

# CO<sub>2</sub> Emission Projection Analysis Based On Cement Consumption In Indonesia

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## ABSTRACT

Climate change is a global issue driven by the increasing concentration of greenhouse gases, particularly carbon dioxide (CO<sub>2</sub>) in the atmosphere. The cement industry contributes approximately 5% of global greenhouse gas emissions. Economic growth and urbanization have caused cement consumption to continue to increase during the period 1980-2014. This study aims to analyze cement consumption and project CO<sub>2</sub> emissions from the calcination process based on cement consumption in six major regions of Indonesia: Java, Sumatra, Kalimantan, Sulawesi, Bali-Nusa Tenggara, and Eastern Indonesia in 2025-2050. The study utilized cement consumption data from 2008 to 2022, obtained from the Statistics Indonesia (BPS). Cement emissions were calculated using the IPCC cement consumption approach. This study used GIS to visualize cement emissions based on cement consumption in Indonesia. Future emissions projected under a business-as-usual (BAU) scenario. Java Island was identified as the region with the highest cement consumption and production during the 2008–2023 period, with Jakarta, West Java, East Java, and Banten as the largest consumers. Cement consumption in all regions peaked in 2016, driven by extensive infrastructure projects, particularly in transportation and irrigation. The emission pattern follows the consumption trend, with Java recording the highest emissions with total CO<sub>2</sub> emissions of 11,095,722 ton of CO<sub>2</sub> in 2023. Java is projected to experience a decline in emissions by 2050, while other regions, especially Kalimantan and Eastern Indonesia, are expected to continue to experience emissions growth due to ongoing infrastructure expansion. The trend of cement emissions based on consumption follows the value of cement consumption in the region. The results of emission calculation and projections are very important in achieving the Nationally Determined Contribution.

**Keywords:** Business-as-Usual, Cement, Climate Change, CO<sub>2</sub>, Emission

## 1. INTRODUCTION

Climate change is characterized by an increase in the earth's temperature. The earth's temperature which has continued to increase over the past 50 years is directly proportional to the concentration of carbon dioxide in the atmosphere (Fig 1). Carbon dioxide is a greenhouse gas that is largely produced by anthropogenic processes such as the industrial sector, transportation, household consumption, etc. In 2020, CO<sub>2</sub> emissions from the electricity and heat utilization sector reached 15.18 billion tons of CO<sub>2</sub> e followed by the transportation sector (7.29 billion tons of CO<sub>2</sub> e) in second place, and industry manufacturing (6.22 billion tons of CO<sub>2</sub> e) in third place (Ritchie et al., 2020).

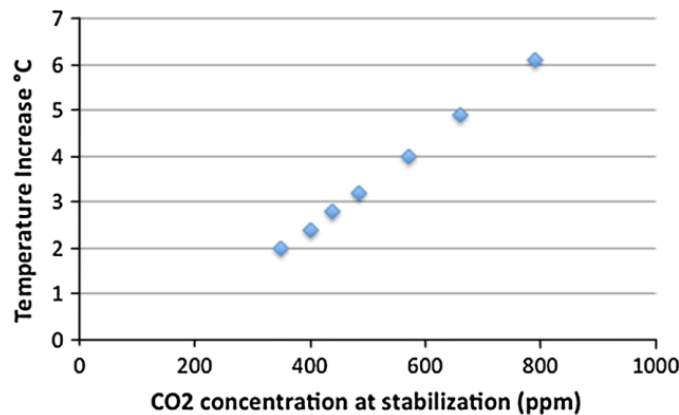


Figure 1 Graph of the relationship between CO2 concentration and temperature increase (IPCC, 2007)

The cement industry sector is one of the major industries that also contributes to emissions. The cement industry contributes 5% of global anthropogenic CO<sub>2</sub> emissions (Fonta, 2017; Hason et al., 2020; Hassan et al., 2007). CO<sub>2</sub> emissions from the cement industry sector globally are estimated at around 2.46 gigatons (GT) in 2019, indicating an increase of 186% since 1990 (Chen et al., 2022). CO<sub>2</sub> emissions from the cement industry are increasing due to the increasing demand and production of cement. Economic growth and urbanization have caused cement production and consumption to continue to increase during the period 1980-2014. The growth of cement production in the world is estimated to reach 12-23% in 2050. (Sanjuán et al., 2020).

The industrial and processing sector ranks sixth as a sector that produces CO<sub>2</sub> emissions after the energy sector, FOLU, forest fires, waste, and agriculture in Indonesia. In 2020, the amount of CO<sub>2</sub> emissions from the industrial and processing sector in Indonesia reached 57,194.08 Gg CO<sub>2</sub> e (KLHK, 2023). Cement is one of the products produced from the limestone processing process. Indonesia has a total of 14 cement processing Limited Liability Companies (PT) which are members of The Indonesia Cement Association (ICA) or the Indonesian Cement Association (ASI) and are spread across all major islands in Indonesia. The average amount of greenhouse gas emissions in 2001-2006 in the cement industry in Indonesia reached 28,803 Gg/year or 28,803 million kg/year (Purwanta, 2010).

Currently, the condition of the Indonesian cement industry is expected to experience a crisis. Since 2014 until now, Indonesian cement companies have experienced over-capacity. The amount of cement production capacity in all companies in Indonesia continues to increase. On the other hand, the amount of cement purchases and needs tend to be constant. In 2020, domestic production capacity reached 115 million tons while domestic needs were only 62 million tons per year (Suarly et al., 2023). The growth of cement industry capacity is faster (2.7%), while cement demand growth fell (-0.7%) in 2020. The Covid-19 pandemic in 2020 caused the amount of cement demand to decrease further. This is a problem that needs to be evaluated considering that increasing cement capacity and production will be followed by increasing CO<sub>2</sub> emissions.

CO<sub>2</sub> emissions by the cement industry are divided into 2, namely direct and indirect emissions. Direct emissions are emissions that come from the company directly, while indirect emissions are emissions that result from the consequences of the company's activities but the source comes from other companies. An example of direct emissions from the cement industry is emissions resulting from the calcination process, while indirect emissions are emissions resulting from the use of fuel for cement distribution (Venkata Sudhakar & Umamaheswara Reddy, 2023). In the calcination process, the source of CO<sub>2</sub> emissions in the cement industry comes from the combustion process and the use of coal energy (Li et al., 2011). Coal is used during the limestone burning process. This burning process produces pollutants in the form of dust, CO<sub>2</sub>, SO<sub>2</sub>, NO<sub>2</sub>, and others. (Suryani & Gunawan, 2010). Cement processing and production produces residual products in the form of CO<sub>2</sub> gas from the chemical process in the production of clinker (one of the components of cement). Limestone (CaCO<sub>3</sub>) is converted into lime (CaO) and produces residue in the form of CO<sub>2</sub> during the combustion process. The use of energy in the form of coal in the limestone combustion process also produces CO<sub>2</sub> emissions from the energy utilization sector (IPCC, 2006). The equalization of development and urbanization throughout Indonesia will cause an increase in emissions, both direct and indirect emissions from the cement industry.

This study aims to (1) analyze the trend of CO<sub>2</sub> emissions from the cement industry based on consumption in Indonesia in 2008-2023, (2) project CO<sub>2</sub> emissions from the cement industry in 2025-2050.

## 2. METHODS

### 2.1 Carbon Dioxide Emission

The cement production process consists of 3 main stages, namely raw material preparation, clinker production, and grinding and mixing clinker with other mineral components. Carbon dioxide emissions in the cement industry are divided into direct emissions and indirect emissions. Direct emissions come from fuel in the kiln system and the calcination process. Indirect emissions come from the use of external electricity and off-side transportation.

The limitations and scope of emission sources based on the Greenhouse Gas Protocol in the cement and limestone industry are divided into 3 scopes, including:

**Table 1.** Scope Greenhouse Gas Protocol Cement Industry

| <i>Scope 1</i>                                                                       |  | <i>Scope 2</i>                                                              |  | <i>Scope 3</i>                                                  |  |
|--------------------------------------------------------------------------------------|--|-----------------------------------------------------------------------------|--|-----------------------------------------------------------------|--|
| - Emissions from calcination processes                                               |  | - Stationary combustion (purchased electricity consumption, heat and steam) |  | - Stationary combustion (material production, waste combustion) |  |
| - Stationary combustion (clinker kilns, raw material drying, electricity production) |  |                                                                             |  | - Purchased clinker and limestone                               |  |

| <i>Scope 1</i>                              | <i>Scope 2</i> | <i>Scope 3</i>                                                                                                                                                                                                          |
|---------------------------------------------|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| - Mining operations, on-site transportation |                | production process emissions<br><br>- Mobile combustion (transportation, employee business trips)<br><br>- Fugitive emissions (mining and landfill CH <sub>4</sub> and CO <sub>2</sub> emissions outsourcing processes. |

The method of calculating CO<sub>2</sub> emissions in the cement industry has 3 tiers, namely the cement-based approach, the clinker-based approach, and the consumption carbonate-based approach (IPCC, 2006). The cement-based approach calculates CO<sub>2</sub> emissions based on the amount of cement produced or consumed, while the clinker-based approach is a method of calculating CO<sub>2</sub> emissions based on the amount of clinker produced. This study uses the cement consumption-based approach method to calculate direct emissions from the calcination process (direct emissions). This study uses the tier 1 method to calculate emissions from the calcination process of the cement industry (scope 1). This study uses secondary data on Indonesian cement consumption from Statistics Indonesia (BPS). The equation used to calculate CO<sub>2</sub> emissions from cement production in Indonesia can be seen below:

$$\text{CO}_2 \text{ Emission} = [(M_{ci} \times C_{cli}) - Im + Ex] \times EF_{clc} \quad (1)$$

$$EF_{clc} = 0.51 \times 1.02 (\text{corection CKD}) = 0.52 \text{ ton} \frac{\text{CO}_2}{\text{ton}} \text{clinker} \quad (2)$$

CO<sub>2</sub> Emission : CO<sub>2</sub> emission from cement consumption (ton)

M<sub>ci</sub> : Mass of type I cement produced (ton)

C<sub>cli</sub> : Clinker fraction in type I cement

Im : Import clinker (ton)

Ex : Export clinker (ton)

EF<sub>clc</sub> : Emission factor (ton CO<sub>2</sub>/ton clinker)

## 2.2 CO<sub>2</sub> Emission Projections

Carbon dioxide emission projections are used to predict CO<sub>2</sub> emissions due to increased cement demand and production. Previous studies have predicted carbon emission figures using per capita cement demand projections (Wei & Cen, 2019). In the research related to CO<sub>2</sub> emissions of the cement industry and landscape capacity in Indonesia, the projection of CO<sub>2</sub> emissions of the cement industry uses the business as usual (BAU) approach. This approach is often used in greenhouse gas projections. In the BAU approach, historical trends are used to analyze future climate change projections (Cheng et al., 2023). BAU is a scenario that describes the level of future emissions without considering or considering policy interventions, mitigation, economic growth, and others. The BAU approach can be called the worst-case climate projection approach or SSP5-8.5.

$$LE = \left[ \left( \frac{E_t}{E_{t0}} \right)^{\frac{1}{t-t_0}} \right] - 1 \quad (3)$$

$$E_j = E_{j-1} + (E_{j-1} \times LE) \quad (4)$$

|                  |                                                               |
|------------------|---------------------------------------------------------------|
| LE               | : CO <sub>2</sub> emission rate (tons CO <sub>2</sub> e/year) |
| E <sub>t</sub>   | : Emissions year t (reference) (tons CO <sub>2</sub> e)       |
| E <sub>t0</sub>  | : Emissions year t0 (reference) (tons CO <sub>2</sub> e)      |
| t                | : years t                                                     |
| t <sub>0</sub>   | : years t0                                                    |
| E <sub>j</sub>   | : Emissions year t (projection) (ton CO <sub>2</sub> e)       |
| E <sub>j-1</sub> | : Emissions year t0 (projection) (ton CO <sub>2</sub> e)      |

## 3. RESULTS AND DISCUSSIONS

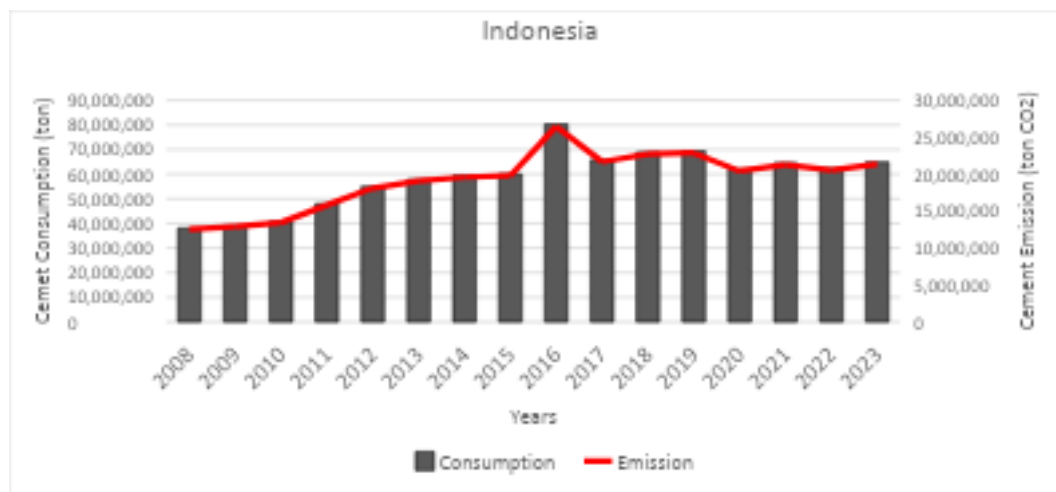
### 3.1 Carbon Dioxide Emission

Indonesia is an archipelagic country with the second highest production rate in Southeast Asia after Vietnam. In general, the level of cement consumption in Indonesia continues to increase until 2016 and then decreases until 2023. During the period 2008 to 2023, the amount of cement consumption in Indonesia experienced its highest peak in the period 2016-2019. The highest level of cement consumption in Indonesia was in 2016. The level of cement consumption in 2016 increased due to Indonesia's policy of increasing equity in regional infrastructure development. The average growth in cement consumption in Indonesia reaches 4% per year.

Indonesia is the country with the fifth largest infrastructure building asset value in Southeast Asia (Dewi, 2018). The infrastructure owned in Indonesia in 2015 included

38,569.82 km, 375.27 km of bridges, 209 dams, 3,321 reservoirs, 406 irrigation areas, 18,216 rusunawa units, 6361 special houses, and 13,500,000 housing units. In 2016, the progress of dam construction reached 49.2% of the target, airports 33.3%, electricity 31%, toll roads 26.5%, ports 18.3%, and railways 15%. The government's 2016 policy encouraged Indonesia to continue to develop regional infrastructure. This can be seen and proven by the very high level of cement consumption in 2016. This condition occurs throughout the islands and regions in Indonesia. In 2016, the Indonesian government issued a Government Work Plan policy to accelerate infrastructure development. This policy is supported by Presidential Regulation (Perpres) Number 4 of 2016, Presidential Regulation (Perpres) Number 3 of 2016, Regulation of the Minister of Finance (PMK) Number 130/PMK.08/2016), and Regulation of the Minister of Public Works and Public Housing (Permen PUPR) Number 09/PRT/M/2016.

The emission trend in Indonesia in general continues to increase until 2016 (Figure 2). The highest emission peak in Indonesia was in 2016. In this year, Indonesia carried out large-scale development in various sectors throughout its territory. This year, Indonesia has recorded 209 dam centers, 406 irrigation areas, 47,536.22 km of roads, and 905.15 km of toll roads (Kementerian PUPR, 2016).



**Figure 2.** Cement Emission Graph Based on Cement Consumption in Indonesia 2008-2023

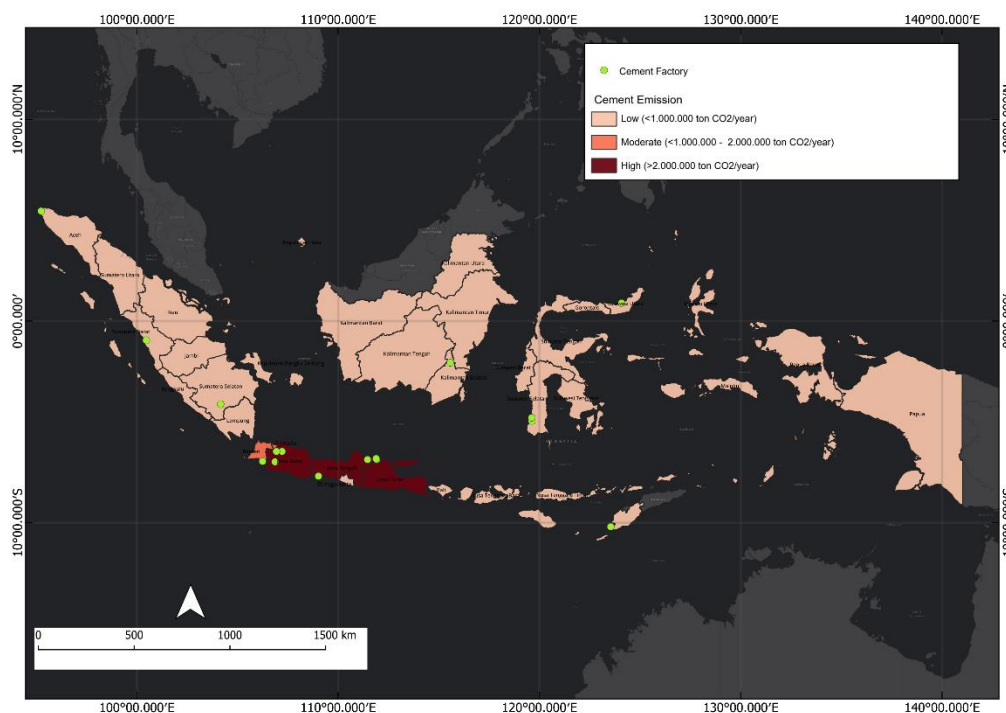
Figure 3 shows the average distribution map of cement emissions based on cement consumption in Indonesia during the period 2008–2023. This map maps the distribution of carbon dioxide (CO<sub>2</sub>) emissions resulting from cement consumption in various provinces. Emissions are categorized into three levels, namely low (<1,000,000 tons CO<sub>2</sub>/year), medium (1,000,000–2,000,000 tons CO<sub>2</sub>/year), and high (>2,000,000 tons CO<sub>2</sub>/year). Green dots indicate the locations of cement production plants in Indonesia that are members of the Indonesian Cement Association (ASI).

Java Island is the region with the highest emission level, marked by dark red. This shows that cement consumption in this region is very large. The high emissions and cement consumption in Java Island are triggered by high infrastructure development activities, industrial area growth, and urbanization. Provinces such as West Java, Central Java, and East

Java dominate the high emission category. The dense concentration of cement factories on this island also supports high carbon emissions in the region.

Provinces outside Java show moderate to low emission levels. Areas such as Kalimantan, Sulawesi, Maluku, and Papua fall into the moderate to low emission group, as shown in Figure 2. This shows that the level of development and cement consumption in these areas is still relatively lower compared to Java. However, several provinces outside Java also have cement factories, such as in South Sulawesi and West Sumatra, which have the potential to increase emissions if consumption continues to increase.

The distribution of cement factory locations is seen to be spread across various islands, although it remains concentrated in Java. The existence of these factories plays an important role in the national cement supply chain, but is also one of the main contributors to carbon emissions due to the very energy-intensive production process. The map of emission distribution and cement production plants provides a clear visual picture of the relationship between cement consumption and carbon emissions in various regions of Indonesia. This data is important as a basis for policy making in efforts to reduce industrial sector emissions, especially in areas with high emission levels such as Java. Mitigation strategies such as increasing energy efficiency, utilizing environmentally friendly alternative materials, and developing sustainable infrastructure can be prioritized in areas with high emissions to support the national net zero emission target.

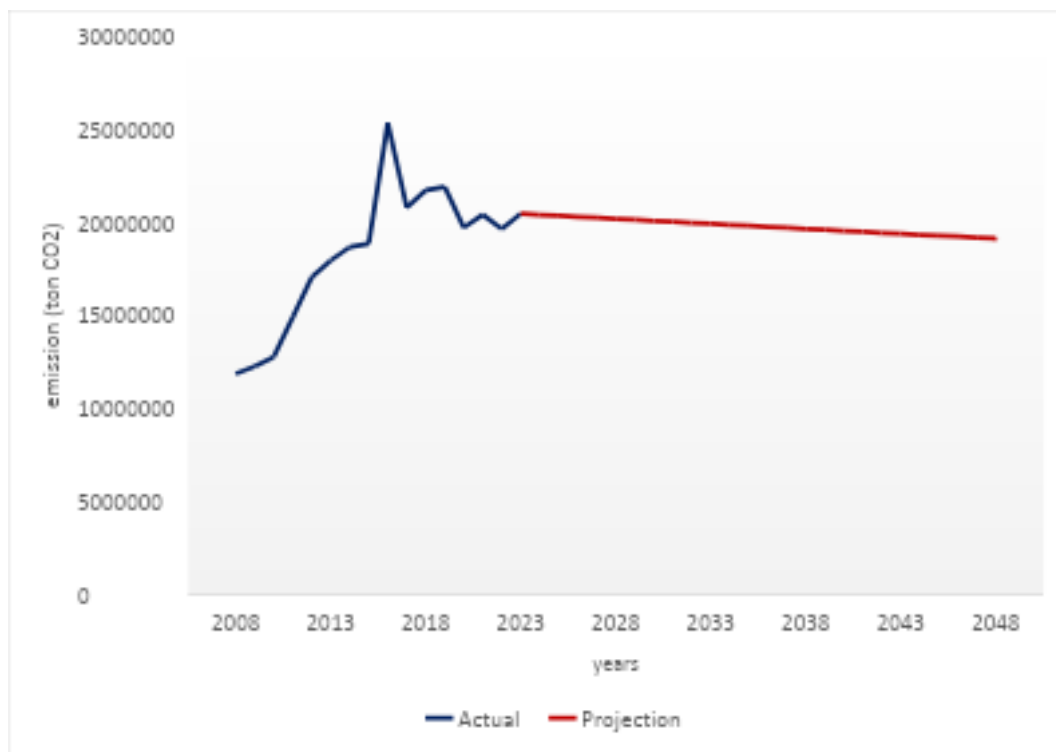


**Figure 3.** Map of Average Emissions Based on Cement Consumption in Indonesia 2008-2023

### 3.2 Carbon Dioxide Emission Projection

The actual and projected trends of carbon dioxide (CO<sub>2</sub>) emissions in Indonesia from 2008 to 2050 are shown in Figure 4. The graph shows a business as usual scenario to predict consumption-based emissions in Indonesia. From the actual data, it can be seen that CO<sub>2</sub> emissions increased significantly between 2008 and 2015, and peaked in 2016 at 25 million tons of CO<sub>2</sub>. After the peak, emissions declined and remained in the high range of around 20 million tons of CO<sub>2</sub> per year until 2025. The high emissions in 2016 were caused by rapid growth in infrastructure development, increased consumption of fossil fuels, and industrialization.

The graph shows the trend of decreasing emissions after 2025. The decrease ranges from around 20 million tons of CO<sub>2</sub> to below 19 million tons of CO<sub>2</sub> by 2050. This reflects the existence of emission mitigation efforts, such as clean energy transition, energy efficiency, and emission control policies in the industrial and transportation sectors. This data is very relevant as a basis for formulating long-term climate policy strategies, including in the context of achieving the Nationally Determined Contribution (NDC) target and Indonesia's commitment in the Paris Agreement to reduce greenhouse gas emissions. Thus, this emission reduction projection needs to be continuously monitored and strengthened with concrete policies, including the development of renewable energy, the application of low-carbon technology, and changes in people's consumption behavior that are more sustainable. Periodic evaluation is also important so that the emission reduction path remains on a consistent trajectory towards net-zero emissions.

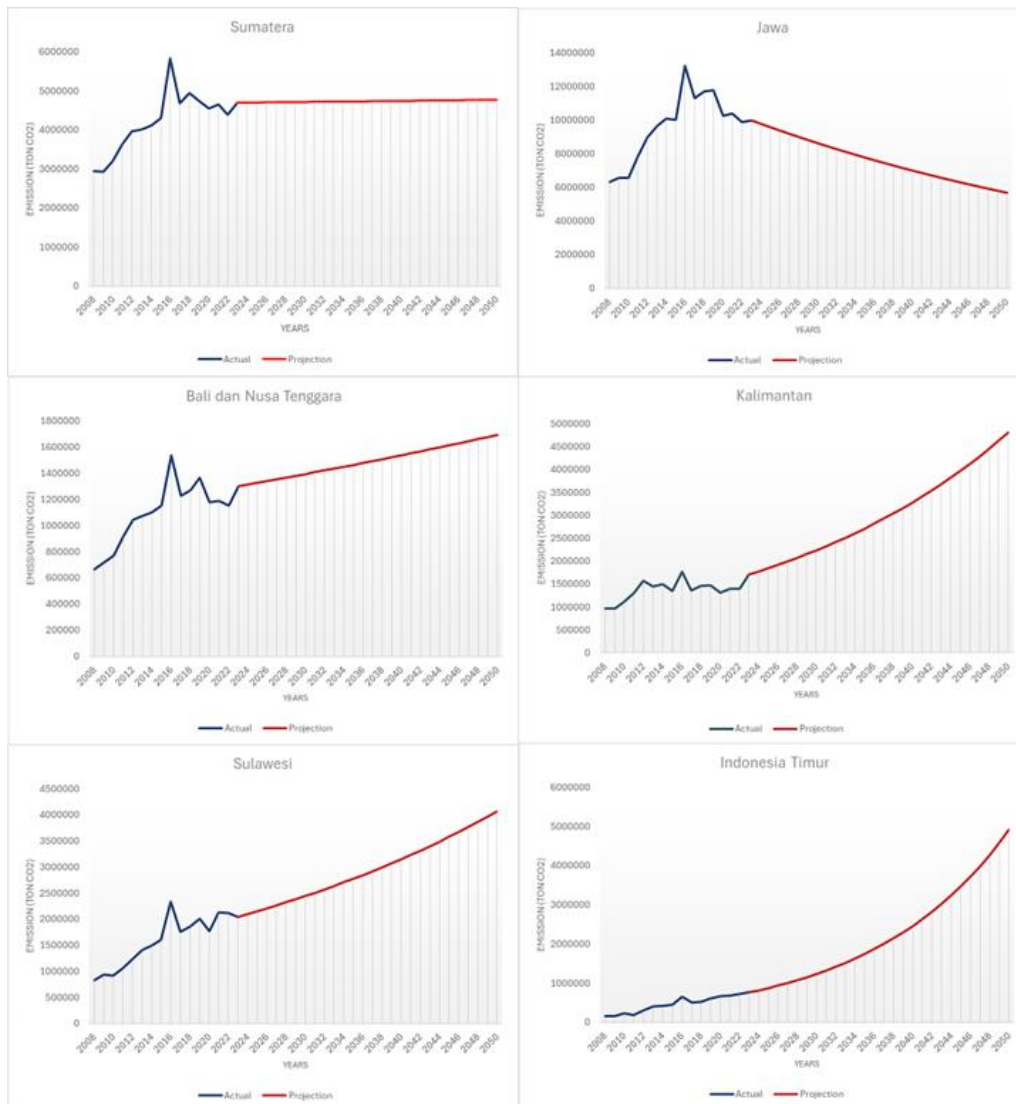


**Figure 4.** Indonesia Emission Projection Chart

The graph of CO<sub>2</sub> emission projections due to cement consumption in six regions of Indonesia (Sumatra, Kalimantan, Java, Sulawesi, Bali and Nusa Tenggara, and Eastern

Indonesia) in the period 2008 to 2050 is shown in Figure 5. The results of data processing show that each region has a unique emission pattern, reflecting differences in the level of development, industrialization, and material consumption (in this case cement). Emission projections are the result of data processing using statistical methods or business as usual with the assumption that historical trends will continue in the future without significant policy or technology intervention. In Sumatra, emissions increased sharply until around 2014, then stabilized or decreased slightly. The projection shows a constant trend until 2050. This can be interpreted that cement consumption-based development in this region is not expected to grow significantly, or even be limited by regulations or decreased infrastructure needs. The Kalimantan region shows a very different pattern. After experiencing a fluctuating trend until 2023, emission projections increase sharply exponentially. This is due to the long-term plan for the development of the new capital city (IKN) and its supporting infrastructure, as well as intensive exploitation of natural resources.

Java Island recorded the highest emissions historically, reflecting its economic and industrial dominance. Emission projections in Java Island show a significant downward trend. This could be due to the shift in growth centers outside Java as well as the implementation of energy efficiency policies and low-carbon industrial transitions in this region. In contrast to Java Island, emissions in Sulawesi show a stable growth pattern with moderate fluctuations. Projections show a gradual increase. The growth of new industrial cities, especially those related to the mining and logistics sectors in this region, is one factor in the increasing consumption of cement in this region. Bali and Nusa Tenggara experienced an increase in emissions in the 2014–2020 period but have since stabilized. Projections show a consistent upward trend, caused by the growth of the tourism sector and the development of supporting infrastructure, such as housing, roads, and public facilities. Eastern Indonesia shows low emissions and projections show a continuing upward trend. This indicates the potential for new environmental pressures due to infrastructure development, population migration, and economic expansion into areas that have previously been relatively underdeveloped.



**Figure 5.** Projected Emissions Graph in Kalimantan, Sumatra, Java, Sulawesi, Bali-Nusa Tenggara, and Eastern Indonesia

### 3. CONCLUSION

The trend of cement emissions based on consumption follows the value of cement consumption in the region. The highest consumption-based cement emissions are in Java. Overall, the highest emissions occurred in 2016 due to the high level of cement consumption. The emission projections for 2025-2050 show different trends in each region in Indonesia. The Java region tends to experience a downward trend in emissions while other regions experience an upward trend in emissions. The Kalimantan and Eastern Indonesia regions are regions that continue to experience an upward trend in emissions. This condition is caused by the high level of regional infrastructure development due to the relocation of the capital city in Kalimantan and the program to improve the economic welfare of the people of Eastern Indonesia.

This study has shortcomings in terms of method. The consumption-based calculation method was developed by the World Bank to calculate emissions borne by consumers, not producers. This causes the emissions referred to in this study not to be emissions that are naturally located in the area around the cement factory but emissions borne by the community due to the consumption process. This study also has another limitations, particularly related to national emission factors. The study still uses the global emission factors established by the IPCC. Emission projections use a business-as-usual approach, which only analyzes emissions growth figures for a specific period of time without considering mitigation efforts or existing infrastructure development policies. In the future, this research can be developed and supplemented with reliable data, especially data related to cement production, clinker production, and emission factors in Indonesia. Uncertainty in the projection results can also be added by considering variables that influence cement consumption and emissions such as regional income, urbanization levels, political policies, emission factors, and other climate change mitigation efforts.

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