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DECOUPLING ANALYSIS OF CARBON EMISSIONS AND DETERMINANTS IN INDONESIA

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Abstract

This study aims to analyze the relationship between economic growth and environmental degradation in 10 provinces in Indonesia during the period 2014–2023. Using the Tapio Index analysis method and panel data regression with the Fixed Effect model (FEM), this study examines the influence of Gross Domestic Product (GDP), industrialization level (IND), and investment (INV) on CO_2 emissions. The results of the Tapio Index analysis indicate that the majority of the observed regions (90%) are still in a coupled status, indicating that economic growth continues to accompany increasing emissions. Only South Kalimantan Province shows a weak decoupling status. The panel data regression results confirm that GRDP has a positive and significant effect on CO_2 emissions. However, the industry variable shows a significant negative effect, indicating an increase in energy efficiency in the sector. Meanwhile, the investment variable is found to have no significant effect on emissions. These findings emphasize the need for more aggressive policy transformation to shift investment to the green sector to achieve sustainable economic growth.

Keywords: CO_2 Emissions, Tapio Index, and Decoupling

INTRODUCTION

More and more people are concerned about climate change and environmental degradation, leading them to question just how sustainable traditional economic growth really is (Teruel-Gutiérrez et al., 2026). The transition to low-carbon economic growth is crucial to the success of global climate efforts (Berahab, 2017). Global efforts to combat climate change have been ongoing for some time. Deepening and promoting the concept of "carbon neutrality" has become a widely accepted and central consensus among nations worldwide (H. Wang & Tan, 2026).

The concept of green growth suggests that an economy can grow while simultaneously reducing its negative impact on the environment. This has become a central issue in policy debates. A crucial component of green growth is decoupling, meaning the relationship between a country's total economic output, known as GDP, and the pressure it places on the environment becomes weaker or more severed. Specifically, absolute decoupling means that emissions must actually decrease even as the economy grows, which is considered essential for achieving the goals of the Paris Agreement and the Sustainable Development Goals (Antal & Van Den Bergh, 2016). If complete decoupling of energy use is possible, it suggests that plans based on new technologies, greater efficiency, and deliberate changes in energy use are effective. If growth and deep decarbonization cannot coexist, then the current way the economy operates may be at odds with climate constraints (Teruel-Gutiérrez et al., 2026).

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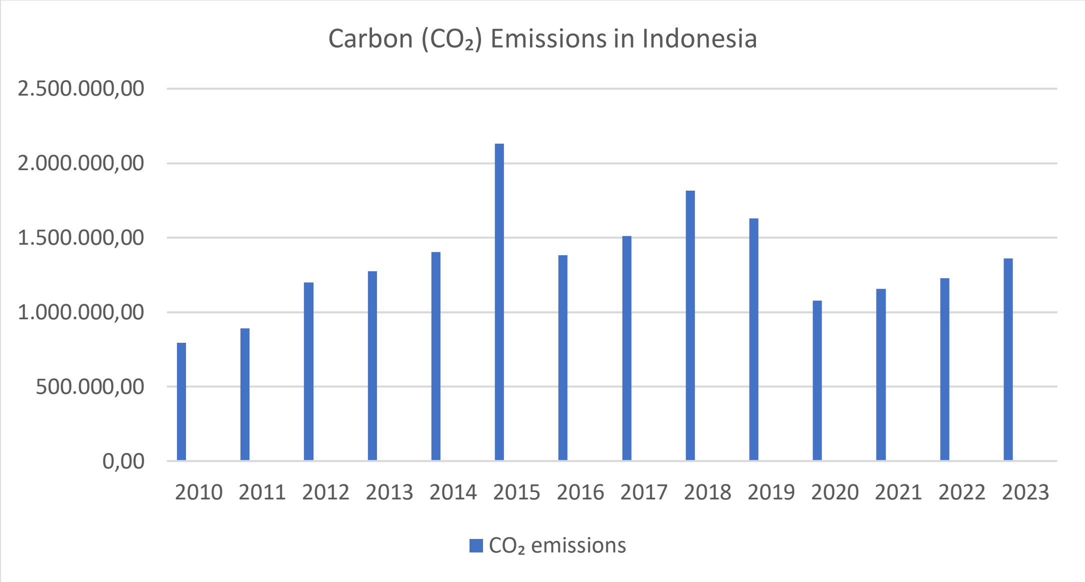

Figure 1. Carbon Emissions (CO_2) 2010-2023

Based on the graph of carbon emissions (CO_2) data in Indonesia for the period 2010–2023, significant fluctuations are visible, with a general trend that tends to increase in the first decade but begins to show a new pattern after 2015. In the period 2010 to 2014, carbon emissions experienced a steady increase, which then jumped sharply to reach a peak in 2015 with a figure exceeding 2,000,000 units. This drastic increase indicates the presence of industrial activity or specific environmental factors that had a major impact on greenhouse gas release in that year. After reaching a peak in 2015, there was a decline in 2016 before finally creeping up again until 2018. However, entering the period 2019 to 2020, there was a fairly sharp decline in emissions, where the emission figure in 2020 reached its lowest level in recent years, namely in the range of 1,000,000 units. This was influenced by the slowdown in economic activity and mobility due to the COVID-19 pandemic. Post-2020, the graph again shows a recovery trend with a consistent increase in emissions until 2023, confirming the close correlation between the recovery of national economic activity and the increase in Indonesia's carbon emissions burden.

Table 1. Carbon Emissions (CO_2) and GDP

Region	**Year**	**Emisi CO_2 (Thousand ton of CO_2e)**	**GDP at constan prices (Billion Rupiah)**
Aceh	2016	400.441	116374.30
	2017	402.904	121240.98
	2018	405.566	126824.37
	2019	407.180	132069.62
	2020	411.012	131580.97
	2021	420.929	135274.04
	2022	416.357	140971.72
	2023	412.135	146932.51
North Sumatera	2016	400.572	463775.46
	2017	402.830	487531.23
	2018	402.927	512762.63
	2019	409.568	539513.85
	2020	413.910	533746.36
	2021	417.848	547651.82

Region	Year	Emisi CO_2 (Thousand ton of CO_2e)	GDP at constan prices (Billion Rupiah)
	2022	411.678	573528.77
	2023	411.874	602235.95
Central Java	2016	400.683	849099.35
	2017	399.972	893750.30
	2018	408.479	941091.14
	2019	407.498	991516.54
	2020	409.913	965227.27
	2021	414.166	997321.13
	2022	413.919	1050278.09
	2023	414.529	1102437.49

Source: BPS and data processed (2026)

Regional economic growth is a key pillar of national development, reflected in the increase in Gross Regional Domestic Product (GRDP) in various provinces. Based on data from 2016 to 2023, large provinces such as DKI Jakarta, Central Java, and North Sumatra continue to show a significant upward trend in GDP at constant prices despite facing the challenges of the pandemic in 2020. However, this rapid economic activity has had logical consequences for the environment, namely an increasing trend in CO_2 emissions, which averages above 400,000 tons of CO_2. This phenomenon indicates a close relationship between economic productivity and the ecological burden that each region must bear.

The economic structure of each province contributes differently to this emissions profile, particularly in terms of the proportion of value-added manufacturing. Provinces with a strong industrial base, such as Banten and Central Java, which have a manufacturing proportion above 30%, face greater challenges in balancing production output with emission reduction targets. Conversely, regions with different economic characteristics, such as Papua and Aceh, demonstrate that despite their relatively small manufacturing proportion, the dynamics of development and land clearing continue to influence fluctuations in greenhouse gas emissions in the region.

Beyond industrial factors, investment flows play a crucial role as a primary driver of regional economic modernization. Over the past eight years, highly dynamic investment fluctuations have been observed across various regions, with Jakarta and Banten recording the highest investment figures, reaching tens of trillions of rupiah in 2023. This investment is not only a driver of GRDP growth but also a key driver in the transition to more environmentally friendly technologies. If investment is directed toward green sectors, GRDP increases do not always have to be offset by a linear increase in emissions. Therefore, an in-depth analysis is needed to determine the extent to which investment and industrialization in Indonesia have adopted sustainable principles. By examining historical data on GDP, CO_2 emissions, and the proportion of manufacturing in various provinces, we can map the effectiveness of current green economy policies. This understanding is crucial for formulating development strategies that can maintain the momentum of economic growth without compromising commitments to climate change mitigation at the regional and national levels.

Indonesia's emissions continue to rise, making it crucial to separate carbon emissions from economic growth. If emissions increase more slowly than economic growth, this is called a situation of relative decoupling. When carbon emissions cause a short-term slowdown in economic growth, it indicates that the economy is completely decoupled from its environmental impacts (Mikayilov et al., 2018). Decoupling means breaking the link between environmental degradation and economic growth, helping to achieve one of the most important goals of environmental planning.

Decoupling is a concept that helps determine a region's position at a particular stage of decoupling, which helps understand how sustainable development works. Sustained economic growth in both developed and developing countries is associated with increasing environmental pressures, which are feared to exceed the ecosystem's capacity to sustain life. Furthermore, decoupling helps determine which tools or policies can help achieve these environmental goals (Mukaromah & Widodo, 2021).

This study generally aims to examine the relationship between economic activity and environmental quality in 10 selected provinces in Indonesia, from Aceh to Papua. Specifically, this study aims to analyze the status and extent of decoupling to identify whether GDP growth in these regions has been freed from dependence on high carbon emissions. Furthermore, this study aims to empirically test the extent to which GDP, level of industrialization, the and investment act as determinants that influence regional carbon emission fluctuations. Through this approach, the study is expected to map the typology of green economy development in each province and formulate relevant policy strategies to balance economic growth targets with commitments to reduce greenhouse gas emissions in Indonesia.

LITERATURE REVIEW AND HYPOTHESIS FORMULATION

The relationship between economic growth, energy use, and the environment can be explained by certain theories (Anwar, 2026). The Environmental Kuznets Curve shows that as a country's economy grows, pollution initially increases, but as the country becomes wealthier, it begins to use cleaner technologies and pollution begins to decline (Islam & Kieu, 2020). Kuznets explained a lot about how economic growth relates to CO_2 emissions, and he created the Environmental Kuznets Curve to show this relationship. Kuznets explained that there is a relationship where CO_2 emissions initially increase with economic growth, but eventually begin to decline after a certain point. Kuznets argued that as a country's per capita income increases, pollution and environmental damage also increase initially during the early stages of economic growth. But over time, as per capita income continues to increase, pollution and environmental damage begin to decline. In Asia, research shows that lower-middle income countries, including Indonesia, tend to remain in a phase where increases in Gross Domestic Product (GDP) are directly proportional to increases in CO_2 emissions. This indicates that the EKC hypothesis has not been fully achieved in the region, as the relationship pattern still shows an increasing trend in emissions along with economic growth, or even forms a U-shaped curve in some cases (Nikensari et al., 2019).

The carbon decoupling effect describes the fractured relationship between economic growth and carbon emissions. This means that even though the economy continues to grow sustainably, carbon emissions no longer increase in line with that growth and, in fact, tend to decrease. The emergence of this decoupling effect is crucial in assessing a country or region's ability to develop sustainably (H. Wang & Tan, 2026).

In environmental economics, decoupling relates to the idea that economic growth does not necessarily lead to increased environmental problems. Decoupling means that greenhouse gas emissions, such as CO_2, no longer increase as the economy grows, but can even decrease as the economy expands. Two indicators are used to indicate the degree of decoupling. First, the indicator provided by the OECD, including: the Organization for Economic Co-operation and Development. The OECD decoupling index shows how the relationship between environmental pressures and the factors that drive them changes, for example, the relationship between CO_2 emissions and economic growth. If CO_2 emissions grow slower than economic growth, this indicates the possibility of decoupling in the research approach. Second, the index proposed by Tapio incorporates the concept of elasticity into the OECD decoupling model and divides it into eight categories: expansive coupling, recessive coupling, weak decoupling, strong decoupling, recessive decoupling, expansive negative decoupling, strong negative decoupling, and weak negative decoupling (X. Wang et al., 2020).

H1: GDP has a positive and significant influence on carbon emissions in Indonesia.
H: The level of industrialization has a positive and significant influence on carbon emissions in Indonesia.
H3: Investment has a positive impact on carbon emissions in Indonesia.

RESEARCH METHODS

Data types and sources

The data used in this study are secondary data sourced from publications by the Central Statistics Agency (BPS) and the Ministry of Investment Coordinating Board (BKPM). The study period is 2014-2023 with an area of 10 provinces in Indonesia, namely Aceh, North Sumatra, South Sumatra, Banten, DKI Jakarta, Central Java, Bali, South Kalimantan, South Sumatra, and Papua. Carbon emissions are used as the dependent variable, while GRDP, the proportion of manufacturing industry to GDP, and investment are used as independent variables. The methods applied in this study are decoupling analysis and panel data regression. The application of the decoupling analysis method aims to evaluate the level of decoupling of each country that is the subject of the study. Furthermore, panel data regression is conducted to determine the effect of GRDP, industrialization, and investment on carbon emissions in Indonesia.

Tapio Decoupling Index

Tapio's decoupling index is a traditional model for understanding the relationship between economic growth and the environmental impact of resources. Its core innovation lies in the introduction of the concept of elasticity (Wang & Tan, 2026). By determining the elasticity coefficient of the rise in carbon emissions in relation to the growth rate of GDP, it allows for a more accurate assessment of the evolving connection between both factors. The formula for this calculation is provided below:

$$e = \frac{\%\Delta Co_2}{\%\Delta \mathrm{GDP}} = \frac{\frac{Co_{2_t} - Co_{2_0}}{Co_{2_0}} \times 100\%}{\frac{GDP_t - GDP_0}{GDP_0} \times 100\%} \text{..ie (1)}$$

Through the assessment of the size and direction of the Tapio decoupling index, the state of decoupling can be categorized into eight distinct types: strong decoupling (SD), weak decoupling (WD), expansive coupling (EC), expansive negative decoupling (END), recessive decoupling (RD), strong negative decoupling (SND), recessive coupling (RC), and weak negative decoupling (WND). When △GDP is greater than 0 and △C is less than 0, this reflects the optimal condition for carbon decoupling, referred to as strong decoupling; this implies that with economic growth, carbon emissions fall, indicating a separation from the dependency correlation between the two.

Table 2. Tapio index classification

Main Category	Sub-Category	Elasticity Condition (e)
Decoupling	Strong decoupling	$e < 0$
	Weak decoupling	$0 < e < 0{,}8$
	Recessive decoupling	$e > 1{,}2$
Coupling	Expansive coupling	$0{,}8 \leq e \leq 1{,}2$
	Recessive coupling	$0{,}8 \leq e \leq 1{,}2$
Negative Decoupling	Expansive negative decoupling	$e > 1{,}2$
	Weak negative decoupling	$0 < e < 0{,}8$
	Strong negative decoupling	$e < 0$

Panel data regression

Panel data regression aims to analyze the relationship between independent variables and dependent variables. Multiple regression analysis is used as the primary method because it allows identification of the influence of one or more independent variables on the dependent variable. Sugiyono (2012:275) explains that this analysis can function as a predictive tool that helps project changes in the dependent variable based on fluctuations in the independent variables. In the context of this research, the regression model used has been adjusted to illustrate the relationship between the variables that are the focus of the study, thus allowing for a deeper understanding of the phenomenon being studied. In the context of this research, the regression model used has been adjusted to describe the relationship between the variables that are the focus of the study, thus allowing for a deeper understanding of the phenomenon being studied.

$$C0_{2_{it}} = \alpha + \beta_1 GDP_{it} + \beta_2 IND_{it} + \beta_3 INV_{it} + e_{it} \text{………………………………ie (2)}$$

RESULTS AND DISCUSSION

Based on data analysis using the Tapio Index, the relationship between economic growth, expressed through GRDP (GDP), and CO_2 emission levels in the ten sample provinces shows a fairly consistent pattern. In general, the majority of the observed regions remain in a "coupling" state, meaning economic growth in these provinces is accompanied by a linear increase in carbon emissions. Based on this data, Bali Province recorded the highest Tapio Index of 0.282, indicating a higher dependence of its economic activity on environmental emissions compared to other provinces. A similar trend is observed in South Sulawesi, although this province recorded the fastest economic growth rate (GDP) among the sample, at 0.400, its status remains in the "coupling" category with an index of 0.108 because its emissions continue to grow significantly in line with its economic progress.

Table 3. Tapio index calculation results

Region	%ΔCO_2	%ΔGDP	Tapio index (e)	Classification
Aceh	0.0292028	0.262585554	0.111212531	Coupling
North Sumatera	0.02821465	0.298550704	0.094505398	Coupling
South Sumatera	0.02827053	0.352660447	0.080163599	Coupling
Banten	0.02517683	0.308354383	0.081649003	Coupling
DKI Jakarta	0.02985101	0.331548798	0.090035035	Coupling
Central Java	0.034556	0.29836101	0.115819408	Coupling
Bali	0.0456328	0.161459674	0.282626583	Coupling
South Kalimantan	0.02242161	0.289281988	0.077507810	Weak decoupling
South Sulawesi	0.04339706	0.400170549	0.108446418	Coupling
Papua	0.0388316	0.279144592	0.139109283	Coupling

Source: Data processed (2026)

On the other hand, an interesting finding emerged in South Kalimantan Province, the only region with a "weak decoupling" status. With the lowest Tapio Index of 0.077, South Kalimantan shows early indications of a transition to a greener economy. This “weak decoupling” condition is achieved because even though CO_2 emissions continue to increase, the growth rate (0.022) is much slower than the economic growth rate (0.289). Overall, this phenomenon illustrates that although most regions in Indonesia still face major challenges in breaking the chain between economic growth and environmental degradation, there is potential for carbon efficiency that is starting to be seen, especially in regions that are able to reduce their emission intensity below the growth rate of their economic output.

Based on the results of the Chow test, a probability value of 0.000 (<0.05) was obtained, so the Fixed Effect (FEM) model is better than the Pooled Least Squares (PLS). Furthermore, the Hausman test was conducted which showed a probability value of 0.000 (<0.05), so the Fixed Effect model was selected as the best model to estimate the influence of the independent variables on the dependent variable in this study.

Table 4. Parameter estimation results

Variable	Coefficient	t-Statistic	Probality
C	451,23	19,50736	0,0000
GDP	2,94	2,61293	0,0111
IND	-3,54	-2,86802	0,0055
INV	-1,05	-1,30351	0,1969

Source: Data processed (2026)

Based on the estimation results using the Fixed Effect (FEM) model, it was found that the GDP at constant prices has a positive coefficient of 2,94 with a significance value of 0.0111. This indicates that real GDP has a positive and significant effect on CO_2 emissions at a 95% confidence level, meaning that any increase in real economic activity will trigger an increase in the amount of emissions in the region. Conversely, level of industrialization (IND) shows a negative coefficient of -3.54 with a significance value of 0.0055, indicating a negative and significant effect on CO_2 emissions. Meanwhile, the investment (INV) partially does not have a significant effect on CO_2 emissions, as indicated by a probability value of 0.1969 which is greater than α=0,05. Simultaneously, this model is declared fit and feasible because the Prob(F-statistic) value of 0.00047 is far below the significance threshold. The R-squared value of 0.386 explains that the ADHK, IND, and INV variables are able to contribute 38.6% to the variation in CO_2 emissions in this model.

The positive relationship between GDP and CO_2 emissions confirms that economic growth in the ten observed provinces remains carbon-intensive. This finding reinforces the previous Tapio Index analysis, which demonstrated the dominance of coupling, where economic expansion still requires significant fossil fuel consumption, thus directly impacting environmental degradation. research results cannot yet explain the theory by Grossman and Krueger who put forward the Environmental Kuznets Curve (EKC). This hypothesis explains the relationship between economic growth and environmental damage, which forms an inverted U-curve model. This occurs because economic growth initially increases environmental damage, but ultimately economic growth itself can reduce environmental damage in the long term (Grossman & Krueger, 1995). This is in line with what happened in lower-middle-income Asian countries (Vietnam, the Philippines, Myanmar, Indonesia, India, Sri Lanka, Bangladesh, Tunisia, Mongolia, and Morocco), where the EKC hypothesis was not proven either currently or in the future (Nikensari et al., 2019). Dawid (2026) stated that global GDP increased by 168%, accompanied by a 67% increase in GHG emissions.

On the other hand, the negative effect of the level of industrialization (IND) on emissions is an interesting and anomalous finding. This indicates that the industrial sector in the sample areas has likely begun to improve energy efficiency or is shifting toward cleaner industrialization, so that increased industrial value-added actually contributes to a relative reduction in emissions. In an analysis of the industrial sector, research on the construction industry shows that the economic development of almost all provinces in China is taking place independently of CO_2 emissions from buildings, with Shanghai showing the best emissions performance. Meanwhile, other provinces such as Jiangsu, Guizhou, and Fujian show significantly negative emissions (Wu et al., 2018) (Zhang et al., 2018). The research results are in line with Anwar (2026) that the industrial sector has a negative relationship with CO_2 productivity in ASEAN.

However, the insignificance of the investment (INV) indicates that capital inflows into the region have not yet had a significant impact on carbon emission mitigation efforts. Existing investments are likely still concentrated in carbon-neutral sectors or have not yet reached the green technology sector on a large scale. Overall, these regression results provide an important signal to policymakers that although industrialization is beginning to show a positive trend towards environmental efficiency, economic growth in general remains highly burdensome for the ecosystem. Therefore, more aggressive policy transformation is needed to shift the orientation of the economy and investment towards a more sustainable direction so that increased welfare is not paid for by worsening environmental damage.

CONCLUSION

Based on the analysis, this study concludes that the majority of provinces in Indonesia are still trapped in a state of coupling, where economic growth (GDP) significantly drives an increase in CO_2 emissions. This finding is reinforced by the fact that only South Kalimantan Province has successfully demonstrated a weak decoupling status, indicating carbon efficiency efforts, although they have not yet reached the ideal stage. Interestingly, although the industrial sector shows a positive trend towards reducing emissions, investment in general has not yet had a significant impact on mitigating environmental damage. This indicates that the national economic structure remains highly dependent on carbon-intensive sectors and fossil fuels.

The policy implication for the government is the need for more aggressive policy transformation to break the chain of dependency between economic growth and environmental degradation. The government needs to formulate stricter regulations to direct investment flows (INV) toward green investment sectors and low-carbon technologies to accelerate the energy transition. Furthermore, incentives for industrial sectors that have demonstrated emissions efficiency need to be strengthened to serve as models for other sectors, ensuring that improved public welfare does not come at the cost of continued ecosystem degradation.

In addition to limitations in sample size and variables, this study also faces limitations in terms of the specification of aggregated CO_2 emission data, which is unable to differentiate detailed emission contributions from various sub-sectors such as transportation, waste, or household energy use. The use of industrialization indicators based solely on the proportion of manufacturing value added also limits the analysis in distinguishing between energy-intensive heavy industry and more environmentally friendly light industry. Furthermore, data anomalies in 2020 due to the COVID-19 pandemic created temporary emission fluctuations rather than permanent structural changes, which may impact the stability of estimates in the long-term model. Finally, this study is unable to integrate specific environmental policy factors at the regional level or regulatory differences between provinces, which actually play a crucial role in influencing the effectiveness of decoupling efforts in each region.

For further research, it is recommended to expand the scope of the study area to all provinces in Indonesia to obtain a more comprehensive national picture. Future researchers are also expected to add other variables such as the technological innovation index, clean energy consumption, or government policy variables to strengthen the model analysis. Furthermore, the use of more complex analytical methods such as spatial econometrics can be considered to examine the inter-regional influence (spillover effect) on the distribution of carbon emissions, thus allowing for more accurate design of climate change mitigation strategies in the future.

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