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Research Article

The DREAM approach to demand-side emissions reductions in Indonesia, 2020–2060

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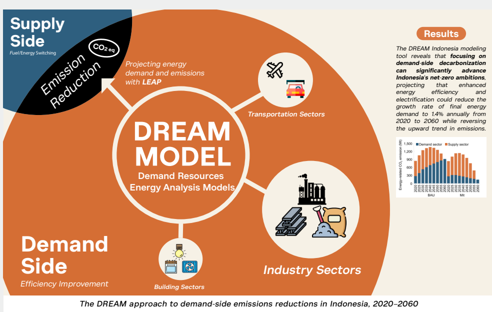
ABSTRACT

Indonesia's current energy system modeling is heavily focused on the supply side, but emissions reductions in the demand sector have a significant impact on advancing Indonesia's ambitious emissions reductions goals. To address the gap, we develop a new modeling tool DREAM Indonesia based on a bottom-up, technology-rich demand side framework and formulate projections of demand-side emissions reductions in Indonesia in 2020–2060. We find that demand-side energy efficiency and electrification can halve the growth rate of final energy demand to 1.4% annually over 2020–2060 and reverse the growing trend of emissions. The feasibility of full electrification by 2060, coupled with rapid adoption of existing technologies, positions the building sector as a model for achievable decarbonization and a cornerstone of Indonesia's emissions reductions ambitions. In the industrial sector, extensive emissions reductions of 87% by 2060 (compared to business-as-usual) are achievable through energy efficiency improvements, alongside enhanced material efficiency measures including optimized material usage, low-carbon substitutions, innovative technologies, and increased circularity. In the transportation sector, balancing final energy demand by incorporating energy efficiency improvements across all transport modes, along with electrification particularly in road transportation, could decrease the emissions by up to 82% in 2060 compared to business-as-usual. This study provides insights and modeling approaches for rapidly growing Asian economies as well as other developing countries facing combined development and decarbonization challenges.



DREAM approach: demand-side strategies for Indonesia's emissions reduction.

KEYWORDS

Demand-side emissions reductions; bottom-up model; DREAM Indonesia; energy system modeling; emissions reductions pathways

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1. Introduction

As part of its nationally determined contribution, Indonesia has set emission reduction targets of 31% and 43% without and with international assistance, respectively, by 2030[1]. At the same time, the country seeks annual economic growth of 6%–7% until 2045[2], and its emissions continue to rise, averaging 10% per year from 2015 to 2020[3].

Achieving these targets requires scaling up renewable energy and enhancing energy efficiency—particularly in the energy and industrial sectors, which together account for 39% of the country's total emissions[3]. Demand-side measures outlined in the nationally determined contribution include enhanced energy management, energy efficiency improvements to equipment, and programs to promote electric vehicles, efficient street lighting, and induction stoves.

Several studies reviewing decarbonization strategies in Indonesia have concluded that increased renewable energy and energy efficiency are crucial steps for decarbonization[4-6]. A more comprehensive analysis of the gaps is presented in the **Electronic Supplementary Materials (ESM).** However, most studies have primarily focused on the supply side, especially the power sector, and they devote limited attention to opportunity sectors such as buildings. Recognizing the gaps in research conducted on Indonesia, this study aims to emphasize decarbonization strategies on the demand side using DREAM Indonesia.

2. The DREAM model

This paper uses a detailed bottom-up energy end-use model called the Demand Resources Energy Analysis Models (DREAM) to develop and assess energy future pathways based on scenarios of energy technology improvements and changes as a result of shifting market and policies. The DREAM modeling framework uses the Low-Emissions Analysis Platform (LEAP), a widely used software tool for energy analysis and emissions assessment developed by the Stockholm Environment Institute[7] (Heaps, 2022). In Indonesia, LEAP serves as a critical modeling platform used by energy planners and policymakers.

Unlike existing LEAP models for Indonesia, DREAM uses a novel approach through a bottom-up and demand side technology-rich modeling framework that prioritizes physical drivers (e.g., building floor area, number of motor vehicles, cement and steel production) rather than economic drivers (e.g., total or sector-specific GDP) for projecting future energy consumption. This approach can properly capture the influence of technological advancement, resource availability, and energy efficiency on likely energy transition pathways in Indonesia. This model can also complement many existing supply-side focused energy models for Indonesia by providing a more detailed basis for demand projections that can be integrated with these broader assessment models.

Indonesia DREAM represents the country at a national level, but it also has region-specific details for seven grouped regions, with a time horizon spanning from 2020 to 2060. To address the research gap in Indonesia's energy system modeling, this model provides detailed technological insights into the building, industry, and transportation sectors. While the analysis is focused on these three demand sectors and sectoral measures for reducing energy demand and emissions, the model does include a very simplified power sector module to represent declining CO_2 emission factors for electricity generation based on existing IEA projections[5]. This allows the model to compute and report both on-site (e.g., fossil-fuel-combustion-generated) CO_2 emissions and off-site or indirect CO_2 emissions from power generation (e.g., from coal-fired power plants) that can be allocated back to the demand sector based on their proportion of electricity demand. While LEAP software enables cost-optimization analysis, the current Indonesia DREAM does not include any cost input data, and future pathway scenarios are based on modeled technological trends described in the ESM.

For each demand sector, future energy consumption trends are calculated by summing up the energy demand of individual technologies or processes, as shown in Table 1. For a given year, annual final energy demand is calculated as a product of each energy-consuming activity and its technology-specific

Table 1. DREAM modeling structure for demand sectors.

Parameters	Building	Industry	Transportation
Levels of energy-consuming activities	By sub-sector: - Residential, urban/rural - Commercial Under sub-sector, by end-use: - Heating - Cooling - Refrigeration - Appliances - Equipment - Lighting	By sub-sector: - Steel - Cement - Pulp and paper - Chemicals - Food and beverages - Textile - Other	By mode: - Road - Air Under mode, by vehicle type: - Passenger car - Motorcycle - Truck - Bus
Drivers/variables of energy consuming activities	- Population - # Households (urban/rural) - m^2 residential by region, vintage - m^2 commercial by region, vintage	- Economic output (value-added) - Physical output (metric ton)	- Population - Vehicle stock - Annual distance travelled per vehicle - Freight ton-km - Passenger-km
Energy technologies' characteristics	Technology: - Saturation - Energy intensities - Efficiency - Usage - Size/features Fuel type: - Coal - Natural gas - Oil and oil products - Electricity	Technology: - Saturation - Energy intensities - Efficiency - Usage Fuel type: - Coal - Natural gas - Oil and oil products - Electricity	Technology: - Saturation - Energy intensities - Efficiency Fuel type: - Natural gas - Oil and oil products - Electricity - Biofuels

fuel intensities and summed across each demand sector. To validate the model structure and data inputs, the model calculated result for 2020 is compared against Handbook of Energy Economics by the Ministry of Energy and Mineral Resources[8]. The 5% lower energy demand in our bottom-up model (5.54 EJ) compared to MEMR's aggregated statistics (5.83 EJ) in 2020 validates our methodology as it realistically captures individual energy-consuming activities while remaining within acceptable modeling uncertainty ranges. For 2020 through 2060, changes in the activity and technology variables shown in Table 1 are based on the analysis of previous activity trends, international trends, technology-specific trends, policy trends, and scenario-specific assumptions, discussed further below. The model then calculates primary energy demand endogenously by considering fuel-specific transformation losses to convert the final energy demand into the required primary energy inputs. The model calculates CO_2 emissions by multiplying fuel-specific emission factors with the fuels consumed, while an exogenous electricity CO_2 emission factor is taken from IEA's Announced Pledges Scenario[5] account for conservative projection of power sector decarbonization.

Unlike supply-focused models, DREAM Indonesia offers a comprehensive analysis of demand-side dynamics crucial for achieving net-zero targets. This study assesses two scenarios from a demand sector perspective:

The Business-As-Usual (BAU) scenario reflects Indonesia's current energy trajectory, where energy demand follows recent trends and efficiency improvements maintain their present pace. While some policies such as energy efficiency standards and biodiesel mandates are implemented, decarbonization efforts remain limited. The energy system follows the moderate transition pathway outlined in IEA's Announced Pledges Scenario[5].

The Mitigation (Mit) scenario charts an ambitious pathway to near-zero emissions through comprehensive demand-side measures alongside an exogenously modeled decarbonizing power sector. The scenario emphasizes widespread electrification and fuel-switching across sectors. In buildings, it emphasizes stringent building codes and efficiency standards. In transportation, it prioritizes electric vehicle adoption, enhanced public transit, and alternative fuels for heavy transportation. The industrial sector transforms through electrification, green hydrogen integration, the best-available technologies, and smart manufacturing systems.

3. Results

3.1 The importance of decarbonizing the demand sectors

The results of the emission trajectory for Indonesia's energy sector using the Indonesia DREAM approach are shown in Fig. 1. Even with decarbonization in the supply sector by 2060, as outlined in the President of the Republic of Indonesia's Regulation 112/2022[1], the total energy-related emissions by 2060 differ significantly between the BAU and Mit scenarios. This trend highlights the critical role of decarbonization in the demand sectors. In the BAU scenario, emissions from the demand sectors experience rapid increases until 2030, then continue to rise, albeit at a slower rate, until 2060. This increase results in total energy-related emissions reaching 1,104 million metric tons of CO_2 by 2060. In contrast, the Mit scenario, through demand sectors' energy efficiency and electrification, leads to a drastic reduction in emissions starting in 2030, ultimately leading to an overall emission decrease of 84% by 2060.

Figure 2 shows the total final energy demand across the demand sectors for both scenarios. In the BAU scenario, total final energy demand across all sectors is projected to grow at an annual rate of 3.5% through 2060. The building and industrial sectors show the most rapid expansion, with their energy footprints nearly tripling between 2020 and 2060. In contrast, the implementation of energy efficiency measures and electrification led to a 60% reduction in the growth rate of final energy demand, lowering it to a more modest 1.4% per annum. In addition, the largest emission reduction occurs in the industrial and transportation sectors, reaching 84% in 2060. The building sector can achieve net-zero emissions in 2050, or 10 years earlier than the supply sector.

3.2 The building sector

The building sector in Indonesia presents a unique opportunity for decarbonization, as it is the only sector where full decarbonization is achievable with technologies available today. In the Mit scenario, this potential is realized through a combination of strategies. Cooling demand, expected to grow tenfold by 2060, is addressed through improved equipment efficiency, integrative building design, and urban-scale solutions, potentially reducing energy use by up to 45% in both residential and commercial buildings. Meanwhile, lighting needs will increase almost fourfold by 2060, as shown in Fig. 3(a), and efficiency improvements can reduce energy needs by up to 67% in the Mit scenario.

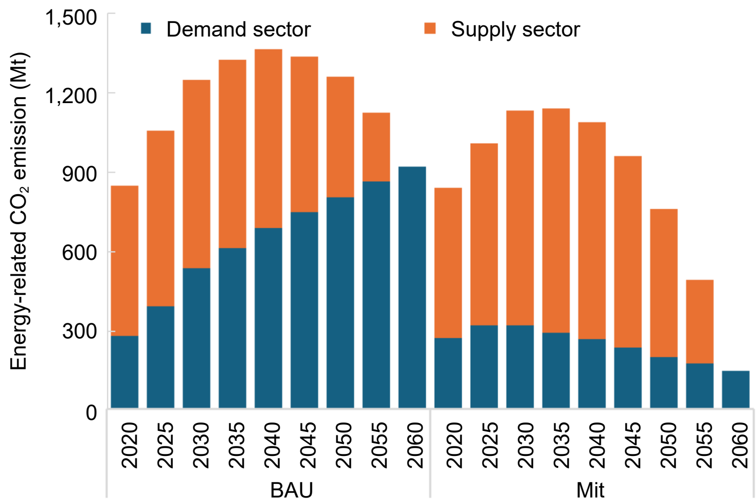

Fig. 1. DREAM model results of energy-related emissions trajectory in Indonesia in 2020–2060.

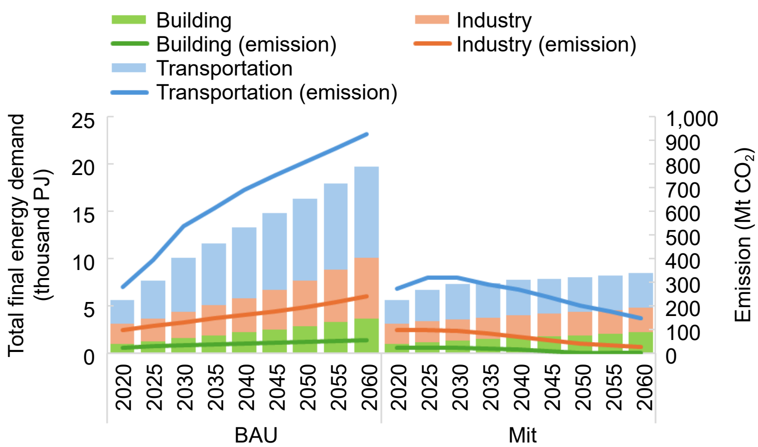

Fig. 2. DREAM model results of total final energy demand and emissions trajectory across sectors in Indonesia in 2020–2060.

Energy efficiency measures across the sector could avoid 203 terawatt hours (TWh) of electricity consumption in 2060, representing 25% of total building electricity demand. These improvements, along with load management strategies, could decrease peak demand requirements and reduce grid battery capacity needs[9]. In terms of emissions reduction, electrifying water heaters and cooking appliances are the two key measures that significantly contribute to lowering emissions in the Mit scenario, as illustrated in Fig. 3(b). The feasibility of full electrification by 2060, coupled with the rapid adoption of existing technologies, positions the building sector as a model for achievable decarbonization and a cornerstone of Indonesia's net-zero ambitions.

3.3 The industrial sector

The industrial sector is the second largest energy consumer in Indonesia, primarily driven by manufacturing, mining, and processing industries. Major energy-intensive industries include iron and steel, cement, textiles, pulp and paper, food and beverages, and chemicals[10,11]. These subsectors rely heavily on a mix of energy sources including coal, natural gas, electricity, and to a lesser extent, renewable energy.

In the Mit scenario, the industrial sector's final energy demand growth is significantly moderated compared to the BAU scenario. It increases at an average annual rate of 0.37%, in contrast to the 2.7% annual growth projected in the BAU scenario. By 2060, the total industrial final energy demand reaches approximately 2,128 PJ, which is 58% lower than the BAU scenario projection (Fig. 4(a)). This substantial reduction is attributed to a combination of energy efficiency improvements, particularly in chemical, cement and steel industries, as well as enhanced material efficiency through measures such as optimized steel usage in manufacturing (for example, using high-strength steel to reduce material requirements in vehicles and construction), material substitution (such as low-carbon alternatives in cement production), innovative low-carbon technologies (e.g., hydrogen-based direct reduction of iron, scrap-based electric arc furnaces) and increased reuse and recycling. The Mit scenario shows that by 2060, the chemical sector, driven largely by ammonia production and petrochemical processes, will remain the largest energy consumer in industry at 29% of total industrial final energy use. As shown in Fig. 4(b), achieving deep decarbonization across industries requires different approaches—from chemicals and cement to steel, pulp and paper, textiles, and food and beverages—reflecting that a multi-pronged portfolio approach is needed to achieve a total emission reduction of 87% compared to BAU.

3.4 The transportation sector

The transportation sector is currently still the main contributor of demand-side emissions, according to Indonesia's Ministry of Environment and Forestry[3]. Similar future trends are unlikely to change its position as the dominant contributor, particularly in the case of road transportation, within the BAU scenario as shown in Fig. 2. The BAU scenario projects an annual 3.9% increase in the transportation sector's final energy demand, primarily driven by population growth, rising passenger vehicle ownership, and increased travel distances. Although two-wheeled vehicles still dominate the number of vehicles in Indonesia[12], which is worth 125 million units in 2022, the largest energy demand will be dominated by four-wheeled vehicles. This is because the growth of vehicle-kilometers of two-wheeled motor vehicles will experience stagnancy starting in 2040, while four-wheeled vehicles will continue to experience vehicle kilometer growth until 2060, although at a lower growth rate than that in 2020.

In contrast, the Mit scenario achieves the leveling of transportation's final energy demand by incorporating energy efficiency improvements across all technologies, focusing on operational and vehicle enhancements in key transport modes (Fig. 5). Notably, this scenario assumes a 2% annual improvement in passenger vehicle efficiency[13]. Additionally, it projects a 5% reduction in road freight energy demand by 2050, attributable to logistical improvements such as enhanced loading practices and dispatch optimization, which collectively reduce freight activity compared to the BAU scenario[14]. In addition to the reduction in final energy demand reaching 62% in 2060, the contribution of fuel-switching also provides a significant reduction so that transportation

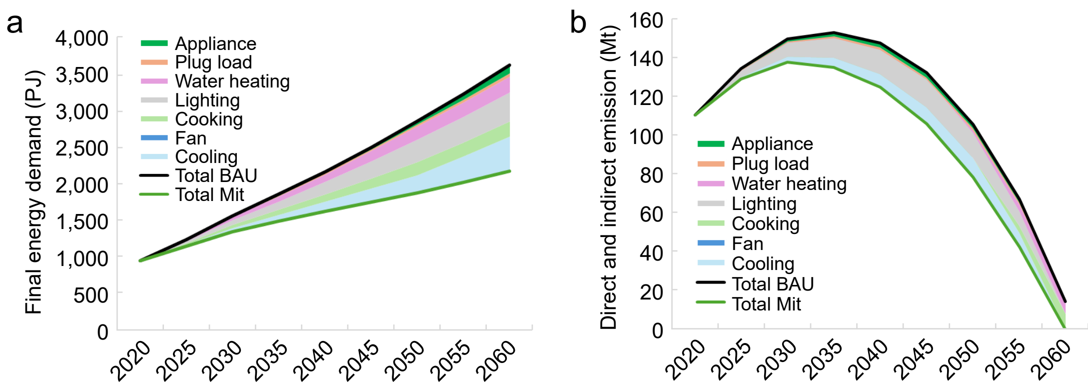

Fig. 3. DREAM model results of final energy demand and emissions of the building sector in Indonesia in 2020–2060. (a) Projections of final energy demand by end uses of the building sector. **(b)** Projections of direct and indirect emissions by end uses of the building sector.

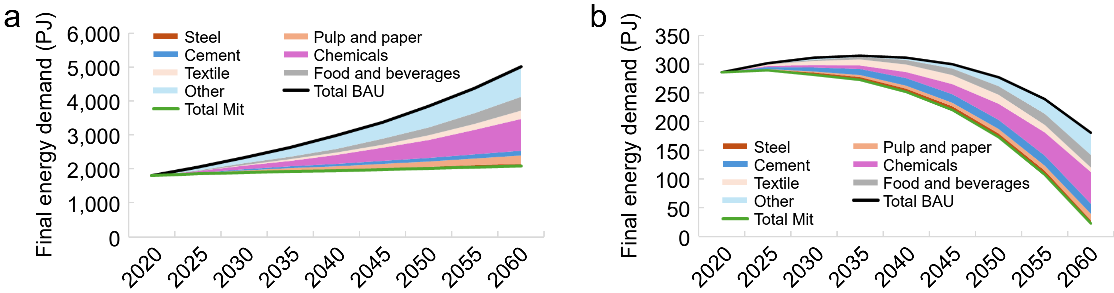

Fig. 4. DREAM model results of final energy demand and emissions of the industrial sector in Indonesia in 2020–2060. (a) Projections of final energy demand by industrial sub sectors. **(b)** Projections of direct and indirect emissions by industrial sub sectors.

sector emissions can decrease by up to 82% in 2060 compared to the BAU scenario as shown in Fig. 1. The emission reduction significantly comes from four-wheeled vehicles, as shown in Fig. 5, due to the electrification (as shown in Fig. 6) alongside a cleaner power grid. Additionally, the aviation sector is making a notable impact on emissions reduction by enhancing energy efficiency by 1% per passenger kilometer each year and using bio jet fuels as shown in Fig. 6[5].

4. Discussion

4.1 Uncertainties and limitations

This analysis faces several data limitations common to modeling exercises in developing economies. The most significant challenge is the limited availability of detailed end-use energy consumption data in Indonesia, particularly for residential and commercial buildings, where energy use patterns are rapidly evolving. Historical data on industrial process efficiency and actual equipment performance is often incomplete or outdated, requiring assumptions based on international benchmarks that may not fully reflect local conditions. Similarly, detailed historical data on mode-specific and vehicle-specific activity is limited, particularly for the aviation sector.

Additionally, the model's projections rely on socioeconomic assumptions about population growth, urbanization rates, and economic development pathways that carry inherent uncertainties. The lack of granular data on regional variations in energy use intensity and technology adoption rates adds another layer of uncertainty to the sectoral projections. While these limitations do not invalidate the overall findings, they highlight the need for improved data collection and monitoring systems to support more robust modeling of Indonesia's energy transition pathways.

4.2 Future applications and development

The DREAM modeling framework provides valuable insights for Indonesia's climate and energy policy planning while highlighting key areas for future development. Our analysis demonstrates significant technical potential for demand-side decarbonization, though realizing this potential will require addressing economic, behavioral, and implementation barriers. Future research should quantify these factors to bridge the gap between technical and achievable emissions reductions. A key priority is incorporating uncertainty and sensitivity analysis to examine how variations in technology adoption rates, energy intensity improvements, and socioeconomic drivers affect projected emissions reductions. Understanding these uncertainties is crucial for robust policy design. Additionally, expanding the economic analysis to include cost considerations, market barriers, and consumer behavior will provide a more complete picture of achievable demand-side decarbonization potential.

Cross-sectoral interactions represent another critical development area. The current analysis examines sectors independently, but significant interconnections exist. For instance, increased electric vehicle adoption affects industrial energy demand through battery manufacturing, while changes in building materials impact cement and steel production. Future work will quantify these cross-sectoral effects to provide a more comprehensive assessment of mitigation pathways.

Moreover, regional differentiation and temporal resolution require better attention. Future iterations will refine energy intensity assumptions to reflect geographical variations across Indonesia's archipelago, enabling more targeted policy recommendations. Implementation of hourly time slices, building on work from McNeil et al.[15] will enable precise modeling of peak load demands and demand-response opportunities. The framework will also incorporate power system optimization driven by bottom-up demand profiles, alongside emerging technologies like green hydrogen and advanced storage.

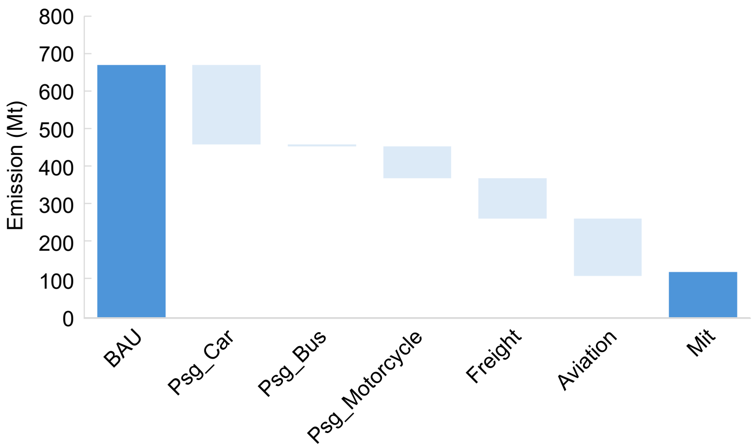

Fig. 5. DREAM model results of transportation sector emission and reduction potential by transport modes in Indonesia in 2060.

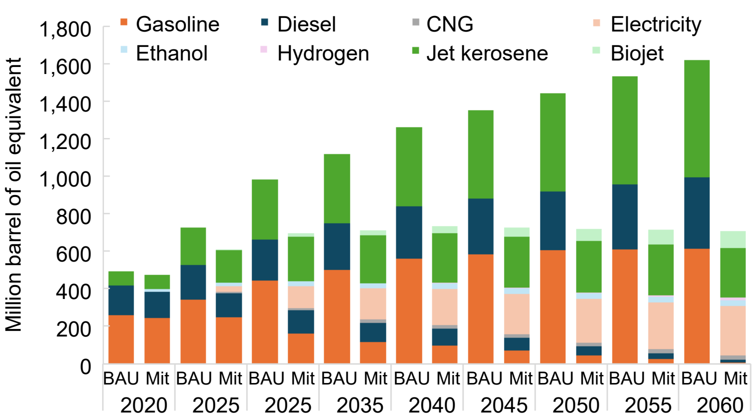

Fig. 6. Projections of fuel consumption of the transportation sector by fuel type in Indonesia in 2020–2060.

5. Conclusion

This study highlights the importance of demand-side decarbonization in achieving emission reductions in Indonesia's energy system, where analysis heavily focused on the supply side. This study has developed the DREAM Indonesia model using a bottom-up, demand-side technology approach that prioritizes physical drivers over economic drivers of energy consumption and emission projections. The study finds that energy efficiency and electrification could reduce the growth rate of final energy demand to 1.4% annually, with full electrification by 2060 and rapid adoption of existing technologies driving significant emission reductions in the building, industrial, and transportation sectors—leading to up to 87% emission reduction in industry and 82% in transportation by 2060 compared to BAU scenario.

This study provides valuable insights for rapidly growing Asian economies facing similar development and decarbonization challenges. Indonesia's case is particularly relevant, as it emerges as Southeast Asia's next manufacturing powerhouse, building on the region's growing role in global supply chains. The modeling analysis by De la Rue du Can et al.[16] reveals pathways to learn from China's rapid but emission-intensive industrialization and India's more gradual development approach. While these earlier industrial powerhouses confronted decarbonization challenges after their initial development phases, Indonesia and other Southeast Asian nations can integrate low-carbon strategies from the start of their industrial expansion, leveraging their diverse industrial base and abundant resources to achieve more sustainable growth. These insights and modeling approaches may also inform the Intergovernmental Panel on Climate Change's upcoming Seventh Assessment Report on achieving net-zero transitions in developing economies while balancing growth objectives.

Electronic supplementary material

Supplementary material is available in the online version of this article at https://doi.org/10.26599/TRCN.2025.9550006.

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Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article. The author Nan Zhou is the Editorial Board Member of this journal.

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