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Decarbonizing Infrastructure in Indonesia: Opportunities, Barriers, and Stakeholder Perspectives

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ABSTRACT

Infrastructure development is a major driver of climate change, accounting for ~79% of global greenhouse gas (GHG) emissions and 88% of adaptation costs since 2022. In Indonesia, emissions are led by the energy sector (31%), which remains coal-dependent for power infrastructure operations. Other contributors include transport (17%), wastewater (8%), solid waste (5%), and process emissions from cement (5%) and iron–steel (6%). While the country has rapidly expanded roads, ports, airports, and dams, these gains have coincided with deforestation and reduced carbon sequestration. This study investigates barriers and stakeholder aspirations for decarbonizing Indonesia's infrastructure by applying a 5M business management lens—material and machine, methodology, money, and manpower—aligned with four decarbonization pillars (reduce, reuse, replace, remove), using evidence from focus group discussions, desktop reviews, and inductive analysis. Findings identify four principal barriers: (i) materials and technology—uptake of low-carbon options is constrained by cost perceptions and limited use of recycled inputs; (ii) standards and regulation—fragmented guidance and weak enforcement of green procurement; (iii) cost and funding—high certification expenses and underdeveloped green finance instruments; and (iv) skills and capabilities—insufficient technical expertise in low-carbon practices. Stakeholders call for systematic material mapping, stronger tax incentives, adoption of harmonized standards, and deeper academia–industry collaboration. The study proposes a policy roadmap to coordinate actors and accelerate infrastructure decarbonization.

Keywords: Climate Policy Integration; Greenhouse Gas Emissions; Infrastructure Decarbonization

ABSTRAK

Pembangunan infrastruktur merupakan salah satu kontributor utama perubahan iklim, dengan menyumbang 79% emisi Gas Rumah Kaca (GRK) global dan 88% biaya adaptasi sejak tahun 2022. Di Indonesia, emisi didominasi sektor energi (31%) yang masih bergantung pada batu bara untuk operasional infrastruktur. Kontributor lain meliputi transportasi (17%), air limbah (8%), sampah padat (5%), serta emisi proses dari industri semen (5%) dan besi–baja (6%). Ekspansi pesat jalan, pelabuhan, bandara, dan bendungan berlangsung bersamaan dengan deforestasi dan turunnya penyerapan karbon. Studi ini menelaah hambatan dan aspirasi pemangku kepentingan dalam dekarbonisasi infrastruktur Indonesia. Analisis menggunakan kerangka manajemen "5M"—material dan mesin, metodologi, uang, serta tenaga kerja—yang disejajarkan dengan empat pilar dekarbonisasi (reduce, reuse, replace, remove), berdasarkan diskusi kelompok terarah, telaah pustaka, dan analisis induktif. Temuan mengidentifikasi empat hambatan utama: (i) material dan teknologi—adopsi opsi rendah karbon terbatasi persepsi biaya dan rendahnya pemanfaatan material daur ulang; (ii) standar dan regulasi—panduan yang terfragmentasi serta lemahnya penegakan pengadaan hijau; (iii) biaya dan pendanaan—tingginya biaya sertifikasi dan belum berkembangnya instrumen pembiayaan hijau; dan (iv) keterampilan dan kapasitas—kurangnya keahlian teknis praktik rendah karbon. Para pemangku kepentingan mendorong pemetaan material, penguatan insentif pajak, adopsi standar yang terharmonisasi, dan kolaborasi akademia–industri yang lebih erat. Sebagai kontribusi praktis, studi ini mengajukan peta jalan kebijakan untuk menyinergikan aktor dan mempercepat dekarbonisasi infrastruktur.

Kata Kunci: Dekarbonisasi Infrastruktur; Emisi Gas Rumah Kaca, Integrasi kebijakan iklim

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INTRODUCTION

Infrastructure is one of the largest contributors to global greenhouse gas (GHG) emissions, accounting for approximately 79% of total emissions and 88% of all climate change adaptation costs since 2022 (Owotemu, 2025). Despite increasing global commitments to decarbonization, only 60% of infrastructure assets worldwide currently have GHG reduction targets that align with net-zero goals.

In Indonesia, the role of infrastructure in emissions is particularly significant, with around 80% of non-FOLU (Forestry and Other Land Use) emissions originating from infrastructure-related sectors. The energy sector, primarily dominated by coal-based power generation, contributes the largest share (31%), followed by transport (17%), waste management (13%), and industrial processes, such as cement and steel production (11%) (Hendri et al., 2022). These emissions have already exacerbated environmental vulnerabilities across the country, including sea-level rise, declining rainfall, extreme temperature increases, and land subsidence.

With a real GDP growth of 5.0% (World Bank, 2024) and a 5.12% year-over-year increase in Q2 2025, Indonesia, the largest economy in Southeast Asia, has maintained consistent economic growth in recent years, indicating sustained economic momentum into 2025. These recent macroeconomic conditions highlight Indonesia's dual challenge: maintaining infrastructure-driven growth while coordinating investment and policy decisions with ambitious climate and decarbonization targets. The International Monetary Fund (2025) also expects that these factors will continue to be generally positive.

To prevent the lock-in of high-carbon assets, it is crucial to align procurement, standards, and financing instruments with climate goals as public and private funds flow into infrastructure projects. These macroeconomic developments support the opportunity and urgency of directing infrastructure investment into low-carbon pathways.

To address these pressures, the Indonesian government has submitted its Enhanced Nationally Determined Contribution (ENDC), pledging to reduce emissions by 31.89% through domestic measures or up to 43.20% with international support, by 2030 (Puteri, 2024). The majority of reductions are expected to come from the forestry and energy sectors, while contributions from waste and industry remain comparatively modest. In parallel, Indonesia is preparing its Second NDC (SNDC), scheduled for 2025, which will introduce updated baselines and targets, with the overarching objective of peaking emissions before 2030.

In alignment with its Net Zero Emissions (NZE) aspiration by 2060—or earlier, contingent on enabling conditions—the government launched the Long-Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR) 2050 (Fitriana et al., 2024). This strategy sets gradual emission reduction pathways for high-emitting industries, e.g., cement and steel, with interventions including the adoption of blended cement, advanced manufacturing technologies, and circular economy practices.

In parallel to policy commitments, Indonesia has experienced unprecedented infrastructure expansion over the past decade, constructing hundreds of thousands of kilometers of roads, multiple new ports and airports, and large-scale water facilities (McCawley, 2015). While these investments have been vital for economic development and connectivity, they have also caused considerable environmental costs. For example, emissions from precast building materials can reach up to 283 $kgCO_2e$ per square meter (Atmo et al., 2017). These trade-offs highlight the need to integrate environmental safeguards and decarbonization strategies directly into infrastructure planning and implementation.

Recent institutional initiatives indicate a shift toward mainstreaming sustainability. The Ministry of Finance, supported by KIAT, launched the ESG Framework and Manual in 2022 (updated in 2024), designed to strengthen project preparation, enhance environmental and social co-benefits, and improve governance mechanisms (Pambudi et al., 2023; Setyowati, 2023). The framework aims to expand access to green financing and blended finance opportunities by aligning projects with global Environmental, Social, and Governance (ESG) standards.

Although Indonesia has yet to establish explicit regulatory targets for infrastructure decarbonization, the Ministry of Public Works has introduced a Roadmap for Implementing Sustainable Construction (2025–2030). The plan is guided by three main principles: boosting the economy, safeguarding the environment, and promoting social equity. By placing decarbonization firmly within the environmental pillar, the roadmap guarantees that reducing carbon emissions is an automatic and integrated consideration throughout infrastructure development (Owojori & Erasmus, 2025)

Within such a context, this study elaborates on how infrastructure decarbonization is developing in Indonesia. Our specific aim is to identify the main challenges to implementation and gather input from key stakeholders. This approach will help craft practical and shared solutions. Pushing decarbonization forward in infrastructure is critical not only for achieving Indonesia's national emission reduction goals but also for maintaining its nation's role in the global fight against climate change.

LITERATURE REVIEW

An increasing body of research suggests that decarbonizing infrastructure extends beyond the adoption of new technologies. It primarily requires driving systemic change by integrating governance, financing mechanisms, and regulatory frameworks (Geels, 2002; Geels et al., 2017; Jordan & Huitema, 2014). Recent studies evaluating emerging economies, which rely heavily on public infrastructure spending, emphasize that institutional resistance, lack of governance coordination, and conflicting policies are significant obstacles to low-carbon transitions (Anguelov, 2024; Owojori & Erasmus, 2025).

Cutting Carbon in Infrastructure: A Look at Global and Indonesian Strategies

The infrastructure sector plays a significant role in economic development; yet, it is also a main source of environmental degradation. Given that it contributes nearly 79% of global GHG emissions and requires 88% of climate adaptation spending, its actions are very critical in determining the world's climate future. The urgency to decarbonize this sector is grounded in climate mitigation theory, which argues that early interventions yield long-term economic and ecological dividends by reducing the costs of delayed action (Stern & Taylor, 2007). Within this framework, decarbonization transcends beyond technological or financial efforts; it is a matter of strategic foresight.

In Indonesia, the tension between infrastructure-driven growth and emission reduction targets is particularly pronounced. Infrastructure-related sectors, including energy, transportation, waste, and industry, are responsible for roughly 80% of national non-FOLU emissions. The dominance of coal-fired power plants places the energy sector at the core of Indonesia's mitigation challenge, while transport, waste, and industrial processes add significant pressure.

To address the above issues, Indonesia has articulated its Enhanced Nationally Determined Contribution (ENDC), targeting 43.20% reduction in emissions with international support, and has further committed to achieving Net Zero Emissions by 2060 or earlier. These institutional commitments reflect climate governance theory, which highlights the need for coordination across multiple levels of government, sectors, and stakeholders to address complex, cross-sectoral environmental challenges (Jordan & Huitema, 2014). Together, the NDCs and the Long-Term Strategy for Low Carbon and Climate Resilience (LTS-LCCR 2050) embody Indonesia's efforts to balance developmental priorities with climate responsibility.

Analytical Framing: Integrating the 5M Framework as a Diagnostic Business Lens and the Four Decarbonization Principles

The 5M framework (Manpower, Materials, Machines, Methods, Measurement) serves as an effective managerial tool for locating operational bottlenecks in infrastructure projects. This paradigm links operational issues at the micro level with policies at the macro level when mapped against the four decarbonization pillars: reduce, reuse, replace, and eliminate. The framework employs specific terms like "replace" (substituting carbon-intensive materials), "decrease" (improving efficiency), "reuse" (circular processes), and "remove" (carbon capture or offsets). Combining these with the decarbonization pillars allows for a complete evaluation of technological, institutional, and behavioral barriers. Studies confirm that construction and Public-Private Partnership (PPP) projects often fail due to interconnected challenges in these non-technical areas, rather than technological deficiencies (Atmo et al., 2017; Roshdi et al., 2023).

Although global agreements set the goals, the implementation of decarbonization requires specialized diagnostic tools to pinpoint specific roadblocks at the project level. To meet this need, the present study employs the 5M Framework, which encompasses Material & Machine, Method, Money, and Manpower. This framework is borrowed from classic literature on operations and quality management which is traditionally used to systematically identify sources of inefficiency and error in industrial processes (Roshdi et al., 2023). In the context of sustainable infrastructure, the framework is adapted to

reveal the interplay between organizational, technical, and financial factors that hinder decarbonization efforts.

For example, constraints related to “Material & Method” may manifest through outdated contract specifications that continue to mandate the use of high-carbon materials, or through entrenched cost perceptions that regard low-carbon alternatives as prohibitively expensive. Meanwhile, “Manpower” constraints arise from insufficient technical expertise and the absence of certification systems that validate low-carbon competencies. “Money,” as a category, captures the persistent financing gaps that discourage investment in green infrastructure, while “Machine” refers to technological obsolescence and the limited dissemination of advanced, low-emission construction technologies.

By categorizing barriers in this manner, the 5M framework not only systematically diagnoses problems but also suggests tailored solutions. For example, it might identify the need for capacity-building efforts under “Manpower” or recommend specific procurement reforms under the “Method” category.

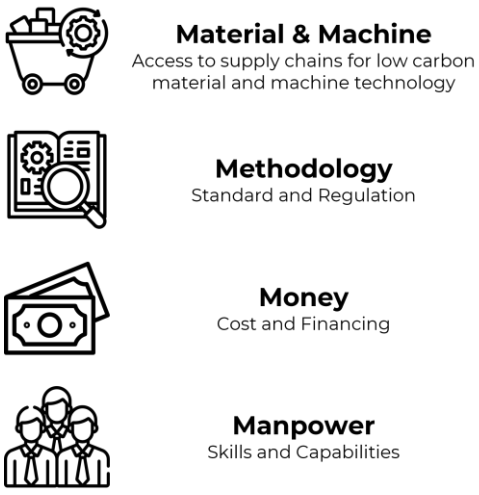

Figure 1. 5M’s Project Management Framework for Barrier Classification

Circular Economy and the 4Rs of Decarbonization

The 5M framework is complemented by the circular economy, which serves as a theoretical lens offering a systems-level view of resource efficiency. At its heart, the circular economy rejects the traditional, wasteful "take-make-dispose" approach. Instead, it promotes closed-loop processes designed to cut down on waste and retain the maximum value from materials. To put this into practice for decarbonization, this study adopts the “4Rs” as its guiding principles: Reduce, Reuse, Replace, and Remove (Geissdoerfer et al., 2017). Each of these strategies offers a method to lower the carbon intensity of infrastructure. Specifically, “Reduce” emphasizes minimizing the consumption of raw materials and energy; “Reuse” focuses on extending the lifespan of materials like steel and concrete; “Replace” encourages substituting carbon-heavy inputs with sustainable alternatives (such as blended cements); and “Remove” highlights the need to phase out dependence on fossil fuels.

Circular economy practices in Indonesia are still in the very early stages. Currently, regulatory systems do not offer sufficient incentives for the recycling of construction materials, and technological limitations restrict the use of innovative replacement materials. Despite these hurdles, examples from other places prove that progress is achievable. For instance, Thailand’s zero-OPC cement policy sets a regional standard for effective regulatory action, while the European Union’s Circular Economy Action Plan shows how harmonized policies can successfully guide transitions across entire sector (Korhonen et al., 2018; Kurniawan et al., 2024). Taken together, these examples demonstrate that the 4Rs can function as both a theoretical basis and a practical roadmap for Indonesia’s efforts to achieve decarbonization.

Recent trends underscore the vital role of circular economy concepts in infrastructure planning. The circular economy, as defined by researchers like Geissdoerfer et al. (2017) and Korhonen et al. (2018), is a systemic model aimed at boosting resource efficiency and drastically cutting waste throughout a project's life cycle. By incorporating these ideas into the 5M method, we can connect project-level management with sustainability policies, thereby strengthening the analytical capacity of decarbonization frameworks.

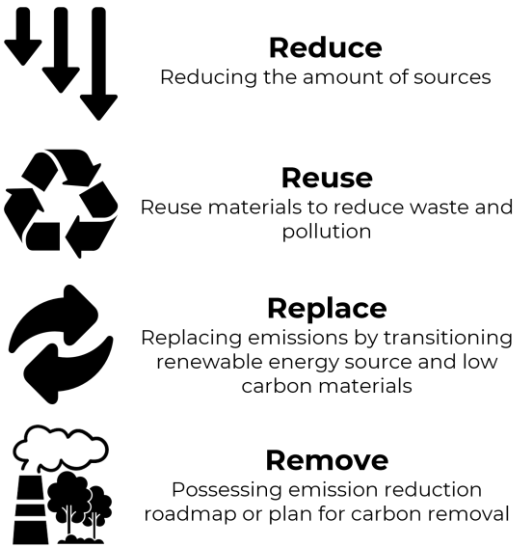

Figure 2. 4R' Decarbonization Strategies for Initial Approach

Public-Private Partnership (PPP) and Institutional Economics

In Indonesia, Public-Private Partnerships (PPPs) are becoming an increasingly prevalent mechanism to fund and deliver infrastructure projects. These arrangements are heavily influenced by institutional economics, which emphasizes that transaction costs, incentive structure design, and clear regulations ultimately determine a project's success (Chou & Leatemia, 2016). When it comes to green infrastructure, PPPs encounter unique obstacles. The need for complicated certification and fragmented approval processes leads to high transaction costs. At the same time, vague financing mechanisms create uncertainty for investors. These inefficiencies stem from weak institutional arrangements and unequal access to information (information asymmetries), which are key concerns in New Institutional Economics.

Despite the challenges, PPPs create opportunities to integrate decarbonization goals directly into the project contracts. For example, by linking emission reduction metrics to performance indicators, these agreements can better align incentives, lower agency costs, and boost accountability (Akomea-Frimpong et al., 2022). Furthermore, using risk-sharing tools—such as government guarantees or viability gap funding—could reduce the perceived risks for private investors, ultimately unlocking more green capital. Thus, institutional economics is valuable because it both explains current weaknesses and provides a guideline for designing more effective PPPs that are better aligned with climate goals.

Skills Gap and Human Capital Theory

A lack of skilled human resources is a significant barrier to developing low-carbon infrastructure, alongside financial and institutional challenges. According to human capital theory, investing in people, through education and training, leads directly to innovation and productivity. For the infrastructure sector, this means we urgently need to embed sustainability skills across all levels of professional development, from engineering schools to vocational programs, to create a competent green workforce.

However, in Indonesia, this integration of skills is still limited. Major professional organizations like BNSP and LPJK have not fully incorporated climate-related competencies into their official certification standards. Consequently, many engineers and

contractors lack the necessary training to adopt advanced materials, energy-efficient design, and digital tools needed for low-carbon construction (Gui et al., 2024). Bridging this skills gap requires coordinated efforts among educators, industry groups, and government bodies. Furthermore, the human capital perspective suggests that such investments will deliver more than just environmental benefits; a better-skilled workforce will also boost innovation, cut project costs, and enhance Indonesia's competitiveness in both regional and global markets.

Climate Finance and Risk Mitigation Frameworks

Ultimately, securing financing is the determining factor in how rapidly infrastructure can decarbonize. Climate finance theory emphasize the need to find ways to mobilize both public and private capital, typically through instruments, such as bonds, blended finance, and various guarantees (Stoll et al., 2021). Despite their potential, these instruments are underutilized in Indonesia due to market issues, including information gaps, high risk perception, and missing eligibility standards. The risk-return framework clarifies the situation: investors pull back when private partners are forced to take on disproportionate risk without adequate safeguards in place.

Developments such as PT PII's initiative to launch a green guarantee prove that offering de-risking mechanisms successfully boosts project bankability and increases participation from the private sector (Anguelov, 2024). Such instruments can accelerate the flow of investment into low-carbon infrastructure by decreasing uncertainty, enhancing creditworthiness, and lowering capital costs. Achieving Indonesia's decarbonization targets will require a concerted effort to both expand these mechanisms and simultaneously strengthen the regulatory clarity and investors' confidence.

Policy Tools: Focusing on Green Procurement and De-Risking Finance

Green Public Procurement (GPP) is one of the most pivotal demand-side policies for boosting the use of low-carbon products and technologies. Although Indonesia has regulations to support GPP, evidence shows that there are still challenges in setting technological standards, ensuring sufficient institutional capacity, and effectively enforcing compliance (International Institute for Sustainable Development, 2024). The government's purchasing authority cannot successfully direct the market toward sustainable infrastructure solutions in the absence of well-organized procurement procedures. Procurement reform is also essential to institutionalizing low-carbon transitions, according to research conducted in other ASEAN countries (Gui et al., 2024).

Significant financial barriers remain on the supply side. Low-carbon initiatives are sometimes viewed as risky by private investors because of their lengthy payback periods and unpredictable revenue streams. Research on de-risking tactics suggests that first-loss facilities, blended finance, and guarantee systems can mitigate perceived risks and raise private capital (Anguelov, 2024; OECD, 2024). The *Green Infrastructure Investment Opportunities (GIIO) Indonesia Report* illustrates how fiscal incentives and catalytic capital can stimulate private sector engagement in green infrastructure (Climate Bonds Initiative, 2022). The "Methods" and "Measurement" parts of the 5M framework, which focus on the institutional design and performance monitoring, completely align with these processes.

Capacity Building and Measurement Systems

While funding and regulations are vital, the success of infrastructure decarbonization fundamentally depends on human capital and green skills. Research in Southeast Asia indicates persistent deficits in the ability to conduct environmental audits, apply life-cycle assessment (LCA) methods, and effectively manage Measurement, Reporting, and Verification (MRV) systems (Cook et al., 2025; Gui et al., 2024). Without adequate technological capability, policies like GPP and other sustainable procurement rules risk being merely symbolic. To prevent this problem, we need to coordinate investments that close these gaps, specifically in technical training, certification programs, and institutional development for both the people doing the work and the regulators.

Successful decarbonization requires reliable measurement and data transparency. Research confirms this view: Chen et al. (2023) proposed a flow-based carbon accounting system for power grids, showing how detailed emission tracking can lead to better infrastructure planning. In the same vein, Royapoor et al. (2023) illustrated that using digital MRV tools in infrastructure projects boosts accountability and helps meet national climate targets. This evidence confirms the central importance of "Measurement" within the 5M framework.

Recent Technological and Policy Developments (2023–2025)

Recent evaluations have led to a better understanding of decarbonization technologies and how they interact with policy tools. Wang et al. (2025) offer a strategic reference for infrastructure project design by categorizing global decarbonization technologies, such as hydrogen, CCUS, and renewable energy, into discrete routes that align with sectoral settings. In order to achieve substantial decarbonization across the U.S. energy sector, the Annual Review of Environment and Resources (2024) highlights the interdependence of governance reform and technology innovation. This is a useful insight for rising economies such as Indonesia. In the meantime, Soares et al. (2025) emphasize the significance of city-scale decarbonization plans in areas like digital infrastructure, transportation, and building, which reiterate the necessity of cross-sectoral collaboration.

The social aspect of infrastructure changes is further emphasized by Smith et al. (2025), who contend that fair and inclusive methods improve legitimacy and long-term success. To resolve transition impediments, these new insights support adopting frameworks that explicitly connect technological, financial, institutional, and social factors, such as the integrated 5M and decarbonization pillars.

Synthesis and Research Gap

An analytical framework that integrates technical, institutional, financial, and human-capacity viewpoints is necessary for the transition to low-carbon and climate-resilient infrastructure systems. Few studies empirically investigate how operational bottlenecks interact with institutional and policy barriers in actual infrastructure projects, especially in the Indonesian context, regardless the fact that global and regional scholarship offers strong insights into decarbonization technologies, finance, and governance. These issues are often treated separately in existing studies.

This study closes that gap by identifying interconnected impediments across material, institutional, financial, and human-capacity dimensions using an integrated 5M–Decarbonization Pillar framework. This study combines focus groups, in-depth

interviews, and document analysis to provide a multifaceted, grounded understanding of Indonesia's infrastructure decarbonization landscape. Building on the previously discussed concepts and frameworks, this qualitative study investigates the systemic obstacles to decarbonizing Indonesia's infrastructure sector.

METHODOLOGY

The theoretical viewpoints examined in the previous part served as a guide for the research design. The assessment of barriers to decarbonizing infrastructure in Indonesia is structured around a combination of the "5M" business management approach and four interrelated pillars of decarbonization. Using the 5M framework combined with four decarbonization pillars, we assessed barriers across the infrastructure value chain.

The team applied a mixed qualitative design: FGD with the Ministry of Public Works and Housing (MPWH); twelve in-depth interviews over three months (academia, R&D, government, construction/inspection firms, finance/guarantee institutions, and industry associations); and a validation seminar/workshop with >200 participants – from the same respondent categories. The data were transcribed, clustered, coded, and thematically linked and triangulated with policy documents, recent literature, and the validation workshop.

Research Framework

The framework used in this study is structured around four dimensions.

1. The availability of supply chain technology

Our investigation within this pillar addresses two connected challenges. First, we identify barriers to low-carbon technology adoption and propose strategies for boosting energy efficiency, integrating renewables, conserving water, and cutting emissions. Second, we analyze the infrastructure material supply chain—both its current status and areas showing advanced practices. We combine these elements because the supply chain profoundly influences how infrastructure materials are manufactured and used.

2. Standards and regulations

Because the regulatory environment dictates the pace of decarbonization, this part of the analysis focuses on reviewing existing policies and regulations in Indonesia. The goal is to identify enabling conditions required to accelerate the transition to low-carbon infrastructure (Adityawarman et al., 2025). Special consideration is given to harmonizing the technical standards, procurement requirements, and sustainability criteria that apply across the board.

3. Cost and financing

Since economic concerns often decide whether low-carbon practices are viable, this part of the analysis examines funding opportunities for decarbonization. We specifically look at the role of incentive and penalty mechanisms and assess the broader economic impacts of using green materials in infrastructure systems (Madadizadeh et al., 2024). A further goal of the analysis is to determine how well innovative financial mechanisms can overcome the barriers posed by significant initial costs and investor risk perceptions.

4. Skills and capabilities

Decarbonization heavily relies on human resources. This section evaluates the Indonesian workforce's capacity to implement and scale green technologies and materials, while specifically identifying the gaps in training, certification, and technical

know-how. In doing so, the study clarifies the current professional abilities and helps prioritize investments in skill development.

The study applied a mixed qualitative methodology, involving in-depth interviews, Focus Group Discussions (FGDs), desktop reviews, and inductive reasoning, to make the framework operational. Interviews targeted four key stakeholder groups: government bodies, industry professionals and associations, academic and research organizations, and financial institutions and investors. We selected these participants for their specialized knowledge across key domains: workforce capacity, technological access, supply chain viability for low-carbon materials, and financial feasibility.

FGDs were employed to gather collective perspectives, explore stakeholders' views on the issues, and identify both new problems and the priorities of various actors in the infrastructure sector. To supplement the primary data, desktop reviews were conducted to synthesize existing academic literature, policy documents, and case studies concerning decarbonization in Indonesia and similar countries. The entire dataset was then analyzed using inductive reasoning, which allowed us to identify recurring patterns, connections, and core themes systematically. The method aligns with established qualitative research practices, which allowed us to draw conclusions grounded in empirical evidence while remaining open to discoveries.

To fully detail the data gathering process, we employed a qualitative, exploratory methodology, including focus group discussions, in-depth interviews, and a desktop review, to investigate the hurdles involved in decarbonizing Indonesia's infrastructure. The study team conducted stakeholder engagement in 2025 through series of Focus Group Discussions (FGDs) and in-depth interviews. These sessions were designed to identify cross-cutting issues and practical barriers hindering infrastructure decarbonization in Indonesia.

The discussions involved a wide array of participants, including government representatives, industry groups, academia, research institutions, and financial actors. The 90 to 120-minute discussions were systematically structured using the 5M analytical framework (Manpower, Machine, Method, Money) to ensure comprehensive coverage of technological, regulatory, financial, and human-capacity challenges.

The stakeholder engagement sessions generated practical insights that support and deepen our qualitative review of policy and literature. The following points summarize the key findings from the FGDs and interviews, which reflect the direct experiences of relevant institutional and industrial actors.

1. Availability of skills (manpower)

The participants called for the government to financially support the growth of green skills by providing subsidies, establishing publicly financed national training programs, and improving collaboration with training institutions. A major concern raised was the failure to integrate emission benchmarks and technical standards into professional certification systems, underscoring the immediate requirement to mainstream GHG-related competencies for engineers and project managers.

2. Availability of technology (machine)

To accelerate the use of low-carbon construction technology, participants highlighted the importance of implementing incentives, improving international collaboration, and achieving inter-sectoral

policy consistency. They agreed that standardization efforts (like SNI for green materials) and robust digital emission tracking systems are essential to enable national-scale deployment.

3. *Access to supply chains for low-carbon construction (material)*

Stakeholders called for mandatory procurement policies that prioritize low-carbon materials, supported by financial incentives aimed at mitigating risk for sustainable production innovations. To boost local supply chains, they also suggested improving the promotion of low-carbon construction products and creating stronger collaborative networks across government, industry, and academia.

4. *Cost and financing (money)*

The primary deterrent is the steep upfront cost of decarbonization. To address this, respondents suggested creating subsidy schemes for alternative fuels and implementing tax incentives for low-carbon sectors. They also recommended simplifying green product certification and using financial instruments like guarantees and concessional financing more broadly to attract greater private participation in these projects.

5. *Standard and regulation (method)*

The participants called for integrated policy formulation across ministerial lines and the immediate adoption of mandatory emission reduction standards in construction. They also stressed the need for broad awareness campaigns targeting the industry. Finally, a national monitoring dashboard was recommended to track implementation progress and ensure all parties are accountable for achieving decarbonization goals.

6. *Other findings*

The general recommendations included launching national awareness campaigns for low-carbon infrastructure, developing clear carbon trading mechanisms, and creating a multi-stakeholder roadmap to foster cooperation across ministries, academia, and industry groups. It was also recommended that a formal coordination forum be established to align public–private initiatives and facilitate the sharing of best practices and strategies.

Collectively, these findings highlight how infrastructure decarbonization relies mainly on the interdependence of institutional reform, financial incentives, and capacity building. The multi-stakeholder format of the engagement was crucial as it enables diverse actors to successfully exchange perspectives, agree on shared priorities, and co-develop feasible entry points for both policy and project interventions.

Data Collection and Analysis

In addition to gathering stakeholder perspectives on future decarbonization strategies, the FGDs examined four elements drawn from the 5M framework: materials and technology, standards and regulations, cost and financing, and skills and capacities. With participant consent, all conversations were audio recorded, verbatim transcribed, and cross-referenced with secondary data from technical reports, policy documents, and pertinent literature. Furthermore, to validate and enhance the ideas gleaned from the group talks, many informants from the same institutional categories participated in in-depth interviews to supplement the FGDs. To synthesize previous research, national policy frameworks, and comparative case analyses, a desktop review was also conducted.

Inductive theme analysis was used to analyze the data, and conventional qualitative coding techniques were adopted from Braun & Clarke (2006). To guarantee alignment among institutional impediments, stakeholder perceptions, and the conceptual structure of the 5M framework, themes and subthemes were identified iteratively. Triangulation of focus group discussions, interviews, and document reviews improved the validity of the results and enabled a more comprehensive understanding of the behavioral and structural elements affecting Indonesia's infrastructure decarbonization.

RESULTS

This section presents empirical findings derived from FGD notes, in-depth interviews, and validation-seminar feedback, which were then linked thematically and triangulated to strengthen the evidence. Reporting follows the 5M lens, with "Material & Machine" combined due to the close linkage between low-carbon material availability/properties and process/technology readiness in the decarbonization context.

In line with this section's purpose, findings are presented as factual outputs—recurring patterns, convergent statements, and paraphrased illustrative quotations—without interpretation or recommendations; further interpretation is provided in the Discussion. Institutional affiliations are disclosed in general terms to preserve credibility and confidentiality.

Mismatch Supply and Demand on Low Carbon Material and Technology Use in the Material Manufacturing

The adoption of low-carbon materials within Indonesia's construction sector remains at a nascent stage (Chan et al., 2022). Although the Ministry of Public Works has issued directives encouraging the use of non-Ordinary Portland Cement (non-OPC), actual implementation has been limited, primarily due to outdated technical specifications embedded in contract documents, which continue to favor conventional materials. In parallel, the adoption of technology in construction logistics also lags. For instance, Electric Vehicles (EVs) have yet to be deployed for transporting construction materials, with contractors instead relying on equipment with short operational lifespans as interim measures to reduce emissions.

The procurement system remains primarily price-oriented, and participants noted that contractors often face disincentives to adopt environmentally preferable but higher-cost materials. According to stakeholder feedback, PPP schemes provide greater contractual flexibility, though sustainability clauses are not yet systematically included in project terms. Participants reported that concrete recycling is considered a more feasible pathway than direct material reuse, which continues to face technical and operational constraints.

Stakeholders also noted persistent dependence on fossil fuels for material transport. According to FGD discussions, industries such as iron, steel, and cement are in the early stages of exploring low-carbon alternatives. Yet, they currently rely on limited green energy sources and lack clear economic incentives for large-scale adoption.

Lack of Harmonization of Standard and Regulation in Supporting Industry Sectors

Participants identified regulatory misalignment as a key obstacle to sector-wide decarbonization. The absence of harmonized standards was frequently cited in FGDs as a barrier to scaling low-carbon practices. Large contractors, such as PT Waskita Karya (Persero) Tbk, expressed concerns that decarbonization measures increase

operational costs and reduce competitiveness under current public tender regulations that prioritize the lowest bidder.

Participants noted increasing pressure to adopt emission calculation methodologies, particularly in response to the growing requirements of sustainable financing instruments. They highlighted the lack of a standardized and cost-effective roadmap adapted to local conditions. Respondents also reported that, although Minister of Public Works and Housing Regulation No. 9 of 2021 prioritizes local materials, the implementation remains inconsistent across projects.

Limited Availability of Green Financing Instrument to De-Risk Decarbonization Cost

Participants widely acknowledged that access to finance remains the main factor influencing the pace of decarbonization. Several green financing instruments have been introduced through banks and state-owned financial entities, including Special Mission Vehicles (SMVs), but their utilization in infrastructure projects remains limited. Stakeholders stated that while fiscal incentives exist, information on eligibility criteria and application procedures is not clearly communicated to potential project developers.

PT Penjaminan Infrastruktur Indonesia (Persero) is currently developing a green guarantee mechanism designed to enhance the bankability of sustainable projects. According to stakeholders, this initiative remains in the early stages of development and has not yet been fully implemented.

Gap in Skills and Capability on Infrastructure-based Emission Management and Technology

Human capital limitations further constrain Indonesia's decarbonization trajectory. A skills gap persists in both emission management and the application of low-carbon technologies within infrastructure development (Gui et al., 2024). Findings from a recent validation workshop revealed that the current engineering certification frameworks do not adequately incorporate competencies related to greenhouse gas (GHG) emissions measurement, monitoring, and mitigation. At present, only seven institutions in Indonesia are accredited to perform GHG verification and validation, reflecting a severe shortage in national capacity.

Participants reported that current capacity-building initiatives are fragmented and not yet aligned with the nine industrial sectors developing decarbonization roadmaps. Respondents noted limited coordination among ministries and training institutions responsible for developing these programs

DISCUSSION

Theoretical Interpretation of Key Barriers

The theoretical and empirical insights previously covered are used to explain these findings in the following discussion, connecting them to practical and policy consequences. The results show a complicated network of interconnected obstacles that work together to prevent Indonesia's infrastructure sector from being carbon neutral.

The challenges spanning material technology, regulatory frameworks, financing mechanisms, and human capital are not isolated problems; instead, they are signs of more profound systemic and institutional weaknesses when analyzed through the integrated 5M framework and the four decarbonization pillars (reduce, reuse, replace, remove). Therefore, the empirical data offer not only a glimpse of the current

implementation issues but also an opportunity to analyze them using more comprehensive theoretical frameworks that clarify the reasons for the obstacles' persistence and provide solutions.

Obstacles to decarbonization function concurrently on the "material and machine," "method," "money," and "manpower" dimensions. Stakeholder talks reveal how material and technological limitations, such as restricted access to low-carbon products and outdated contract specifications, reflect what Roshdi et al. (2023) refer to as structural inefficiencies ingrained in supply chain and procurement procedures. It emphasizes that institutional inertia, not only technical flaws, is the cause of operational-level inefficiencies. The idea that technological adoption depends on market incentives and regulatory clarity is supported by the continued use of high-carbon materials despite increased policy attention (Chan et al., 2022).

Comparative studies show that the lack of standardized sustainability criteria slows down the shift to low-carbon construction. This problem is directly mirrored in Indonesia's procurement system, which still prioritizes selecting the lowest-cost bid over using value-based criteria (Kurniawan et al., 2024). Ultimately, these findings validate the 5M framework's effectiveness in diagnosing how the combined influence of institutional rules, market forces, and operational decisions determines the pace of decarbonization.

Institutional and Regulatory Fragmentation

Fragmented institutional frameworks—evidenced by inconsistent standards and regulations—are slowing down decarbonization. These institutional misalignments, as noted by North (1990) and Chou and Leatemia (2016), increase transaction costs and stifle innovation, particularly where national procurement rules clash with sustainability goals. Enforcement of these goals by ministries remains weak due to conflicting mandates and poor coordination.

From an institutional economics perspective, this fragmentation creates uncertainty, which discourages both public and private investment in green technology. Clear regulatory signals, such as Thailand's successful zero-ordinary Portland cement program, can accelerate the market shift by aligning incentives and lowering perceived risk. Therefore, Indonesia's regulatory environment needs a more cohesive structure that fully integrates sustainability into its technical standards, procurement, and monitoring systems.

Financial Governance and Investment De-Risking

Financial limitations compound these institutional challenges. Although domestic banks and Special Mission Vehicles (SMVs) have introduced green financing mechanisms, their application in infrastructure projects remains limited due to complex administrative procedures and unclear eligibility requirements. It aligns with findings from Stoll et al. (2021) and the OECD, who noted that information asymmetries and high transaction costs often deter private investment in climate infrastructure.

Drawing on climate finance theory, de-risking tools—such as blended finance, guarantees, and concessional loans—are essential for shifting the risk-return balance toward low-carbon projects. The move by PT Penjaminan Infrastruktur Indonesia (Persero) to establish a green assurance mechanism is a significant step in the right direction. However, these tools will not be truly transformative unless they are expanded and backed by clear financial incentives. We can

boost project viability and investor confidence by improving financial governance through streamlined processes, unambiguous eligibility criteria, and structured technical support.

Human Capital and Capacity Constraints

A significant obstacle also arises from limitations in human capital. Specifically, the lack of greenhouse gas (GHG)-related skills in engineering certification and the shortage of accredited GHG verification organizations are slowing down the practical deployment of low-carbon infrastructure. This problem underscores the principles of human capital theory, which holds that investing in training and skills eventually leads to greater productivity and innovation.

According to studies by Cook et al. (2025) and Gui et al. (2024), sustainability activities risk remaining aspirational if climate capabilities are not purposefully incorporated into professional certification and education. Consequently, it is crucial to integrate decarbonization information into professional accreditation, occupational training, and university curricula. To ensure that human resource development directly supports national emission targets, training programs should align with the industry decarbonization roadmaps currently being developed.

Circular Economy and the 4R Approach

Indonesia's infrastructure sector still lacks a firm grasp of circular economy ideas, as seen by the low use of circular processes and the restricted usage of recycled materials. The 4R strategies described by Geissdoerfer et al. (2017) and Korhonen et al. (2018) are in line with this observation. By incorporating these ideas into project design, procurement, and monitoring systems, the gap between the goals of policy and its actual application would be closed.

Policymakers would be better able to pinpoint areas where linear practices continue, especially in the material and machine dimensions, by integrating the 4Rs with the 5M framework. They could then create focused interventions like required material audits, performance-based tendering, and financial incentives for recycled inputs. This integration would transform current infrastructure delivery models into systems that internalize environmental costs and, in turn, promote resource efficiency.

Governance Synthesis and Stage-Based Policy Implications

Indonesia's decarbonization challenges are better viewed as a governance issue rather than just a technological or financial one. A systemic imbalance between macro-level policy aims and micro-level implementation mechanisms is shown in the interaction of fragmented regulation, restricted financing, and inadequate capacity. It is crucial to integrate policies to address these issues.

Government spending would be in line with sustainability results if procurement and regulatory frameworks were harmonized. Additionally, incorporating decarbonization indicators into PPP contracts might strengthen market signals and institutionalize accountability. According to Royapoor et al. (2023), increasing data openness through digital Measurement, Reporting, and Verification (MRV) systems would boost investor confidence and monitoring accuracy. Cross-sectoral cooperation between financial institutions, industry groups, and ministries is essential at the institutional level to ensure that low-carbon goals are integrated throughout project lifecycles.

To facilitate shared learning and minimize effort duplication, public agencies should serve as facilitators of multi-stakeholder collaboration. Financially, increasing tax

breaks, guarantee systems, and green bond frameworks will be essential to growing private investment.

These financial and institutional ties highlight the need to view Indonesia's decarbonization initiatives as a continuum of activities integrated across the infrastructure project cycle rather than as a collection of disjointed measures. Therefore, a more stage-based approach can help define the starting point for reform initiatives and the best way to order them.

Three strategic directions are crucial from a policy standpoint. To provide consistent incentives for low-carbon behaviors, it is first necessary to increase institutional coherence by harmonizing technical standards and procurement mechanisms. Then, to encourage private investment and improve project bankability, new financial tools, including guarantees, fiscal incentives, and blended finance, should be made available. Last, to integrate decarbonization competencies into professional training, certification, and education systems, a thorough framework for capacity-building is required. To better align Indonesia's infrastructure development with its long-term emission reduction goals under the LTS-LCCR 2050 and Enhanced NDC frameworks, these three dimensions should be strengthened.

To draw private investment into low-carbon projects, the financing stage must be reorganized to prioritize de-risking measures and incentive-based tools like guarantees, concessional loans, and blended finance plans. Consistent use of performance-based contracts and green procurement standards will be essential during implementation to uphold accountability and guarantee that decarbonization goals are met locally. Last but not least, maintaining progress throughout all stages requires institutional coordination and capacity building to make sure that contractors, funders, and project planners all grasp the same low-carbon goals.

Thus, our research leads to three strategic imperatives. *First*, all infrastructure planning should be guided by institutional coherence, which can be achieved through integrated project screening tools and standardized procurement regulations. *Second,* to maintain long-term investment flows and encourage private participation, financial innovation must increase risk-sharing and fiscal incentives. *Third,* all phases of implementation should be supported by the acquisition of capacity through national certification and training systems. The study advances academic knowledge and practical avenues for infrastructure decarbonization in Indonesia by linking empirical findings to theoretical perspectives and transforming them into feasible policy strategies.

CONCLUSION

This study identified four main barriers hindering Indonesia's infrastructure sector's decarbonization: (i) a lack of technology and materials; (ii) fragmented regulations; (iii) financial constraints; and (iv) insufficient technical skill capability. Instead of being discrete operational problems, these difficulties show interrelated structural and institutional flaws, which underscore the necessity of focused reforms at every stage of the infrastructure project cycle.

Three areas of change are suggested to improve the way policies are implemented. *First,* to avoid locking in high-carbon assets, sustainability indicators should be included in feasibility studies, cost-benefit assessments, and design requirements during the project planning phase. *Second,* to attract private investment and reduce the perceived risks of green projects, the government and financial institutions should increase the use of de-

risking instruments at the financing stage, such as blended finance, tax incentives, and green guarantees. *Third,* to enforce adherence to standardized low-carbon requirements and prioritize lifecycle carbon performance, procurement procedures should be updated during implementation. All of these phases should be accompanied by capacity building to ensure that practitioners have the institutional and technical 'know-how' needed to operationalize decarbonization goals.

Although this study offers a fresh empirical understanding of the structural barriers to infrastructure decarbonization, the generalizability of the findings is constrained by its qualitative focus. To measure the impact of each obstacle and assess the long-term efficacy of specific policy tools, future research should use mixed-method approaches. However, policymakers and other stakeholders looking to initiate and advance reforms toward low-carbon, climate-resilient infrastructure development in Indonesia will find this report offers a valuable starting point.

As a practical implementation path of the policy, improvements should be sequenced along the project cycle: (i) planning—mainstream emission targets, a low-carbon material inventory, and a project-level MRV plan in feasibility/early design; (ii) financing—expand green guarantees and clarify eligibility; (iii) implementation—adopt performance-based procurement and contract-bound, measurable green standards; and (iv) M&E—mandate project-level MRV to ensure target–outcome consistency. This staged roadmap clarifies the starting point and short-term priorities.

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