



Comparative Analysis of Inter-Island Carbon Emissions

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Abstract

Carbon emissions are a major driver of global climate change, and Indonesia, as the world's fourth-largest archipelagic nation, faces significant challenges in managing its carbon footprint. The National Action Plan for Greenhouse Gas Emission Reduction allocates emission reduction targets to key sectors such as forestry and peatlands, agriculture, energy and transportation, industry, and waste management. Therefore, a thorough understanding of the comparison of carbon emissions across Indonesia's islands is crucial for designing more targeted and effective mitigation strategies to achieve national and global sustainability goals. This study analyzes the comparison of carbon emissions across six major Indonesian islands/regions: Java, Sumatra, Kalimantan, Sulawesi, Bali, Nusa Tenggara, and Maluku-Papua. The analysis was conducted on 43 economic sectors that contribute to direct CO₂ emissions. The primary objectives of this study were to identify differences in carbon emissions between islands and determine whether these differences are statistically significant, as well as to identify the unique characteristics of each island in its contribution to national emissions. The analysis revealed statistically significant differences in carbon emissions across islands in Indonesia. The analysis revealed extreme regional disparities in emission contributions. Java dominates, contributing 63.70% of total national emissions. Sumatra ranks second with 21.48%, while other islands contribute much less. The oil and gas mining sector contributes nearly a third of total national emissions, followed by the cement industry and electricity generation. This research makes an important contribution to understanding Indonesia's carbon emissions profile from a regional and sectoral perspective.

Introduction

Carbon emissions are one of the main causes of global climate change, and Indonesia, as the world's fourth-largest archipelagic country, faces significant challenges in managing its carbon footprint (Ramadhan & Rahman, 2025). From 1970 to 2022, Indonesia's CO₂ emissions have increased drastically by almost twenty times, reaching 728.9 Mt in 2022. International Energy Agency projects that total CO₂ emissions from energy and industrial use in Indonesia will increase by almost 60% by 2050 compared to current levels. The coal industry sector is the main contributor to CO₂ emissions in Indonesia, accounting for 404.6 Mt in 2022, followed by oil at 214.3 Mt and gas at 80.0 Mt.

Although previous studies have often focused on the national level (Putri et al., 2024), there is significant heterogeneity in greenhouse gas emissions and carbon footprints across provinces in Indonesia. The Java region, for example, was identified as a net importer of carbon emissions, while Sumatra and Kalimantan functioned as net exporters. This difference is

striking, with average carbon footprints per capita varying from 2 t CO₂e/capita in East Nusa Tenggara to 13.84 t CO₂e/capita in East Kalimantan (Putri et al., 2024). This variability is also seen in the analysis of the Greenhouse Gas (GHG) footprint of crude palm oil production where Kalimantan and Sumatra show the greatest variability between districts (Shimada et al., 2001).

The main cause of high emissions in Indonesia is multifaceted. Deforestation is a major contributor to land-based carbon emissions, with Indonesia accounting for about 61% of total forest loss in Southeast Asia between 1990 and 2010 (Elistia & Syahzuni, 2018)). Indonesia is also known as a country with a high rate of deforestation and a producer of smoke from forest and land burning (Pambudi et al., 2023). In addition, the loss of mangrove forests, with about 800,000 hectares vanishing in the last three decades, also releases large amounts of greenhouse gases into the atmosphere (Arifanti et al., 2021);(Al-Asadi et al., 2024). Degradation of tropical peatlands, due to drought, burning, drainage, and deforestation, also significantly increases CO₂ emissions (Deshmukh et al., 2023);(Hirano et al., 2024).

In response to these challenges, Indonesia has set ambitious targets for peak GHG emissions by 2030, reaching 540 Mt CO₂e by 2050, and achieving net-zero emissions by 2060. The government has committed to reducing emissions by 29% unconditionally or 41% with international support from the baseline projection of 2030 (Rum et al., 2024). The National Action Plan on Reducing Greenhouse Gas Emissions allocates emission reduction targets to key sectors such as forestry and peatlands, agriculture, energy and transportation, industry, and waste management (Puig et al., 2018). Thus, a deep understanding of the comparison of carbon emissions on each island in Indonesia is very important to design mitigation strategies that are more targeted and effective in achieving national and global sustainability goals.

Despite a global focus on Indonesia's carbon footprint, studies on the specific carbon emission profile per island are still limited (Dwiartama et al., 2024). Therefore, this study aims to analyze the comparison of carbon emissions on each major island in Indonesia, identify the main drivers in each region, and evaluate the relevant policy implications to achieve national climate mitigation targets (Dwiartama et al., 2024); (Haris et al., 2023). The study will identify differences in carbon emissions between islands, taking into account Indonesia's geographical, economic, and demographic diversity. Specifically, this study will examine the contribution of key sectors such as energy, industry, and land use to total emissions on each island, as well as analyze the effectiveness of mitigation policies that have been implemented (Tang, 2025).

Methods

This study was designed within a quantitative research framework that emphasizes systematic measurement and statistical comparison in order to examine regional disparities in carbon emissions across major islands in Indonesia. A quantitative approach was considered appropriate because the objectives of this research require numerical representation, objective comparison, and empirical testing of differences among regions. Through this approach, emission patterns can be analyzed in a structured manner, allowing the study to generate evidence based conclusions that are grounded in measurable data.

The research relied on secondary data obtained from official national statistical publications and sectoral emission reports issued by authorized government institutions and internationally recognized agencies. These sources were selected because they apply standardized procedures in calculating and reporting carbon dioxide emissions, thereby ensuring data reliability and comparability. The dataset consisted of emission records from forty three economic sectors

distributed across six main island regions, namely Sumatra, Java, Kalimantan, Sulawesi, Bali Nusa Tenggara, and Maluku Papua. Each sector within each island was treated as an analytical unit, enabling the study to capture both regional and sectoral variations in emission levels.

After data collection, a systematic data preparation process was conducted to ensure analytical accuracy. All emission values were examined for completeness, consistency, and logical coherence. Records containing missing values or inconsistencies were carefully reviewed and corrected where possible based on reference sources. Measurement units were standardized into tons of carbon dioxide to establish uniformity across datasets. This preparation stage was essential to minimize technical bias and to ensure that subsequent analyses were based on valid and comparable information.

Following data preparation, an initial descriptive exploration was carried out to understand the general structure of the dataset. Descriptive statistical analysis was employed to summarize central tendencies and dispersion patterns of carbon emissions in each island. This analysis included the calculation of mean values, standard deviations, and range indicators. Through this process, the study was able to identify dominant regions and highly emitting sectors, as well as to observe preliminary patterns of inequality in emission distribution. These descriptive findings provided an empirical foundation for deeper inferential investigation.

Building upon the descriptive results, inferential statistical analysis was subsequently applied to test whether observed differences among islands were statistically meaningful. A one way Analysis of Variance was employed to compare average emission levels across the six regions simultaneously. This technique was selected because it allows the evaluation of multiple groups within a single analytical framework while controlling for random variation. In this context, island regions were treated as independent groups, while sectoral emission values served as the dependent variable. The null hypothesis stated that no significant differences existed among islands, whereas the alternative hypothesis proposed the presence of at least one region with distinct emission characteristics. A significance level of five percent was adopted to determine statistical acceptance or rejection of these hypotheses.

When the Analysis of Variance indicated significant overall differences, further examination was conducted through pairwise comparison tests. Independent sample t tests were applied to compare emission levels between individual pairs of islands. This step was undertaken to identify specific regional relationships that contributed to the overall variance detected in the previous analysis. By conducting systematic comparisons among all possible island pairs, the study was able to generate a more nuanced understanding of inter regional disparities. In interpreting these results, both statistical significance and practical relevance were taken into account, particularly in light of high variability and sectoral heterogeneity within the dataset.

All statistical procedures were performed using established statistical software to ensure computational accuracy and analytical consistency. The software facilitated data management, calculation of descriptive indicators, implementation of inferential tests, and verification of results. The use of digital analytical tools also supported transparency and reproducibility, allowing the analytical process to be traced and evaluated by other researchers.

Results and Discussion

Overview of National Carbon Emissions and the Contribution of Islands in Indonesia

The results of the analysis showed that the total national carbon emissions from the six islands studied reached 463,171,115.60 tons of CO₂. This figure represents the contribution of various economic sectors operating throughout Indonesia. The distribution of emissions between islands shows enormous inequality, with very high concentrations of emissions on certain islands, particularly Java and Sumatra. This distribution pattern reflects regional disparities in terms of industrialization, population density, and economic activity in Indonesia.

From a geographical perspective, there is a pattern of reducing emissions from west to east of Indonesia. The islands of Java and Sumatra, which are located in the western part, have much higher emissions compared to the islands in the eastern part such as Sulawesi, Bali, Nusa Tenggara, and Maluku-Papua. This pattern is in line with the historical distribution of economic and industrial development in Indonesia, where the western region, especially Java, has been the center of economic growth since the colonial era until the present (Agusta, 2014).

Table 1. Sequence of Inter-Island Carbon Emissions in Indonesia

Sequence	Islands	Total Emissions (tons CO ₂)	Percentage
1	Javanese	295.051.762,15	63,70%
2	Sumatra	99.466.065,54	21,48%
3	Kalimantan	28.900.684,31	6,24%
4	Sulawesi	25.529.122,30	5,51%
5	Bali & Nusa Tenggara	12.577.318,87	2,72%
6	Maluku-Papua	1.646.16,43	0,36%

Source: Processed (2025)

Based on the table above, it can be seen that Java Island shows a very strong dominance in the contribution of national carbon emissions with total emissions reaching 295,051,762.15 tons of CO₂, or equivalent to 63.70% of total national emissions. This figure shows that almost two-thirds of all Indonesia's carbon emissions come from the island of Java. This dominance can be explained by several key factors. First, Java is a national industrial center with a concentration of large factories, especially the cement, iron and steel, textiles, food and beverage industries, and the chemical industry (Sjöberg & Sjöholm, 2004). Second, Java has the highest population density in Indonesia with more than 60% of the national population living on the island, resulting in a high demand for energy for household consumption and transportation (Muzayanah et al., 2022). Third, Indonesia's largest power generation infrastructure is concentrated in Java, with the majority still using fossil fuels, especially coal (Ordonez et al., 2022). Fourth, Java is a center of trade and services that produces intensive economic activities that require large amounts of energy (Gunawan et al., 2020).

A comparison of Java's emissions with other islands shows a surprising disparity. Java's emissions are almost three times higher than Sumatra, the island with the second highest emissions. Even more dramatic, Java's emissions are 179 times higher than Maluku-Papua. This extreme disparity indicates that there is a huge inequality in economic development and

industrialization between regions in Indonesia. This phenomenon also reflects a highly centralized development model, in which Java is the main locus of national economic and industrial activity (Handayani, 2013).

Furthermore, the island of Sumatra occupies the second position with total emissions of 99,466,065.54 tons of CO₂ or 21.48% of total national emissions. Although far below Java, Sumatra's contribution remains significant and reflects the economic characteristics rich in natural resources. High emissions in Sumatra mainly come from the oil and gas mining sector, which is one of the largest contributors to national emissions. In addition, Sumatra has a vast plantation industry, especially oil palm, which contributes through processing and deforestation. Coal mining in several provinces in Sumatra is also a source of emissions. (Mahroini & Chien, 2024).

Sumatra's emission characteristics differ from Java in terms of its sectoral composition. If Java's emissions are dominated by the manufacturing industry and power generation sectors, Sumatra's emissions are more dominated by extractive sectors such as mining and plantations. This difference reflects the specialization of the regional economy, where Sumatra plays a more role as a supplier of raw materials and energy, while Java is a center for chemical processing and manufacturing (Sjöberg & Sjöholm, 2004). Nevertheless, the combined contribution of Java and Sumatra reaches 85.18% of total national emissions, showing that these two islands are the main focus in efforts to mitigate Indonesia's carbon emissions.

The islands with medium emissions are Kalimantan and Sulawesi where these islands occupy the third and fourth positions with emissions of 28,900,684.31 tons of CO₂ (6.24%) and 25,529,122.30 tons of CO₂ (5.51%) respectively. These two islands have different emission characteristics but are in the medium category when compared to Java and Sumatra. Borneo, known as the "island of a thousand rivers," has a major source of emissions from highly intensive coal mining (Essen, 2021). Indonesia is one of the largest coal exporters in the world, and most of its coal mines are located in Kalimantan, especially East Kalimantan and South Kalimantan. In addition to mining, deforestation for oil palm plantations also contributes significantly to emissions in Kalimantan (Mahroini & Chien, 2024).

Sulawesi, on the other hand, has a more diverse emission profile. Although it also has a mining sector (mainly nickel), Sulawesi's emissions also come from the agriculture, fisheries, and processing industries sectors on a smaller scale than Java. Sulawesi's relatively lower level of industrialization compared to Java is reflected in much smaller emissions (Nasution et al., 2024). However, it is important to note that these two islands are experiencing rapid economic growth, and without proper policy interventions, their emissions have the potential to increase significantly in the future (Raihan et al., 2022).

The comparison between Kalimantan and Sulawesi shows an interesting pattern. Although Borneo's emissions are slightly higher than Sulawesi's, the difference is not too big (only about 3.4 million tonnes of CO₂ or 13% higher). This indicates that although Kalimantan has a more intensive extractive industry, Sulawesi also has significant economic activity in producing emissions (Agrawal et al., 2018). These two islands represent regions with high economic growth potential, and therefore require special attention in low-carbon development planning.

Meanwhile, the islands with low carbon emissions are Bali-Nusa Tenggara and Maluku-Papua which occupy the bottom position in the emission ranking with contributions of 12,577,318.87 tons of CO₂ (2.72%) and 1,646,162.43 tons of CO₂ (0.36%) respectively. The relatively low

emissions of these two regions can be explained by several factors. First, the level of industrialization is much lower than that of other islands. Bali's economy is dominated by the tourism and agriculture sectors, which have lower emission intensity than the manufacturing industry (Dewantara & Gaud, 2022). Second, lower population density results in smaller energy consumption (Muzayanah et al., 2022). Third, the limited industrial infrastructure makes large-scale production activities not as much as in Java or Sumatra (Sandee, 2016).

Maluku-Papua has the lowest emissions with a contribution of only 0.36% of the national total. This region includes the provinces of Maluku, North Maluku, Papua, and West Papua, which are the regions with the lowest level of infrastructure and industrial development in Indonesia (Syam, 2025). Although the region is rich in natural resources, including minerals such as copper and gold, the exploitation of these resources is relatively limited compared to Borneo or Sumatra. In addition, most of the Maluku-Papua region is still primary forest and has a very low population density, which contributes to minimal emissions (Vujanovic, 2017).

The position of Bali, Nusa Tenggara and Maluku-Papua is actually a strategic opportunity in the context of climate change mitigation. These two regions have the opportunity to implement a low-carbon development model from the start, avoiding the high-emission development path that Java and Sumatra have already taken. Concept "*leap-frogging*" or jumping beyond the conventional development stage towards clean technology can be applied in these areas. Thus, economic growth can be achieved without having to follow the high emission patterns that have occurred on other islands (Tan et al., 2013).

Differences in Carbon Emissions Between Islands Based on ANOVA and Pairwise Comparison Tests

To determine whether the observed differences in emissions between islands are statistically significant, an Analysis of Variance (ANOVA) test was conducted. This test was chosen because of its ability to compare the averages of more than two groups simultaneously. The zero (H_0) hypothesis in this test is that there is no difference in average emissions between islands, while the alternative hypothesis (H_1) states that there is at least one island that has significantly different average emissions from the other islands.

The results of the ANOVA test showed an F-statistical value of 2.7894 with a p-value of 0.0180. Using the significance level $\alpha = 0.05$ as Standard Threshold, The obtained p-value (0.0180) is less than α , which means we reject the zero hypothesis. These statistical results are very important because they indicate that the differences in emissions we observe between islands are not the result of random or accidental variations, but rather reflect real and systematic differences in the industrial, economic, and development characteristics of each island (Yorucu & Ertac Varoglu, 2020).

This significance has important implications. First, validating that regional disparities in carbon emissions are real issues that require policy attention (Liang et al., 2016). Second, it shows that the unique characteristics of each island in terms of economic structure, industrialization rate, and population density play an important role in determining emission levels (Khan et al., 2020). Third, it supports the argument that the "one-size-fits-all" In the emission mitigation policy will not be effective, and a strategy is needed that is tailored to the specific conditions of each region (Daniell et al., 2017).

However, it is important to understand that the ANOVA test only tells us that there are significant differences between the groups tested, but does not tell us which pairs are specifically different. For this reason, further analysis is needed through a pairwise comparison test to identify which island pairs have significant differences.

Paired t-test (Pairwise T-Tests) is done to compare each pair of islands individually (Lydersen, 2021). Out of a total of 15 possible pairs (a combination of 6 islands), the results showed interesting findings and were slightly contradictory to the ANOVA results. None of the island pairs showed a significant difference at the rate of $\alpha = 0.05$. These results may seem at odds with the significant ANOVA results, but this phenomenon can be explained through several statistical perspectives.

First, the ANOVA test is a global test that detects overall differences among all groups simultaneously, while the paired t-test is a more conservative test that compares only two groups at a time. Second, the very high variability in the emission data (coefficient of variation $> 300\%$ across all islands) reduces the statistical power to detect differences between individual pairs. Third, the relatively small sample size (43 sectors) for each island also contributes to the limited power statistic (Kao & Green, 2008).

Although neither pair reached significance at $\alpha = 0.05$, some pairs showed p-values close to the significance threshold ($p < 0.10$), indicating a fairly strong divergence trend. The Sumatra vs Maluku-Papua pair shows a p-value of 0.056, which is the closest to significance. This makes sense considering Sumatra is the island with the second highest emissions (99.47 million tonnes of CO₂) while Maluku-Papua has the lowest emissions (1.65 million tonnes of CO₂), with a difference ratio of around 60:1. The Java vs Maluku-Papua pair also shows a p-value of 0.062, which is also close to significance. The difference between these two islands is even more extreme, with a ratio of about 179:1.

Kalimantan Couple vs Maluku-Papua showed a p-value of 0.066. Although Kalimantan has much lower emissions than Java or Sumatra, the difference with Maluku-Papua is still considerable (ratio of about 17:1), which is reflected in p-value that is close to significance. The pattern that emerged from these results was that the pairs involving Maluku-Papua tended to show p-value (close to significance), indicating that Maluku-Papua does indeed have a very different emission profile from the rest of the islands (Rosita et al., 2024). Although there are enormous practical differences between islands, the high variability in the data makes these differences not always reach statistical significance in paired comparisons. However, from a public policy perspective, this large practical difference remains highly relevant and requires intervention (Bovaird, 2014).

Table 2. Pairwise T-Tests

Yes	Island Couple	t-statistic	P-value
1	Sumatra vs Java	-1,1999	0,2336
2	Sumatra vs Bali Nusa Tenggara	1,7035	0,0922*
3	Sumatra vs Kalimantan	1,3419	0,1832
4	Sumatra vs Sulawesi	1,4092	0,1625
5	Sumatra vs Maluku-Papua	1,9358	0,0563*
6	Java vs Bali Nusa Tenggara	1,8208	0,0722*
7	Java vs Kalimantan	1,7098	0,910*

8	Java vs Sulawesi	1,7319	0,0870*
9	Java vs Maluku-Papua	1,8931	0,0618*
10	Bali Nusa tenggara vs Kalimantan	-1,0090	0,3159
11	Bali Nusa tenggara vs Sulawesi	-0,8198	0,4147
12	Bali Nusa tenggara vs Maluku-Papua	1,5452	0,1261
13	Kalimantan vs Sulawesi	0,1659	0,8687
14	Kalimantan vs Maluku-Papua	1,8647	0,0657*
15	Sulawesi vs Maluku-Papua	1,6825	0,0962*

Data sources processed (2025)

**Sig. $\alpha=0.0$; *Sig. $\alpha=0.1$

Analysis of the Highest Emitting Sectors

The oil, gas, and geothermal mining sector occupies the top position as the largest contributor to emissions with total emissions reaching 146,512,800 tons of CO₂, or equivalent to 31.64% of total national emissions. This figure is very significant because it shows that almost a third of all Indonesia's carbon emissions come from just one sector. The dominance of this sector can be explained by several factors. First, Indonesia is one of the largest oil and gas producers in Southeast Asia, with highly energy-intensive extraction and processing operations (Rudenko & Tanasov, 2022). Second, the oil and gas extraction process produces huge direct emissions, both from the combustion of unused gas (flaring) and from the operation of heavy machinery (Barati & Pirozfar, 2019). Third, the sector also includes gas-based power plants that produce large amounts of CO₂ emissions (Hong et al., 2019).

The distribution of emissions in this sector is uneven between islands. Java accounts for the largest contribution from this sector, followed by Sumatra which has many oil and gas fields, especially in Riau, South Sumatra, and Aceh. Kalimantan also has a significant contribution, especially from the gas field in East Kalimantan. This geographical concentration reflects the distribution of oil and gas natural resources in Indonesia, which is mostly located in sedimentary basins in the western part of Indonesia (Maulana & Ranaputri, 2024).

From a climate change mitigation perspective, the sector is a top priority for intervention. Significant emission reductions can be achieved through several strategies, namely first, reducing gas practices *Flaring* and increasing the utilization of gas that has been burned (Barati & Pirozfar, 2019). Second, improving operational efficiency through the adoption of cleaner technology (Elrayah & Keong, 2023). Third, apply *carbon capture and storage (CCS)* in major facilities (Liu et al., 2018). Fourth, gradually reduce dependence on fossil fuels and switch to renewable energy (Holechek et al., 2022). However, this transition must be undertaken carefully given the national economy's dependence on the sector and the socio-economic implications of declining oil and gas production (Dongo & Relvas, 2025).

The cement industry occupies the second position with an emission contribution of 54,583,450 tons of CO₂ or 11.79% of total national emissions. The high emissions from the cement industry are caused by two main sources. First, the process of calcination of limestone (limestone) to produce *clinker* (the main component of cement) produces CO₂ directly as a result of chemical reactions. This process is unavoidable in conventional cement production and accounts for about 60% of the total emissions of the cement industry (Bosoaga et al., 2009). Second, the

burning of fossil fuels (mainly coal) to heat kilns (furnaces) to very high temperatures (around 1450°C) produces significant additional emissions (Mateus et al., 2023).

Indonesia is one of the largest cement producers in Southeast Asia, with demand continuing to increase along with massive infrastructure development. The cement industry in Indonesia is mostly concentrated in Java, which has the highest demand due to intensive construction activities (Panjaitan et al., 2020). Several large cement factories are also located in Sumatra and Sulawesi to serve the regional market. This geographical concentration is in line with the pattern of urbanization and infrastructure development in Indonesia.

The decarbonization of the cement industry is a complex technical challenge due to the emissions of the process (*process emissions*) inherent in cement production (Wiranjaya, 2024). However, several strategies can be implemented to reduce emissions. First, the substitution of fossil fuels with alternative fuels such as biomass or *waste-derived fuels* (Phogat, 2025). Second, increasing energy efficiency in the production process (Mawson & Hughes, 2019). Third, using substitute materials *clinker* (such as *Fly Ash* or *Stroke*) to reduce the ratio *clinker* against cement (Gartner & Sui, 2018). Fourth, developing low-carbon cement or alternative cement with different chemistry (Shubbar et al., 2019). Fifth, applying technology *Carbon Capture* in large cement factories (Hills et al., 2016). Some cement producers in Indonesia have begun to adopt some of these strategies, but penetration is still limited and requires stronger policy support (Wiranjaya, 2024).

Power generation occupies the third position with emissions of 46,804,390 tons of CO₂ or 10.11% of total national emissions. This sector is crucial because electricity is a basic necessity for all modern economic activities and household consumption (Kabeyi & Olanrewaju, 2021). The high emissions from this sector are mainly due to the dominance of fossil fuel power plants, especially coal, in Indonesia's energy mix. Based on PLN data, more than 60% of electricity in Indonesia is still generated from coal-fired steam power plants (PLTU), which have very high emission intensities (Shirley, 2025).

The geographical distribution of power plants reflects energy consumption patterns. Java, as the island with the highest population density and industrial activity, has the largest concentration of power plants. Several large-scale coal-fired power plants are located in West Java, Central Java, and East Java. Sumatra also has several large coal-fired power plants, especially in South Sumatra and Lampung. Kalimantan and Sulawesi have smaller, more dispersed power plants, serving more limited local needs (Fawwaz, 2024).

The energy transition in the power generation sector is a top priority in Indonesia's decarbonization efforts. The Indonesian government has set a target to increase the portion of renewable energy in the energy mix to 23% by 2025 and 31% by 2050 (Yudiarsono et al., 2023). Strategies that can be implemented include first, a moratorium on the construction of new coal-fired power plants and the acceleration of early retirement of old coal-fired power plants (Shirley, 2025). Second, the massive development of renewable energy such as solar, wind, geothermal, and hydro power. Indonesia has a huge renewable energy potential but has not been utilized optimally (Pambudi et al., 2023). Third, modernizing the transmission and distribution network to accommodate renewable energy *Intermittent* (Kabeyi & Olanrewaju, 2021). Fourth, the development of an energy storage system (*Battery Storage*) to address the variability of renewable energy (Ertugrul, 2016). Fifth, increasing energy efficiency on the demand side to reduce the need for generation (Yudiarsono et al., 2023).

The heavy industrial and manufacturing sectors, including the iron and steel, food and beverage, textiles, and chemical industries, collectively account for a very large portion of national emissions. The basic iron and steel industry occupies the fourth position with 27,308,240ton CO₂ emissions (5.90%), followed by the food and beverage industry with 25,632,110ton CO₂ (5.53%), and the textile and apparel industry with 24,181,040ton CO₂ (5.22%). These three sectors alone account for more than 16% of total national emissions.

The iron and steel industry has high emissions due to its highly energy-intensive production processes and involve chemical reactions that produce CO₂. Steel production through *Blast Furnace* using coke (processed coal) as *reducing agent*, which produces large amounts of CO₂ emissions (Griffin & Hammond, 2019). Indonesia has several large steel mills, mainly in Java and Sumatra, that serve domestic and export needs. The decarbonization of the steel industry is a global challenge that requires technological innovations such as the use of hydrogen as a *reducing agent (green steel)* that use electricity from renewable sources (Muslemanni et al., 2021).

The food and beverage industry has high emissions due to its enormous scale of operations and diverse processes. Emissions come from various sources such as the use of energy for heating, cooling, and processing processes; transportation of raw materials and finished products; as well as emissions from fermentation and organic decomposition processes (Martindale et al., 2023). Indonesia as an agricultural country with a large food processing industry has many factories spread across various islands, especially Java and Sumatra. Energy efficiency and the use of renewable energy are key strategies to reduce emissions from this sector.

The textile and apparel industry is a very important manufacturing sector for the Indonesian economy, especially for exports. The high emissions from this sector mainly come from the process *Dyeing* (coloring) and *Finishing* which requires large amounts of heat energy, as well as intensive use of chemicals. The majority of Indonesia's textile industry is located in Java, especially in West Java and Central Java (Dewi et al., 2019). Emission reduction strategies include the adoption of more efficient dyeing technologies, the use of natural or more environmentally friendly dyes, and the transition to renewable energy for the heating process (Bhadbhade et al., 2020).

The analysis shows that Indonesia's carbon emissions are highly concentrated in a small group of sectors. The top five sectors (oil and gas mining, cement industry, power generation, iron and steel industry, and food and beverage industry) account for 64.97% of total national emissions. If expanded to the top ten sectors, its contribution reaches 83.03% of total emissions. This very high concentration has important strategic implications for mitigation policies.

First, this concentration suggests that targeted interventions in key sectors can produce very significant emission reduction impacts. By focusing on the top 10-15 sectors, Indonesia has the potential to reduce more than 80% of its emissions. This is much more efficient than an approach that spreads to all sectors of the economy. Second, this concentration indicates that Indonesia's economic structure is still highly dependent on fossil energy-based sectors and heavy industries. Structural transformation towards a more service-based economy and low-carbon technology will automatically reduce emissions (Li et al., 2025).

Third, these high-emission sectors are generally also economically very important sectors, both for state revenue, labor absorption, and contribution to GDP. Therefore, the decarbonisation strategy must take into account socio-economic aspects and ensure that the transition is carried

out fairly (*Just Transition*) without sacrificing the well-being of the communities that depend on these sectors (Bai et al., 2021). Fourth, this concentration also shows that the majority of Indonesia's economic sectors actually have relatively low emissions, so that economic growth in these sectors can continue without major concerns about increased emissions (Shahbaz et al., 2013).

Policy Implications and Recommendations

The finding that there are significant differences in carbon emissions between islands necessitates the adoption of a differentiated policy approach based on the unique characteristics of each region. Approach "*one-size-fits-all*" will not be effective given the enormous disparities in emission levels, economic structure, and mitigation capacity between islands (Daniell et al., 2017). For the island of Java, which accounts for nearly two-thirds of total national emissions, very ambitious emission reduction targets and aggressive interventions are needed. The top priorities in Java should be directed at the decarbonization of the power generation sector through the transition from coal-fired power plants to renewable energy, the modernization of heavy industries with low-carbon technology, and the development of a massive public transportation system to reduce emissions from the transportation sector (Fahmi, 2025).

For Sumatra, which has high emissions mainly from the extractive sector, the main strategy should focus on sustainable management of natural resources. These include reducing flaring gas practices in the oil and gas sector, implementing stricter environmental standards for coal mining, and stopping deforestation for plantations. Sumatra also has great potential for renewable energy, especially geothermal and hydro, which must be massively developed to replace dependence on fossil energy (Hasan et al., 2012).

For Kalimantan and Sulawesi, which are in a phase of rapid economic growth, the right approach is to prevent the replication of the high-emission development pattern that has occurred in Java. Concept "*Green Industrialization*" must be adopted from the beginning, where new industrial investment is directed at clean technology and renewable energy. Kalimantan, with abundant coal resources, faces a dilemma between economic exploitation and climate mitigation (Teller, 2023). A balanced policy is needed, which may include a moratorium on the expansion of new coal mines while maximizing the economic value of existing reserves, with most of it for export rather than domestic consumption.

For Bali, Nusa Tenggara and Maluku-Papua, which have low emissions, the main strategy is to maintain a low emission profile while still encouraging economic growth. Concept "*leap-frogging*" skip the conventional development stage can be applied, where these regions immediately adopt clean technologies without having to go through a phase of fossil-based industrialization (Sikwebu & Aroun, 2021). The focus can be directed to the development of a sustainable tourism-based economy, the blue economy (sustainable use of marine resources), and environmental services. Both regions also have vast forests and natural ecosystems that serve as carbon sinks, so ecosystem conservation and restoration should be a priority (Casson et al., 2007).

Based on the principle of "*common but differentiated responsibilities*" adapted to the national context, each island must have different emission reduction targets according to its contribution and capacity. Java, as the largest contributor, should have the most ambitious absolute reduction targets. For example, Java can be targeted to reduce its emissions by 30-40% from *baseline* by 2030, focusing on key sectors such as power generation, the cement industry, and

transportation. This target is indeed very challenging but *achievable* with the right investment in renewable energy and energy efficiency.

Sumatra, as the second contributor, should also have significant reduction targets, although it may be slightly lower than Java given its economic dependence on the extractive sector. A 20-30% reduction target can be set, with a focus on the oil and gas, deforestation, and power generation sectors. For Kalimantan and Sulawesi, the target can be directed at limiting emissions growth (*emission intensity target*) rather than an absolute reduction, considering that these two islands are still in the economic development phase. However, emissions growth must be maintained so that it does not follow the pattern *business-as-usual*, but rather follow a low-carbon path (Hausfather & Peters, 2020).

For Bali, Nusa Tenggara and Maluku-Papua, the target can be focused on maintaining or even improving *Carbon Sink* through forest conservation and ecosystem restoration, while ensuring that economic growth does not result in significant increases in emissions (Casson et al., 2007). This approach recognizes that these regions have an important role to play in climate change mitigation not through emission reductions (because their emissions are already low), but through carbon sequestration and conservation.

The implementation of these differentiated targets requires a mechanism *Monitoring, Reporting, and Verification (MRV)* strong at the regional level (Korwatanasakul, 2022). Greenhouse gas emission inventory systems should be strengthened at the provincial and district/city levels to ensure accountability and transparency. In addition, clear incentive and disincentive mechanisms are needed to encourage the achievement of targets, including possible implementation *carbon pricing* at the regional level (Novita, 2021).

Given the very high concentration of emissions in a small group of sectors, intervention priorities should be directed at these key sectors. For the oil and gas mining sector, which accounts for almost one-third of total national emissions, priority interventions include first, regulations that require the use of gas that has been used to reduce the amount of gas that has been used to produce gas in the oil and gas sector. *flaring*, with a target *Zero Routine Flaring* in 2030 (Barati & Pirozfar, 2019). Second, implementation *carbon capture, utilization, and storage (CCUS)* in large facilities (Liu et al., 2018). Third, improving operational efficiency through adoption *Best available technology* (Obiki-Osafiele et al., 2024). Fourth, economic diversification in oil and gas producing areas to reduce dependence on this sector in the long term (Kakabayev et al., 2024).

For the cement industry, the priority of intervention includes first, *mandatory blending* with substitute materials *clinker* such as *Fly Ash* or *Stroke* to reduce process emissions (Gartner & Sui, 2018). Second, the transition from coal to cleaner alternative fuels (Phogat, 2025). Third, implementation *Carbon Capture* in large cement factories located in Java (Hills et al., 2016). Fourth, the promotion of the use of low-carbon cement in government infrastructure projects to create *Demand* and encourage innovation. Fifth, research and development of alternative cement with different chemicals that can reduce process emissions *Fundamentals* (Shubbar et al., 2019).

For the power generation sector, the highest priority is the acceleration of the energy transition from coal to renewable energy. The concrete strategy includes, first, a moratorium on the construction of new coal-fired power plants, with very limited exceptions only for projects that are already highly advanced and cannot be canceled (Shirley, 2025). Second, the *early*

retirement for old and inefficient coal-fired power plants, with a fair compensation mechanism for workers and affected communities (Musayeva, 2020). Third, the massive development of solar power plants (PLTS), especially *Solar rooftop* in Java to reduce network load (Haryadi et al., 2022). Fourth, the acceleration of geothermal development, where Indonesia has the largest potential in the world but only utilizes about 5% of the (Pambudi et al., 2023). Fifth, modernization of transmission and distribution networks to accommodate higher penetration of renewable energy (Kabeyi & Olanrewaju, 2021).

For heavy industries (iron and steel, food and beverage, textiles), priorities include first, the implementation of stricter energy efficiency standards with a clear timeline (Laustsen, 2008). Second, fiscal incentives (*Tax break*, interest subsidies) for investments in low-carbon production technologies (Curtin et al., 2017). Third, *Mandatory Energy Audit* for large factories with the obligation to implement the recommendations that *feasible* economically (Nabitz & Hirzel, 2019). Fourth, the *capacity building* and technology transfer to assist small and medium-sized industries in the adoption of clean technologies (Karakosta et al., 2010). Fifth, the development of industrial clusters or *Eco-industrial park* where *Waste* from one industry can be an input to another, improving overall efficiency (Tian et al., 2014).

The implementation of an ambitious mitigation strategy requires enormous funding. Rough estimates show that to achieve significant emissions reduction targets, Indonesia will need investments in clean energy and energy efficiency reaching tens to hundreds of billions of dollars in the coming decade. This funding cannot rely solely on the government budget, so it is necessary to mobilize diverse funding sources.

First, it is necessary to develop a mechanism *Green Finance* strong, including *Green bonds*, *green loans*, and *Green Sukuk*. Indonesia has published several *Green Sukuk* that are successful in the international market, but the scale and frequency need to be increased (Alam et al., 2023). Second, it is necessary to maximize access to *International Climate Finance*, including *Green Climate Fund*, *Clean Technology Fund*, and various bilateral and multilateral mechanisms (Han & Cheng, 2023). Third, it is necessary to develop a mechanism *Public-Private Partnership (PPP)* of interest for renewable energy and energy efficiency projects (Othman & Khallaf, 2022). Fourth, implementation *carbon pricing* (either through *Carbon Tax* or *Emissions trading system*) can produce *Revenue* that can be allocated to mitigation and adaptation programs (Narassimhan et al., 2018).

Especially for transfers between regions, it is necessary to develop a mechanism *Equalization Fund* or a special balance fund for climate change mitigation. Islands with greater fiscal capacity (especially Java) can contribute more to funding mitigation programs on other islands. This mechanism is in line with the principle *common but differentiated responsibilities* and can help overcome capacity inequality between regions. These funds can be allocated to programs such as renewable energy development in remote areas, forest conservation, and *capacity building* for local governments (Sovacool, 2012).

Technology transfer is also crucial to ensure that areas with limited technical capacity can adopt low-carbon technologies. Needs to be developed *Technology Hub* or centers of excellence (*Centers of Excellence*) on various islands that can serve as focal points for the diffusion of technology (Pigato et al., 2020). Cooperation with developed countries and international institutions needs to be strengthened to facilitate technology transfer, including through mechanisms *Technology Mechanism* under the UNFCCC. In addition, it is necessary to develop

training programs and *capacity building* to build a skilled workforce that can operate and maintain clean technologies (Pueyo et al., 2012).

Conclusion

This study has comprehensively analyzed the comparison of carbon emissions in six main islands/regions of Indonesia and tested the statistical significance of the observed differences. The results of the analysis stated that there are statistically significant differences in carbon emissions between islands in Indonesia. The analysis reveals a very extreme regional disparity in emissions contributions. Java dominates with a contribution of 63.70% of total national emissions, almost two-thirds of the total. This dominance reflects the concentration of industry, population, and economic activity in Java. Sumatra occupies the second position with a contribution of 21.48%, while the other islands contribute much less. This disparity creates both challenges and opportunities in Indonesia's climate change mitigation efforts.

Indonesia's carbon emissions are highly concentrated in a small group of sectors. The oil and gas mining sector alone accounts for nearly one-third of total national emissions, followed by the cement industry and power generation. The top five sectors accounted for almost 65% of total emissions, while the top ten sectors accounted for more than 83%. These very high concentrations suggest that targeted interventions in key sectors can produce very significant emission reduction impacts.

The policy implications of the findings of this study are very significant. First, mitigation approaches should be differentiated based on the unique characteristics of each island. Java and Sumatra need very ambitious reduction targets given their dominant contributions, while other islands can focus on low-carbon development and conservation. Second, interventions should be prioritized in the highest key emitting sectors to maximize impacts with limited resources. Third, a strong funding and technology transfer mechanism is needed to support the implementation of mitigation strategies in various regions with different capacities.

This research makes an important contribution in understanding Indonesia's carbon emission profile from a regional and sectoral perspective. These findings can be a strong evidence base for the formulation of more effective, efficient, and equitable climate change mitigation policies. With huge regional disparities and emissions concentrations in key sectors, Indonesia has the opportunity to achieve significant emissions reductions through appropriately targeted interventions. However, the success of these efforts requires strong political commitment, adequate investment, and close collaboration between various stakeholders at the national, regional, and local levels.

Finally, it's important to remember that climate change mitigation is not just about reducing emissions, but also about transforming towards a more sustainable, inclusive, and equitable model of development. The transition to a low-carbon economy must be carried out by considering socio-economic aspects and ensuring that no group of people is left behind (just transition). With the right approach, Indonesia can achieve its climate targets while still driving economic growth and improving the welfare of its people. This research is expected to contribute to these collective efforts by providing rigorous analysis and actionable recommendations.

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