faces a dual challenge: meeting the rising demand for electricity at an affordable cost while also adhering to the decarbonization targets set under the Paris Agreement. Sani, et al. [39] explores cost-effective pathways for power sector development that align with climate goals. Using the Low Emissions Analysis Platform (LEAP) software, a power system expansion model was developed for Sumatra, analyzing four scenarios: business as usual, current development plans, and two mitigation pathways consistent with national climate targets. Special attention was given to bioenergy, a resource often overlooked in previous studies.

The findings indicate that although the national plans include mitigation measures, they do not adequately reduce coal dependence. Furthermore, current plans are not cost-effective and result in high marginal abatement costs for emissions reduction. In contrast, the two mitigation scenarios show improved environmental outcomes at lower system costs. The study demonstrates that bioenergy deployment can significantly contribute to meeting Indonesia's GHG reduction targets of 19% and 24%, while better utilization of modern renewables and natural gas can help decrease Sumatra's reliance on coal.

Reyseliani and Purwanto [40] evaluates Indonesia's power system transition to achieve 100% renewable energy by 2050. The pathway is determined through least-cost optimization using the TIMES model, comparing 27 power plants and 3 energy storage technologies, alongside an hourly demand and supply operational profile over 24-hour time slices. The findings suggest that nuclear energy and utility-scale solar PV will play significant roles, contributing 16% and 70%, respectively, to a total electricity production of 1396 TWh by 2050. The investment cost in 2050 is projected to be three times higher than in a Business as Usual scenario, reaching 95 billion USD, while emissions would be reduced by six times to 215 million tons of CO2 equivalent.

The renewable energy mix under current policies is expected to have a higher CO2 abatement cost of 120 USD per ton of CO2 equivalent by 2050. Optimistic demand forecasts indicate an 82% increase in coal usage under the Business as Usual scenario, while nuclear and utility-scale solar PV would grow by 126% and 62%, respectively, under a 100% renewable energy scenario. Excluding nuclear energy would lead to an increased reliance on solar PV and batteries, requiring 78%-83% more land, adding supply variability, and raising electricity production costs by 9.7%.

Figure 22 illustrates the projected installed capacity and power generation mix for Indonesia’s Business As Usual (BAU) scenario up to 2050, highlighting the continued dominance of coal and the gradual growth of renewable energy and storage technologies. Additionally, Figure 23 shows the projected installed capacity and power generation mix for Indonesia’s 100% renewable energy scenario up to 2050, illustrating the replacement of coal and fossil fuels with nuclear, solar PV, biomass, and energy storage technologies.

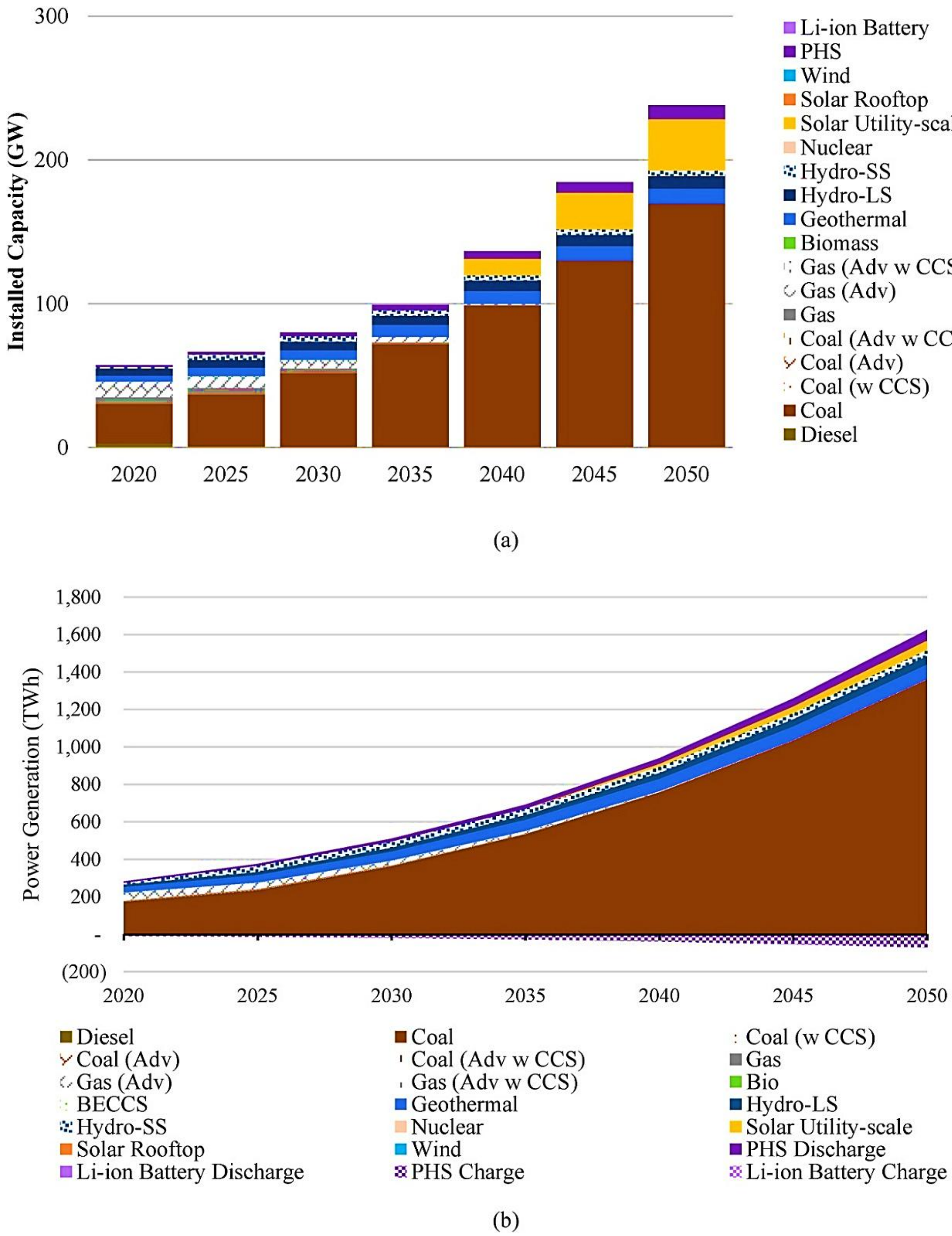
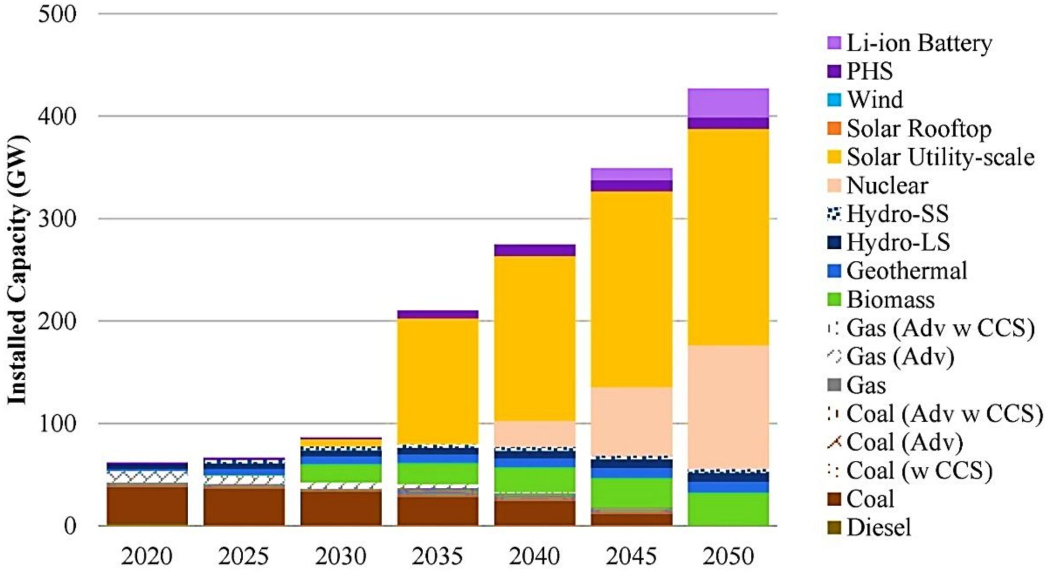


Figure 22. (a) Installed capacity of power plants & (b) electricity generation mix for Indonesia's BAU scenario, showing reliance on coal and fossil fuels & increasing contributions from renewable energy and storage systems, adapted from [40].



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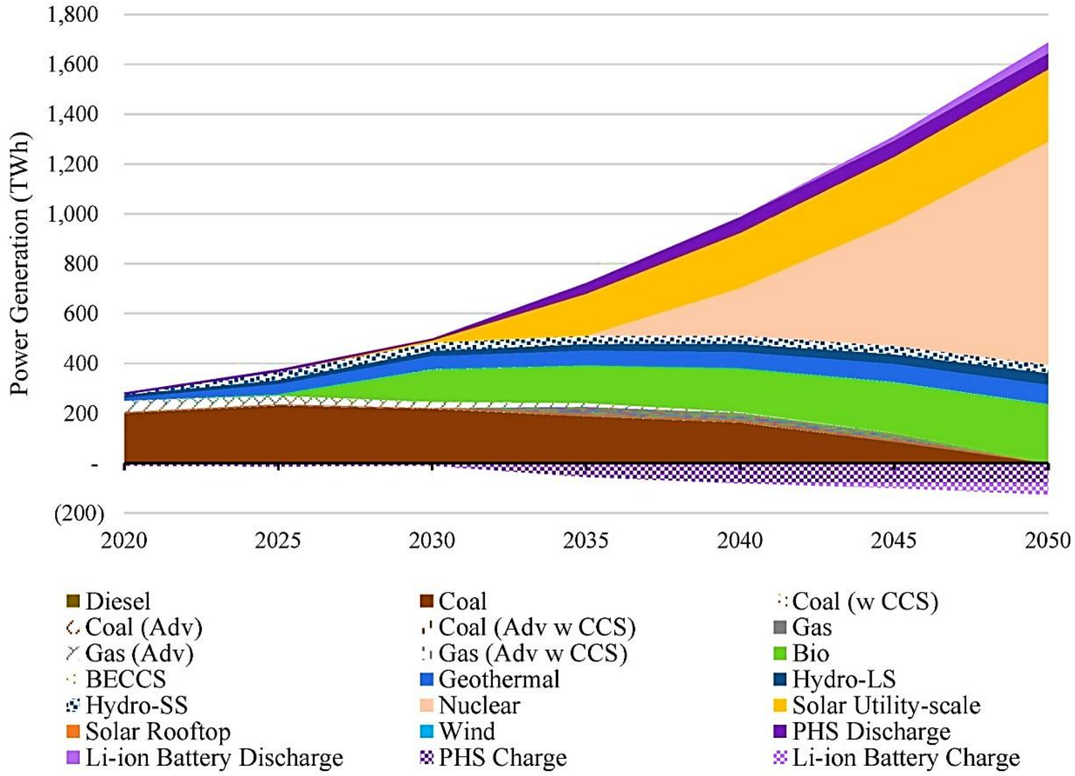

(b)

Figure 23. (a) Installed capacity of power plants & (b) electricity generation mix for Indonesia's 100% renewable energy scenario, demonstrating rapid decline of coal and fossil fuels and the increasing roles of nuclear, solar PV, biomass, and energy storage in achieving a fully renewable electricity sector by 2050, adapted from [40].

Reyseliani, et al. [41] analyzes Indonesia's electricity system transition from 2020 to 2050 in order to meet the Paris Agreement targets, using the TIMES model. It evaluates three scenarios: Reference Case, Current Policy, and Paris Agreement. In the Reference Case, 77% of the electricity system will rely on unabated coal power, while the Current Policy scenario only reduces coal's share by 10% by 2050. Emissions from both scenarios are still half of the estimated electricity emissions in the Nationally Determined Contributions (NDC), highlighting a gap between policy targets and current demand levels. To meet the long-term target of staying well below a 2°C rise, 50% of electricity production must come from renewable energy, and 40% from IGCC-CCS. This would require a 48% increase in investment compared to the Reference Case, while electricity production remains constant at current levels. The uncertainty of the carbon budget may not impact the timing of the emissions peak or solar PV deployment, but it will affect the timing and capacity of IGCC-CCS deployment and the role of BECCS through 2050. Indonesia's electricity system needs reform due to technological changes, shifting investment trends, the need for faster technological readiness, and the current state of market structure and electricity prices. Figure 24 presents investment mixes for three scenarios (RC, CP, and PA) in 2030 and 2050, illustrating the shift from coal-dominated investments to low-carbon technologies such as geothermal, BECCS, IGCC with CCS, and solar PV utility-scale.

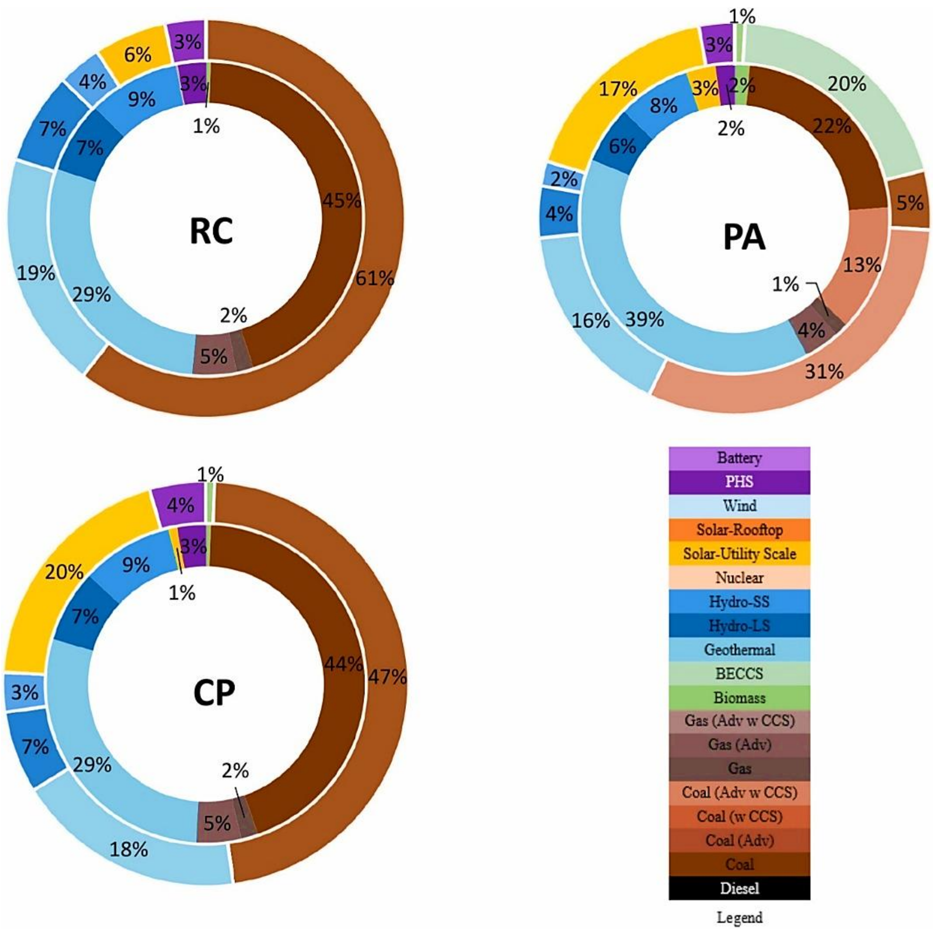

Figure 24. Investment composition for the Reference Case (RC), Current Policy (CP), and Paris Agreement (PA) scenarios in 2030 (inner circle) and 2050 (outer circle), highlighting the increasing role of low-carbon technologies and the declining share of coal in future energy investments, adapted from [41].

7. Policy Framework for Low-Carbon Energy Transition in Indonesia

Creating policies that support a transition to low-carbon energy systems necessitates a deep understanding of the specific political and economic contexts of each country regarding energy and climate policy. Jakob, et al. [42] introduces a generalized AOC ('Actors, Objectives, Context') political economy framework that facilitates the comparison of various country case studies, focusing on how economic structures, political institutions, and the political environment shape policy outcomes. The actor-centered approach posits that the policies enacted align with the goals of the most influential actors in policy decisions. Implementing the framework involves four steps: identifying key societal and political actors in energy and climate policy, clarifying their objectives, assessing the relevant economic and institutional contexts, and analyzing the dynamic interactions among these factors to understand their collective impact on policy outcomes. This framework accommodates various theoretical perspectives and is illustrated through case studies on coal use in India, Indonesia, and Vietnam, ultimately highlighting opportunities for policy change. Figure 25 visually represents the Actor-Objective-Context (AOC) framework, illustrating how the interplay of policy objectives, societal and political actors, and contextual factors shapes policy outcomes.

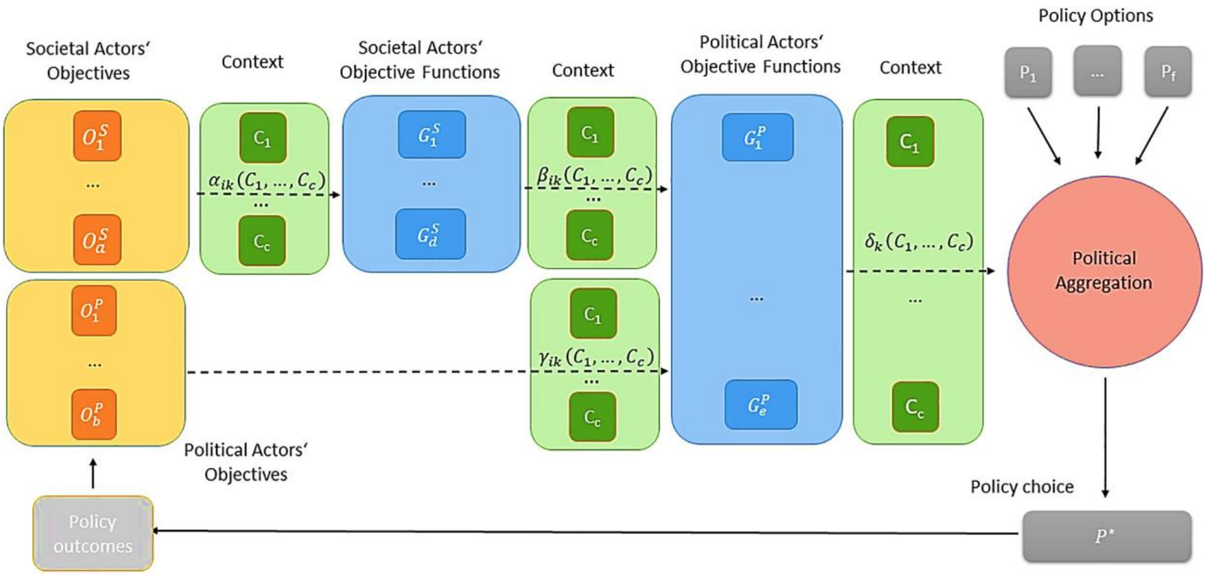

Figure 25. Graphical representation of the AOC framework, depicting the relationships between societal and political actors, their respective objectives, and the contextual factors influencing policy processes and outcomes, adapted from [42].

This policy framework (Table 2) serves as a structured tool to guide and evaluate Indonesia's journey toward a low-carbon energy future. It consists of 10 key policy areas, reflecting the critical dimensions identified in the uploaded file: regulatory frameworks, financial incentives, stakeholder engagement, research and development support, capacity building and training, sustainability standards, monitoring and evaluation, public awareness and education, infrastructure development, and integration with national energy plans. The table not only highlights existing policies—such as fossil fuel subsidy reforms, feed-in tariffs for renewable energy, and licensing frameworks for rooftop solar—but also emphasizes innovative and community-driven approaches like biomass valorization and inclusive energy planning.

Table 2. Policy framework for low-carbon energy transition in Indonesia.

Regulatory Framework	Financial Incentives	Stakeholder Engagement	Research & Development Support	Capacity Building & Training	Sustainability Standards	Monitoring & Evaluation	Public Awareness & Education	Infrastructure Development	Integration with National Energy Plans
Revision of fossil fuel subsidies (e.g., phasing out subsidies, fuel price adjustments)	Feed-in tariff (FIT) system for geothermal and renewable energy	Involvement of national and provincial actors (multi-level governance)	Funding for geothermal exploration and biomass conversion technologies	Technical training for local actors in energy transitions	Renewable energy targets (e.g., 23% by 2025, 100% by 2050)	Evaluation of rooftop PV policies (e.g., net metering vs net billing)	Programs like affordable clean cookstoves and LTSHE	Support for rooftop PV adoption and distributed generation	National Energy Plan (RUEN) and power sector RUKN alignment
Licensing for renewable energy projects (e.g., biomass, solar)	Tax incentives and subsidies for renewable investments	Civil society involvement in regional energy planning	System dynamics models to assess policy tools' effectiveness	Capacity-building initiatives for local governments	Standards for energy efficiency and emissions in buildings	Tracking progress on SDG 7 and carbon reduction targets	Campaigns for rooftop solar and low-carbon technology adoption	Investment in renewable generation, transmission, storage	Consistency amongst planning documents, e.g. between RPJPN 2025-2045 and National Energy Policy (KEN)
Reforms to improve bioenergy and wood pellet regulations	Carbon pricing (proposed: $5–77/ton CO_2)	Engagement of marginalized communities in energy decisions	Integrated energy-carbon-economy modeling for power planning	Community-based renewable project governance capacity	Development of fair and inclusive community RE programs	Scenario analysis of energy mix and emissions	Educational programs to boost acceptance of solar PV	Electrification in rural and remote areas	Coordinated national and regional energy plans
Permits and frameworks for rooftop solar net metering	Investment guarantees and risk-sharing for renewables	Collaboration with private sector (e.g., ESCos for energy efficiency)	Research into renewable energy potential (solar, biomass, geothermal)	Technical assistance for modern energy technology adoption	Strengthening governance to address LCD barriers	Monitoring spatial inequality in energy access	Raising awareness of the benefits of modern energy access	Expansion of grid interconnections and renewable integration	Integration with SDG 7 and Paris Agreement targets
Favorable policy on rooftop PV adotption as means to empower community development	Government support for biodiesel blending and incentives	Local leadership and political will in energy transitions	Evaluation of policy effectiveness (e.g., feed-in tariffs)	National training for energy planners and policymakers	Standards for green development in energy policies	Evaluation of carbon emissions reduction under policy scenarios	Awareness campaigns for energy poverty reduction	Grid strengthening to alleviate concerns on the renewable integration	Coordination of stakeholder actions in energy transition
Updates to national standards for household energy efficiency	Green bonds and low-interest financing for renewable projects	Involvement of academia and research institutions	Use of system dynamics and scenario analysis for planning	Training for decentralized renewable energy system maintenance	Fair energy access and inclusivity principles in policy	Periodic reviews of household energy access (rural and urban)	Community-focused awareness programs (e.g., Sumba Island example)	Investment in resilient and climate-smart energy infrastructure	Alignment of energy plans with SDGs and climate mitigation goals
Support for integrating biomass into energy policy	Blended financing schemes for low-carbon projects	Facilitation of community-based renewable energy initiatives	Research and development of CCS and BECCS technologies	Technical capacity for green hydrogen, bioenergy, CCS	Adoption of sustainability certifications for biomass and wood pellets	Evaluation of co-benefits for emissions and economic development	Educational campaigns for sustainable cooking fuels and technologies	Investment in transmission upgrades to enable RE integration	Incorporation of sustainability principles into the national energy roadmap

Each column represents a crucial element in ensuring that Indonesia's energy transition is just, equitable, and effective. Regulatory frameworks ensure that legal structures are updated to support clean energy, while financial incentives—such as carbon pricing, tax incentives, and green bonds—make investments in renewable energy more attractive. Stakeholder engagement underscores the importance of involving government, civil society, and the private sector, especially local actors who can drive change on the ground. Research and development support addresses the need to foster innovation in clean energy technologies and planning models, while capacity building ensures that local communities and policymakers have the skills to manage this transition.

Sustainability standards ensure that the shift to renewables upholds environmental and social justice, complementing robust monitoring and evaluation systems that track progress towards national targets like SDG 7 and Paris Agreement commitments. Public awareness and education campaigns play a vital role in building trust and acceptance for new technologies like rooftop PV and community-based renewables. Infrastructure development—including expanding grid interconnections and building resilient systems—is essential to enable these low-carbon strategies. Finally, integration with national energy plans, such as the RUEN and regional development strategies, ensures policy coherence and alignment with broader sustainability goals. Overall, Table 2 provides a comprehensive, holistic policy framework to guide Indonesia's transition to a low-carbon energy system,

8. Conclusion

Indonesia's transition to a low-carbon energy future is at a pivotal moment, reflecting both promising strides and persistent challenges. Over the past two decades, regulatory reforms, financial incentives, and energy planning frameworks have been developed to support renewable energy deployment and energy efficiency improvements. Policies such as the feed-in tariff for geothermal energy, the rooftop photovoltaic net metering scheme, and the national renewable energy target of 23% by 2025 illustrate Indonesia's ambition to reduce reliance on fossil fuels. However, the journey toward a sustainable and equitable energy transition is far from complete.

The findings highlight that the country's energy landscape remains dominated by fossil fuels, particularly coal, due to subsidies, outdated infrastructure, and economic structures favoring conventional energy sources. Biomass and bioenergy, despite their significant potential, face technical and governance barriers that limit their contribution to the national energy mix. Moreover, spatial and socio-economic inequalities persist, with marginalized and remote communities disproportionately affected by energy poverty and lacking the capacity to participate in decision-making processes.

Research and development, capacity building, and stakeholder engagement are critical to overcoming these challenges. The analysis suggests that strengthening multi-scalar governance—bridging national, provincial, and community-level actors—will be vital for achieving a just energy transition. Incorporating local perspectives and indigenous knowledge can enrich energy policy design and foster ownership at the community level. Financial incentives, such as green bonds and blended finance schemes, must be aligned with these social goals to ensure inclusive and fair outcomes.

Effective monitoring and evaluation systems are also essential to track progress and inform policy adjustments. The integration of policies into the National Energy Plan (RUEN) and the alignment with Indonesia's Sustainable Development Goals (SDGs) and Paris Agreement commitments provide a solid foundation for long-term sustainability. However, policy coherence across different sectors and scales—addressing interlinkages between energy, climate, and social development—remains a work in progress.

Ultimately, Indonesia's experience offers valuable lessons for other emerging economies navigating similar challenges. By prioritizing energy justice, addressing governance gaps, and fostering technological innovation, Indonesia can position itself as a regional leader in clean energy transition. Moving forward, policymakers should focus on scaling up renewable energy solutions, phasing out fossil fuel subsidies, and empowering local actors and communities. These actions are crucial not only for meeting climate goals but also for ensuring a more equitable and sustainable energy system that supports broader human development objectives.

Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

CRediT Authorship Contribution Statement

All authors contributed equally to the conception, analysis, writing, and final approval of the manuscript. Each author has read and agreed to the published version.

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