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Carbon Accountability in Indonesia's State-Owned Assets Management

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ABSTRACT

Research Originality: This study is among the first to introduce an Environmentally Extended Input-Output (EE-IO) framework to quantify the carbon externalities of state-owned assets (BMN) management in Indonesia. This area has received limited empirical attention.

Research Objectives: The study aims to systematically measure direct and indirect carbon emissions associated with BMN utilization and assess their implications for public asset governance.

Research Methods: An EE-IO model is constructed using Indonesia's 2016 input-output table, sectoral emission intensities, and audited government electricity expenditure data to estimate emission multipliers and carbon impacts.

Empirical Results: The Electricity and Gas Supply sector exhibits the highest emission multiplier (4,919.05 tons CO_2 per billion Rupiah). Electricity-related BMN expenditure is estimated to generate 28.4 million tons of CO_2, revealing a substantial but previously under-recognized source of environmental burden.

Implications: The findings support emission-informed budgeting, emission-based performance indicators, and the integration of carbon accountability into public asset management.

Keywords:

environmentally extended input-output analysis; carbon emission multiplier; Indonesia's climate policy; emission-based budgeting; public asset governance

How to Cite:

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INTRODUCTION

As climate change intensifies, public institutions face mounting challenges in managing the environmental risks embedded within national infrastructure and development systems (Markolf et al., 2018). The climate crisis increasingly manifests as systemic stress on state-controlled assets—transport corridors, public facilities, energy grids—that were often designed without accounting for environmental volatility (Jentsch & Beierkuhnlein, 2008; Weiskopf et al., 2020). Rising temperatures, extreme weather events, and ecological degradation threaten service delivery and impose long-term fiscal burdens. Carbon dioxide (CO_2), the principal driver of global warming, persists in the atmosphere for centuries, amplifying the urgency of mitigation efforts (Davis & Caldeira, 2010; Eby et al., 2009; Solomon et al., 2009). Climate risk must therefore be understood not only as an ecological crisis but also as a governance challenge affecting pubic asset management.

Indonesia plays a pivotal role in the global climate landscape. It is the largest carbon emitter in Southeast Asia and consistently ranks among the top global CO_2 emitters, with national greenhouse gas emissions reaching approximately 1.2 Gt CO_2-equivalent in 2021 (Wiloso et al., 2024; Zhong et al., 2025). With a 13.14% year-on-year increase in emissions, it ranks fourth in terms of emission growth rate. It is the largest contributor in Southeast Asia (Amheka et al., 2022), reinforcing Indonesia's strategic importance in global mitigation efforts. Indonesia's updated Nationally Determined Contribution (NDC) in 2022 raises its mitigation targets to 31.89% unconditionally and 43.20% conditionally. However, nearly 97% of the projected reductions are concentrated in two sectors—forestry and land use and energy —leaving limited attention to other high-impact sectors, including infrastructure governance and public asset management.

Despite its central role in Indonesia's development agenda, the infrastructure sector receives comparatively limited attention in the country's climate strategy (Hsiao & Kuipers, 2025; Republic of Indonesia, 2022). This is a critical oversight. Sustainable infrastructure both contributes to emissions and offers transformative mitigation potential (Gómez-Villarino et al., 2021; Kadić et al., 2025; Sang & Pan, 2024). Evidence from Thacker et al. (2019) underscores this point: infrastructure systems are linked—either directly or indirectly—to 121 out of 169 Sustainable Development Goal (SDG) targets, including SDG 3 (Health), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 11 (Sustainable Cities and Communities). The absence of an integrated, climate-conscious approach to state asset governance therefore represents a critical blind spot in Indonesia's climate strategy.

The urgency highlighted by Thacker et al. (2019) is reinforced by the property and construction sector's status as one of the most carbon-intensive domains, accounting for more than one-third of global emissions (Chen et al., 2022). In this context, Indonesia's state-owned assets (Barang Milik Negara, or BMN)—which are fully under government control—represent a strategically important yet underutilized level for sustainable

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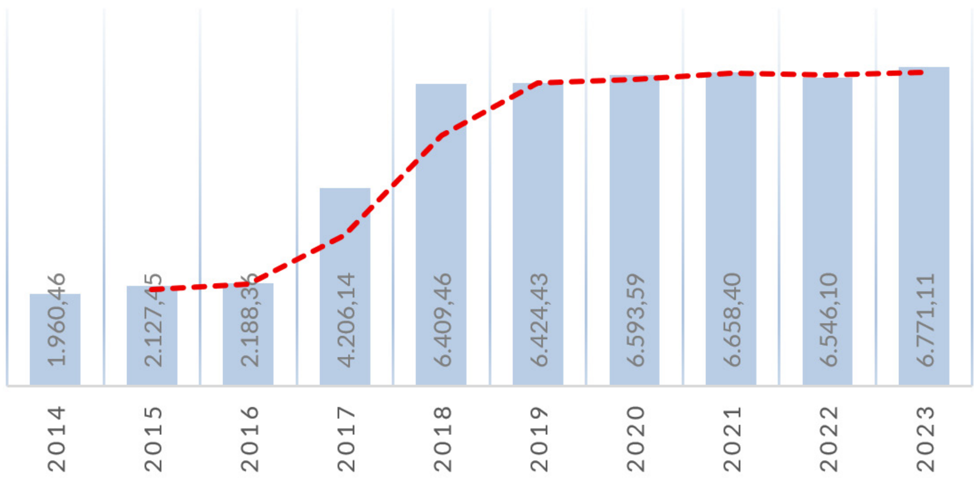
development. The total value of state-owned assets (BMN) has grown nearly 2.5 times over the past decade—from IDR 1,960.46 trillion in 2014 to IDR 6,771.11 trillion in 2023 (Figure 1)— reflecting the expanding scale of publicly managed infrastructure. As this value grows, so too does its contribution to carbon emissions, arising from the construction, operation, and maintenance of these assets (Kwok et al., 2016).

Figure 1. State-Owned Assets (BMN) Value (2014–2023 in Trillion Rupiah)



Historical growth in the total value of Indonesia's state-owned assets (BMN) over a 10-year period.
Source: Author's work based on State-Owned Assets Report 2023 Audited.

Given their scale and administrative reach, state-owned assets (BMN) can serve as a platform for embedding climate accountability within public infrastructure governance by evolving from a purely administrative and economic orientation toward a more holistic framework (Surachman, 2024). Integrating principles of resource efficiency, carbon reduction, and climate resilience into national asset management practices would strengthen Indonesia's sustainable development trajectory (Focardi & Fabozzi, 2020). However, such transformation requires a robust carbon accounting framework capable of systematically quantifying emissions, both direct and indirect, associated with asset-related activities (Hong et al., 2016; Kaur et al., 2023).

Existing infrastructure-related carbon studies predominantly employ Life Cycle Assessment (LCA), focusing on individual buildings or specific lifecycle stages (Bakindi et al., 2025; Li et al., 2025). Li et al. (2025) used LCA to identify emission hotspots primarily in the production and operation phases of an individual high-rise residential building in Beijing. Similarly, Dsilva et al. (2023) apply LCA to an individual multi-use building in Dubai to evaluate how proactive material selection during early construction phases can mitigate embodied carbon. Kumar et al. (2025) further note that LCA integration remains limited in early design, with many assessments restricted to cradle-to-gate or cradle-to-site boundaries because detailed data for later lifecycle stages is often unavailable during conceptual design. While valuable, these studies do not capture wider supply-chain effects or inter-sectoral dependencies.

In parallel, Environmentally Extended Input-Output (EE-IO) analysis has been widely applied to assess the carbon footprint of broad economic systems and sectors. This approach builds on traditional Input-Output models by integrating environmental dimensions, including carbon emissions, resource use, and energy consumption. EE-IO enables a comprehensive, economy-wide analysis of environmental impacts and their relationships with sectoral economic activities (Demeter et al., 2021). Amheka et al. (2022) used an environmentally extended Multi-Region Input-Output model in the ASEAN region to demonstrate that significant carbon reductions can be achieved while maintaining GDP growth, particularly through decarbonizing the electricity sector. He and Hertwich (2019), using the EXIOBASE database, traced global embodied carbon flows across 49 regions and showed that manufacturing remains the largest source of indirect emissions in developing economies. In the Indonesian context, Irfany and Klasen (2017) found that household expenditure—especially on fuel and transportation—drives carbon footprints. At the infrastructure scale, Martinez et al. (2022) employed EE-IO to quantify embodied environmental impacts in a diversion dam project, revealing that steel and cement alone account for nearly three-quarters of total impacts. Collectively, these studies demonstrate the strength of EE-IO in revealing indirect and upstream emissions embedded within economic activities.

Despite growing attention to carbon emissions from infrastructure and the built environment, existing empirical studies remain limited in their analytical scope. Project-level assessments predominantly rely on LCA, focusing on individual buildings, construction materials, or specific lifecycle stages, thereby overlooking wider inter-sectoral and supply-chain effects. In parallel, EE-IO models have been extensively applied to estimate economy-wide, sectoral, and consumption-based carbon footprints, offering a broader perspective, capturing indirect or upstream emissions that are often overlooked (Demeter et al., 2021). However, although EE-IO models have been widely applied in environmental–economic analysis, there remains a notable absence of empirical frameworks that operationalize EE-IO to measure the carbon footprint of state-owned asset (BMN) governance. Existing applications of EE-IO largely focus on sectoral emissions, consumption-based accounting, or specific projects, and do not explicitly link public asset management activities and government fiscal operations to economy-wide carbon emission multipliers. As a result, the environmental consequences of managing state-owned assets (BMN) remain largely invisible within prevailing policy, fiscal, and analytical frameworks.

This gap is particularly consequential in Indonesia, where state-owned assets (BMN) represent a substantial component of public capital formation and infrastructure delivery. Without an analytical framework capable of tracing both direct and indirect emissions, policymakers lack systematic tools to reposition public asset governance as an instrument of climate mitigation rather than a passive contributor to emissions.

This study explicitly addresses this research gap by developing an analytical framework grounded in Environmentally Extended Input-Output analysis to systematically quantify both direct and indirect carbon emissions associated with the operational management of state-owned assets (BMN) in Indonesia. Accordingly, this study is guided by the following

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research question: How can an Environmentally Extended Input-Output framework be operationalized to measure the direct and indirect carbon emissions embedded in the management of Indonesia's state-owned assets? The novelty of this research lies in integrating EE-IO methodology into the domain of public asset governance, an area that has received limited empirical attention in existing literature. Unlike prior studies that focus on individual construction projects, private-sector assets, or isolated economic sectors, this study conceptualizes state-owned assets (BMN) as an economy-wide emission driver and a strategic public-sector policy instrument. By doing so, the study provides a data-driven foundation for emission-informed budgeting, climate-conscious asset governance, and sustainable infrastructure planning, while strengthening Indonesia's alignment with SDG 9 (Industry, Innovation, and Infrastructure) and SDG 11 (Sustainable Cities and Communities), as well as its commitments under the Paris Agreement.

METHODS

This study employs three datasets to construct an analytical framework for measuring the environmental impact—particularly carbon emissions—associated with the management of state-owned assets (BMN) using the Environmentally Extended Input-Output approach. The first dataset is the Input-Output (IO) Table of Domestic Transactions at Producer Prices, published by Statistics Indonesia (BPS) (BPS, 2021). This IO table provides detailed information on inter-industry linkages across the Indonesian economy, covering 52 industrial sectors. At the time this study was conducted, the most recent available IO table was from 2016. Despite its time lag, the 2016 IO table remains the authoritative representation of Indonesia's inter-sectoral economic structure and is widely used in applied input-output and environmental-economic studies.

The second dataset is sector-specific greenhouse gas (GHG) emission intensity data published by BPS in 2022 (BPS, 2024), which reports carbon dioxide (CO_2) emission intensities for seven aggregated industrial sectors. Emission intensity is defined as the ratio of total sectoral CO_2 emissions to total sectoral output and serves as the environmental extension of the IO framework. The third dataset is government electricity expenditure related to state-owned asset (BMN) operations, obtained from audited State Budget (APBN) records published by the Ministry of Finance. Electricity expenditure is treated as final demand directed to the electricity sector within the input-output table. This expenditure represents operational spending on energy consumption for state-owned assets (BMN) and serves as the entry point for linking state-owned assets (BMN) management activities to the input-output framework.

To ensure compatibility between the 52-sector IO table and the seven-sector emission intensity dataset, the IO sectors are aggregated into seven composite sectors following the International Standard Industrial Classification (ISIC) Revision 4. This harmonization step, while reducing sectoral granularity, is commonly applied in EE-IO studies. It enables consistent integration of economic and environmental data while preserving inter-sectoral linkages. The detailed sectoral mapping is provided in the Appendix.

Carbon emissions associated with state-owned assets (BMN) operations are estimated using an EE-IO framework adapted from Miller and Blair (2009) to estimate both direct and indirect emissions. The calculation steps are explained as follows.

The technical coefficient t_{ij} is calculated for each sector in the 2016 IO table. It represents the amount of input from sector i required to produce one unit in sector j.

$$t_{ij} = \frac{v_{ij}}{y_j} \quad (1)$$

where v_{ij} denotes the amount of input from sector i used by sector j, and y_j represents the total output of sector j. All technical coefficients t_{ij} are then organized into a technical coefficient matrix T as shown in Equation 2:

$$T = \begin{bmatrix} t_{11} & \cdots & t_{1n} \\ \vdots & \ddots & \vdots \\ t_{n1} & \cdots & t_{nn} \end{bmatrix} \quad (2)$$

The total output y is then calculated by incorporating the final demand d using the following expression derived from the Leontief Input-Output model:

$$y = (I - T)^{-1}.d \quad (3)$$

where I denotes the identity matrix and $(I - T)^{-1}$ is the Leontief Inverse, which captures the total requirements needed to satisfy final demand.

Next, the greenhouse gas emission intensity data by sector are obtained from BPS (2022). These data are then integrated into the model in the form of a matrix E, where each element e_n represents the amount of carbon emissions generated per unit of output in sector n.

$$E = \begin{bmatrix} e_1 \\ \cdots \\ e_n \end{bmatrix} \quad (4)$$

Finally, the carbon emission multiplier is calculated to identify the total impact of an increase in final demand on carbon emissions—capturing both direct and indirect effects across all sectors in the economy. This multiplier is derived by multiplying the emission intensity matrix E by the Leontief Inverse matrix $(I - T)^{-1}$, as expressed in Equation 5.

$$M = E\,.(I - T)^{-1} \quad (5)$$

Each element in matrix M reflects the total amount of carbon emissions, both direct and indirect, generated per unit increase in output in the respective sector.

In this study, state-owned assets (BMN) related activities are operationalized through government expenditure on electricity consumption associated with the operation of state-owned assets. By mapping electricity spending to final demand in the EE-IO model, the framework captures both direct emissions from electricity generation and indirect emissions embodied in upstream supply chains, providing an empirical basis for assessing the carbon externalities from the operational phase of state-owned assets (BMN) management.

The focus on electricity expenditure reflects current data availability and serves as an initial operational entry point for integrating state-owned assets (BMN) management into

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an EE-IO framework. Comprehensive and standardized data covering the full lifecycle of state-owned assets (BMN)—including construction, maintenance, procurement, and asset disposal—remain limited; therefore, electricity consumption is used as a demonstrative case to develop and test the analytical framework. The resulting model functions as a proof of concept and is designed to be scalable, allowing future research to incorporate more detailed and disaggregated state-owned assets (BMN) expenditure components as data availability and classification systems improve.

RESULTS AND DISCUSSION

Using the Environmentally Extended Input-Output (EE-IO) model, this analysis estimates carbon emission multipliers for Indonesia's major economic sectors (Table 1 and Figure 2). The Electricity and Gas Supply sector (Sector D) records the highest multiplier at 4,919.05 tons CO_2 per billion Rupiah, implying that each additional billion Rupiah of output generates nearly 5,000 tons of economy-wide emissions. This reflects both its high direct emission intensity—driven largely by fossil-fuel-based power generation—and its strong inter-sectoral linkages, as electricity functions as a universal intermediate input for manufacturing, transport, construction, and other activities.

Table 1. Carbon Emission Multiplier and Direct Intensity by Sector

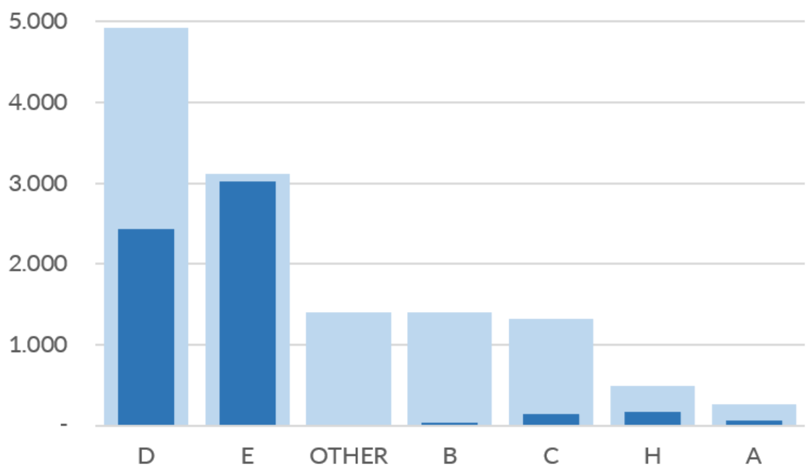
No.	Sector	*(ton CO2 per billion rupiah)*	
		Multiplier Effect	Carbon Intensity
1	A: Agriculture, Forestry, and Fishing	**260.79**	60.20
2	B: Mining and Quarrying	**1,400.23**	34.10
3	C: Manufacturing	**1,322.28**	142.20
4	D: Electricity and Gas Supply	**4,919.05**	2,426.30
5	E: Water Supply, Sewerage, Waste Management, Wastewater, and Remediation Activities	**3,110.01**	3,023.50
6	H: Transportation	**494.02**	166.50
7	OTHER: Other Industries	**1,401.55**	3.70

Carbon emission multiplier effect and direct carbon intensity across seven aggregated economic sectors in Indonesia. Source: Author's calculation based on EE-IO.

The Water Supply, Sewerage, Waste Management, and Remediation sector (Sector E) follows with a multiplier of 3,110.01 tons CO_2 per billion Rupiah, with a substantial share arising from direct emissions, consistent with the energy-intensive nature of treatment and processing activities. The remaining sectors exhibit considerably lower multipliers, indicating that carbon externalities are concentrated in a limited number of structurally critical sectors. This concentration suggests that decarbonization efforts—particularly within state-managed infrastructure and service provision—would yield greater marginal impact if focused on these high-multiplier sectors.

Table 1 further reveals notable discrepancies between direct emission intensity and total multipliers. The Mining and Quarrying sector (Sector B), for example, shows relatively low direct intensity (34.10 tons CO_2 per billion Rupiah) but a high total multiplier (1,400.23 tons CO_2), reflecting its upstream role in supplying carbon-intensive downstream industries. A similar pattern appears in Other Industries, where low direct intensity (3.70 tons CO_2) corresponds to a multiplier of 1,401.55 tons CO_2. These results indicate that Indonesia's carbon structure is shaped not only by emission-intensive sectors but also by upstream enablers embedded within supply chains. The Electricity and Gas Supply sector is distinctive in combining both high direct intensity and strong inter-sectoral transmission effects. Overall, the multiplier framework demonstrates that reliance on direct emission metrics alone would underestimate the true carbon footprint of economic activities.

Figure 2. Comparison of Direct and Total Carbon Emission Effects by Sector (ton CO2 per billion Rupiah)



This figure compares the direct carbon emission intensity with the total carbon emission multiplier across major economic sectors, illustrating the role of indirect emissions transmitted through inter-sectoral linkages. **Source:** Author's calculation based on EE-IO

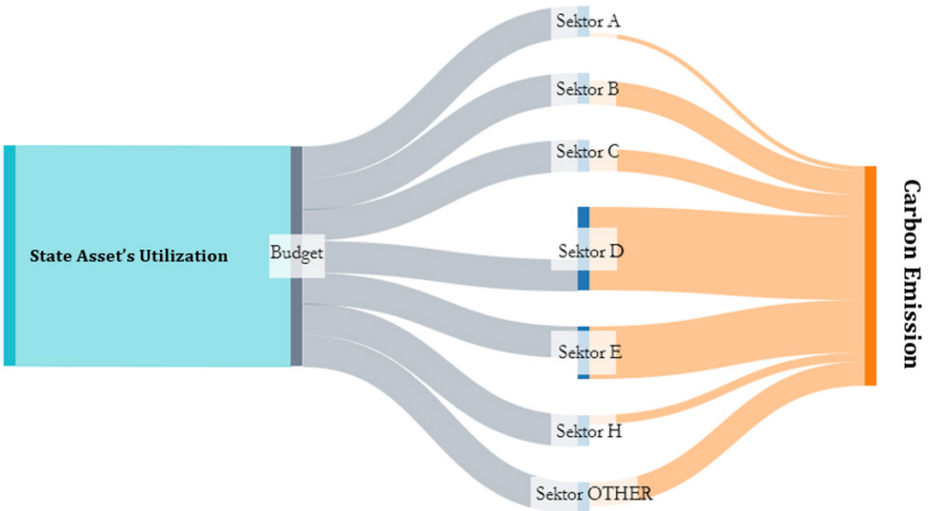
To operationalize the EE-IO framework within public asset governance, this study examines electricity consumption in the operations of state-owned assets (BMN). Given its highest emission multiplier, the Electricity and Gas Supply sector serves as the empirical entry point. According to the 2024 Audited Central Government Financial Statement (LKPP), the central government allocated IDR 5,776.78 billion to electricity expenditure. Applying the sectoral multiplier of 4,919.05 tons CO_2 per billion Rupiah yields an estimated 28.42 million tons of CO_2 emissions.

This estimate reveals a substantial environmental burden embedded in the routine operations of state-owned assets (BMN). Electricity spending—typically treated as an administrative cost—constitutes a significant channel of economy-wide emissions, capturing indirect and upstream effects that remain absent from conventional fiscal reporting. Electricity consumption, therefore, emerges as both an emissions hotspot and a strategic leverage point for mitigation. Improvements in energy efficiency, cleaner energy sourcing, and optimized asset utilization could yield meaningful reductions in emissions across public infrastructure systems. While the estimate does not represent the full lifecycle carbon footprint of state-owned assets (BMN), its magnitude demonstrates that operational expenditures alone can carry significant environmental externalities when assessed through an economy-wide perspective.

The empirical findings are consistent with—and extend—recent EE-IO applications emphasizing indirect and supply-chain-induced emissions in national carbon accounting (Demeter et al., 2021). While prior studies focus on consumption-based emissions, embodied trade flows, or sectoral decarbonization (Amheka et al., 2022; He & Hertwich, 2019; Irfany & Klasen, 2017; Martinez et al., 2022), this study situates EE-IO analysis within public asset governance. It demonstrates that state-owned assets (BMN) function not merely as administrative entities but as structural contributors to economy-wide carbon emissions.

The carbon emission multipliers derived from the EE-IO model provide a practical basis for quantifying environmental externalities associated with the management of state-owned assets (BMN). By linking BMN-related government expenditure to aggregated economic sectors, both direct and indirect emissions can be systematically traced (Figure 3), illustrating how routine fiscal decisions translate into broader economy-wide impacts. Unlike project-level LCA studies that assess emissions at the level of individual buildings or infrastructure assets (Bakindi et al., 2025; Kumar et al., 2025), the EE-IO-based framework developed in this study captures emissions propagated through complex inter-sectoral supply chains. This distinction is particularly relevant for public asset management, where operational decisions—such as electricity consumption—have system-wide emission implications that extend beyond the physical boundaries of individual assets.

Figure 3. Carbon Emission Mapping Framework from State-Owned Assets (BMN) Utilization



This figure illustrates the analytical framework used to trace carbon emissions arising from state-owned assets (BMN) utilization through government budget expenditures. BMN-related operational spending is mapped to seven aggregated economic sectors (A–H and OTHER) within the EE-IO structure, enabling the estimation of both direct and indirect carbon emissions transmitted through inter-sectoral linkages. The framework demonstrates how public asset utilization translates into economy-wide environmental externalities and provides a methodological pathway for integrating carbon accountability into public asset governance.

Source: Author's visualization based on EE-IO model integration.

The dominance of the Electricity and Gas Supply sector aligns with regional EE-IO findings identifying power generation as a primary driver of economy-wide emissions (Amheka et al., 2022; Irfany & Klasen, 2017). This study extends that insight by showing that electricity demand from state-owned assets (BMN) operations constitutes a significant transmission channel of carbon emissions. Similarly, the high multiplier observed in water and waste-related services corresponds with infrastructure-focused EE-IO evidence highlighting substantial indirect emissions in operational services (Martinez et al., 2022).

This framework represents an initial operationalization rather than a full lifecycle assessment of state-owned assets (BMN). Comprehensive tracing across construction, procurement, maintenance, and disposal would require more detailed disaggregation of the State Budget (APBN) and sectoral mapping. Electricity expenditure is therefore used as a strategic entry point due to data availability and its central operational role. Nevertheless, the framework is scalable. With more granular budget data and refined sectoral classification, it can be extended to estimate the full lifecycle carbon footprint of state-owned assets (BMN) management. Beyond empirical estimation, the study establishes a methodological pathway that renders visible the carbon implications of public asset utilization—an area traditionally treated as environmentally neutral within fiscal and administrative systems.

The scale of operational emissions associated with electricity consumption reveals a largely invisible carbon footprint embedded in state governance. Although categorized as routine administrative expenditures, these emissions are substantial when evaluated through an EE-IO lens. This "hidden" carbon burden reflects a critical institutional blind spot that is increasingly incompatible with global climate commitments (Bocken & Short, 2021).

This finding resonates with recent studies on public sector sustainability, which argue that government operations themselves constitute a significant and under-recognized source of emissions (Kaur et al., 2023). While the existing literature emphasizes industrial decarbonization and household consumption (He & Hertwich, 2019; Irfany & Klasen, 2017), this study highlights the environmental significance of the routine operations of state-owned assets (BMN). Addressing this gap requires integrating mitigation considerations into the budget cycle, beginning at the planning stage (Focardi & Fabozzi, 2020). By mapping BMN-related expenditures to aggregated EE-IO sectors, potential carbon impacts can be estimated before allocations are finalized (Demeter et al., 2021). Such emission-linked budgeting introduces a new layer of transparency into public finance. Beyond tracking financial allocations, it enables policymakers to assess the environmental implications of program design and implementation (Kaur et al., 2023). This is particularly relevant in the context of state-owned assets (BMN) governance, where decisions on asset utilization, renovation, and operational intensity directly shape long-term emission trajectories.

More importantly, this framework creates the conditions for strategic intervention. Ministries associated with high projected emissions can be required to adopt mitigation

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measures—such as energy efficiency upgrades or renewable energy integration—while low-carbon operational practices can be incentivized. In this way, climate objectives become embedded within fiscal decision-making rather than treated as external compliance requirements (Bocken & Short, 2021). This integration represents a structural shift in public sector governance, aligning public expenditure with national climate targets and supporting the management of low-carbon infrastructure (Bocken & Short, 2021; Kaur et al., 2023).

Emission-Based Performance Indicators (EPIs) provide a complementary mechanism for operationalizing carbon accountability in the governance of state-owned assets (BMN). Unlike conventional metrics focused solely on budget absorption or output delivery, EPIs assess the environmental efficiency of public operations (Bocken & Short, 2021). Using EE-IO–derived emission multipliers, ministries can establish baseline carbon performance and monitor changes over time (Demeter et al., 2021). Performance can then be evaluated in terms of emissions per unit of output or budget, reorienting bureaucratic incentives toward lower-carbon service delivery—"doing better with less carbon" (Kaur et al., 2023). EPIs also strengthen cross-ministerial coherence. Ministries achieving sustained emission reductions can be recognized through evaluation mechanisms or sustainability-linked incentives. Over time, these indicators can be embedded into routine monitoring frameworks, reshaping how performance is defined and assessed in the public sector (Bocken & Short, 2021).

Integrating EPIs into state-owned assets (BMN) governance, therefore, constitutes an institutional innovation: it aligns administrative accountability with long-term sustainability objectives and embeds carbon considerations within governance structures (Bocken & Short, 2021; Kaur et al., 2023).

The application of the Environmentally Extended Input-Output (EE-IO) model demonstrates its potential as a decision-support tool for environmentally accountable public asset governance (Demeter et al., 2021). By linking state-owned assets (BMN) expenditures to sectoral carbon emission multipliers, the framework quantifies both direct and indirect environmental impacts arising from asset operations, consistent with broader EE-IO applications in infrastructure and public systems (Amheka et al., 2022; Martinez et al., 2022).

To ensure upstream integration, carbon accounting should be embedded within the budget planning cycle. Because government expenditures can be mapped to the aggregated EE-IO sectors, ministries can estimate projected carbon impacts at the program design stage. This enables emission-informed budgeting, where allocation decisions consider environmental performance alongside financial efficiency (Kaur et al., 2023). In parallel, Emission-Based Performance Indicators (EPIs) can complement conventional fiscal and output metrics. By monitoring carbon intensity per unit of service or expenditure, EPIs embed environmental efficiency into routine performance management and strengthen sustainability-oriented accountability (Bocken & Short, 2021). Furthermore, when state-owned assets (BMN) are utilized to generate non-tax state revenue (PNBP), a portion of this income may be earmarked for mitigation measures, such as renewable energy deployment or energy-efficiency retrofits. This helps internalize environmental externalities and align revenue generation with climate objectives.

It is important to acknowledge the limitations of this study's scope. The present analysis operationalizes state-owned assets (BMN) related emissions through electricity expenditure as a demonstrative case and relies on a seven-sector aggregation of the Indonesian input-output table due to data compatibility constraints. While consistent with EE-IO practice, this masks intra-sectoral variation. Future research should therefore (i) disaggregate State Budget (APBN) data to enable full lifecycle mapping of BMN-related activities, and (ii) utilize higher-resolution input-output and emission datasets as they become available. Collectively, these steps would strengthen Indonesia's transition toward carbon-conscious public asset governance and reinforce alignment with national climate commitments, advancing the achievement of SDG 9 and SDG 11, as well as Indonesia's commitments under the Paris Agreement (Bocken & Short, 2021).

CONCLUSION

This study answers the research objective by demonstrating that the environmental externalities of state-owned assets (BMN) management can be systematically measured using an Environmentally Extended Input-Output (EE-IO) framework. By integrating sectoral emission intensities, inter-industry linkages, and government expenditure data, the analysis captures both direct and indirect carbon emissions associated with public asset operations. The results show that electricity-related activities represent a major carbon hotspot, and that several sectors with low direct emission intensity generate substantial indirect emissions through supply chains. This result confirms that multiplier-based approaches are essential for accurately assessing the carbon responsibility embedded in the utilization of state-owned assets (BMN).

Based on these findings, this study proposes three policy-relevant implications. First, carbon accounting should be integrated into the budget planning process through emission-informed budgeting, enabling ministries to anticipate the carbon consequences of state-owned assets (BMN) related expenditures at the planning stage. Second, emission-based performance indicators can complement existing fiscal and output metrics, strengthening accountability for emission-intensive public asset operations. Third, in cases where state-owned assets (BMN) utilization generates non-tax state revenue, a portion of this revenue should be earmarked for carbon mitigation measures, such as energy efficiency improvements, renewable energy adoption, or offset mechanisms linked to public asset operations. These measures provide a practical pathway for embedding carbon accountability into public asset governance, repositioning state-owned assets (BMN) management as a strategic instrument for climate mitigation, and aligning fiscal operations with Indonesia's commitments under the Paris Agreement and the achievement of SDG 9 and SDG 11.

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APPENDIX

Aggregated Input-Output Sectors

Aggregated EE-IO Code	EE-IO Sector	IO Code*
A	Agriculture, Forestry, and Fishing	I-01 - I-07
B	Mining and Quarrying	I-08 - I-11
C	Manufacturing	I-12 - I-27
D	Electricity and Gas Supply	I-28 - I-29
E	Water Supply, Sewerage, Waste Management, Wastewater, and Remediation Activities	I-30
H	Transportation	I-34 - I-39
OTHER	Other Industries	I-31 - I-33 and I-40 - I-52

*Sector descriptions follow the 52-sector BPS (2021) Input–Output classification. Aggregation is conducted to ensure compatibility with sectoral emission data.

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