Towards Inclusive Energy Transition in Indonesia

Simulating the Impact of Energy Sector Decarbonization on the Welfare of Vulnerable Groups

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Extensive climate modelling research has been conducted internationally, particularly on energy transition. However, despite the abundance of research in this field, few modelling efforts explicitly incorporate vulnerable groups, such as women and people with disabilities, particularly in Indonesia. This study is a pioneering effort to identify the challenges and impacts of the energy transition on vulnerable groups in Indonesia, while highlighting opportunities for fiscal responses to achieve distributional objectives. We believe that the meaningful representation and participation of vulnerable groups is crucial to ensuring more inclusive climate policies.

This study was conducted by the Institute for Economic and Social Research (LPEM FEB UI) in partnership with the Australian National University (ANU), the SMERU Research Institute, and the Institute of Essential Services Reform (IESR), with funding support from the Australia Government through KONEKSI (Knowledge Platform Australia – Indonesia). I would like to extend my gratitude to the entire team - Alin Halimatussadiah as the principal investigator, Prof Budy Resosudarmo and Prof Frank Jotzo as the co-principal investigators, our senior researchers Asep Suryahadi, Arianto Patunru, Milda Irhamni, Raden Wiranegara, Yeliz Simsek, our junior researchers Affandi Ismail, Arifa Tariqa Imani, Khairunnisa Rangkuti, Lia Amalia, Fachry Abdul Razak Afifi, Muhammad Yudha Pratama, and Priskila Teresa Nandita, as well as Prof Irwanto, our Disability Specialist, and Diahhadi Setyonaluri, our Gender Specialist.

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We hope this study serves as a call to action for further research into the Gender, Disability, and Social Inclusion (GEDSI) aspects of the energy transition. We also hope it sparks more discussions and collaborative efforts to implement an inclusive energy transition in Indonesia.

Jakarta, September 2024

Chaikal Nuryakin, Ph.D
Director
LPEM FEB UI

ABBREVIATIONS

AFOLU	Agriculture, Forestry and Other Land Use
AIDS	Almost Ideal Demand System
AIM	Asia Pacific Integrated Model
CCS	Carbon Capture and Storage
CGE	Computable General Equilibrium
CIPP	Comprehensive Investment and Policy Plan
EC-MSMR	Environment Canada's Multi-Sector, Multi-Regional
ETM	Energy Transition Mechanism
ETS	Energy Transition Mechanism
GCAM	Global Change Analysis Model
GDP	Gross Domestic Product
GEDSI	Gender, Disability, and Social Inclusion
GFANZ	Glasgow Financial Alliance for Net Zero
GHG	Green House Gases
GIC	Growth Incidence Curve
HEESI	Handbook of Energy and Economics Statistics of Indonesia
IAM	Integrated Assessment Models
IPG	International Partners Group
JETP	Just Energy Transition Partnership
JGCRI	Joint Global Change Research Institute
LTS-LCCR	Long-Term Strategy on Low Carbon and Climate Resilience
MEMR	Ministry of Energy and Mineral Resource
NDC	Nationally Determined Contribution
NZE	Net Zero Emissions
PLN	Perusahaan Listrik Negara/National Electricity Company
PV	Photovoltaic
PWD	Person with Disabilities
RE	Renewable Energy
TIMES	The Integrated MARKAL-EFOM System
UNFCCC	United Nations Framework Convention on Climate Change

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Indonesia has expressed a commitment to decarbonizing its economy with ambitious targets to reduce emissions and increase the share of renewable energy. The nation faces significant challenges in balancing the energy transition with its socio-economic goals, particularly the vision to become a resilient, prosperous, inclusive, and sustainable high-income nation by its 100th independence anniversary in 2045 (Indonesia Emas 2045). Although Indonesia is planning to meet its renewable energy targets, it still struggles with low renewable energy adoption, continued reliance on coal for electricity generation as well as in industry and ensuring reliable electricity access especially in remote areas. The ongoing development of energy transition policies reflects government efforts but achieving a just and inclusive energy transition remains a complex policy challenge.

Recognizing the varied impact of energy transitions on vulnerable communities, this study quantitatively estimate the impact of energy transition through the lens of inclusivity. Specifically, this study intends to examine how different climate target scenarios impact the welfare of vulnerable groups. We utilize the Global Change Assessment Model (GCAM) to simulate different emission target pathways and its impact to commodity price changes, followed by a microsimulation using the Almost Ideal Demand System (AIDS) model to assess the impact of commodity price changes on household income, poverty levels, and the Gini ratio per household group, especially for female-headed households, households with people with disabilities, and household with children or the elderly.

Using different climate target scenarios (Net Zero Emissions/NZE at 2080, 2060, and Reference/No Policy) and accommodating socioeconomic assumptions (population growth and GDP growth), key features of the GCAM modelling suggest that:

1. The emission trajectory for NZE scenarios peaked in 2030 with the assumption that the NDC target is achieved by 2030. After 2030, the emissions will decrease to reach net zero according to NZE target year scenarios.
2. As climate ambition exists in Indonesia such as Net Zero 2050, 2060 and 2080, the diversity of electricity generation using other technologies is increasing. The largest portion of renewable energy source in NZE 2050 scenario is Solar PV (including rooftop solar PV), while for the Reference scenario, coal portion in electricity generation keeps increasing beyond 2060.
3. The electricity price in all NZE scenarios is higher compared to Reference scenario. This reflects greater investment needs for a low-emissions electricity system as well as higher carbon price, which lead to extra burden to either consumers (if the extra cost from the producers is pass-through to the consumers) or the government (through additional subsidy needed to cover the extra cost if the electricity price keeps as fixed). At the same time, revenue generated from the carbon pricing provides the opportunity to stabilize electricity prices through subsidy.
4. The NZE scenarios show a very progressive price index of all commodities over the period of simulation (2020-2045), much higher than the Reference scenario. The NZE 2050 scenario shows a higher price of energy compared to agricultural and food commodities while the Reference scenario shows the opposite.

The commodity prices as the result of GCAM is used as the input variables for the AIDS Microsimulation. The poor household share in consumption commodities is dominated by rice. The simulation result visualizes the welfare impact of the commodity price changes to three type vulnerable groups: female headed household, household with disability, and household with children or elderly. The AIDS modelling result suggest that:

1. All scenarios show decreasing trends of poverty. However, the NZE scenarios will lead to higher poverty rates compared to the Reference scenario, with faster NZE timelines resulting in even greater poverty rates at the end of simulation period (2045). Short term increase in poverty rate is shown in all NZE scenarios and not in the Reference scenario. Vulnerable household groups encounter higher poverty rate compared to the overall groups for all scenarios, with household with disability experience the worst poverty rate.
2. Inequality, reflected by Gini Ratio, is expected to decrease thorough the overall period of simulation, with less reduction for all NZE scenarios compared to the Reference scenario. Achieving more ambitious NZE targets will lead to higher inequality. Female-headed households are showing the least reduction in inequality, with even experiencing an increase in inequality in the last period; leading to the highest Gini ratio among the groups.
3. Moving to NZE without policies to support low-income and disadvantaged groups would slow poverty eradication effort, making it more unlikely to reach the Indonesia Emas target of 0.5-0.8% poverty rate as well as Gini ratio target of 0.377–0.320.
4. The results indicate that social protection policy targeting the vulnerable groups is needed, in particular for female-headed household and household with disability to absorb the shock they experienced from energy transition, especially in the short term. The opportunity lies on designing an inclusive fiscal policy, that could utilize the potential revenue from the implementation of carbon pricing instrument for redistribution.

The results above underscore the importance of government intervention through fiscal policy to protect vulnerable groups from the adverse impact of energy transition. The modelling outcomes for all NZE scenarios indicate that the implementation of fiscal stimulus in combination with carbon pricing can help reduce poverty and inequality. Although vulnerable groups still experience higher poverty rates in all NZE scenarios compared to the reference scenario, but the rates are converging to the reference scenario. Moreover, the fiscal stimulus leads to better outcomes in terms of inequality for all vulnerable groups.

Future research on this issue needs to address several points including the need of good quality and more granular data of all aspects related to inclusive energy transition, the need to develop a more comprehensive modelling system that can incorporate more transmission mechanisms and indicators of economic change such as employment, and the need to further combine quantitative and qualitative research. With these efforts, future research will allow more comprehensive incorporation of Gender, Disability and Social Inclusion (GEDSI) in the energy transition research. Such research, using more refined tools and data, can help promote more inclusive policy for Indonesia's energy transition.

1

Introduction

Towards Inclusive Energy Transition in Indonesia: Examining the Impact of Energy Sector Decarbonization to the Welfare of Vulnerable Groups.

As a signatory of the Paris Agreement, Indonesia has expressed a commitment to decarbonize its economy. Its most recent Nationally Determined Contributions (NDC), referred to as Enhanced NDC, outlines more ambitious targets than the previous versions. The country aims to reduce emissions by 31.2 percent by 2030 compared to business-as-usual level unilaterally or by 43.2 percent with international support. Indonesia's Long-Term Strategy on Low Carbon and Climate Resilience (LTS-LCCR) 2050 includes a goal to achieving net zero emissions (NZE) by 2060 or sooner (UNFCC, 2022).

Given the ambitious targets, there is concern that the energy transition could impede the achievement of Indonesia Emas 2045, a vision that aims to raise the country's per capita income to 30,000 USD. By 2045, the poverty rate is projected to decrease from an estimated 6-7 percent in 2025 to 0.5–0.8 percent, while inequality, measured by the Gini Index, is expected to drop from approximately 0.38 in 2025 to 0.32 in 2045 (Bappenas, 2023).

1.1. Indonesia's Plan and Progress on Energy Transition

Indonesia's plan for achieving NZE includes ambitious sectoral targets. The projected share of renewables in the energy and power sectors is outlined in several climate and energy-related planning documents (Table 1.1). By 2050, the renewable energy (RE) share is expected to range from 34 to 85 percent in the energy sector and from 43.5 to 83 percent in the power sector.

TABLE 1.1 Renewable Energy Share in Energy and Power Sectors

Type of Planning Document – Issuing Institution	Share of RE in Power Sector (%)	Share of RE in Energy Sector (%)
Climate-related document		
LTS-LCCR - MoEF	43.5% in 2050	34% in 2050
LCDI - Bappenas	82% in 2050	85% in 2050
Energy Planning Document		
Roadmap NZE - MEMR	83% in 2060	85% in 2060
RUKN - MEMR	81% in 2060	NA

Source: Authors' compilation (2024)

Further developments in energy transition policies and programs include initiatives such as the Energy Transition Mechanism (ETM) and Just Energy Transition Partnership (JETP), the establishment of the Task Force on Energy Transition (Satgas TEN/Satuan Tugas Transisi Energi Nasional) under the Coordinating Ministry of Maritime and Investment (Kemenkomarves/Kementerian Koordinator Bidang Kemaritiman dan Investasi), and the ongoing development of a New and Renewable Energy Bill. The bill aims to provide legal certainty and enhance investor appeal in the RE sector. The government has also issued regulations on carbon pricing, which are critical for improving the competitiveness of clean energy relative to fossil fuels. In 2021, two key regulations were introduced: the Presidental Decree on Carbon Pricing and the Tax Harmonization Law, which includes the provisions for a carbon tax. In 2023, the government launched the emissions trading system (ETS) for the power sector (following a pilot phase since 2021) and initiated the Indonesia Carbon Exchange (IDXCarbon). The implementation of carbon tax is expected to begin in 2025.

Despite all of these, Indonesia faces challenges in meeting its RE targets (Halimatussadiah et al., 2024, Maulidia et al., 2019). The country aims to achieve a 23 percent share of RE in both the energy and power sectors by 2025. However, as of 2022, only 14.58 percent of its installed power plant capacity comes from RE sources (MEMR, 2024a). In addition to these challenges, Indonesia has historically struggled to provide reliable electricity access, particularly in remote regions such as East Nusa Tenggara, Maluku, and Central Papua, despite a national electrification rate of 99.63 percent in 2022 (MEMR, 2024b). Some areas still experience frequent power outages.

Indonesia has maintained low retail electricity prices, often below the electricity generation costs of PLN (Burke and Kurniawati, 2018). While this strategy ensures affordability, it also requires substantial subsidies, straining fiscal resources. Furthermore, Indonesia's heavy reliance on coal raises concerns about energy sustainability,[AI1] as global trends increasingly shift towards low-carbon technologies. The dominant role of coal—accounting for about 67 percent of power generation (MEMR, 2024a)—highlights the difficulties in providing sustainable electricity access, especially in remote regions (Setyowati, 2020).

The factors outlined above highlight key obstacles to Indonesia's progress toward its energy transition targets. In this context, ensuring a just and inclusive energy transition is not only challenging but also essential for achieving sustainable energy in the country. Balancing the trade-offs between addressing energy poverty, ensuring energy security, and promoting sustainability remains a significant policy challenge for Indonesia's energy sector.

1.2. Understanding Inclusivity in Energy Transition

The impact of energy transition on development outcomes has been examined in recent literature. Adom et al. (2021) demonstrate that energy poverty adversely affects income, education, life expectancy, employment, and access to mobile phone subscriptions, while renewable energy adoption improves these outcomes. The research finds that the risk of higher energy cost associated with renewable energy transitions in the short-term is likely to neutralize in the long run for some of the development outcomes, except for income poverty and environmental risk factors. Nguyen et al. (2019) highlight a transition from traditional to modern energy among Vietnamese households from 2004 to 2016. They indicate that while income, consumption, and electricity poverty have decreased, energy-cost poverty has risen, placing additional burdens on low-income households still reliant on traditional fuels. Similarly, Xie et al. (2022) investigates a clean heating program in northern rural China, revealing that the transition from coal to electricity and natural gas raised heating costs, particularly for lower-income and less educated households, highlighting the urgency to take into account distributional effects in energy transition policies to avoid exacerbating inequalities.

Numerous studies have emphasized the importance of including vulnerable groups in energy transitions, particularly promoting gender equality and the inclusion of people with disabilities.[1] Clancy et al. (2012) demonstrate that energy interventions targeting the poor are likely to benefit women differently from men, due to their distinct capabilities and needs. In a study on the Maldives, Mohideen and Kolantharaj (2024) show how energy transitions can enhance gender and social inclusion outcomes, including women's economic empowerment, affordability, and greenhouse gas emission reduction and improve overall sustainability. Capetillo-Ordaz et al. (2024) map gendered energy-vulnerable areas in Madrid and find that 32 percent of the city's neighborhoods are at risk, with a pronounced impact on elderly women, single-parent households led by women, and women engaged in part-time employment or elementary occupations.

People with disabilities are also more likely to experience energy poverty. Ivanova and Middlemiss (2021) found that households with an economically inactive disabled person earn less, consume less energy than other households, and are more prone to energy poverty. Wolbring and Leopatra (2012) stress that people with disabilities are critically affected by climate change, energy scarcity, and water insecurity, yet their needs are rarely addressed in policy discussions. Using Ghana as an example, Oteng and Gamette (2024) highlight that despite significant progress in energy accessibility, very few energy policies consider people with disabilities due to limited definitions of disability. Greater attention must be given to the needs of disabled households to ensure an inclusive energy transition.

In the case of South Africa, Okyere and Lin (2023) found that the intersection of gender and disability significantly increases their risk of energy poverty, resulting from life dissatisfaction and food insecurity. They also revealed that the energy subsidies are most effective when targeted at women with disabilities, underscoring the need for tailored interventions. Ensuring an inclusive energy transition therefore requires addressing the unique challenges faced by vulnerable groups to promote equitable access to resources.

In November 2023, Indonesia's JETP Secretariat released its first JETP Comprehensive Investment and Policy Plan (CIPP) document. Although JETP's CIPP lacks legal standing and its implementation has been slow, the document may still inform power sector planning and policymaking as part of the JETP process (JETP Indonesia, 2023).[2] The investment plan involves an estimated USD 20 billion

1 Indonesian Constitution No. 16/2016 stated, "Main Material of Paris Agreement: Paris Agreement include substances as follow: (k) Cooperation among Parties in an effort to strengthen the education, capacity building, public awareness, public participation, and public access to the information on climate change."

2 The main document outlining just energy transition for Indonesia would be the CIPP document by JETP https://jetp-id.org/cipp.

in public and private financing from the International Partners Group (IPG) countries and international banks participating in the Glasgow Financial Alliance for Net Zero (GFANZ) working group to support an inclusive energy transition. The plan is committed to addressing the social, economic, and environmental impacts of energy transition investments. However, while it recognizes the need for interventions targeting vulnerable communities, it falls short in developing comprehensive policies, funding plan, and the mechanism necessary to mitigate the impact of energy transition and address inclusivity within the framework. It is crucial for Indonesia to begin integrating Just Energy Transition policies into its broader transition strategy to ensure comprehensive support for all vulnerable communities. While the CIPP document offers a foundational framework for Indonesia's energy transition, a critical gap remains in addressing the needs of vulnerable groups, an issue similarly observed in the broader field of climate modeling.

1.3. Research Objective

There has been extensive research in climate modeling focusing on energy transitions. Ugwoke et al. (2021), Zhang & Luo (2023), and Simsek et al. (2020) examine energy transitions in Nigeria, China, and Chile, while Reyseliani et al. (2021, 2022, 2024), Yudiartono et al. (2023), Destyanto et al. (2017), and IESR, Agora Energiewende, & LUT University (2021) focus on Indonesia. In examining the socio-economic impacts of energy transition, past studies has employed a combination of climate model and economic model. For example, Indonesia's LTS-LCCR 2050 employs the Asia Pacific Integrated Model (AIM) alongside a Computable General Equilibrium (CGE) model to model the energy sector, focusing on power supply, energy prices, and consumption. Similarly, the TIMES model has been integrated with CGE to analyze China's energy transition, where TIMES determines optimal electricity generation technologies, and CGE simulates economic scenarios based on electricity costs and prices (Timilsina, Pang, and Yang, 2019). The GCAM-CGE model has also been used, as demonstrated by Gilmore et al. (2023), to assess economic costs for different decarbonization pathways that meet global temperature targets. These models share a common link through key variables such as energy prices, technology choices, and emission pathways.

Despite several studies has examined the socio-economic impactsFew studies incorporate vulnerable groups, such as women and people with disabilities, into their analysis. A key challenge in climate and energy modeling is that most models operate in silos and are not designed to assess the impact of climate or energy transitions on vulnerable groups. Bridging this gap requires additional steps, such as using microsimulations to link energy models with micro-level analysis. For example, Effendi & Resosudarmo (2022) combine a CGE model with microsimulations to analyze the socio-economic impacts of increasing RE-generated electricity across household income groups. Integrating models is also essential to address gender equality, disability, and social inclusion (GEDSI) considerations.

Recognizing the varied impact of energy transitions on vulnerable communities, this study aims to examine the impact of energy transition through the lens of inclusivity.

2 The main document outlining just energy transition for Indonesia would be the CIPP document by JETP https://jetp-id.org/cipp.

We employ the Global Change Assessment Model (GCAM) to simulate energy pathways and commodity price changes, followed by a microsimulation using the Almost Ideal Demand System (AIDS) model to estimate the impact on poverty and inequality among vulnerable groups. In this study, these groups are defined as female-headed households, households with disability, and households with children or elderly members. Understanding how energy transition affects different groups of the population is essential for helping policymakers design more inclusive climate change mitigation and adaptation policies. Additionally, we emphasize the urgency of fiscal response to address the price shocks caused by energy transition.

This report is organized as follows. The introduction outlines Indonesia's commitment to decarbonizing the energy sector, identifies challenges in achieving this goal, and highlights inclusivity as a key focus of the study, along with the research objectives. The second section details the study's methodology, followed by the third section, which presents the results and analysis. The report concludes with a final conclusion and discussion.

2

Methodology

This study seeks to analyze the effects of Indonesia's energy transition from an inclusivity perspective. We employ the GCAM to simulate energy pathways and their impacts to commodity prices changes, followed by a microsimulation using the AIDS model to assess the impact on poverty rates and the Gini coefficient across various household groups, with particular attention to female-headed households, those with members who have disabilities, and household with children or elderly members. We develop NZE scenarios within the energy sector. The simulation period spans from 2025 to 2080 for the GCAM and from 2025 to 2045 for the microsimulations. Chapter 2 is structured as follows: it begins with an explanation of the methodologies for the GCAM and AIDS model, including the bridging method between them, followed by a description of the scenarios and underlying assumptions.

2.1. Model Development

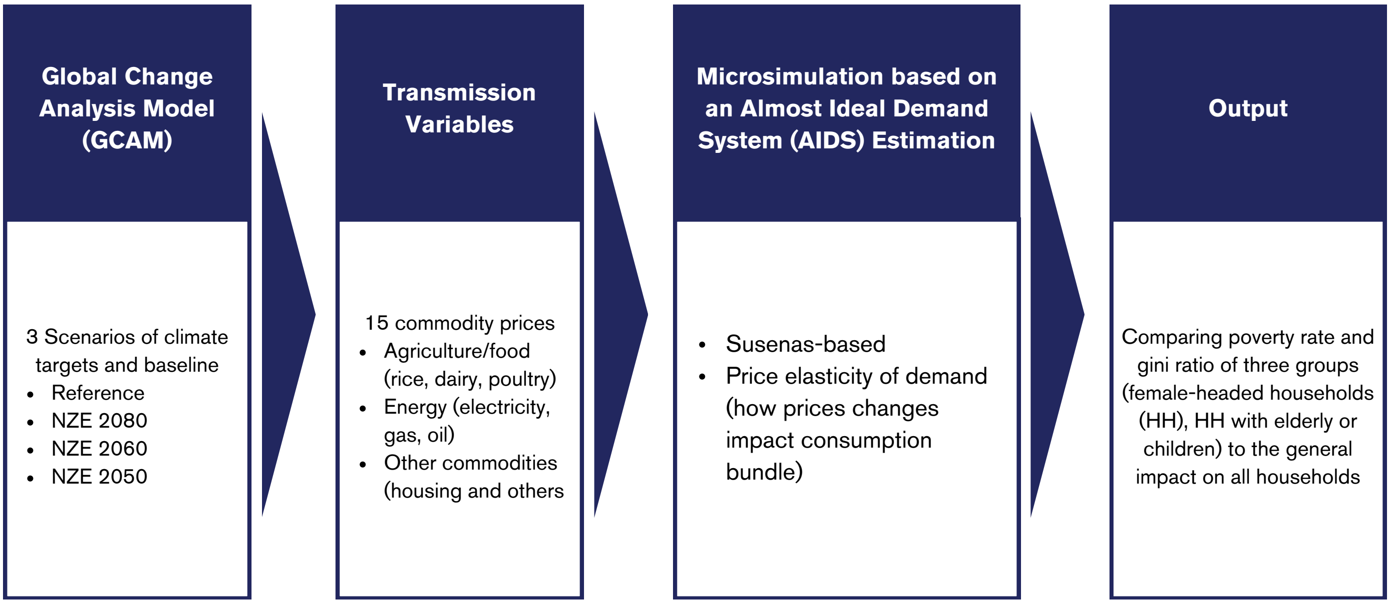
Integrating technical and economic models has been employed in several research to ensure that both technical and economic aspects of energy transition have been accommodated. For example, Indonesia's LTS-LCCR 2050 employs the Asia Pacific Integrated Model (AIM)/Computable General Equilibrium (CGE) for the energy sector and macroeconomic modeling. Similarly, Japan's Nationally Determined Contributions (NDC) also combined the technology selection model (AIM) with CGE (Oshiro, Masui & Kainuma, 2017). The key linkages for AIM-CGE models include power supply, energy price, and energy consumption. AIM features a detailed technology selection module that evaluates the impact of introducing advanced technologies, which can effectively be integrated with the CGE model to analyze macroeconomic variables.

Another example of combining two models is the integration of the Integrated MARKAL-EFOM System (TIMES) with the CGE model. Timilsina, Pang, and Yang (2019) applied this approach to analyze China's energy transition. In their study, the TIMES model determines the optimal mix of electricity generation technologies to meet projected electricity demand and estimates the average cost of supplying both electricity and overall energy. The CGE model is then used to simulate scenarios, analyzing the discrepancies between these average electricity costs and actual electricity prices. Therefore, the TIMES-CGE and AIM/CGE models share a similar linking variable.

GCAM has also been combined with the CGE model in various studies. Gilmore et al. (2023) used the GCAM-CGE model to evaluate the economic costs of different decarbonization scenarios. In this approach, GCAM is employed to determine emission pathways that align with the 2°C global warming target. The pathways are then used as inputs for Environment Canada's Multi-Sector, Multi-Regional (EC-MSMR) CGE model.

In this study, we model the potential impact of the energy transition on the welfare of vulnerable groups by integrating GCAM, which provides changes in commodity prices, with the AIDS model to analyze consumption patterns and corresponding welfare changes at the household level. The framework of model integration is illustrated in Figure 2.1.

FIGURE 2.1. GCAM and AIDS Model Integration



Source: Author's analysis

We integrate the GCAM and AIDS models to analyze the distributional impacts of different climate target scenarios, with a specific focus on poverty and the Gini ratio for female-headed households, households with disabilities, and households with children or elderly members. The primary linkage between these models is through commodity prices, which are then used as inputs for the AIDS model to capture shifts in household expenditures. The details of both GCAM and AIDS model are explained in the following sections.

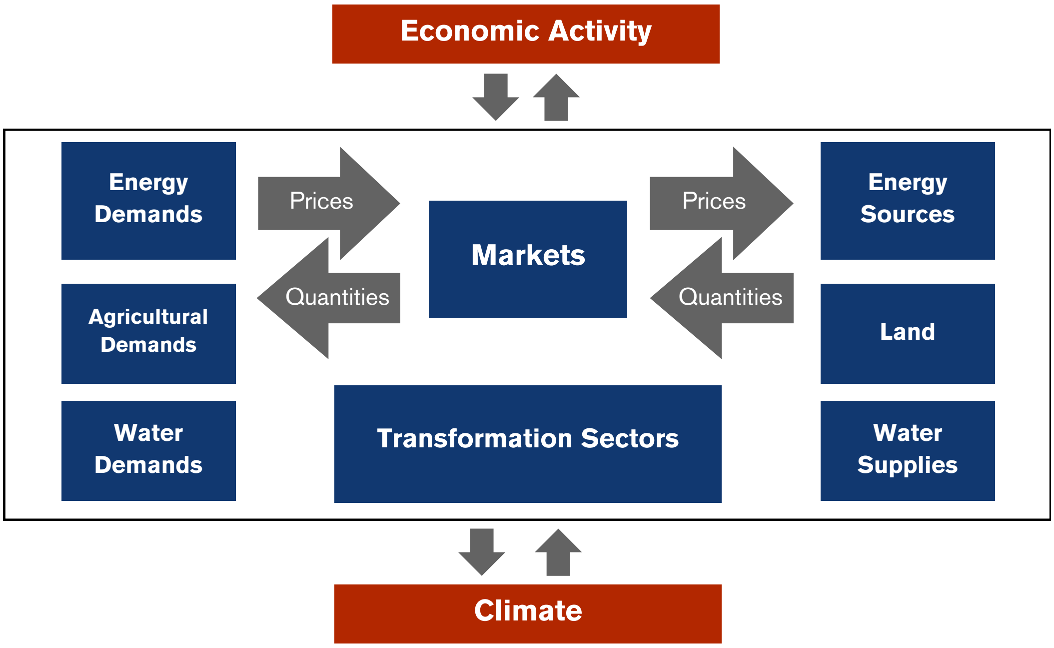
2.1.1. Climate Model - GCAM

Global Change Assessment Model (GCAM) is an integrated assessment model developed by the Joint Global Change Research Institute (JGCRI)[3] that uses projections of socio-economic variables, such as population and GDP, to model the potential changes in the energy and other sectors, including land use and water, under various climate policy scenarios. The GCAM energy system includes representations of fossil resources (coal, oil and gas), uranium, and renewable sources (wind, solar, geothermal, hydro and biomass, and traditional biomass) (JGCRI, 2023). It also accounts for processes that convert these resources to final energy carriers, such as electricity generation, refining, hydrogen production, gas processing and district heat. These energy carriers are then used to meet the demand of end-use sectors, including residential and commercial buildings, transportation, and industry.

GCAM is a dynamic-recursive, market-equilibrium model that operates in five-year intervals from 2010 to 2100. It solves equilibrium prices and quantities across energy, agriculture, water, land-use, and GHG markets in each time period region, beginning in 2019. The year 2019 was chosen for calibration instead of 2020, as the model cannot account for large-scale idling or underuse of capital stock (IAMC, 2023).

3 A collaborative project formed between Pacific Northwest National Laboratory (PNNL) and the University of Maryland, USA.

FIGURE 2.2. GCAM Framework



Source: JGCRI (2023)

Among integrated assessment models (IAMs), GCAM offers several advantages. Its modular structure runs at the regional scale globally, allowing users to modify input files depending on the focus region. It can be applied for any region and data of interest, with detailed technology specification and sector representation. Users can also define various policy options, such as carbon pricing, taxes, and subsidies. A diagnostic package facilitates comparison and analysis of different policy scenarios. Its modular design and open-source software make it adaptable for customized configurations.

Numerous publications demonstrate GCAM's wide applications, including studies on the role of biomass in deep decarbonization in the US (Vimmerstedt et al., 2023), the global role of hydrogen in the energy transition (O'Rourke et al., 2023), the impact of solar and wind on sustainable transition (Woodard et al., 2023), and coal phase-out strategies (Maria et al., 2024). GCAM has been applied across various regions, including the U.S., Canada, Indonesia, China, and Korea (Nathan et. al., 2024).

In this study, GCAM provides a key linking variable—commodity prices—which serve as inputs for the AIDS model. The interaction of supply and demand in the land-use and energy sectors generates equilibrium prices and quantities for the economy. Changes in commodity prices across scenarios will then feed into the AIDS model.

2.1.2. Microsimulation - AIDS Model

In estimating the impact on household welfare, this study used a microsimulation analysis based on an AIDS estimation (Deaton and Muellbauer, 1980; Poi, 2012). We utilized data from the nationally representative Susenas household survey. Two main indicators of welfare were considered: poverty and inequality. The poverty rate, or poverty headcount ratio, was measured by the proportion of individuals living below the poverty line based on their monthly expenditure. We applied the provincial poverty lines (urban and rural) as determined by Statistics Indonesia. The same expenditure data was used to measure inequality using the Gini ratio.

For this method, we use two datasets: the March 2019 Susenas data as the main data set, and inputs form GCAM. We aligned all types of expenditure in the survey into 15 commodity groups to ensure consistency with the commodity classification in GCAM results. We then estimated a linear demand system (Deaton and Muellbauer, 1980) using the expenditure share (w) equation for commodity i (with k=15 commodities), regressed by each commodity price (p) and total expenditure (m), normalized by the price index ($a(p)$):

EQUATION 1

$$w_i = a_i + \sum_{j=1}^{k} \gamma_{ij} ln p_j + \beta_i ln\left\{ \frac{m}{a(p)} \right\},\ i = 1, \dots, k$$

Using the estimated demand system from the previous equation, we then compute the uncompensated price elasticity of good i with respect to change in the price of good j as follows (own price elasticity is when i=j):

EQUATION 2

$$\in_{ij} = -\delta_{ij} + \frac{1}{w_i}\left(\gamma_{ij} - \beta_i \left(\alpha_j + \sum_{l} \gamma_{ij} ln p_l \right) \right)$$

Meanwhile, the expenditure elasticity for good i is:

EQUATION 3

$$\mu_i = 1 + \frac{1}{w_i}\beta_i$$

The simulation models change in consumption resulting from shifts in commodity prices every five years, based on GCAM outputs. Our goal is to estimate how the energy transition could lead to changes in commodity prices and, consequently, change in household expenditure allocation from 2020 to 2045, through price elasticity of demand and expenditure elasticity. Price elasticity of demand measures how households respond to price shock from GCAM, while expenditure elasticity captures their response to income shocks from assumed GDP growth. To simulate the expenditure change, we multiply the price elasticity by the commodity prices from GCAM and multiply expenditure elasticity of each good by the assumed GDP per capita growth from GCAM. However, household responses to changes in GDP per capita growth may vary. To account for this, we use the Growth Incidence Curve (GIC) from Susenas 2014 to 2019 to estimate how household expenditures might increase relative to GDP per capita growth, allowing for different reactions across household expenditure percentiles. The GIC is presented in Appendix 3a.

2.1.3. Bridging GCAM and AIDS

To integrate two models, linking variables are necessary to establish a connection (Oshiro et al., 2017; Timilsina et al., 2019; Gilmore et al., 2023). A key linking variable in this methodology is the commodity price factor, which serves as a bridge between the GCAM model and microsimulation. Changes in commodity prices, driven by decarbonization efforts, directly influence household expenditures, making it crucial to account for these shifts when assessing social impacts.

GCAM and Susenas share common commodities, although not all commodities in one dataset are present in the other. Despite this variation, the presence of common commodities allows for meaningful linkage between these two datasets. By linking common commodities between GCAM and Susenas, we can connect macroeconomic modeling results with household-level consumption data. This linkage provides a more comprehensive understanding of how changes in commodity prices, as simulated by GCAM in response to climate-related policy scenarios, may impact household welfare, poverty, and inequality, as reflected in Susenas.

For the analysis, we utilize the Susenas March 2019 dataset as the baseline to capture a more accurate representation of general consumption patterns, given the disruption caused by the pandemic in subsequent years. Using the data from March 2019 ensures a stable foundation for the analysis, avoiding distortion by the unprecedented circumstances of the pandemic. However, to incorporate the effect of COVID-19 on the poverty rate, we opt to use the March 2020 poverty line instead of the March 2019 poverty line.

2.2. Model Assumptions

2.2.1. Assumptions for GCAM

In this study, we use version 7.0 of the GCAM model, available in the JGCRI public repository on GitHub.[4] We make key revisions to update the model's socio-economic assumption using the latest population and GDP projection. For Indonesia, we incorporate UN population projections to update the GCAM database.[5] Additionally, recent GDP projections from the OECD are used to revise the GDP data in the model. The detailed GDP growth rate and population assumptions are presented in Appendix 1, Table II and Table III.

IIn addition, we update the historical power generation database to align with Indonesian electricity generation mix with data from MEMR's latest Handbook of Energy and Economic Statistics of Indonesia (HEESI). We limit the alignment to the year 2020, allowing GCAM to project future periods based on various scenarios.

4 https://github.com/JGCRI/gcam-core/releases/tag/gcam-v7.0

5 https://population.un.org/wpp/

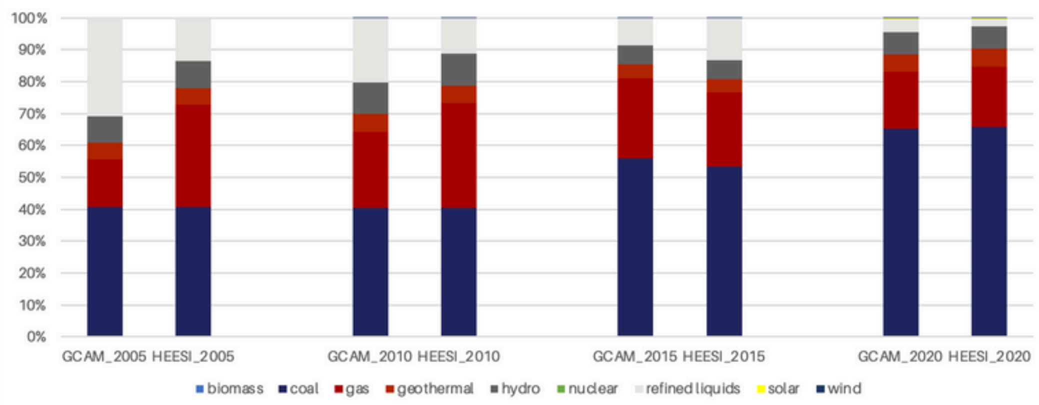
TABLE 2.1. GDP Growth Rate (%) and Population (Million)

Year	2025	2030	2040	2050	2060	2070	2080
GDP Growth Rate (%)	4.72	4.72	3.84	3.31	2.74	2.74	2.74
Population (million)	282	292	308	317	319	318	313

Source: Authors' calculation based on OECD and UN data

As seen in Figure 2.3., HEESI's generation mix is largely reflected in the GCAM's projections. However, there are some discrepancies, particularly in the share of refined liquids and gas, which are quite prominent within the period of 2005.[6]

FIGURE 2.3. HEESI Generation Mix (percent, 2005-2020)



Source: Authors' simulation

GCAM includes a global database for electricity generation technology costs. Nevertheless, we have adjusted the cost of several generators, as listed in Appendix 1 Table IV, according to the MEMR's Technology Data for Indonesian Power Sector, which has been tailored to Indonesia. The remaining generators, including the solar, wind, and geothermal, are left to be using GCAM's global database. GCAM has a unique approach to hydropower, where energy output for each region and period is treated as exogenous. As a result, hydropower costs are not estimated and do not factor into electricity price calculations in the model.

2.2.2. Assumptions for AIDS Model

The microsimulation based on the AIDS model utilizes data from an annual, nationally representative household survey called Susenas. The welfare indicators will be analyzed for three focused household group namely, female-headed household, household with people with disabilities, and household with children or elderly members.

6 Adjusting the GCAM to match the share of these resources with the ones in the HEESI was carried out during the course of this project. Unfortunately, the calculation always ended up with an 'unsolvable market' error. Tending the error may require further adjustment in the supply of the energy resources. In the interest of time, this have not been looked at in the current analysis. The modified datasets are available from the authors upon request.

The main assumptions of the microsimulations are based on the concordance between GCAM outputs and household expenditure in Susenas. The concordance results in 14 commodity categories, plus one additional bundle covering other commodities. These 15 categories are classified into Agriculture/Food (e.g., rice, dairy, poultry), Energy (e.g., electricity, gas, oil), and Other Commodities (e.g., housing and other services). Detailed results are provided in Appendix 1 Table V.

The concordance captures 83 percent of the total household expenditures (Figure 2.4a) and 85 percent for poor households (Figure 2.4b), with the remainder classified as other commodities (see Appendix 1 Table V for detailed expenditure shares). In both groups, agricultural and food commodities account for more than 50 percent of household expenditures. However, the main difference between the two groups is that, for all households, the largest spending category is other commodities followed by housing, whereas for poor households, the largest expenditure is on rice, followed by other commodities.

FIGURE 2.4 Share of Expenditure per Commodity (percent)

FIGURE 2.4a Overall Household Group

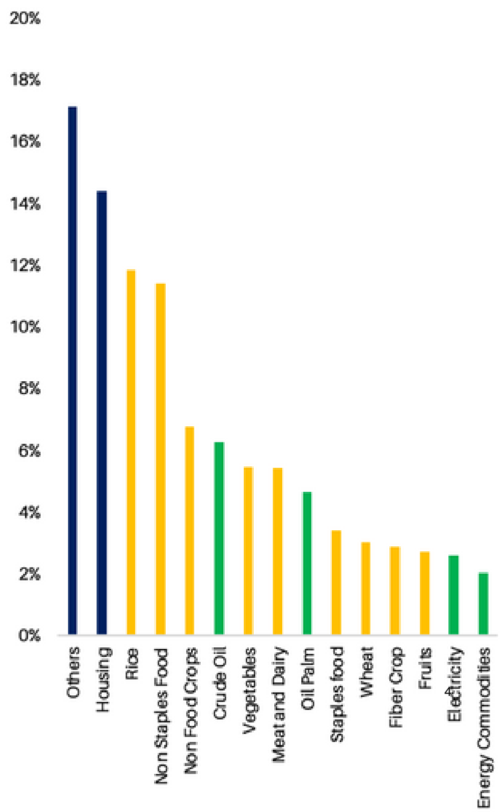
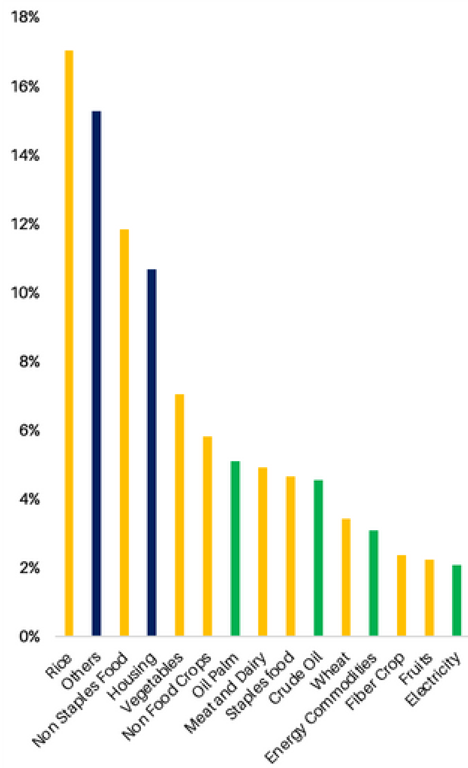


FIGURE 2.4b Poor Household Group



Source: Authors' simulation

Note: The Color Code is used for categorizing commodities. Yellow represents food or agricultural commodities, green signifies energy commodities, and blue is used for commodities that do not fall into either the food/agricultural or energy categories.

The prices of the concordance commodities are also the main inputs used to estimate the simulated expenditures of household groups. However, for commodities that are merged, such as energy commodities consisting of biomass and coal, the prices cannot be directly used for these estimations. Instead, we cal-

7 Other commodity categories refer to the unmatched commodities between the GCAM and household expenditure categories in the Susenas database. The majority of household expenditures in this category are primarily services spending, such as education, health, taxes, and other services.

FIGURE 2.5 Price Index Assumptions

FIGURE 2.5a Overall Household Group

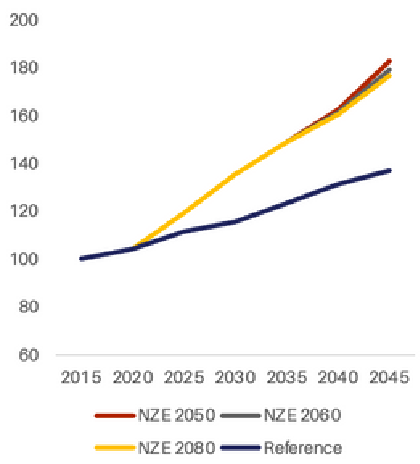


FIGURE 2.5b Fisher Price Index Reference Scenario

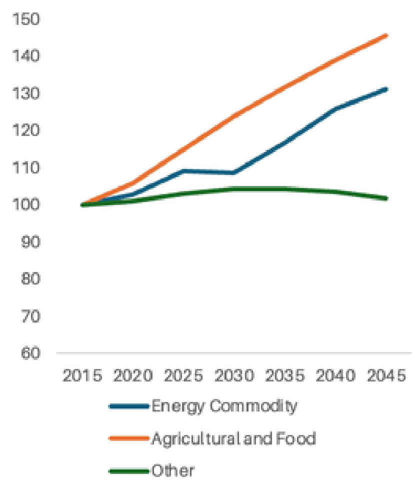
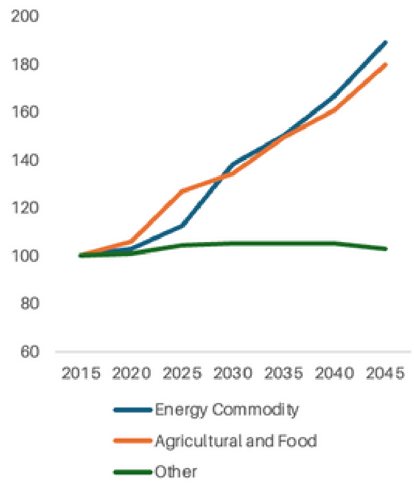


FIGURE 2.5c Fisher Price Index NZE 2050 Scenario



Source: Authors' simulation

culate a price index using the Fisher Price Index method. The price index results (Figure 5a) show that, despite all scenarios start with the same index value at the beginning of the period, the trajectories diverge over time. The scenario with the most ambitious NZE target, which aims for a faster reduction in emissions,[8] shows a steeper increase in the price index. This indicates that more aggressive policies to achieve NZE targets push the price levels higher compared to the less ambitious scenarios. The higher price index is reflected in the composite index, which is supported by three commodity indices, all of which are rising. Both agriculture & food and energy commodities show rapid increases. The increase in both commodity groups in the NZE scenarios (Figure 2.5c) is more pronounced compared to the reference scenario (Figure 2.5b). However, in the NZE scenario, the increase in energy commodities surpasses that of agriculture and food commodities, while in the reference scenario, agriculture and food commodities show a higher increase.

A limitation of the microsimulations in this study is that the dataset provides only a limited sample for vulnerable groups, which may lead to underrepresentation of these groups in the results. Additionally, this study assumes that there is revenue recycling from carbon pricing policies, which depends on the presence of strong institutions. Furthermore, the analysis focuses solely on welfare from the expenditure side, even though GEDSI issues are more related to other aspects such as access to energy. We also assume that the impact of climate policies on welfare occurs solely through price changes, with the study relying on static elasticity and GIC to estimate these effects.

2.3. Model Scenarios

2.3.1. Climate Target Scenarios

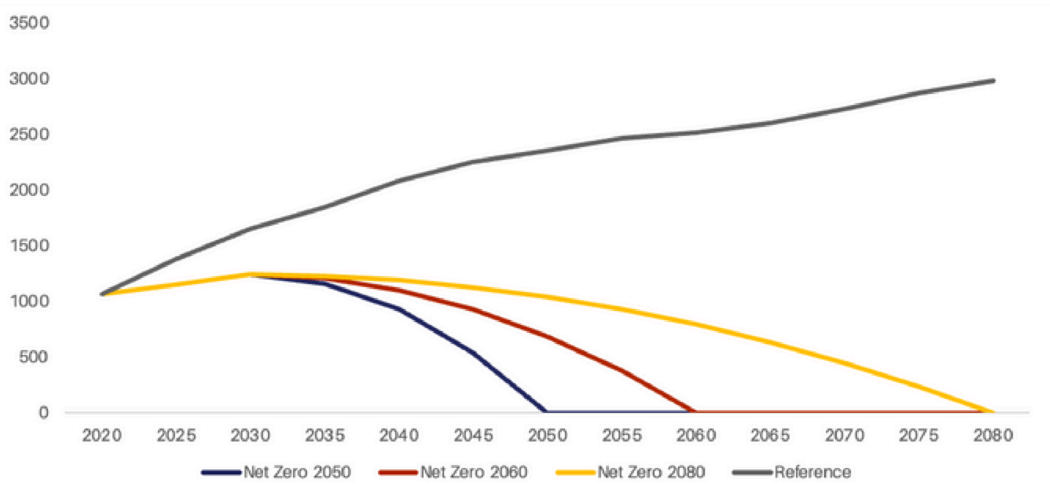
8 The Fisher Price Index (FPI) is a composite price index that combines the Laspeyres Price Index (LPI) and the Paasche Price Index (PPI) to provide a more accurate measure of changes in price levels over time.

$$\text{FPI} = \sqrt{LPI\ x\ PPPI}$$
$$\text{LPI} = \frac{\Sigma(P_t \times Q_0)}{\Sigma(P_0 \times Q_0)}$$
$$\text{PPI} = \frac{\Sigma(P_t \times Q_t)}{\Sigma(P_0 \times Q_t)}$$

Where P_t is the price in the current period, P_0 is the price in the base period, Q_t is the quantity in the current period, and Q_0 is the quantity in the base period.
The FFI is chosen because the method provides a balanced approach by mitigating the biases present in the individual Laspeyres and Paasche indices, resulting in a more reliable measure of price changes over time.

We run four scenarios: one is the reference scenario, in which no climate policies are considered, and the remaining three considers different climate actions for Indonesia to meet its Net Zero target by 2050, 2060, and 2080.

FIGURE 2.6 Emissions for Net Zero scenarios in Indonesia (in MT CO2-EQ)



Source: Authors' simulation

Figure 2.6 presents the emission targets of the Reference and three NZE scenarios. The emission trajectory for the Reference scenario, as shown, is[8] the result of the GCAM simulation where no climate policy is applied. For the NZE scenarios, we use Indonesia's NDC emission targets up to 2030. After 2030, emissions are projected to decrease to reach net zero by the respective NZE target year. This post-2030 downward trajectory is not linear but slightly concave, based on the assumption that, before the target year, clean technology will reach a readiness level that enables rapid adoption, accelerating the emission reductions towards Net Zero. The following function is used to set the emission targets:

EQUATION 4

$$Emission\ Target = Emission_{2030} - Emission_{2030} \times \left(\frac{t - 2030}{NZE\ Target - Year\ 2030}\right)^2$$

Where *Emission Target* is the emission pathway (in Million Tonnes CO2-eq) to reach net zero in a certain year. *Emission2030* (in Million Tonnes CO2-eq) is the emission at year 2030 which follows Indonesia's Enhanced NDC, *t* is the current year, and *NZE Target Year* is the year in which net zero target is achieved. The emission target is assigned for the overall energy system model, not only the power sector.

We use GCAM due to its advantages, as discussed in the previous sections. However, it has limitations. It runs scenarios at a 5-year interval, is not a country-specific model, and has fixed socio-economic assumptions (population growth and GDP). Additionally, since this study focuses on Indonesia, climate actions of other regions are not considered.

2.3.2. Fiscal Stimulus Scenario

So far, the microsimulation mechanism has involved only two sources of shocks: price changes from GCAM output and increases in expenditure based on GDP per capita assumptions. To account for fiscal redistribution triggered by the NZE implementation, we incorporate two channels. These involve a welfare shift from the industrial (emitter) sector (predominantly urban households) to the Agriculture, Forestry and Other Land Use (AFOLU) (absorber) sector (predominantly rural households), and a redistribution of the carbon tax, which partly funds social protection (approximately 2 percent of the government's budget). The welfare shifts from urban to rural households (due to carbon absorption) is reflected in varying GDP per capita growth rates, while the social protection scheme (cash transfer) funded by the carbon tax is directly added to each household's expenditure. The amounts of carbon absorption per capita and cash transfers per household are presented in Appendix 3b.

3

Results and Analysis

In this section, we present the results and analysis of GCAM and microsimulation separately and highlight key points beyond the model which could be explored in future studies.

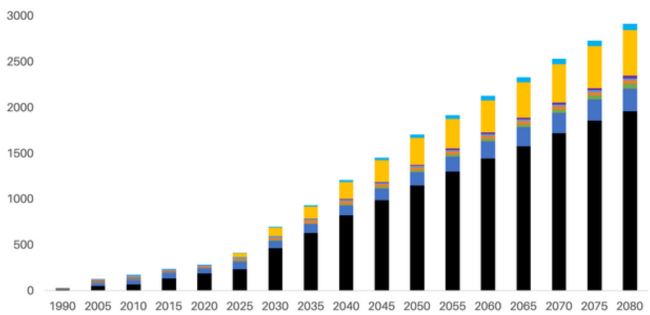
3.1. Climate Model - GCAM Results

3.1.1. Electricity Generation Results

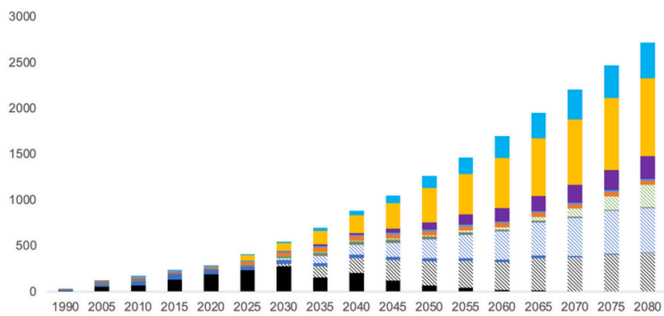
The first output presented is the energy mix used for electricity generation in Indonesia across the four scenarios. The purpose of the analysis is to examine how the technology mix changes as climate ambition increases and how this is affected by technology availability. As previously mentioned, the emission target is applied to the overall energy system, not just the power sector. However, for this example, we focus on the results of decarbonization in the power sector.

FIGURE 3.1 Generation Mix Results (in TWh)

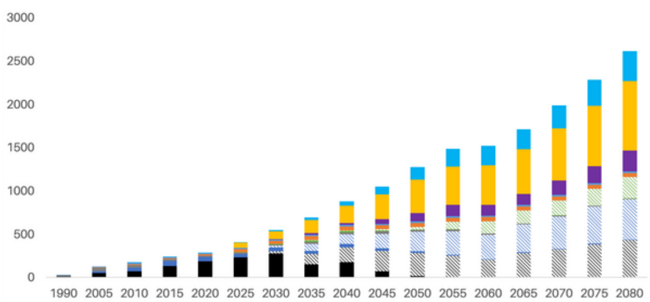
a Reference



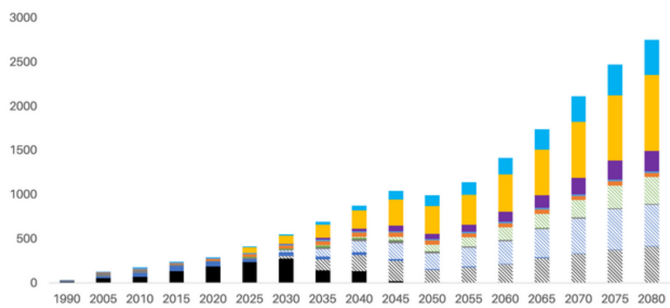
b NZE 2080



c NZE 2060



c NZE 2050



Source: Authors' simulation

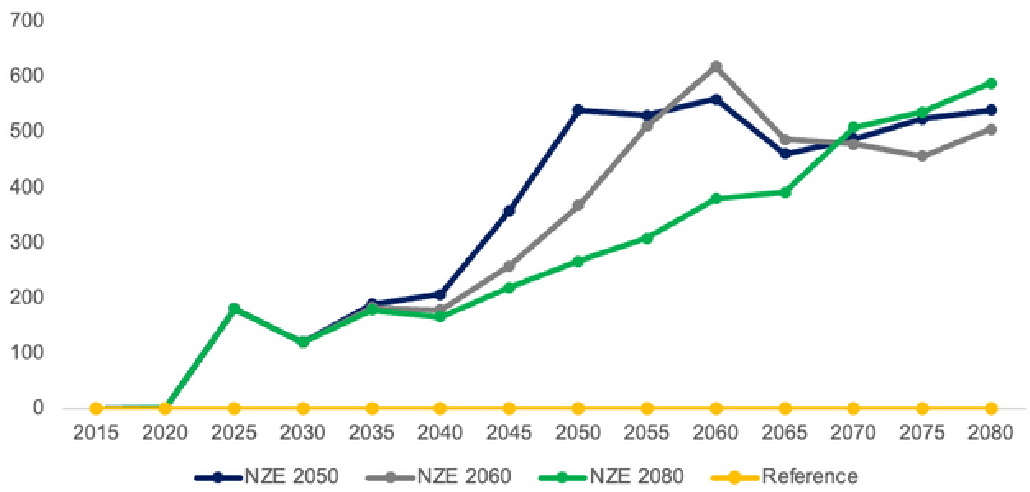
The results highlight that Indonesia adopts more ambitious climate target, such as NZE by 2050, 2060, and 2080, the diversity of electricity generation technologies increases, which is important for energy security. In the Reference scenario (Figure 3.1, panel a), coal remains the dominant technology, followed by solar PV and gas. While fossil fuels such as coal and gas still contribute to electricity production, they are paired with Carbon Capture Storage (CCS) technology. Additionally, the dominance of solar, including rooftop solar PV, become more prominent, followed by wind power.

Solar PV technology is emerging as a dominant force in NZE scenarios, reflecting its critical role in the global transition to sustainable energy. In scenarios where NZE targets are set for earlier dates, such as 2050, the phase-out of coal is accelerated to align with the NZE target year. These NZE scenarios also reveal a demand kink in the target year, with a noticeable drop in total electricity demand observed in NZE 2050 and 2060.

3.1.2. Carbon Price

In this section, the primary results based on GCAM modelling for Indonesia are explained. Figure 3.3 shows carbon prices for each Net Zero scenario. The sooner the net zero target is reached, the higher the carbon price will be. Depending on the target year, the carbon price peaks between 550-620 $/tCO2. In this study, it is assumed that the Reference has no carbon price, as there are no emission constraints to meet. The carbon price trends are reasonable, with each NZE scenario showing a peak carbon price at its respective net zero year, followed by a tapering off in subsequent years.

FIGURE 3.3 Carbon Prices (2024$/tCO2) for Three NZE Scenarios



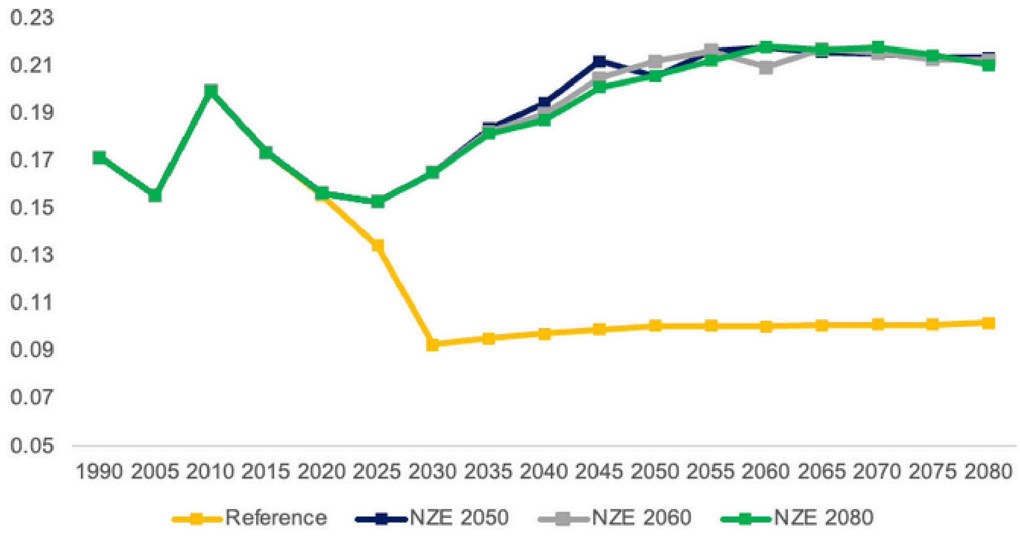
Source: Authors' simulation

3.1.3. Electricity Price

GCAM provides a wide range of commodity prices. The concordance results, along with the price index, are provided in Section 3. As an example, the electricity price results from GCAM are illustrated in Figure 3.4. Figure I and II in Appendix 1 present the price results for rice and poultry, respectively.

The electricity prices are similar for the three NZE scenarios. In contrast, the reference scenario shows lower electricity price because the carbon price increases the cost of electricity generation in the NZE scenarios. There are two reasons why the NZE scenarios yield similar results:

FIGURE 3.4 Electricity Prices (2024$/tCO2) for Three NZE Scenarios



Source: Authors' simulation

1. The carbon price is implemented economy-wide, therefore the effects on a single commodity are diluted.
2. Changing or limiting a technology, such as CCS, would affect the price, but not significantly when adjusting the net-zero targets. Since we do not differentiate between technology options across net-zero targets, we observe minimal price differences. This argument is supported by our sensitivity analysis on limiting CCS and biomass, which is provided in Appendix 2.

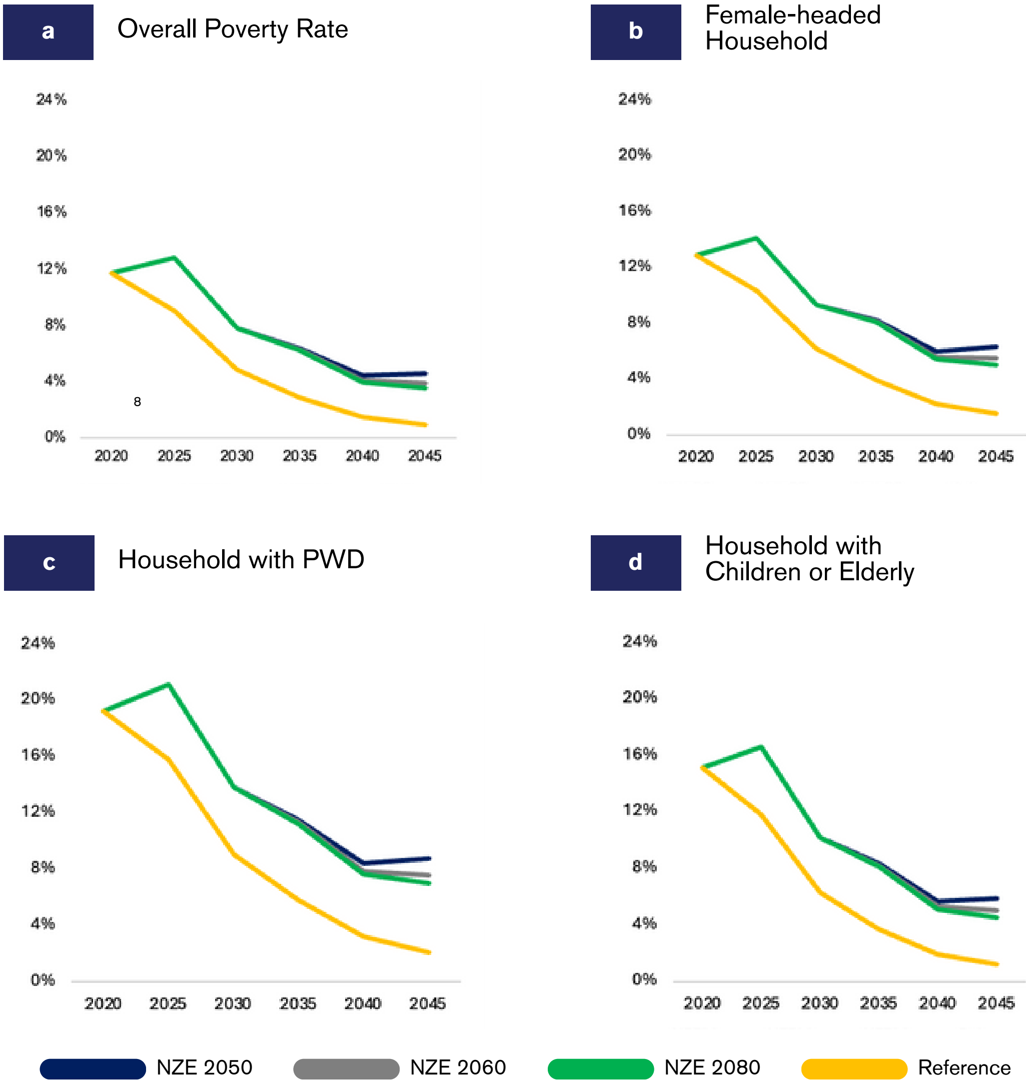
3.2. Microsimulation - AIDS Model Results

3.2.1. The Impact of Energy Transition on Poverty Rates

The microsimulation results indicate that the efforts to achieve the NZE target will result in a higher poverty rate compared to the reference scenarios. Overall, the efforts to achieve NZE by 2050 would result in the highest poverty rate in 2045, at 4.60 percent, followed by the NZE 2060 and 2080 scenarios. In contrast, the reference scenario shows the lowest poverty rate, reaching 0.93 percent (Figure 3.5) . These results also imply that the period for achieving the NZE target influences the poverty rate—the faster the NZE target is achieved, the higher the poverty rate will be at the end of simulation period. This increase in poverty can occur due to higher carbon pricing imposed to push the achievement of NZE, which raises commodity prices and slows the decline of the poverty rate. These findings are consistent across all household groups.

Among the targeted household groups, all have higher poverty rates in 2045 compared to the overall results. For instance, households with disabilities, which start with the highest baseline poverty rate (19.28 percent), continue to show the highest poverty rate despite experiencing the greatest decrease, reaching 8.77 percent in the NZE 2050 scenario. Meanwhile, female-headed households, which begin with the lowest poverty rate among the groups (12.90 percent), have a higher poverty rate compared to households with children or the elderly (15.14 percent) in all NZE scenarios by 2045. The gap in poverty rates between the reference scenario and the NZE 2050 scenario is higher for all targeted groups compared to the overall poverty rate. This implies that the NZE target will have a greater impact on slowing the decline of poverty rates in the focused groups compared to the reference scenario.

FIGURE 3.5 Impact of NZE on Poverty Rate 2020-2045



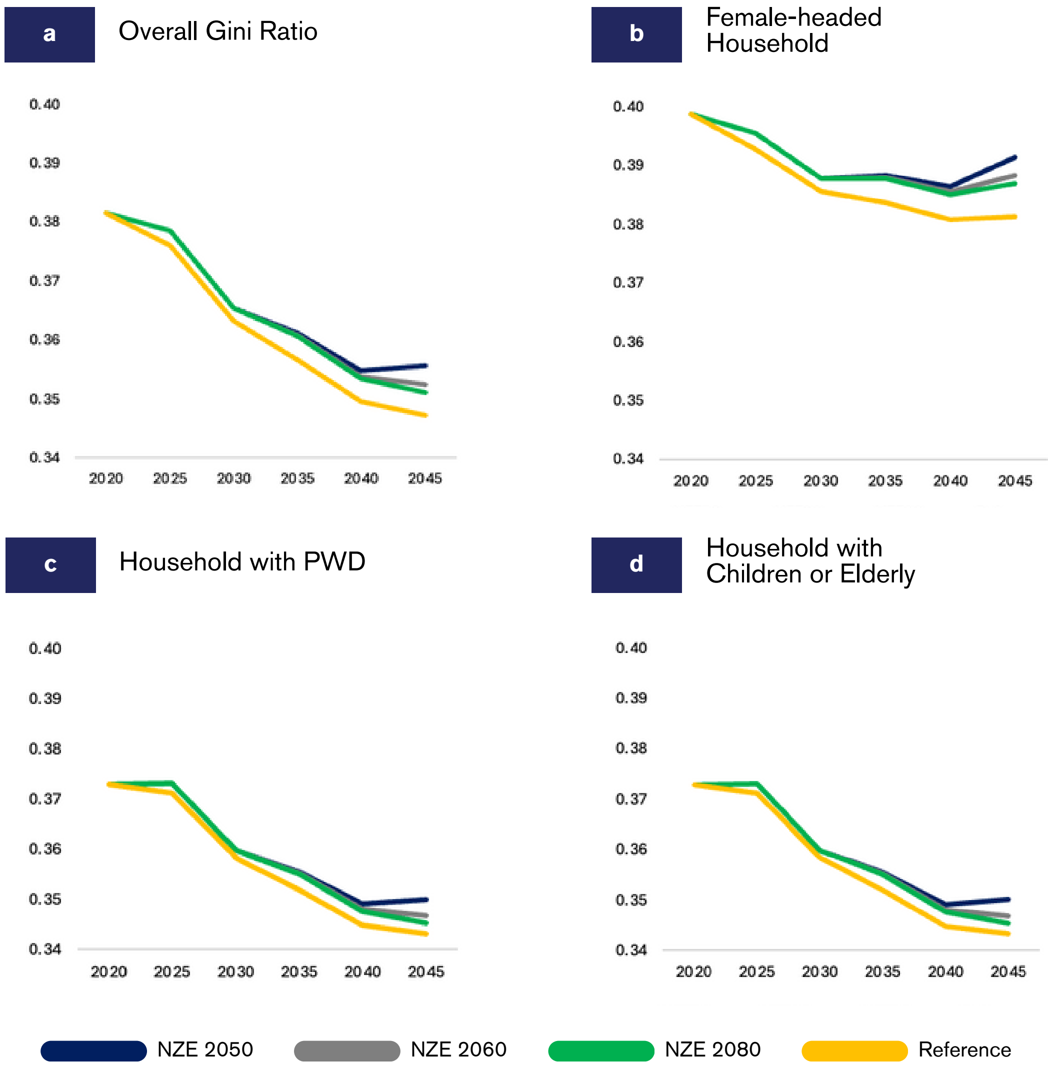
Source: Authors' simulation

3.2.2. The Impact of Energy Transition on Inequality

The Gini ratio results provide similar insight to the poverty rates, indicating that more ambitious NZE targets will result in wider inequality. Overall, the effort to achieve NZE by 2050 would result in higher inequality in 2045, with a Gini ratio of 0.355, compared to 0.347 in the reference scenario (Figure 3.6). The Gini ratio for the NZE 2050 scenario shows an increasing trend from 2040 to 2045. While households with disabilities and households with children and elderly follow the same trend as he overall household groups, the Gini ratio for female-headed households shows the lowest decline. In fact, from 2040 to 2045, the inequality increases for female-headed households, resulting in the highest Gini ratio of 0.392.

The results in both welfare indicators show that the effort to achieve NZE will pre-

FIGURE 3.6 Impact of NZE on Gini Ratio 2020-2045



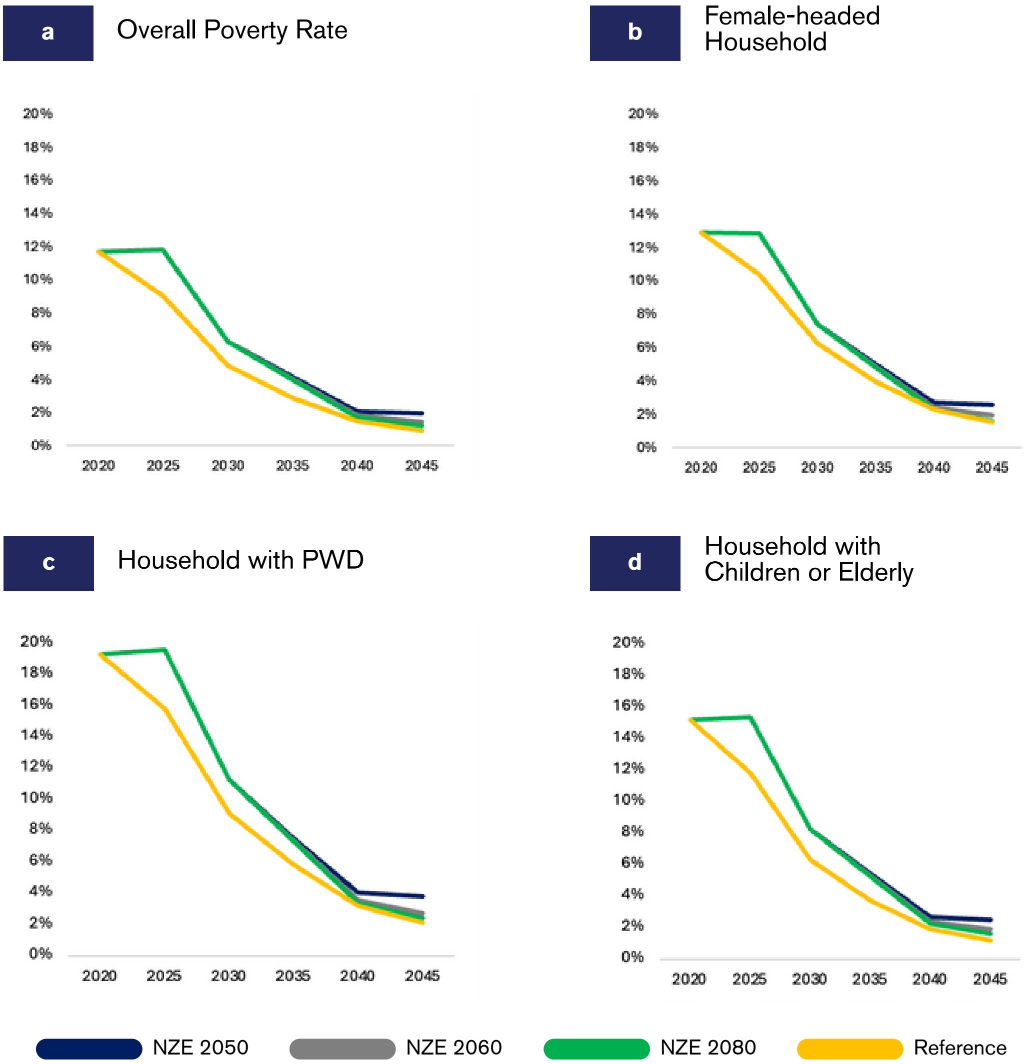
Source: Authors' simulation

vent Indonesia to reach the Indonesia Emas 2045 Vision to become a high-income country. The energy transition will slow the decline in Indonesia's poverty rate, making it unlikely to reach the Indonesia Emas target of 0.5–0.8 percent. This may occur because the carbon pricing policy aimed at achieving NZE will drive up commodity prices, resulting in a decrease in total expenditure, which in turn leads to a higher poverty rate. Similarly, the energy transition will also slow the decline of the Gini ratio, making it higher than the Indonesia Emas 2045 target of 0.377–0.320. The impact on vulnerable households is even greater, as these groups are more sensitive to price increases compared to non-vulnerable groups. This sensitivity forces vulnerable households to significantly reduce their expenditure in response to rising prices, leading to an increase in the Gini ratio. These results underscore the importance of government intervention to support the vulnerable groups through fiscal policy.

3.3. The Impact of Fiscal Stimulus on Scenario

The results from the scenario where fiscal stimulus is implemented alongside carbon indicate a reduction in poverty across all scenarios. For every household group, the poverty rate gap between the NZE scenarios with the fiscal stimulus and the reference scenario narrows. For instance, in the NZE 2050 scenario, the fiscal stimulus reduces the overall household poverty rate by 2.68 percent, bringing it down to 1.92 percent in 2045. Among vulnerable groups, households with PWD still experience the highest poverty rate in the NZE 2050 scenario compared to other vulnerable groups. However, the poverty rates of all vulnerable groups are expected to gradually align with those of the overall household groups by the end of the period. Despite these improvements, the current carbon stimulus scenarios still fall short of achieving Indonesia's Emas 2045 poverty rate target.

FIGURE 3.7 Fiscal Stimulus and Poverty Rate



Source: Authors' simulation

Despite not achieving the highest bound of the Gini ratio reduction target of Indonesia Emas 2045, the fiscal stimulus has resulted in a significant decline in inequality, with overall Gini levels in each scenario being lower compared to the reference scenario. This trend is consistent across all groups. The graphs reveal a noticeable decline in the overall Gini ratio across all scenarios (NZE50, NZE60, NZE80), with the fiscal stimulus effectively lowering poverty rates compared to the reference scenario. For female-headed households, the fiscal stimulus helps reduce Gini ratio more significantly than the reference scenario. Households with PWD also experience a decline in Gini ratio, though their levels remain higher compared to other groups. However, the fiscal stimulus helps bring Gini ratio closer to that of the overall household group by the end of the period. Similarly, households with children or the elderly benefit from the fiscal stimulus, with their Gini ratio steadily declining and aligning more closely with the overall household rates by 2045.

FIGURE 3.8 Fiscal Stimulus and Gini Ratio

Source: Authors' simulation

The simulation results underscore the positive impact of the fiscal stimulus in reducing inequality and demonstrate significant progress in lowering poverty through the effective redistribution of carbon tax revenues, even if the ambitious targets of Indonesia Emas 2045 are not fully met.

This desirable outcome can only be achieved through strong institutions committed to two key principles. First, the effective implementation of carbon pricing is essential to drive the necessary economic and environmental changes. Second, a firm commitment to a revenue recycling policy is crucial to ensure that the generated funds are redistributed to support vulnerable groups. Only with these robust institutional frameworks in place can the benefits of reduced poverty and inequality, as demonstrated by the fiscal stimulus scenarios, be fully realized, paving the way for a more equitable and sustainable future.

4

Conclusion and Discussions

Indonesia has set an ambitious energy transition target, aiming to reduce emissions around 31.2 percent below the business-as-usual level by 2030. However, one pressing question amidst this goal is how the policy will impact vulnerable groups.

Extensive climate modeling research has been conducted internationally, especially on energy transition. Yet, few models have consciously incorporated vulnerable groups, such as women and people with disabilities. Currently known models, GEM-E3 and E3ME-FTT (Ciscar et al, 2012; Mercure et al, 2018), can only incorporate the distributional impacts of income across heterogeneous groups.

One of the challenges in incorporating GEDSI components into climate modeling is that most climate models are not readily equipped with the ability to analyze the impacts of climate change or climate policy on vulnerable groups. This is because these models typically operate at the macro-level. In this study, we attempt to bridge the macro and micro models through combining a climate model (namely GCAM) with microsimulation process (AIDS model). The linking variables are the commodity prices, which serve as outputs of GCAM and as the inputs for AIDS model.

The results of the modeling exercise show the potential risk of energy transition in terms of energy consumption, poverty, and Gini ratio. Implementing emission reduction measures to achieve a net zero target leads to an increase in the carbon price, which impacts various sectors across the economy. In the electricity generation sector, a higher carbon price increases generation costs, resulting in higher electricity prices. GCAM also projects impact on other commodities. For instance, increased biomass usage creates competition for land, leading to higher prices for commodities like rice and poultry.

Regarding poverty, the effort to achieve NZE is expected to slow the decline of poverty rate, primarily due to raising carbon price, which in turn drives up commodity prices. A faster NZE target would result in a higher poverty rate. For example, under the NZE 2050 scenario, the poverty rate in 2045 is projected to be 4.60 percent, compared to just 0.93 percent in the reference scenario. Notably, the poverty rates for all specific vulnerable household groups in 2045 are higher than the overall average.

Similarly, the Gini ratio results indicate that the more ambitious NZE targets lead to greater inequality. Achieving NZE by 2050 is projected to result in higher inequality in 2045, with a Gini ratio of 0.355, compared to 0.347 in the reference scenario. While most household groups follow this trend, female-headed households experience the highest inequality, with their Gini ratio reaching to 0.392 by 2045, indicating the highest inequality among all groups. These results underscore the risks associated with the energy transition, especially for vulnerable groups.

Some of these risks can be mitigated through fiscal transfer, such as implementing carbon pricing policies designed to support the energy transition. Microsimulation results show that combining fiscal stimulus with carbon pricing helps reduce poverty and inequality caused by the energy transition across all scenarios. The fiscal stimulus effectively narrows the poverty rate gap between NZE scenarios and the reference scenario, reducing the overall household poverty rate by 2.68 percent in the NZE 2050 scenario, bringing it to 1.92 percent by 2045. Although vulnerable groups, such as households with PWD still experience higher poverty rates, these rates are expected to gradually converge with the overall household average.

Similarly, the fiscal stimulus significantly reduces the Gini ratio, indicating lower inequality in all scenarios compared to the reference scenario. Female-headed households and other vulnerable groups, like households with children or the elderly, also experience notable declines in poverty rates, aligning more closely with the overall household rates by 2045. This indicates that fiscal stimulus can be a powerful tool to mitigate the adverse impacts of energy transition on vulnerable groups by effectively redistributing carbon tax revenues.

However, GCAM has several limitations that need to be addressed. First, it is not a country-specific model, yet this study focuses on Indonesia. The model does not account for climate actions taken by other regions, which could influence Indonesia's results if those regions also implement measures. Second, GCAM operates with fixed socio-economic assumptions, such as population growth and GDP, without considering the feedback effects between climate damage and socio-economic conditions, which are also important. Third, the study assumes an economy-wide carbon price, but the carbon market outcomes could vary across different sectors. Fourth, electricity is treated as a commodity, obtained from the weighted average cost of all technologies. The technology costs themselves are the sum of exogenously defined levelized non-fuel costs, endogenously calculated fuel, emission prices, and any other policy-related subsidies or taxes. Yet, electricity is a basic necessity subsidized by the Indonesian government to ensure affordability, which is not accounted for in this model. Finally, GCAM runs scenarios at 5-year intervals without using optimization techniques, leading to significant fluctuations, especially around the peak emission targets.

There are also several limitations of the microsimulations using AIDS in this study. First, the dataset provides only a limited sample for vulnerable groups, which may lead to their underrepresentation in the results. Second, the study assumes that revenue recycling from carbon pricing policies is feasible, which requires strong institutional support. Third, the study assumes that the impact of climate policies on welfare is solely driven by price changes, and it relies on static elasticity and the GIC to estimate these effects. Lastly, the analysis considers welfare only from the expenditure side, even though GEDSI issues are often more closely related to factors like energy access.

Related to the last point, although the model shows that fiscal transfer can help mitigate some adverse impacts of energy transitions to these vulnerable groups, it is important to acknowledge more fundamental issues pertaining to these groups. The modeling exercise is built on the assumptions and data of the current existing system where structural barriers for women and people with disability remains entrenched. Unfortunately, the current modeling techniques, as shown in this exercise, cannot fully capture the dynamics at the micro level with fine details. For example, the model lacks an internal mechanism to incorporate scenarios where women and people with disability actively participated in green energy jobs.

CONCLUSION AND DISCUSSIONS

The exercise highlights several points that future research must address. First, there is a need to develop a better modeling system that can incorporate internal mechanisms of change, such as how labor market shifts influence climate projection. Second, effective modeling requires comprehensive data with proper level of granularity. One key challenge in the process is the lack of micro-level data, which is crucial for providing a more complete picture of the impacts. The underrepresentation of PWD in national data must be taken seriously. Third, addressing these issues will require conscious efforts to mainstream GEDSI aspects in energy transition research. This effort can incorporate quantitative approaches, like the modelling used in this paper, or qualitative research that offers a deeper understanding of the problems or a combination of the two.

Lastly, research must be connected to the government policies through direct and indirect channels. An inclusive energy transition requires collaboration between grassroots organizations, academia, and policy makers. Therefore, creating an environment for evidence-based policymaking should also be a critical part of the solution.

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TABLE I Emission Targets for Net Zero Scenarios

Year	Emission Targets (MT CO2 eq)		
	Net Zero 2050	Net Zero 2060	Net Zero 2080
2020	1068.00	1068.00	1068.00
2025	1155.00	1155.00	1155.00
2030	1242.00	1242.00	1242.00
2035	1164.38	1207.50	1229.58
2040	931.50	1104.00	1192.32
2045	543.38	931.50	1130.22
2050	0	690.00	1043.28
2055	0	379.50	931.50
2060	0	0	794.88
2065	0	0	633.42
2070	0	0	447.12
2075	0	0	235.98
2080	0	0	0
2085	0	0	0
2090	0	0	0
2095	0	0	0
2100	0	0	0

Source: Indonesian NDC (2022) and Author's Calculation

TABLE II Population Projections for Indonesia

Year	Population (thousand)	Growth Rate (%)
1990	181,413	
2005	226,289	1.48%
2010	238,519	1.06%
2015	255,588	1.39%
2020	270,204	1.12%
2025	282,004	0.86%
2030	292,150	0.71%
2035	300,883	0.59%
2040	308,165	0.48%
2045	313,667	0.35%
2050	317,225	0.23%

2055	318,980	0.11%
2060	319,421	0.03%
2065	318,961	-0.03%
2070	317,715	-0.08%
2075	315,818	-0.12%
2080	313,216	-0.17%
2085	309,920	-0.21%
2090	305,948	-0.26%
2095	301,492	-0.29%
2100	296,624	-0.33%

Source: UN (2024). https://population.un.org/wpp/

TABLE III GDP Projections for Indonesia

Year	GDP (million 1990$)	GDP Growth Rate (%)	GDP per capita (1990$)
1990	204,381		1126.61
2005	376,810	4.16%	1665.17
2010	498,117	5.74%	2088.38
2015	651,844	5.53%	2550.37
2020	742,914	2.65%	2749.46
2025	935,604	4.72%	3317.69
2030	1,178,272	4.72%	4033.10
2035	1,422,734	3.84%	4728.53
2040	1,717,916	3.84%	5574.67
2045	2,022,040	3.31%	6446.46
2050	2,380,005	3.31%	7502.57
2055	2,724,968	2.74%	8542.75
2060	3,119,931	2.74%	9767.45
2065	3,572,141	2.74%	11199.32
2070	4,089,895	2.74%	12872.83
2075	4,682,694	2.74%	14827.21
2080	5,361,414	2.74%	17117.31
2085	6,138,510	2.74%	19806.76
2090	7,028,240	2.74%	22971.99
2095	8,046,929	2.74%	26690.36
2100	9,213,269	2.74%	31060.48

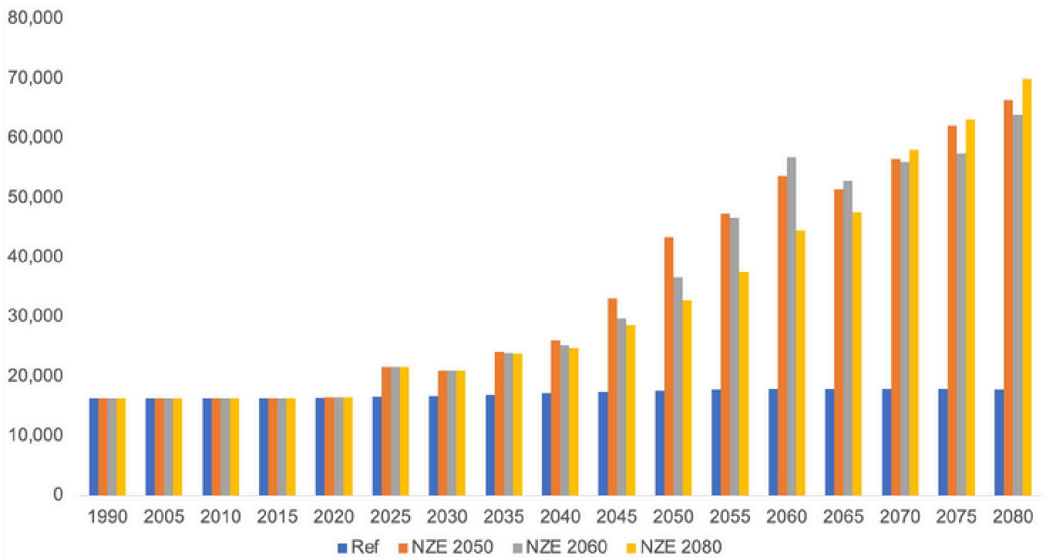
Source: OECD (2024). https://stats.oecd.org/viewhtml.aspx?datasetcode=EO114_LTB&lang=en

TABLE IV Generation Technology Cost Assumption

Generator	Build Cost ($/kw)			FOM ($/Kw/Year)			VO&M ($/MWh)		
	2023	2030	2050	2023	2030	2050	2023	2030	2050
Coal - conventional (subcritical)	1,880	1,820	1,760	51.6	50	48.55	1.5	1.45	1.4
Coal - conventional (supercritical) + CCS	3,840	3,460	2,770	97	90.2	72.8	4.5	4.2	3.7
Coal - IGCC	2,730	2,510	2,320	68.4	66.3	64.3	13.7	13.3	12.9
Coal - IGCC + CCS	4,770	4,290	3,430	123	121.8	116.9	22	21.78	21.12
Gas - open cycle	1,120	1,060	990	26.5	25.7	24.9	3.6	3.5	3.4
Gas - combined cycle	1,080	1,030	950	26.8	26	25.2	2.6	2.5	2.4
Gas - combined cycle + CCS	2,390	2,150	1,720	59	50.2	37.8	4.96	4.36	3.62
Refined liquid - diesel	910	910	890	9.12	9.12	8.8	7.3	6.84	6.61
Biomass - conventional	2,280	2,070	1,820	54	49.7	43.2	3.4	3.13	2.72
Nuclear PWR	9,000	7,900	6,800	127	120	113	2.4	2.3	2.2
Nuclear SMR		9,600	7,300		110	102		2.2	2.1

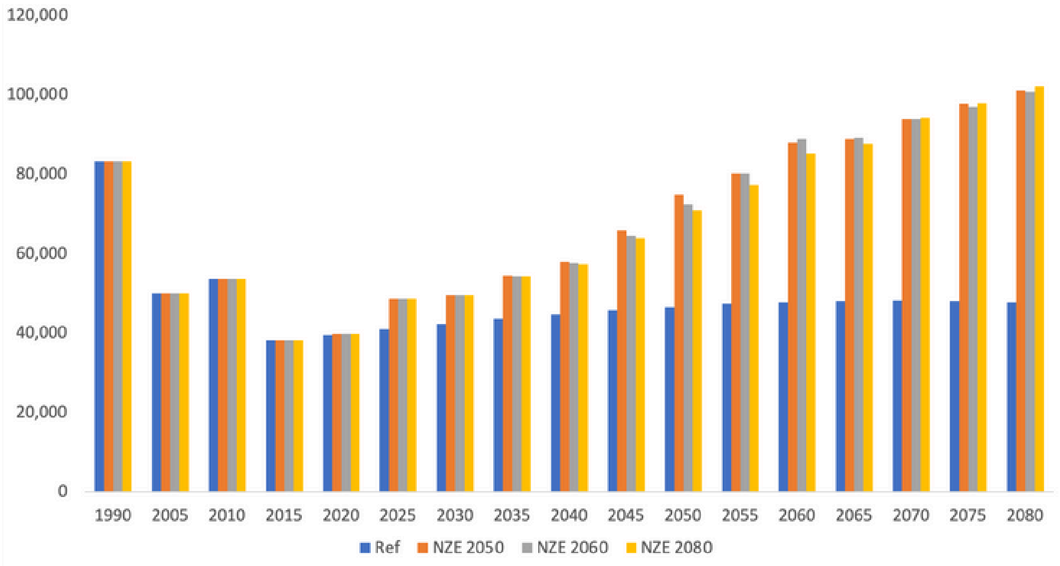
Source: MEMR (2024c).

FIGURE I Price of Rice by NZE Scenarios (Rp/kg)



Source: Authors' simulation

FIGURE II Price of Poultry by NZE Scenarios (Rp/kg)



Source: Authors' simulation

TABLE V Concordance from GCAM and SUSENAS

No	Category	GCAM	Name in Susenas 2019	Serial Number in Susenas 2019	Unit
1	Energy Commodities	Gas	LPG	215	Rp/month
			City Gas	217	Rp/month
			Biogas	223	Rp/month
		Coal	Charcoal/Coal/Briquettes	221	Rp/month
		Biomass	Firewood and other fuels	224	Rp/month
2	Staples Food	Legumes	Shelled Peanuts	99	kg
		Nuts Seeds	Other Nuts	101	kg
		Corn	Wet Corn with Husk	4	kg
			Shelled Corn/Corn Rice	5	kg
		Soybean	Soybeans	100	kg
			Tofu	102	kg
			Tempeh	103	kg
			Oncom	104	kg
3	Non Staples Food	Feed Crops	Pets and plants, including maintenance costs (cage food, health, fertilizer, etc.)	295	Rp/month

		Oil Crop	Coconut Oil	121	Rp/month
			Other Coconut Products	124	Rp/month
		Sugar Crop	Granulated Sugar	126	Rp/month
			Brown sugar, liquid sugar (palm tree, coconut, lontar)	127	Rp/month
		Non Staples Food Demand	Tea Powder	128	Rp/month
			Tea Bags	129	Rp/month
			Coffee	130	Rp/month
			Other Beverage Ingredients	132	Rp/month
			Instant Coffee	131	Rp/month
			Salt	134	Rp/month
			Candlenut	135	Rp/month
			Coriander	136	Rp/month
			Pepper	137	Rp/month
			Tamarind	138	Rp/month
			Shrimp Paste	139	Rp/month
			Soy Sauce	140	Rp/month
			Flavor Enhancer	141	Rp/month
			Ready-made Sambal	142	Rp/month
			Tomato Sauce	143	Rp/month
			Ready-made Cooking Spices	144	Rp/month
			Other Kitchen Spices (nutmeg, ginger, turmeric, etc.)	145	Rp/month
			Crackers	148	Rp/month
			Baby Porridge	149	Rp/month
			Other Food Ingredients	150	Rp/month
			Fried Food	156	Rp/month
			Green Bean Porridge	157	Rp/month

			Soto, Gule, Soup, Rawon, Chopped Beef	163	Rp/month
			Sate, Tongseng	165	Rp/month
			Bakso Noodles, Instant Noodles	166	Rp/month
			Instant Noodles (ready to eat)	167	Rp/month
			Children's Snacks, Chips	168	Rp/month
			Cooked Fish	169	Rp/month
			Chicken Porridge	172	Rp/month
			Siomay, Batagor	173	Rp/month
			Other Ready-to-Eat Food	174	Rp/month
			Packaged Tea, Carbonated Drinks	177	Rp/month
			Packaged Fruit Juice, Health Drinks, Energy Drinks	178	Rp/month
			Ready-to-Eat Drinks (coffee, coffee with milk, tea, milk, chocolate, etc.)	179	Rp/month
			Ice Cream	180	Rp/month
			Other Ice	181	Rp/month
			Alcoholic Drinks	182	Rp/month
4	Meat and Dairy	Pork	Pork	55	kg
		Beef	Beef	53	kg
			Brisket trim	60	kg
		Poultry	Broiler Chicken Meat	56	kg
			Free-range Chicken Meat	57	kg
			Broiler Chicken Eggs	63	kg
			Free-range Chicken Eggs	64	kg
			Duck Eggs	65	kg
			Other Eggs	66	kg

			Other Fresh Meat	58	kg
			Preserved Meat	59	kg
			Other (Liver, etc.)	61	kg
			Cooked Chicken/Meat (fried chicken, rendang, etc.)	170	kg
			Processed Meat (sausage, nuggets, smoked meat, etc.) cooked	171	kg
		Dairy	Factory liquid milk	67	kg
			Sweetened Condensed Milk	68	kg
			Powdered Milk	69	kg
			Baby Formula	70	kg
			Other Milk Products and Dairy Products	71	kg
		Sheep Goat	Goat/Sheep Meat	54	kg
5	Housing	Construction	If owned/self-rented, estimated rent per month	191	Rp/month
			If contracted, contract value per month	192	Rp/month
			If rented, rental value per month	193	Rp/month
			If official or other, estimated rent per month	194	Rp/month
			Home maintenance and minor repairs (paint, wood, lime, wall paint, roof, glass windows, hinges, etc.)	195	Rp/month
			PBB	298	Rp/month

			Levies/fees (neighborhood association fees, garbage collection, security, cemetery, etc.)	300	Rp/month
		Consumer Durables	Furniture (tables, chairs, beds, wardrobes, display cabinets, shoe racks, etc.)	280	Rp/month
			Household appliances (sewing machine, refrigerator, fan, washing machine, AC, etc.)	281	Rp/month
			Household equipment (mattresses, pillows, tablecloths, bed sheets, pillowcases, blankets, curtains, prayer rugs, carpets, mats, etc.)	282	Rp/month
			Household tools (iron, broom, scissors, knife, machete, hoe, saw, vacuum cleaner, clothes hanger, clothesline, soldering iron, etc.)	283	Rp/month
			Kitchen/eating utensils (plate rack, stove, pot, pan, bucket, kitchen knife, frying pan, spoon, thermos, plate, glass, mixer, rice cooker, blender, microwave oven, and other glassware/ceramic/melamine/plastic, etc.)	284	Rp/month
			Decorations/ornaments (wall decorations, aquarium, ceramic decorations, porcelain, onyx, marble, wood, etc.)	285	Rp/month
			Repair of household furniture, equipment, and tools	286	Rp/month

			Purchase of mobile phones/smartphones and accessories, including repairs	287	Rp/month
			Purchase of cameras, glasses, video cameras, other optical devices, including repairs	288	Rp/month
			Purchase of watches, umbrellas, bags, suitcases, including repairs	289	Rp/month
			Expensive jewelry made of precious metals and stones (gold, diamonds, pearls, etc.), including repairs	290	Rp/month
			Purchase of children's toys (tricycles), cheap and imitation jewelry, including repairs	291	Rp/month
			Purchase of televisions, radios, video, DVD, radio cassette, guitar, piano/organ, computer, laptop, tablet, including repairs	292	Rp/month
			Purchase of sports equipment (chess, racket, ball, net, bat, stick, swimming clothes, gymnastics clothes, football shoes/roller, swimming goggles), including repairs	293	Rp/month
			Purchase of vehicles for transportation (car, motorcycle, bicycle, motorboat, etc.)	294	Rp/month
			Other durable goods (electrical/telephone/water installations, swings, baby carriages, etc.), including repairs	296	Rp/month

6	Non Food Demand Crops	Non Food Demand Crops	Filtered Kretek Cigarettes	184	kg
			Unfiltered Kretek Cigarettes	185	kg
			White Cigarettes	186	kg
			Tobacco	187	kg
			Other Cigarettes and Tobacco (specify):..........	188	kg
7	Fruits	Fruits	Grapefruit	107	kg
			Mango	108	kg
			Apple	109	kg
			Rambutan	110	kg
			Duku Langsat	111	kg
			Durian	112	kg
			Salak	113	kg
			Ambon Banana	114	kg
			Other Bananas	115	kg
			Papaya	116	kg
			Watermelon	117	kg
			Tomato	118	kg
			Other Fruits	119	kg
			Coconut	123	kg
8	Rice	Rice	Rice (local, medium, premium, and imported)	2	kg
			Glutinous Rice	3	kg
			Other Grains (specify)	7	kg
			Mixed Rice/Rames	159	kg
			Fried Rice	160	kg
			White Rice	161	kg
			Lontong/ketupat sayur	162	kg
9	Electricity	Electricity	Electricity	196	

10	Vegetables	Vegetables	Spinach	73	kg
			Water Spinach	74	kg
			Cabbage	75	kg
			Chinese Cabbage	76	kg
			Green Mustard	77	kg
			Beans	78	kg
			Long Beans	79	kg
			Cherry Tomato	80	kg
			Carrot	81	kg
			Cucumber	82	kg
			Cassava Leaves	83	kg
			Eggplant	84	kg
			Bean Sprouts	85	kg
			Pumpkin	86	kg
			Soup/Cooked Vegetable Ingredients	87	kg
			Sour Soup Ingredients	88	kg
			Young Jackfruit	89	kg
			Young Papaya	90	kg
			Jengkol	91	kg
			Shallot	92	kg
			Garlic	93	kg
			Red Chili	94	kg
			Green Chili	95	kg
			Bird's Eye Chili	96	kg
			Other Vegetables	97	kg
			Cooked Vegetables (stir-fried, cooked in coconut milk, etc.)	164	kg
			Gado-Gado, Ketoprak, Pecel	158	kg

11	Fiber Crop	Fiber Crop	Ready-made Clothes for Adult Men (suits, uniforms, shirts, jackets, sarongs, trousers, T-shirts, undergarments, etc.)	271	Rp/month
			Ready-made Clothes for Adult Women (uniforms, gowns, long cloth, blouses, women's blazers, nightgowns, warm clothes, skirts, sarongs, shawls, angkin, undergarments, etc.)	272	Rp/month
			Ready-made Clothes for Children (uniforms, shirts, trousers, T-shirts, undergarments, etc.)	273	Rp/month
			Clothing materials for men, women, and children (wool, polyester, cotton, silk, etc.)	274	Rp/month
			Sewing wages, clothing repairs, sewing threads, and other sewing necessities	275	Rp/month
			Footwear (shoes, sandals, socks, etc.)	276	Rp/month
			Headgear for men, women, and children (hats, skullcaps, veils, etc.)	277	Rp/month
			Other (towels, belts, shoe polish, ties, laundry, hangers, mukena, raincoats, etc.)	278	Rp/month

12	Palm Oil	Oil Palm	Cooking Oil (palm, sunflower)	122	Rp/month
			Bath soap, toothpaste, toothbrush, and shampoo	232	Rp/month
			Beauty products (perfume, hair oil, deodorant, powder, braces, contact lenses, scissors, wigs, lipstick, comb, etc.) and sanitary napkins	233	Rp/month
			Skin, face, nail, and hair care (haircut fees, curling, rebounding, cream bath, body scrub/spa, etc.)	234	Rp/month
			Laundry soap (bar, powder, cream, and liquid)	235	Rp/month
			Clothing care products (fabric softener, fragrance, bleach, ironing aid, etc.)	236	Rp/month
13	Wheat	Wheat	Plain Bread	152	kg
			Sweet Bread/Other Bread	153	kg
			Cookies, Biscuits, Semprong	154	kg
			Wet Cakes (layer cake, Bika Ambon, Lemper, etc.)	155	kg
			Wheat Flour	6	kg
			Instant Noodles	147	kg
14	Crude Oil	Crude Oil	Fuel for Generator	200-202	Rp/month
			Lubricating Oil for Generator	203-204	Rp/month
			Generator Maintenance and Repair	205	Rp/month

			Gasoline for Motor Vehicles	206-207	Rp/month
			Diesel Fuel for Motor Vehicles	208-209	Rp/month
			Kerosene for Motor Vehicles	210-211	Rp/month
			Lubricating Oil for Motor Vehicles	212-213	Rp/month
			Motor Vehicle Repair and Maintenance	214	Rp/month
			Kerosene for Other Uses	219	Rp/month
			Other Postal and Telecommunication Costs (starter number, parcel delivery, etc.)	230	Rp/month
			Land Transportation Costs	261	Rp/month
			Air Transportation (tickets, airport tax, etc.)	262	Rp/month
			Sea Transportation	263	Rp/month
			Other Transportation Costs	264	Rp/month
			Hajj (BPIH) umroh and pilgrimage costs	308	Rp/month

APPENDIX 2

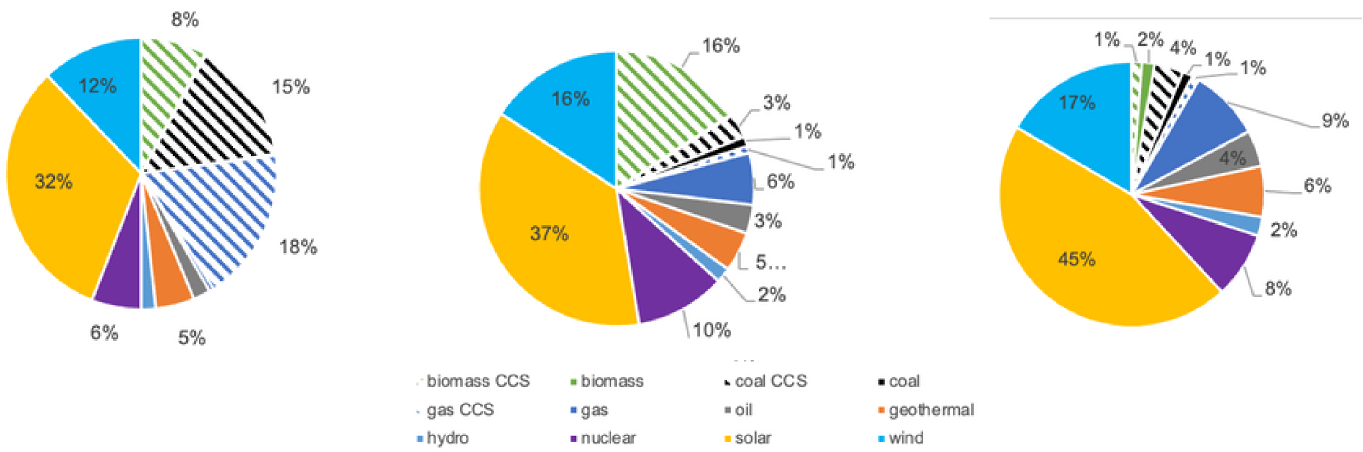
Sensitivity Analysis for GCAM Simulation

We have carried out a sensitivity analysis on the use of CCS and biomass in power generation. For simplicity we only focus on the NZE 2050 scenario. Two additional scenarios were developed, namely limited use of CCS in coal, coal-IGGC, and gas power generation (limit CCS), and limited use of CCS in coal, coal-IGCC, gas, biomass, and biomass-IGCC (limit CCS+biomass).

Notable changes can be observed in the generation mix and electricity. Limiting the adoption of CCS and biomass may cause a rapid increase in electricity from 2025 onwards before levelling post-2050, which may have been triggered by the increase of total cost of technology and the large capacity build up for solar, including rooftop, and wind as a measure to deal with the intermittency. As biomass is limited in the case of 'NZE 2050 limit CCS+biomass', an increase in the total cost of technology for the geothermal may have propelled the electricity even higher than the rest of scenarios. Carbon price is relatively similar between the scenarios. The 'NZE 2050' scenario, however, shows a slightly higher carbon price in 2050 than the rest due to large adoption of abated coal and gas power plants, despite the use CSS, still emitting a small amount of CO_2.

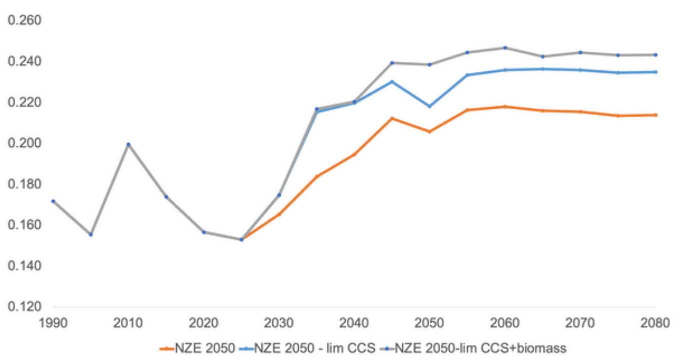
FIGURE AP2.1 Generation mix in 2050 of all scenarios

a NZE 2050 **b** NZE 2050 - Limit CCS **c** NZE 2050 - Limit CCS + Biomass



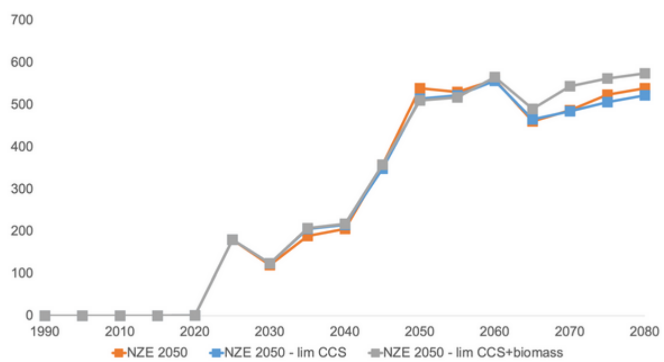
Source: Authors' simulation

FIGURE AP2.2. Electricity price of all scenarios (2024$/kWh)



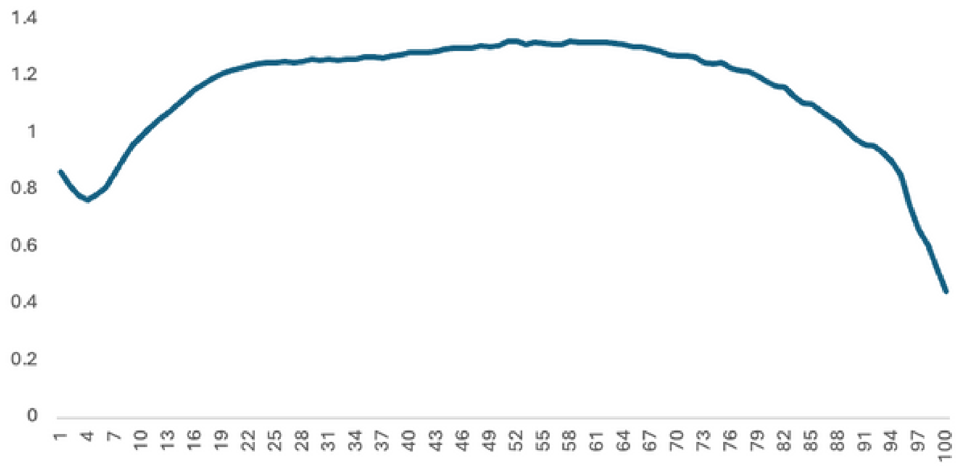
Source: Authors' simulation

FIGURE AP2.3. Carbon price of all scenarios (2024$/tCO2)



Source: Authors' simulation

APPENDIX 3a. GIC per GDP growth, 2014 - 2019



Source: Authors' simulation

APPENDIX 3b. Total Carbon Value (in 2019 Rupiah) per HH, monthly

Scenarios	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070	2075	2080
NZE 2050	187.42	55,919.24	40,119.09	59,109.57	51,587.32	52,140.63	-	-	-	-	-	-	0
NZE 2060	187.42	55,919.24	40,119.09	59,153.73	52,945.20	64,448.23	68,030.85	51,998.57	-	-	-	-	0
NZE 2080	187.42	55,919.24	40,119.09	59,003.32	52,937.90	66,360.27	74,523.09	76,915.51	81,024.39	66,464.88	60,963.57	34,000.06	0
Reference	0	0	0	0	0	0	0	0	0	0	0	0	0

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