The Impact of CO2 Emissions in Indonesia's Construction Industry: A Human Development Perspective

Manotar Tampubolon *

Posted Date: 22 January 2025

doi: 10.20944/preprints202501.1668.v1

Keywords: CO2 emissions; construction industry; Indonesia; human development; sustainability

Article

The Impact of CO2 Emissions in Indonesia's Construction Industry: A Human Development Perspective

Manotar Tampubolon

Universiti Teknologi MARA, Malaysia; justitie234@gmail.com

Abstract: The construction industry in Indonesia plays a crucial role in the country's economic growth, but it is also one of the top contributors to CO2 emissions, raising important concerns about its effects on environmental sustainability and human development. This study explores the relationship between the carbon footprint of the construction sector and its effects on Indonesia's human development indicators, including health, education, and income. By employing a mixed-methods approach that combines an analysis of CO2 emission data from major construction activities with a review of government policies and frameworks, this research identifies trends and assesses mitigation strategies. The findings indicate that the construction sector is responsible for a significant portion of national greenhouse gas emissions, primarily due to energy-intensive processes and a slow uptake of green technologies. However, the evidence suggests that strategic interventions, such as encouraging green construction practices and implementing regulatory measures, can effectively reduce emissions while also providing socioeconomic benefits. The study concludes that it is essential to incorporate sustainable practices within the construction industry to align environmental objectives with human development goals. These insights provide practical recommendations for policymakers and stakeholders to achieve a balance between growth and sustainability.

Keywords: CO2 emissions; construction industry; Indonesia; human development; sustainability

1. Introduction

The construction industry plays a vital role in Indonesia's rapid urbanization and economic growth, contributing around 10% to the country's GDP in recent years (1). However, it is also a major source of global CO2 emissions, which presents challenges for environmental sustainability and human development. The link between construction activities and carbon emissions in Indonesia is particularly urgent, given the country's dependence on energy-intensive processes and materials like cement and steel, along with ongoing infrastructure development to accommodate a growing population (2). The environmental consequences of these activities intersect with essential aspects of human development, such as health, housing, and economic opportunities, creating a complex issue that demands immediate attention.

The need to tackle CO2 emissions in Indonesia's construction sector arises from its dual role as a catalyst for socio-economic progress and an environmental burden. As Indonesia works to fulfill its commitments under the Paris Agreement, which includes a target of reducing greenhouse gas (GHG) emissions by 29% by 2030 (3), the impact of the construction industry has become a key focus for policymakers and researchers. Studies have shown that this sector disproportionately contributes to total emissions, with estimates suggesting that construction-related activities account for over 30% of Indonesia's CO2 emissions (4). This underscores the urgent need to investigate innovative strategies for decarbonizing the industry while still advancing human development objectives.

Research highlights the challenges of finding a balance between environmental sustainability and development. Studies show that adopting green building practices and low-carbon technologies, like energy-efficient designs and sustainable materials, is possible (5). However, obstacles such as

 doi:10.20944/preprints202501.1668.v1

high costs, a lack of technical expertise, and weak regulatory enforcement still pose significant issues (6). The differing viewpoints within the field add to the complexity of the discussion. Some researchers focus on the potential of technological innovation to revolutionize the industry, while others stress the need for systemic changes in governance and collaboration among stakeholders to achieve sustainable progress (7, 8). Debates also continue over the trade-offs between economic growth and environmental protection. Critics of strict emission-reduction policies argue that these could impede Indonesia's development, especially in areas where construction is vital for job creation and infrastructure (9).

On the other hand, advocates for strong climate action warn that neglecting to reduce CO2 emissions will worsen climate vulnerabilities, disproportionately impacting marginalized communities and hindering long-term human development (10,11). This study aims to reconcile these discussions by exploring the relationship between CO2 emissions in the construction sector and human development in Indonesia. By utilizing data-driven insights and examining both the challenges and opportunities, the research intends to enhance understanding of how sustainable construction practices can align with national development goals. Ultimately, this work seeks to guide policies that harmonize environmental sustainability with socio-economic growth, promoting a resilient and equitable future for Indonesia.

1.1. Human Development and C02 Emissions in Indonesia

The construction sector in Indonesia plays a significant role in CO2 emissions, largely due to the heavy reliance on cement, steel, and other materials that require energy-intensive production methods. The International Energy Agency (12) reports that the cement industry alone is responsible for about 7% of global CO2 emissions, with Indonesia being a key player in Southeast Asia. Fossil fuels primarily meet the energy needs of construction activities, which further increases greenhouse gas emissions. This situation has serious implications for public health, as research (13) indicates that air pollution, including CO2 and particulate matter, is associated with respiratory and cardiovascular diseases, potentially leading to a decrease in life expectancy.

Additionally, the connection between emissions from construction and education reveals indirect yet significant effects. High pollution levels have been linked to cognitive decline and poorer educational outcomes, especially in children. A study by An et al. (14) found that long-term exposure to polluted environments can hinder cognitive development, which in turn affects the effectiveness of education systems. Indonesia's urban areas, where construction activity is most intense, are particularly susceptible to these issues. While developing educational infrastructure is essential, its advantages may be compromised by the negative environmental impacts of the construction processes involved.

Income levels significantly influence this relationship. On one hand, construction activities stimulate economic growth by generating jobs and enhancing infrastructure, which can boost income levels and improve overall quality of life. Conversely, the environmental damage resulting from these activities can incur long-term economic costs. For example, health issues related to pollution can lead to increased healthcare expenses and decreased workforce productivity, as highlighted by Syuhada et al. (15). In Indonesia, the tension between immediate economic benefits and long-term environmental repercussions presents a major challenge for policymakers striving for sustainable development.

To tackle this challenge, it is essential to emphasize green construction practices and incorporate sustainability metrics into urban planning. Approaches such as implementing energy-efficient technologies, harnessing renewable energy sources, and enforcing stricter environmental regulations can help alleviate the negative impacts of construction activities. For instance, using recycled materials in construction has been proven to significantly lower CO2 emissions (16). The Indonesian government has launched various initiatives to encourage green building practices, but their execution has been inconsistent, underscoring the necessity for stronger enforcement and increased public awareness campaigns.

 doi:10.20944/preprints202501.1668.v1

Table 1: Relationship between Human Development and CO2 Emissions in Indonesia.

Investments in renewable energy infrastructure can provide a twofold benefit. By decreasing reliance on fossil fuels, Indonesia can cut down on CO2 emissions while also generating job opportunities and promoting economic growth within the renewable energy sector. Research (17) has shown that renewable energy projects typically offer better long-term returns than traditional energy investments. In Indonesia's case, these investments could harmonize economic progress with environmental protection, improving societal indicators such as life expectancy, education, and income. Incorporating social equity into sustainability initiatives is also crucial. It is essential to prioritize communities that are disproportionately impacted by pollution from construction, often low-income and marginalized groups, in policy decisions. This means ensuring they have access to healthcare, clean air, and educational opportunities. A study by van Nierek (18) suggests that fair distribution of resources can enhance the positive effects of environmental and economic policies, leading to inclusive growth and better societal outcomes.

The interplay between construction activities, CO2 emissions, and societal metrics is further shaped by global trends and international collaboration. Indonesia’s commitment to the Paris Agreement highlights the need to align national policies with worldwide climate objectives. Working together with international organizations and neighboring nations can help facilitate the sharing of green technologies and best practices. For example, partnerships with countries like Japan and Germany have already led to the implementation of advanced construction technologies that lower emissions (19,20). Such collaborations can strengthen Indonesia’s ability to tackle the environmental challenges that come with its rapid development.

The complex relationship between construction activities, CO2 emissions, and social indicators in Indonesia highlights the importance of a comprehensive approach to sustainable development. By focusing on green construction methods, investing in renewable energy, promoting social equity, and fostering international collaboration, Indonesia can reduce the negative impacts of urbanization while improving life expectancy, education, and income levels. This all-encompassing strategy not only tackles pressing environmental issues but also establishes a groundwork for enduring societal health and economic success.

1.2. Material Production and Its Environmental Impact

Material production is one of the most carbon-intensive phases of construction, with cement and steel leading the way in this environmental issue. Cement production is responsible for about 8% of global CO2 emissions, and Indonesia’s construction sector mirrors this trend (21). The calcination process, a crucial part of cement manufacturing, releases large amounts of CO2, which contributes to global warming. Likewise, steel production depends on energy-intensive blast furnaces that burn fossil fuels, emitting greenhouse gases (22). These emissions are further exacerbated by the extraction of raw materials like sand and gravel, which involves diesel-powered machinery (23). Given these facts, the need to shift towards sustainable practices is clear. Advocates suggest using recycled materials, low-carbon alternatives, and innovative technologies to lessen environmental impacts. These strategies align with global objectives for reducing emissions and fostering a more sustainable future.

Addressing the carbon intensity of material production presents significant economic opportunities. Indonesia, similar to many other countries, has the chance to take the lead in developing and adopting low-carbon alternatives like geopolymer cement or recycled aggregates [24]. These materials not only help in reducing emissions but can also improve resource efficiency and lower production costs over time. Additionally, shifting to renewable energy sources in material manufacturing—such as utilizing electric arc furnaces for steel production—can greatly reduce reliance on fossil fuels while promoting a green economy. The increasing global demand for sustainable construction practices could further boost Indonesia's competitiveness in the international market. By focusing on innovation and investing in sustainable technologies, the

 doi:10.20944/preprints202501.1668.v1

construction sector can minimize its environmental impact and stimulate economic growth through the creation of green jobs and export opportunities.

Transitioning to low-carbon materials holds great promise, but it faces significant challenges, especially in developing economies like Indonesia. One of the primary hurdles is the cost associated with adopting new technologies and materials. Low-carbon options, such as geopolymer cement, often necessitate specialized production processes and raw materials that may not be easily accessible or affordable for all manufacturers [25]. Moreover, retrofitting existing facilities to integrate these innovations requires substantial financial investment, which many companies may find daunting. Another challenge is the absence of standardized regulations or certification systems to guarantee the quality and performance of new materials, making them less appealing to developers who are cautious about risks. The logistical difficulties of sourcing recycled materials and managing supply chains further complicate the widespread implementation of sustainable practices. As a result, critics argue that these obstacles impede the feasibility of immediate and large-scale transitions within the construction industry.

Cultural and institutional factors also significantly contribute to the resistance to change in the construction sector. Traditional building materials like cement, steel, and bricks are deeply rooted in construction practices due to their proven reliability, availability, and cost-effectiveness [26]. Many construction companies and stakeholders may not be aware of or willing to consider alternative materials, often viewing them as untested or inferior. Additionally, Indonesia's regulatory framework for the construction industry still favors conventional methods, offering little incentive for innovation. Policies that promote sustainable practices are frequently poorly enforced or underdeveloped, limiting their effectiveness. The combination of resistance from industry professionals and inadequate government support creates a challenging environment for advancing low-carbon materials, even when their environmental advantages are clear.

1.3. Transportation Emissions in the Supply Chain

Reducing CO2 emissions from transportation is crucial for achieving sustainability in the construction industry. Institute for Essential Services Reform (IESR) (28) reports that logistics activities, including the transportation of construction materials, contribute to about 15% of the country's CO2 emissions. This figure underscores the significant impact of transportation on greenhouse gas emissions. Supporters emphasize the need for immediate measures to reduce these emissions to fulfill Indonesia’s commitments under the Paris Agreement. By utilizing electric or alternative-fuel vehicles, the construction sector could greatly decrease its carbon footprint (29).

Another important benefit of localized supply chains is their potential to cut emissions. The long-distance transportation required for importing materials like steel and timber increases the carbon footprint. For example, importing construction materials often leads to higher emissions due to the maritime and road transport involved (30). Shifting to local procurement not only helps lower emissions but also supports local economic development. Proponents argue that this change would align with Indonesia's broader objectives of reducing reliance on imported materials while boosting domestic industries.

Those against strict measures to cut CO2 emissions from transportation in the construction industry contend that these efforts pose significant economic and logistical hurdles. The shift to electric or alternative-fuel vehicles demands a considerable initial investment. In Indonesia, the existing infrastructure for electric vehicles (EVs), including charging stations, is still lacking, especially in rural and remote regions where many construction projects take place (31). As a result, many contractors find that sticking with traditional diesel-powered trucks is the most feasible and cost-effective choice. Moreover, moving towards localized supply chains could compromise the quality and cost of materials. Imported materials, particularly steel and timber, are often favored for their higher quality and better pricing compared to locally sourced options (32). Mandating local procurement might drive up project expenses, which could ultimately be passed on to consumers.

 doi:10.20944/preprints202501.1668.v1

Detractors warn that focusing on reducing transportation emissions could unintentionally hinder construction progress, impacting the overall growth of the industry.

Supporters of emission reduction highlight the importance of technological advancements and supportive policies in addressing these issues. The use of renewable energy-powered transportation options, like solar or hydrogen-fueled trucks, has demonstrated potential in various pilot projects around the world (33). With the right government incentives and subsidies, these technologies could become more widely available in Indonesia. For example, offering tax breaks or subsidies for the purchase of electric trucks could motivate construction companies to shift towards greener alternatives. Additionally, utilizing digital technologies for optimizing supply chains can help reduce unnecessary transportation and emissions. Tools like real-time tracking and route optimization software enable more efficient transportation resource use, leading to lower fuel consumption and reduced emissions (34). Proponents believe that combining innovative technologies with well-designed policies could make emission reduction efforts both practical and economically viable for the construction industry.

Despite advancements in technology, some skeptics believe that the adoption of these measures in Indonesia is still quite limited. The country's scattered geography and dependence on road transportation present logistical challenges that technology alone cannot easily overcome. For instance, areas in Eastern Indonesia often lack the necessary infrastructure to support alternative transportation systems (35). This gap in infrastructure complicates the large-scale implementation of electric or hydrogen-fueled trucks. Additionally, critics argue that the construction sector is grappling with more immediate issues, such as ensuring projects are completed on time and managing costs effectively. Focusing on green transportation initiatives could potentially distract from these critical priorities. They propose a more balanced approach that gradually incorporates emission reduction strategies while still relying on traditional practices, allowing the sector to sustain its productivity during the transition to more sustainable methods.

1.4. On-Site Operations and Their Carbon Footprint

On-site construction activities play a major role in carbon dioxide (CO2) emissions, particularly in Indonesia, where there is a heavy dependence on diesel-powered machinery like excavators, cranes, and generators (36). These operations also release particulate matter, which negatively impacts air quality and public health. Temporary facilities, such as accommodations for workers, often rely on non-renewable energy sources, further worsening the situation. Critics contend that these emissions are an inevitable part of the construction industry, driven by economic needs and infrastructure demands (37). Nevertheless, advancements in renewable energy technologies and better energy management present potential solutions. Supporters of these initiatives argue that sustainable practices can coexist with industry growth without sacrificing environmental objectives.

Proponents of traditional construction methods emphasize the economic advantages and practicality of diesel-powered machinery. Diesel engines deliver high power output, are cost-effective, and are readily available, making them essential for large-scale projects in developing nations like Indonesia. Shifting to renewable energy-powered equipment necessitates substantial initial investment and training, which can lead to delays and increased project costs. Critics also point out the current limitations of green technologies, such as inadequate battery capacity for electric machinery and the absence of widespread charging infrastructure (38). These challenges reinforce the reliance on conventional equipment as the most feasible choice for timely project completion.

Electrifying construction equipment and optimizing energy usage can greatly lower the industry's carbon footprint while improving public health by reducing particulate matter emissions. Research shows that machinery powered by renewable energy and efficient scheduling could cut energy consumption by as much as 30%, aiding both national and global climate objectives (39). Additionally, government incentives and international collaboration could ease the financial strain of moving towards greener options, facilitating a gradual yet significant transformation in industry practices.

 doi:10.20944/preprints202501.1668.v1

The integration of renewable energy in construction aligns with Indonesia's commitment to the Paris Agreement, which aims for a 29% reduction in emissions by 2030 (40). Policies that encourage renewable technologies in construction could open up new market opportunities, fostering innovation and job creation. However, implementing these solutions necessitates systemic changes, including upgrading energy grids and revising industry standards, which may take years to accomplish. Without proactive government policies and collaboration within the industry, reaching these objectives could remain a challenge.

Finding a balance between environmental sustainability and economic viability is a significant challenge for the construction industry in Indonesia. Although some critics point out the limitations and expenses tied to implementing greener practices, the pressing reality of climate change demands that we take action. By fostering collaboration among stakeholders—such as policymakers, construction companies, and energy suppliers—we can promote a shift towards more sustainable practices while still supporting industry growth. Thus, tackling emissions from on-site construction requires a thoughtful strategy that combines immediate practicality with long-term sustainability objectives.

2. Case Studies Highlighting Emissions in Specific Projects

The case studies from Indonesia’s construction sector underscore the urgent need to tackle carbon dioxide (CO2) emissions in a thorough manner. Proponents of sustainable practices argue that embracing green building standards and energy-efficient technologies can lead to a significant reduction in emissions. The Jakarta-Bandung high-speed rail project serves as a prime example of how emissions from material production and on-site diesel generators can be lessened through greener alternatives, such as renewable energy sources and low-carbon materials (41).

Furthermore, similar insights from Surabaya highlight the impact of transportation on emissions. Previous study claims that by prioritizing local sourcing and streamlining supply chains, transportation-related emissions could be greatly reduced, providing the added benefits of environmental protection and cost efficiency (42). On the other hand, transitioning to renewable energy and low-carbon materials often demands considerable investment, which can put a strain on project budgets, especially in developing nations like Indonesia (43). Moreover, the fragmented structure of the construction industry complicates uniform implementation, as smaller contractors may not have the resources to adopt sustainable practices. This inequality could create an uneven playing field, putting smaller businesses at a disadvantage and potentially hindering overall progress in the industry (44).

One argument in favor of sustainable practices in construction highlights the long-term economic advantages. Research has shown that energy-efficient buildings lead to lower operational costs, making them financially sustainable over time (45). In Indonesia, urban development projects that embrace green standards could significantly cut energy use in both residential and commercial areas, resulting in considerable cost savings. Additionally, implementing energy-efficient technologies can improve public health by reducing pollution and creating healthier urban spaces (46). Advocates believe these advantages outweigh the initial implementation costs, making a strong case for government incentives to encourage green practices. On the other hand, critics warn against relying too heavily on green technologies without tackling underlying issues, such as regulatory shortcomings and enforcement difficulties. For example, although there are policies in place to support sustainable construction, ineffective implementation and oversight often limit their success Detractors argue that without strong governance, even well-meaning initiatives may not achieve significant environmental benefits.

3. Policy and Regulatory Frameworks Addressing Emissions

Indonesia's efforts to cut CO2 emissions in the construction sector show promising steps toward sustainability, yet the results are still debated. Claim that the Nationally Determined Contributions

 doi:10.20944/preprints202501.1668.v1

(NDC) under the Paris Agreement highlight Indonesia's dedication to global climate objectives, targeting a notable 29% reduction in emissions by 2030 through domestic initiatives, and up to 41% with international assistance (47). The rollout of the Green Building Code in city like Jakarta has made strides in urban sustainability by establishing standards for energy efficiency and promoting the use of environmentally friendly materials (48). These policies are in line with global trends and present economic opportunities in the green construction sector, including new markets for sustainable technologies and materials. Furthermore, they contribute to building a culture of environmental awareness among developers and the public, leading to long-term societal benefits.

On the other hand, the success of these initiatives is hampered by weak enforcement and inadequate incentives for compliance (49). Regulatory frameworks are often applied inconsistently across different regions, leading to gaps in implementation. For example, smaller cities and rural areas may lack the necessary resources and expertise to effectively enforce building codes, which limits the overall impact on a national level (51). Additionally, the financial burden of implementing sustainable practices and technologies tends to fall heavily on smaller developers, who may find it challenging to manage the costs without significant government support or subsidies. This raises concerns about the fairness of these measures and their accessibility for all stakeholders.

Enhancing these policies could bring about significant environmental and economic advantages. Financial incentives, like tax breaks or grants for eco-friendly construction projects, could promote wider adoption of sustainable practices (51). International partnerships, as outlined in the NDC, could also be crucial by supplying the necessary funding and technical know-how for large-scale implementation. Success stories from other countries indicate that investing in green technologies not only cuts emissions but also boosts competitiveness in the global construction market. Therefore, with appropriate policy changes and increased financial backing, Indonesia could set a benchmark for sustainable construction practices in the region.

3.1. Opportunities for Reducing Co2 Emissions

Emerging technologies and innovative practices offer both opportunities and challenges for reducing CO2 emissions in Indonesia’s construction sector. For instance, the use of alternative materials like geopolymer concrete, which has a significantly lower carbon footprint than traditional cement, shows great promise (52). Additionally, Building Information Modeling (BIM) enhances resource efficiency, minimizes waste, and indirectly lowers emissions (53). The integration of renewable energy sources, such as solar panels for temporary power on construction sites, can also aid in reducing emissions during the building process (54). Implementing a circular economy approach by reusing construction waste helps to decrease emissions associated with material production (55).

On the other hand, these innovations encounter several challenges. The high costs associated with implementing advanced materials like geopolymer concrete and BIM systems hinder widespread adoption, particularly among small to medium-sized construction firms (56). Moreover, the shortage of skilled labor and technical expertise necessary for effectively utilizing these technologies poses a significant obstacle (57). Renewable energy sources, such as solar panels, demand substantial upfront investments and may not be practical for all construction sites due to varying energy needs or limited infrastructure.

Additionally, moving towards a circular economy necessitates considerable changes in industry practices and regulatory frameworks, which can be time-consuming and often face resistance (58). These challenges underscore the complexity of achieving sustainability objectives in the construction sector. Finding a balance between the potential of emerging technologies and the practical challenges they present requires a strategic approach. Incentives like tax breaks, subsidies, and government-led training programs can promote the wider adoption of sustainable practices (59). While the opportunity to reduce CO2 emissions is evident, it is essential to tackle financial, technical, and regulatory barriers to ensure that Indonesia's construction sector can transition effectively towards sustainability without sacrificing development goals.

 doi:10.20944/preprints202501.1668.v1

3.2. Co2 Emission Impact on Human

Urban and rural areas show notable differences in the types and levels of emissions they produce, which in turn affect public health, quality of life, and environmental conditions. In urban environments, emissions mainly arise from industrial activities, vehicle traffic, and energy production. These sources release harmful pollutants like nitrogen oxides (NOx), sulfur dioxide (SO2), carbon monoxide (CO), and particulate matter (PM2.5 and PM10), all of which are closely associated with respiratory and cardiovascular diseases. Research has shown that long-term exposure to elevated air pollution levels in urban areas leads to higher rates of asthma, bronchitis, and lung cancer among residents (60). Moreover, urban residents often face a diminished quality of life due to the combined effects of noise pollution, traffic congestion, and worsening air quality (61). On the other hand, rural areas deal with emissions from agricultural activities and biomass burning, leading to different but equally serious health consequences. The release of ammonia (NH3) from fertilizers and methane (CH4) from livestock farming are significant factors in environmental degradation and climate change (62).

The relationship between emissions and environmental conditions in both urban and rural areas goes beyond just health effects; it also plays a crucial role in maintaining ecological balance. Urban emissions lead to the heat island effect, causing cities to be warmer than their rural counterparts. This situation increases energy use for cooling and heightens the risk of heat-related illnesses, particularly during heatwaves (63). Furthermore, pollutants like heavy metals and acid rain can harm soil and water quality in nearby ecosystems, negatively affecting biodiversity and agricultural output (64). In rural areas, emissions from deforestation and changes in land use result in habitat destruction and a reduced ability to sequester carbon (65). The indirect consequences of these emissions include shifts in weather patterns and a greater susceptibility to natural disasters, which disproportionately affect communities reliant on agriculture (66). The overall impact of these environmental changes highlights the critical need for effective mitigation strategies that can reconcile development with ecological sustainability.

Public health disparities linked to emissions underscore the urgent need to tackle the socioeconomic aspects of pollution. Residents in urban areas, especially those from low-income neighborhoods, face a greater risk of exposure to high levels of pollutants due to their closeness to industrial sites and major roadways (67). This situation worsens existing health inequalities, resulting in increased hospitalization rates and reduced life expectancy for at-risk populations. In rural regions, the lack of access to healthcare services intensifies the health effects of emissions from farming practices and biomass burning (68). Additionally, the indirect consequences, such as diminished crop yields and food insecurity caused by soil and water pollution, further burden public health systems in these areas (69). To effectively address these disparities, it is essential to implement comprehensive policies that combine public health efforts with strategies for reducing emissions, ensuring fair outcomes for all communities. Below is Table 2, which summarizes the various stages and factors that contribute to CO2 emissions in Indonesia's construction sector.

Table 2: Overview of the various stages and factors contributing to CO2 emissions in Indonesia's construction sector

4. Sustainable Materials and Circular Economy in Construction

The construction sector in Indonesia plays a significant role in emissions, largely due to the reliance on unsustainable materials and inefficient building practices. For instance, cement production is a major contributor to carbon dioxide emissions, responsible for about 7% of global emissions (70). Acknowledging this challenge, the Indonesian government is actively seeking ways to lower emissions in construction by encouraging the use of alternative materials and methods.

One effective approach is the adoption of sustainable materials like bamboo, which is plentiful in Indonesia and has a smaller carbon footprint compared to traditional materials such as concrete and steel (71). Bamboo can serve various purposes, including structural components, flooring, and

 doi:10.20944/preprints202501.1668.v1

insulation, offering an environmentally friendly substitute for conventional materials. Additionally, the innovation of "green concrete," which utilizes industrial byproducts like fly ash or slag, has the potential to significantly decrease the carbon intensity of construction activities in Indonesia. While several local companies are already testing these materials, broader implementation will require enhanced policy support, education, and investment in research and development.

Embracing a circular economy in construction could further help in reducing emissions by encouraging the reuse and recycling of building materials. By adopting practices like deconstructing buildings instead of demolishing them, valuable materials can be salvaged and repurposed for new projects, thus decreasing the demand for new materials and minimizing waste (72). The Indonesian government could motivate construction firms to embrace circular economy principles by offering tax incentives, subsidies for recycling initiatives, and fostering public-private partnerships to expand these practices.

5. Energy-Efficient Construction Methods and Retrofitting Existing Buildings

Energy-efficient construction methods are essential for lowering emissions, especially in the residential and commercial sectors. Indonesia's rapid urban growth has resulted in a notable rise in building stock, much of which lacks energy efficiency. Upgrading existing buildings to align with modern energy efficiency standards is a practical approach to reduce emissions without the need for new construction. This retrofitting process includes enhancing insulation, installing energy-efficient windows and doors, and utilizing smart building technologies to optimize energy use (73). These actions can significantly decrease energy demand and emissions over time. Encouraging energy-efficient construction practices is vital for speeding up the adoption of these methods. The government could implement stricter building codes and standards that mandate energy-efficient designs for new constructions and provide financial incentives for retrofitting older buildings.

Additionally, offering training programs for architects, engineers, and construction workers on the advantages and application of energy-efficient technologies can promote industry-wide transformation. Partnering with international organizations, particularly in green building technologies, can further enhance Indonesia's initiatives in advancing energy-efficient construction practices. A transition towards green building certification programs like LEED (Leadership in Energy and Environmental Design) could also motivate the private sector to invest in energy-efficient construction. The government might consider offering incentives such as tax reductions for buildings that achieve high sustainability ratings, thereby creating a market-driven demand for green buildings.

6. Effects of CO2 Emissions on the Human Development Index (HDI) in Indonesia

The increasing levels of CO_2 emissions in Indonesia have serious consequences for the Human Development Index (HDI), which assesses health, education, and living standards. Elevated carbon emissions lead to environmental harm, worsening air pollution, deforestation, and climate change. These environmental issues disproportionately impact vulnerable communities, harming public health through respiratory diseases and raising the incidence of vector-borne illnesses. Such health problems put pressure on the healthcare system, resulting in lower life expectancy, a key factor in HDI. Additionally, climate-related disasters like floods and droughts disrupt educational systems by damaging infrastructure and displacing families, which reduces school attendance and overall educational success.

The economic effects of CO_2 emissions also impede progress in HDI. Environmental degradation reduces agricultural output and fisheries, which are vital for livelihoods and food security in Indonesia. This economic uncertainty worsens poverty and restricts access to essential resources, such as clean water and electricity, which are crucial for improving living standards. The government's need to allocate resources to tackle the environmental and health crises stemming from

 doi:10.20944/preprints202501.1668.v1

emissions diverts funding from education and social programs, hindering overall development. To counter these effects, Indonesia needs to shift towards sustainable energy sources and implement stricter environmental regulations. By proactively addressing CO_2 emissions, the country can improve environmental quality, protect public health, and foster equitable development, ultimately leading to a higher HDI. The various impacts of CO2 emissions from industry on the Human Development Index in Indonesia are presented in Table 3.

Table 3: The possible impacts of CO_2 emissions on the Human Development Index (HDI) in Indonesia.

6.1 Environmental and Health Implications

The construction industry plays a major role in CO2 emissions, both worldwide and in Indonesia. The creation of materials like cement and steel, along with the energy-heavy nature of construction work, positions this sector as a key contributor to greenhouse gas emissions. In Indonesia, the rapid pace of urbanization and infrastructure growth has intensified these emissions, especially in major cities like Jakarta and Surabaya. The effects on human development are complex, starting with health concerns. Elevated levels of CO2 and related air pollutants, such as particulate matter (PM2.5), lead to respiratory illnesses, heart problems, and shorter life spans. Long-term exposure to air pollution lowers quality of life and worsens health disparities in at-risk communities [74]. These health issues hinder the development of human capital, affecting the productivity and well-being of Indonesia's workforce.

6.2. Economic Consequences and Inequalities

The economic costs associated with CO2 emissions in the construction sector are significant, impacting human development indicators like income levels and poverty rates. Countries with high CO2 emissions face greater economic challenges due to health-related expenses, reduced labor productivity, and costs for climate adaptation [75]. In Indonesia, the construction sector's role in CO2 emissions particularly affects low-income communities, who often live near industrial areas and construction sites. This spatial inequality worsens socio-economic gaps, as these populations suffer from environmental damage without benefiting from urban growth. For example, marginalized communities on the outskirts of cities experience higher rates of pollution-related health issues and have less access to healthcare services [76]. These inequalities impede the country's efforts to achieve fair human development, as reflected in measures like education, health, and living standards.

6.3. Policy and Regulatory Frameworks

Addressing the impact of CO2 emissions from the construction industry requires strong policy interventions and regulatory frameworks. Indonesia has made notable progress in this area, including its commitment to the Paris Agreement and the establishment of Nationally Determined Contributions (NDCs). The government aims to cut greenhouse gas emissions by 29% by 2030, or 41% with international support (77). Specific policies aimed at the construction sector, such as green building certifications and incentives for using sustainable materials, have been introduced to meet these targets. However, the implementation of these policies is often inconsistent, frequently hampered by bureaucratic inefficiencies and a lack of enforcement mechanisms. Research from Cities Climate Finance Leadership Alliance (78) shows that while awareness of sustainable practices is increasing among industry stakeholders, adoption rates remain low due to high costs and limited technical expertise. Strengthening regulatory frameworks and encouraging public-private partnerships are crucial for closing this gap and promoting sustainable construction practices that align with human development goals.

 doi:10.20944/preprints202501.1668.v1

6.4. Social Awareness and Community Engagement

Community engagement and social awareness are essential in reducing the impact of CO2 emissions in the construction sector. Public advocacy and grassroots movements can create a demand for eco-friendly construction methods, shaping market trends and influencing policy decisions. Educational campaigns that emphasize the health and environmental consequences of CO2 emissions can empower communities to push for cleaner technologies and sustainable urban planning. For example, initiatives like the GBC Indonesia have effectively raised awareness about the advantages of energy-efficient buildings, resulting in a greater uptake of green certifications (79). Additionally, involving local communities in decision-making processes can improve the credibility and success of sustainability efforts. By focusing on social inclusion and equity, Indonesia can ensure that the shift to a low-carbon economy supports broader human development objectives, promoting resilience and prosperity for all its citizens.

7. Conclusion

The construction industry in Indonesia is crucial for the country's economic growth, yet it significantly contributes to CO2 emissions. These emissions have detrimental effects on environmental sustainability and, in turn, on human development indicators like health, education, and economic opportunities. The decline in air quality and the increase in temperatures due to emissions from construction activities have led to a rise in respiratory and cardiovascular diseases, particularly affecting vulnerable communities. Additionally, climate change, worsened by CO2 emissions, disrupts agricultural productivity, food security, and access to vital resources, all of which are essential for human development. Although there have been some initiatives to implement green construction practices, the adoption of environmentally sustainable solutions in Indonesia's construction sector is still insufficient to mitigate these negative impacts. It is essential to develop comprehensive policies, foster technological innovation, and encourage collaboration across the industry to ensure that construction practices align with sustainable human development objectives.

Future research should emphasize a multidisciplinary approach to better understand the relationship between emissions from the construction industry and human development. Studies should aim to quantify the specific contributions of different construction activities to CO2 emissions and their direct and indirect effects on various aspects of human development, including public health, access to education, and economic resilience. Additionally, research should investigate how effective green building technologies and the integration of renewable energy can reduce emissions while fostering sustainable construction practices. Comparative studies between Indonesia and other countries with similar developmental challenges could provide valuable insights into effective strategies. Lastly, research should consider the socioeconomic effects of moving towards sustainable construction, ensuring that the solutions proposed are fair and inclusive for all stakeholders involved.

Funding: The author receives no funding

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing is not applicable to this article.

Conflicts of Interest: The author declares no conflicts of interest.

References

1. Badan Pusat Statistik (BPS). *Construction Indicators, 2nd Quarter-2024*. Vol. 18, no. 4, 2024. Accessed January 20, 2025. https://www.bps.go.id/en/publication/2024/10/01/e8a778f9d4847e1510a595bb/construction-indicator--2nd-quarter-2024.html

2. United Nations Climate Change. *Long-Term Strategy for Low Carbon and Climate Resilience 2050 (Indonesia LTS-LCCR 2050)*. July 22, 2021. https://unfccc.int/sites/default/files/resource/Indonesia_LTS-LCCR_2021.pdf
3. Ministry of Environment and Forestry. *FOLU Net Sink: Indonesia's Climate Actions Towards 2030*. The Ministry of Environment and Forestry of the Republic of Indonesia, 2023.
4. Rum, I. A., A. Tukker, R. Hoekstra, A. d. Koning, and A. A. Yusuf. 2024. "Exploring Carbon Footprints and Carbon Intensities of Indonesian Provinces in a Domestic and Global Context." *Frontiers in Environmental Science* 12: 1325089. https://doi.org/10.3389/fenvs.2024.1325089.
5. Jaradat, Haytham, Omar Adeeb Mohammad Alshboul, Islam Mohammed Obeidat, and Mohammad Kamal Zoubi. "Green Building, Carbon Emission, and Environmental Sustainability of Construction Industry in Jordan: Awareness, Actions and Barriers." *Ain Shams Engineering Journal* 15, no. 2 (February 2024): 102441. https://doi.org/10.1016/j.asej.2023.102441.
6. Erizaputri, Sharmila, Ronja Bechauf, and Liesbeth Casier. *Green Public Procurement in Indonesia: Policies, Practices, and Ways Forward*. IISD Report. Winnipeg: International Institute for Sustainable Development, November 2024. Accessed January 20, 2025. https://www.iisd.org/system/files/2024-11/green-public-procurement-indonesia.pdf
7. Dunyo, Samuel Kwesi, Samuel Amponsah Odei, and Wiyada Chaiwet. "Relationship between CO_2 Emissions, Technological Innovation, and Energy Intensity: Moderating Effects of Economic and Political Uncertainty." *Journal of Cleaner Production* 440 (February 10, 2024): 140904. https://doi.org/10.1016/j.jclepro.2024.140904
8. United Nations Climate Change. *Long-Term Strategy for Low Carbon and Climate Resilience 2050 (Indonesia LTS-LCCR 2050)*. https://unfccc.int/documents/299279
9. The Ministry of Environment and Forestry of the Republic of Indonesia. *FOLU Net Sink: Indonesia's Climate Actions Towards 2030*. 2023.
10. Teshome, Martha. 2024. "The Human Health Burden of Climate Change: Non-Economic Losses and Ethical Considerations Towards Achieving Planetary Health." *The Journal of Climate Change and Health* 19 (September–October): 100336. https://doi.org/10.1016/j.joclim.2024.100336
11. Adekoya, Oluwasegun B., Joshua K. Olabode, and Syed K. Rafi. "Renewable Energy Consumption, Carbon Emissions and Human Development: Empirical Comparison of the Trajectories of World Regions." *Renewable Energy* 179 (December 2021): 1836–48. https://doi.org/10.1016/j.renene.2021.08.019
12. International Energy Agency (IEA). *Total CO2 Emissions from Energy. Indonesia*. 2022. Accessed January 20, 2025. https://www.iea.org/countries/indonesia/emissions#what-are-the-main-sources-of-co2-emissions-in-indonesia
13. World Health Organization. "Ambient (Outdoor) Air Pollution." October 24, 2024. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health
14. An, Farun, Jiying Liu, Wanpeng Lu, and Daranee Jareemit. "A Review of the Effect of Traffic-Related Air Pollution Around Schools on Student Health and Its Mitigation." *Journal of Transport & Health* 23 (December 2021): 101249. https://doi.org/10.1016/j.jth.2021.101249
15. Syuhada, G., Akbar, A., Hardiawan, D., Pun, V., Darmawan, A., Heryati, S. H. A., Siregar, A. Y. M., Kusuma, R. R., Driejana, R., Ingole, V., Kass, D., and Mehta, S. 2023. "Impacts of Air Pollution on Health and Cost of Illness in Jakarta, Indonesia." *International Journal of Environmental Research and Public Health* 20, no. 4: 2916. https://doi.org/10.3390/ijerph20042916.
16. Zhang, Z., Lei, Y., Liew, J.Y.R., et al. "Embodied Carbon Saving Potential of Using Recycled Materials as Cement Substitute in Singapore's Buildings." *npj Materials Sustainability* 2 (2024): 27. https://doi.org/10.1038/s44296-024-00032-w
17. Egli, Florian. "Renewable Energy Investment Risk: An Investigation of Changes Over Time and the Underlying Drivers." *Energy Policy* 140 (May 2020): 1114-28. https://doi.org/10.1016/j.enpol.2020.111428
18. van Niekerk, A. J. 2020. "Inclusive Economic Sustainability: SDGs and Global Inequality." *Sustainability* 12, no. 13: 5427. https://doi.org/10.3390/su12135427
19. Japan International Cooperation Agency (JICA). *Indonesia's Development and Japan's Cooperation: Building the Future Based on Trust*. 2018.

 doi:10.20944/preprints202501.1668.v1

https://www.jica.go.jp/Resource/publication/pamph/region/ku57pq00002izqzn-att/indonesia_development_en.pdf

20. TanahAir.net. "Indonesia-Germany Launch 48 Projects to Tackle Climate Change and Biodiversity Crisis." September 23, 2024. https://tanahair.net/indonesia-germany-launch-48-projects-to-tackle-climate-change-and-biodiversity-crisis/
21. Rohmah, Rizka Lailatul. "Sustainable Infrastructure Development in Indonesia: A Quantitative Evaluation of CO2 Emission Reduction from Fly Ash-Cement Substitution in Ready-Mix Concrete." *E3S Web of Conferences* 530 (2024): 04005. 14th International Conference on Future Environment and Energy (ICFEE 2024). https://doi.org/10.1051/e3sconf/202453004005
22. Hasjanah, Kurniawati, and Uliyasi Simanjuntak. "Decarbonization of the Iron and Steel Industry Needs a Comprehensive Roadmap." Institute for Essential Services Reform (IESR), March 20, 2024. https://iesr.or.id/en/decarbonization-of-the-iron-and-steel-industry-needs-a-comprehensive-roadmap/#:~:text=Currently%2C%2080%25%20of%20iron%20and,for%20exports%2C%20and%20carbon%20trading
23. Panjaitan, Togar W.S., Paul Dargusch, David Wadley, and Ammar A. Aziz. "Meeting International Standards of Cleaner Production in Developing Countries: Challenges and Financial Realities Facing the Indonesian Cement Industry." *Journal of Cleaner Production* 318 (October 10, 2021): 128604. https://doi.org/10.1016/j.jclepro.2021.128604
24. Shaikh, F.U. Ahmed, P. Nath, A. Hosan, M. John, and W.K. Biswas. "Sustainability Assessment of Recycled Aggregates Concrete Mixes Containing Industrial By-Products." *Materials Today Sustainability* 5 (September 2019): 100013. https://doi.org/10.1016/j.mtsust.2019.100013
25. Ikotun, Jacob O., Gbenga E. Aderinto, Makungu M. Madirisha, and Valentine Y. Katte. 2024. "Geopolymer Cement in Pavement Applications: Bridging Sustainability and Performance." *Sustainability* 16, no. 13: 5417. https://doi.org/10.3390/su16135417
26. Galmarini, Bianca, Paolo Costa, and Leonardo Chiesi. 2022. "Natural Building Materials and Social Representations in Informal Settlements: How Perceptions of Bamboo Interfere with Sustainable, Affordable, and Quality Housing." *Sustainability* 14, no. 19: 12252. https://doi.org/10.3390/su141912252
27. Mubarak, A., and I. Rahman. 2020. "A Comparative Analysis of Carbon Emissions from Transportation and Logistics of the Consumer Goods Industry in Southeast Asia." *International Journal of Technology* 11, no. 2: 333-341. https://doi.org/10.14716/ijtech.v11i2.3466
28. IESR. *Indonesia Energy Transition Outlook 2023: Tracking Progress of Energy Transition in Indonesia: Pursuing Energy Security in the Time of Transition*. Jakarta: Institute for Essential Services Reform (IESR), 2022.
29. Ghodsian, Nazanin. *Let's Investigate How the Majority of Climate Action in the Building Industry So Far Has Been to Efficiently Reduce Carbon Emission in Construction.* Neuroject, February 3, 2024. https://neuroject.com/reduce-carbon-emission-in-construction/
30. IESR. *A Transition Towards Low Carbon Transport in Indonesia: A Technological Perspective*. Study Report. 2020. https://iesr.or.id/wp-content/uploads/2020/10/Towards-a-Low-Carbon-Transport_Oct_2020.pdf.
31. Nugroho, Sinung Adi, and Sunu Widianto. "Exploring Electric Vehicle Adoption in Indonesia Using Zero-Shot Aspect-Based Sentiment Analysis." *Sustainable Operations and Computers* 5 (2024): 191-205. https://doi.org/10.1016/j.susoc.2024.08.002.
32. Yang, M., L. Chen, J. Wang, et al. "Circular Economy Strategies for Combating Climate Change and Other Environmental Issues." *Environmental Chemistry Letters* 21 (2023): 55–80. https://doi.org/10.1007/s10311-022-01499-6.
33. Kurc, Beata, Xymena Gross, Natalia Szymlet, Łukasz Rymaniak, Krystian Woźniak, and Marita Pigłowska. "Hydrogen-Powered Vehicles: A Paradigm Shift in Sustainable Transportation." *Energies* 17, no. 19 (2024): 4768. https://doi.org/10.3390/en17194768.
34. Olawade, David B., Oluwaseun Fapohunda, Ojima Z. Wada, Sunday O. Usman, Abimbola O. Ige, Olawale Ajisafe, and Bankole I. Oladapo. "Smart Waste Management: A Paradigm Shift Enabled by Artificial Intelligence." *Waste Management Bulletin* 2, no. 2 (June 2024): 244–263. https://doi.org/10.1016/j.wmb.2024.05.001.

 doi:10.20944/preprints202501.1668.v1

35. Nasori. "Logistics and Infrastructure Become Major Obstacle." *PwC Indonesia*, September 20, 2024. https://www.pwc.com/id/en/media-centre/infrastructure-news/september-2024/-logistics-and-infrastructure-become-major-obstacle.html.
36. IEA. 2022. *An Energy Sector Roadmap to Net Zero Emissions in Indonesia.* Paris: IEA. https://www.iea.org/reports/an-energy-sector-roadmap-to-net-zero-emissions-in-indonesia.
37. Dsilva, Jacinta, Saniya Zarmukhambetova, and Jasmina Locke. 2023. "Assessment of Building Materials in the Construction Sector: A Case Study Using Life Cycle Assessment Approach to Achieve the Circular Economy." *Heliyon* 9 (10): e20404. https://doi.org/10.1016/j.heliyon.2023.e20404.
38. Candra, Cliford Septian. "Evaluation of Barriers to Electric Vehicle Adoption in Indonesia through Grey Ordinal Priority Approach." *International Journal of Grey Systems* 2, no. 1 (2022): 38–56. https://doi.org/10.52812/ijgs.46.
39. Agarwal, Al, Ashwin Balasubramanian, Fadhila Discha, and Khoon Tee Tan. "Indonesia's Green Powerhouse Promise: Ten Bold Moves." *McKinsey & Company*, April 22, 2024. https://www.mckinsey.com/id/our-insights/indonesias-green-powerhouse-promise-ten-big-bets-that-could-pay-off
40. Framework Convention on Climate Change (FCCC). *Record of the Facilitative Sharing of Views at the Fifty-Eighth Session of the Subsidiary Body for Implementation: Indonesia*. 15 August 2023. Accessed https://unfccc.int/sites/default/files/resource/FSVR3_Indonesia.pdf.
41. Xiangming Chen, Michael Hutahaean, and Irvin Nathaniel Tobing. "A Ground-Breaking Railway: Is the Jakarta-Bandung High-Speed Railway a Game-Changer for Indonesia?" *The European Financial Review*, July 2, 2024. https://www.europeanfinancialreview.com/a-ground-breaking-railway-is-the-jakarta-bandung-high-speed-railway-a-game-changer-for-indonesia/.
42. Jemima Nathenia, Ruthmedy, and Pius Ginting. *Urban Public Transportation Study Series: SURABAYA*. Jakarta: Perkumpulan Aksi Ekologi dan Emansipasi Rakyat (AEER), 2023.
43. Mustika, Mutya. *Unlocking Indonesia's Renewable Energy Investment Potential*. July 2024. Institute for Energy Economics and Financial Analysis (IEEFA). https://ieefa.org/resources/unlocking-indonesias-renewable-energy-investment-potential.
44. Shang, Tao, Xue Hu, Ke Ye, and Victor W.Y. Tam. "Will Contractors Pursue Unsustainable Practices Following Environmental Recovery? A Highway Case in China." *Engineering, Construction and Architectural Management* 30, no. 3 (2023): 1165–1182. https://doi.org/10.1108/ECAM-07-2021-0581.
45. Grainger, Guy. "Why Having Low-Carbon Buildings Also Makes Financial Sense." *World Economic Forum*, September 18, 2024. https://www.weforum.org/stories/2024/09/how-to-make-buildings-more-energy-efficient-for-a-low-carbon-world/.
46. Hanifi, Hassan. "Sustainable Strategies for Enhancing Urban Environments." Paper presented at the 4th International Congress on Civil Engineering, Architecture, Building Materials and Environment, November 20, 2024, Helsinki, Finland.
47. United Nations Development Programme. *Indonesia: Climate Promise*. November 24, 2023. https://climatepromise.undp.org/what-we-do/where-we-work/indonesia#:~:text=Indonesia%20submitted%20its%20enhanced%20NDC,Plan%20on%20Climate%20Change%20Adaptation.
48. Danish Energy Agency and EBTKE, Direktorat Jenderal Energi Baru, Terbarukan dan Konservasi Energi. *Roadmap for an Energy Efficient, Low-Carbon Buildings and Construction Sector in Indonesia*. February 24, 2022.
49. Imafidon, Henry, Melvin Enwerem, and Ayodeji Boye. 2024. "Adapting Green Building Practices and Smart Technology in Developing Countries: A Review." *African Journal of Environmental Sciences and Renewable Energy* 16 (1): 183–202. https://doi.org/10.62154/ajesre.2024.016.010407.
50. Okosun, Andrew E., Francis O. Okeke, Ajuluchukwu E. Igwe, Emmanuel C. Ezema, and Cyriacus O. Okpalike. 2023. "Rural Area Infrastructural Challenges and the Role of Architecture in Urban-Rural Development in Nigeria." *European Journal of Sustainable Development* 12 (4): 305. https://doi.org/10.14207/ejsd.2023.v12n4p305.
51. Tunley Environmental. "How to Best Implement Sustainability in Construction." *Tunley Environmental*, June 13, 2024.

52. Marini, L., M.A. Mannan, A.B.H. Kueh, A.A. Abdullah, F. Abed, and K. Gunasekaran. "An Analysis of the Environmental Effects of Three Types of Concrete: Ready-Mixed, Reactive Powder, and Geopolymer." *Ain Shams Engineering Journal* 15, no. 9 (September 2024): 102926. https://doi.org/10.1016/j.asej.2024.102926.
53. Alsehaimi, Abdullah, Ahsan Waqar, Khaled A. Alrasheed, Abdulrahman S. Bageis, Hamad Almujibah, Omrane Benjeddou, and Abdul Mateen Khan. "Building a Sustainable Future: BIM's Role in Construction, Logistics, and Supply Chain Management." *Ain Shams Engineering Journal* 15, no. 12 (December 2024): 103103. https://doi.org/10.1016/j.asej.2024.103103.
54. Reddy, Vennapusa Jagadeeswara, N. P. Hariram, Mohd Fairusham Ghazali, and Sudhakar Kumarasamy. 2024. "Pathway to Sustainability: An Overview of Renewable Energy Integration in Building Systems." *Sustainability* 16 (2): 638. https://doi.org/10.3390/su16020638.
55. Bellini, Alessia, Bjørn Andersen, Nora Johanne Klungseth, and Allen Tadayon. "Achieving a Circular Economy through the Effective Reuse of Construction Products: A Case Study of a Residential Building." *Journal of Cleaner Production* 450 (April 15, 2024): 141753. https://doi.org/10.1016/j.jclepro.2024.141753.
56. Shehata, Nabila, O.A. Mohamed, Enas Taha Sayed, Mohammad Ali Abdelkareem, and A.G. Olabi. "Geopolymer Concrete as Green Building Materials: Recent Applications, Sustainable Development and Circular Economy Potentials." *Science of The Total Environment* 836 (August 25, 2022): 155577. https://doi.org/10.1016/j.scitotenv.2022.155577.
57. Rikala, Pauliina, Greta Braun, Miitta Järvinen, Johan Stahre, and Raija Hämäläinen. "Understanding and Measuring Skill Gaps in Industry 4.0 — A Review." *Technological Forecasting and Social Change* 201 (April 2024): 123206. https://doi.org/10.1016/j.techfore.2024.123206.
58. AlJaber, Abdulaziz, Esam Alasmari, Pedro Martinez-Vazquez, and Charalampos Baniotopoulos. 2023. "Life Cycle Cost in Circular Economy of Buildings by Applying Building Information Modeling (BIM): A State of the Art." *Buildings* 13, no. 7: 1858. https://doi.org/10.3390/buildings13071858.
59. Kwilinski, Aleksy, Oleksii Lyulyov, and Tetyana Pimonenko. "Reducing Transport Sector CO2 Emissions Patterns: Environmental Technologies and Renewable Energy." *Journal of Open Innovation: Technology, Market, and Complexity* 10, no. 1 (March 2024): 100217. https://doi.org/10.1016/j.joitmc.2024.100217.
60. Fu Chen, Wanyue Zhang, Manar Fawzi Bani Mfarrej, Muhammad Hamzah Saleem, Khalid Ali Khan, Jing Ma, António Raposo, and Heesup Han. "Breathing in Danger: Understanding the Multifaceted Impact of Air Pollution on Health Impacts." *Ecotoxicology and Environmental Safety* 280 (July 15, 2024): 116532. https://doi.org/10.1016/j.ecoenv.2024.116532.
61. European Court of Auditors. *Special Report 02/2025: Urban Pollution in the EU – Cities Have Cleaner Air but Are Still Too Noisy.* Luxembourg: Publications Office of the European Union, 2025. Accessed January 14, 2025. https://www.eca.europa.eu/en/publications/SR-2025-02
62. Chataut, Gopi, Bikram Bhatta, Dipesh Joshi, Kabita Subedi, and Kishor Kafle. "Greenhouse Gases Emission from Agricultural Soil: A Review." *Journal of Agriculture and Food Research* 11 (March 2023): 100533. https://doi.org/10.1016/j.jafr.2023.100533.
63. United States Environmental Protection Agency (EPA). "Learn About Heat Island Effects." Last modified December 10, 2024. https://www.epa.gov/heatislands/learn-about-heat-island-effects.
64. Haghighizadeh, Atoosa, Omid Rajabi, Arman Nezarat, Zahra Hajyani, Mina Haghmohammadi, Soheila Hedayatikhah, Soheila Delnabi Asl, and Ali Aghababai Beni. 2024. "Comprehensive Analysis of Heavy Metal Soil Contamination in Mining Environments: Impacts, Monitoring Techniques, and Remediation Strategies." *Arabian Journal of Chemistry* 17, no. 6 (June): 105777. https://doi.org/10.1016/j.arabjc.2024.105777.
65. Veisi Nabikandi, Bahman, Farzin Shahbazi, Ahmad Hami, and Brendan Malone. 2024. "Exploring Carbon Storage and Sequestration as Affected by Land Use/Land Cover Changes Toward Achieving Sustainable Development Goals." *Soil Advances* 2 (October): 100017. https://doi.org/10.1016/j.soilad.2024.100017.
66. Saleem, A., Anwar, S., Nawaz, T., et al. "Securing a Sustainable Future: The Climate Change Threat to Agriculture, Food Security, and Sustainable Development Goals." *Journal of Umm Al-Qura University for Applied Sciences*, 2024. https://doi.org/10.1007/s43994-024-00177-3.
67. Xu, Junshi, Milad Saeedi, Jad Zalzal, Mingqian Zhang, Arman Ganji, Keni Mallinen, An Wang, Marshall Lloyd, Alessya Venuta, Leora Simon, Scott Weichenthal, and Marianne Hatzopoulou. "Exploring the Triple

Burden of Social Disadvantage, Mobility Poverty, and Exposure to Traffic-Related Air Pollution." *Science of The Total Environment* 920 (April 10, 2024): 170947. https://doi.org/10.1016/j.scitotenv.2024.170947.

68. Stem, Arthur D., Matthew Gibb, Carlos A. Roncal-Jimenez, Richard J. Johnson, and Jared M. Brown. 2024. "Health Burden of Sugarcane Burning on Agricultural Workers and Nearby Communities." *Inhalation Toxicology* 36 (5): 327–42. https://doi.org/10.1080/08958378.2024.2316875.
69. Münzel, Thomas, Olga Hahad, Andreas Daiber, and Philip J. Landrigan. "Soil and Water Pollution and Human Health: What Should Cardiologists Worry About?" *Cardiovascular Research* 119, no. 2 (2023): 440–449. https://doi.org/10.1093/cvr/cvac082.
70. Junianto, Iman, Sunardi, and Dadan Sumiarsa. "The Possibility of Achieving Zero CO2 Emission in the Indonesian Cement Industry by 2050: A Stakeholder System Dynamic Perspective." *Sustainability* 15, no. 7 (2023): 6085. https://doi.org/10.3390/su15076085.
71. BritCham Indonesia. "Indonesia to Reduce Carbon Emissions with Low-carbon Materials." November 2, 2023. https://britcham.or.id/indonesia-to-reduce-carbon-emissions-with-low-carbon-materials/.
72. Kuis, Joe. "Demolishing Buildings Is Bad for the Planet – Here's an Alternative." *The Conversation*, July 23, 2024. https://theconversation.com/demolishing-buildings-is-bad-for-the-planet-heres-an-alternative-223596.
73. Iwuanyanwu, Obinna, Ifechukwu Gil-Ozoudeh, Azubuike Chukwudi Okwandu, and Chidiebere Somadina Ike. "Retrofitting Existing Buildings for Sustainability: Challenges and Innovations." *Engineering Science & Technology Journal* 5, no. 8 (August 2024): 2616-2631. https://doi.org/10.51594/estj.v5i8.1515.
74. Putra, Bayu Rahmadi, and Sulistya Rusgianto. "Analysis of Energy Consumption and Carbon Emissions in Indonesia." *Jurnal Ekonomi Pembangunan* 21, no. 1 (2023): 31-45. https://doi.org/10.22219/jep.v21i01.25337.
75. Zhao, Mengzhen, et al. "Labour Productivity and Economic Impacts of Carbon Mitigation: A Modelling Study and Benefit–Cost Analysis." *The Lancet Planetary Health* 6, no. 12 (2022): e941–e948.
76. Laksono, A. D., R. D. Wulandari, N. Rohmah, R. Rukmini, and T. Tumaji. "Regional Disparities in Hospital Utilisation in Indonesia: A Cross-Sectional Analysis Data from the 2018 Indonesian Basic Health Survey." *BMJ Open* 13, no. 1 (2023): e064532. https://doi.org/10.1136/bmjopen-2022-064532.
77. Global Buildings Performance Network [GPBN]. *Indonesia Launches National Roadmap for Green Building Implementation.* October 2024.
78. CCFLA, Purnomo, and Nurfitriani, et al. *Financing Green Buildings in Indonesia: An Analysis of Policy and Financial Instruments.* Climate Policy Initiative, 2024. https://www.climatepolicyinitiative.org/wp-content/uploads/2024/03/Financing-Green-Buildings-in-Indonesia.pdf.
79. GBC Indonesia. *Towards Net Zero.* 2025. https://nz.gbcindonesia.org/netzero/advancing.
80. Antara. "Decarbonizing Cement to Pursue Green Development." June 10, 2024. https://en.antaranews.com/news/315678/decarbonizing-cement-to-pursue-green-development#:~:text=Though%20the%20road%20map%20will,and%20the%20use%20of%20cement
81. International Energy Agency (IEA). *An Energy Sector Roadmap to Net Zero Emissions in Indonesia*. Paris: IEA, 2022. https://www.iea.org/reports/an-energy-sector-roadmap-to-net-zero-emissions-in-indonesia. License: CC BY 4.0.
82. Gronwald, Victoria, Nicolas Eslava, Olivia Lyster, Nayan Mitra, and Vovia Witni. *Construction Raw Materials in India and Indonesia: Market Study and Potential Analysis, Final Report*. May 2021. Germany: Bundesanstalt für Geowissenschaften und Rohstoffe (BGR).
83. Rum, I.A., A. Tukker, R. Hoekstra, A.D. Koning, and A.A. Yusuf. "Exploring Carbon Footprints and Carbon Intensities of Indonesian Provinces in a Domestic and Global Context." *Frontiers in Environmental Science* 12 (2024): 1325089. https://doi.org/10.3389/fenvs.2024.1325089.
84. Hanif, Hanif, Ahmed Z. Khan, Muhammad Idrus Alhamid, and Yohei Yamaguchi. "Building Stock and Emission Models for Jakarta." *Resilient Cities and Structures* 3, no. 4 (December 2024): 63-82. https://doi.org/10.1016/j.rcns.2024.10.002.
85. Nabila, Ghyna, and Wendy Aritenang. "Indonesia's Path to Net-Zero Emission: Measuring Road Transport Emissions as the Foundation for a Sustainable Transport Policy." January 12, 2024. WRI Indonesia. https://wri-indonesia.org/en/insights/indonesias-path-net-zero-emission-measuring-road-transport-emissions-foundation.

 doi:10.20944/preprints202501.1668.v1

86. International Energy Agency. *An Energy Sector Roadmap to Net Zero Emissions in Indonesia, International Energy Agency Special Report*. n.d. Accessed January 21, 2025. https://iea.blob.core.windows.net/assets/b496b141-8c3b-47fc-adb2-90740eb0b3b8/AnEnergySectorRoadmaptoNetZeroEmissionsinIndonesia.pdf.
87. Sandhy, Wahyu Widyasari. "RAILPOLITICS: The Jakarta–Bandung High-Speed Rail Project and Engraving of International Credibility." *Community Practitioner* 21 (July 23, 2024). Zenodo. https://doi.org/10.5281/zenodo.12800243.
88. Yunus Fransiscus Liem, Aulia Ulfah Farahdiba, I.D.A.A. Warmadewanthi, and Joni Hermana. "Transition of Greenhouse Gas Emission Reduction from the Management of Municipal Solid Waste in Surabaya, Indonesia: Assessment on Past and Future Prospective Conditions." *Case Studies in Chemical and Environmental Engineering* 10 (December 2024): 100995. https://doi.org/10.1016/j.cscee.2024.100995.
89. Prasetyawan, Sigid, Rossy Armyn Machfudiyanto, and Titi Sari Nurul Rachmawati. 2023. "Incentives and Barriers to Green Building Implementation: The Case of Jakarta". *Journal of the Civil Engineering Forum* 9 (3), 287-302. https://doi.org/10.22146/jcef.7150.
90. Murti, C. K., and F. Muslim. 2024. "Analyzing the Awareness, Drivers, and Barriers of Building Information Modelling (BIM) Implementation for Sustainable Construction: Indonesia Construction Industry." In *Proceedings of the 3rd International Civil Engineering and Architecture Conference. CEAC 2023*, edited by M. Casini, Lecture Notes in Civil Engineering, vol. 389. Singapore: Springer. https://doi.org/10.1007/978-981-99-6368-3_74.
91. Adi, Bayu Kusuma, Tri Joko, and Onny Setiani. "Life Cycle Assessment, Is it Beneficial for Environmental Sustainability? A Literature Review." *Journal of Sustainable Engineering* 7, no. 3 (2022): 3243-3251. https://ojs.serambimekkah.ac.id/jse/article/view/4349.
92. Hatta, M., Aziz, H., Permana, D., Rohaeni, E. S., and Ahmad, S. N. 2024. "Bioindustry Development of Environment Friendly Organic Granular Fertilizer at Farming Groups in West Kalimantan, Indonesia." *IOP Conference Series: Earth and Environmental Science* 1297, no. 1: 012074. https://doi.org/10.1088/1755-1315/1297/1/012074.