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Clean Energy Reform: The Correlation Between Carbon Tax on Production Costs and Emissions of Power Plants

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ABSTRACT

This study examines the relationship between carbon tax payments, electricity production costs, and carbon emission indicators in coal-fired power plants (PLTU) in Indonesia following the implementation of the carbon tax policy in 2022. Using post-implementation operational data, this study applies a descriptive and associative quantitative approach, acknowledging the potential endogeneity and mechanical relationships embedded in emission-based fiscal variables. The results indicate that carbon tax payments are not significantly associated with electricity production costs, suggesting that cost structures remain dominated by coal prices and operational efficiency. In contrast, a strong positive association is observed between carbon tax payments and carbon emission intensity, reflecting the mechanical linkage between emission-based taxes and emission indicators rather than policy effectiveness. These findings imply that the current carbon tax in Indonesia functions primarily as a fiscal and emission-reporting instrument, rather than an effective environmental control mechanism. The study highlights the need for complementary policies, technological upgrades, and more robust empirical designs to properly evaluate the environmental effectiveness of carbon taxation

Keywords: *carbon tax, electricity production costs, emission indicators, coal-fired power plants*

Introduction

Global environmental degradation drives the need to reevaluate development strategies, particularly in the development of clean energy and the production of environmentally friendly products. This situation demands a new approach that is more innovative and long-term oriented to achieve sustainable economic development and be able to address environmental challenges in the future. One of the biggest challenges is climate change, which is a consequence of the accumulation of human activities since the Industrial Revolution (Kish, 2025). Since the 18th century, industrial development has driven major transformations in the global economic system (Affardi et al., 2025). Although it brings significant progress, industrialization also causes serious environmental impacts, especially climate change. These changes essentially occur naturally, but since the 19th century the rate of change has accelerated due to human activities, such as burning fossil fuels, deforestation, and industrial activities (Qanita & Sadiawati, 2025). These activities lead to an increase in carbon dioxide concentration in the atmosphere, which contributes as a major cause of global warming and ecosystem imbalance.

Coal-fired power plants are one of the main contributors to carbon emissions that cause negative externalities, such as air pollution, environmental degradation, and the acceleration of climate change, because their combustion process produces greenhouse gases and residual waste that significantly impacts ecosystems and public health (Pratama et al., 2022). As concerns about the environmental impact of power plant emissions increase, controlling carbon dioxide emissions has become crucial to maintaining the sustainability of environmental functions. The government is working to reduce the impact of air pollution through regulation of the combustion process as well as discussions on implementing fiscal policies such as carbon taxes. The establishment of strict emission standards needs to be based on scientific data and health risk assessments, incorporating parameters such as hazardous gas content (CO, NOx, SO_2), fine particulate matter (PM2.5 and PM10), ozone, and other pollutants as a form of protection for public health (Rachmania et al., 2025).

Indonesia formally introduced a carbon tax under Law No. 7 of 2021 on the Harmonization of Tax Regulations, with initial implementation targeting coal-fired power plants beginning in 2022. The policy aims to support national emission reduction commitments while contributing to fiscal revenue. However, empirical evaluation of the carbon tax's implications for production costs and emission-related indicators at the plant level remains limited. Efforts to reduce carbon emissions resulting from human activities demand a comprehensive economic and social transformation, which relies on technological innovation as well as commitment from the government and industry sector (Pratama et al., 2022). The cost of electricity production at coal-fired power plants is basically relatively low due to affordable coal prices and operational efficiency. However, with the implementation of a carbon tax, electricity production costs have the potential to increase due to the high emissions produced, thereby encouraging companies to switch to more efficient and environmentally friendly energy (Ariyandi et al., 2024). In addition, carbon emission intensity, which reflects the amount of carbon dioxide emissions per unit of energy output, becomes an important indicator in assessing the effectiveness of this policy. An increase in emission intensity not only worsens environmental quality but also adds to the country's fiscal burden, making measurement at coal-fired power plants crucial for formulating appropriate emission control policies (Rachmania et al., 2025).

Although carbon tax policies have been extensively studied from the perspectives of regulation and macroeconomic impact, empirical studies that directly assess their correlation on the performance of coal-fired power plants in Indonesia are still rare, creating a research gap that needs to be addressed. Most existing studies assess carbon taxes from a macroeconomic or regulatory perspective. Empirical evidence at the operational level of power plants in Indonesia, particularly using post-implementation data, is still scarce. This study addresses that gap by examining statistical associations between carbon tax payments, electricity production costs, and carbon emission indicators at coal-fired power plants after the introduction of the policy. Importantly, this study does not aim to establish causal inference, given the inherent endogeneity and mechanical relationships between emission-based variables, but rather provides a diagnostic assessment of observed patterns following policy implementation.

Theoretical Framework and Hypothesis

Externality and Pigouvian Tax Theory

Externalities arise when an individual's actions affect the welfare of others without any reward or compensation, causing the market to fail to achieve efficiency because these effects are not considered by market participants (Pratama et al., 2022). This is in line with the view that externalities reflect the losses or burdens that society must bear as a result of the economic activities of others, where the actors of these activities do not directly bear the impact, thus creating a difference between private costs and social costs (Zhang et al., 2025). Externalities are understood as the indirect impacts of economic activities. According to (Zhang et al., 2025), externalities can be either negative or positive. This thinking aligns with Pigou's theory, which emphasizes the importance of fiscal instruments, such as taxes and subsidies, so that market prices can reflect the social impact of an economic activity (Siahaan et al., 2025).

The Pigovian tax introduced by Arthur Cecil Pigou (1920) emphasizes the role of the government in addressing market failures caused by negative externalities by encouraging economic actors to consider the social impacts of their actions. This policy encourages industries to reduce emissions through improvements in energy efficiency or the use of more environmentally friendly technologies. This, Pigovian taxes are considered one of the effective policy instruments to address market failures arising from negative externalities, particularly those related to environmental issues. Through this mechanism, the social cost burden is shifted to economic actors, motivating them to consider the broader societal impact (Siahaan et al., 2025). The concept of Pigovian taxes has since been developed and implemented in modern policies, such as carbon taxes, which aim to reduce greenhouse gas emissions while also encouraging a transition toward sustainable economic activities (Baiardi & Menegatti, 2011).

Carbon Tax in the Perspective of Environmental Economics

A carbon tax is applied to emissions generated from the use of fossil fuels as an effort to address market failures caused by negative externalities, such as air pollution and climate change (Qanita & Sadiawati, 2025). A carbon tax is a levy imposed on all types of air pollution that affect the environment, including carbon dioxide, methane, and other greenhouse gases (Affardi et al., 2025). This tax serves as an emissions control tool to support environmental preservation, while also being a regulatory instrument used by the government to achieve certain objectives, including the reduction of carbon emissions (Gao et al., 2024). Carbon tax is one of the key policy instruments in environmental economics designed to internalize the negative externalities arising from greenhouse gas emissions into the cost structure of economic agents (Kish, 2025). Within the framework of welfare economics, carbon taxation is rooted in the concept of Pigouvian taxes, which aim to align private costs with the social costs generated by environmentally harmful activities (Affardi et al., 2025). A substantial body of literature suggests that carbon pricing can serve as an economically efficient instrument for reducing emissions, particularly when applied broadly and at rates that reflect the social cost of carbon (Zhang et al., 2025). However, the literature also emphasizes that the effectiveness of carbon taxation is highly context-dependent. (Fang et al., 2013) and (Tu et al., 2022) demonstrate that the impact of carbon taxes on emission behavior critically depends on the level of the tax rate, the elasticity of energy demand, and the availability of low-carbon technological alternatives. In developing countries, heavy reliance on fossil fuels and limited substitution options often weaken the incentive effects of carbon taxation on production behavior.

Empirical Evidence on the Impact of Carbon Taxation on Emissions

Empirical studies in developed countries generally find that carbon taxes are associated with reductions in carbon emissions over the medium to long term. Lin & Li (2011) findings The mitigation effects of carbon tax are weakened due to the tax exemption policies on certain energy intensive industries in the Denmark, Finland, Sweden, Netherlands, and Norway. Xu & Zhang (2025) found that carbon tax policies that balance economic growth, social equity, and environmental sustainability. Similar findings are reported by Qanita & Sadiawati (2025), who show that carbon taxes can effectively reduce emissions when supported by comprehensive energy and environmental policies. Riyono & Widianingsih, (2024) carbon tax implementation across multiple sectors effectively lowers carbon emissions while increasing government revenue, indicating its importance as a key environmental policy that should be considered by countries planning to adopt it. Nevertheless, the literature also highlights that such empirical results are typically derived from research designs that enable causal inference, including cross-country panel data, difference-in-differences approaches, or the use of control groups.

Carbon Taxation, Production Costs, and Industrial Competitiveness

A number of studies raise concerns that carbon taxes may increase production costs and reduce the competitiveness of energy-intensive industries. Zhang et al (2025) suggest that while carbon pricing may raise short-term production costs, it can also stimulate green innovation and improve long-term productivity. In contrast, other studies find that the impact of carbon taxes on production costs is often relatively small compared to fluctuations in primary energy prices such as coal and oil. In the electricity generation sector, External costs from pollution and other environmental instruments need to be considered in electricity sector policies, as this encourages energy efficiency and accelerates the transition to low-carbon energy sources (Zhang et al., 2025). Production costs in fossil-based power plants drive adjustments in electricity selling prices to maintain economic sustainability. Within this framework, carbon emissions become an important indicator for assessing the environmental impact of power plants, in accordance with the principle of internalizing external costs from the theory of negative externalities (Affardi et al., 2025).These findings are particularly relevant for the Indonesian context, where coal prices and operational factors remain the dominant determinants of electricity production costs.

Hypothesis

Carbon Tax and Electricity Production Costs

Several studies indicate that the implementation of a carbon tax can increase the burden of electricity production costs, as every emission generated from coal combustion is subject to a levy according to the applicable rate. Affardi et al., (2025) states that the carbon tax is one of the factors that increase the cost components in fossil fuel power plants. Fei & Jia, (2024) found that electricity production costs are influenced by coal quality, combustion efficiency, as well as fiscal instruments such as the carbon tax. These findings confirm that the existence of a carbon tax can drive up production costs in coal-fired power plants. Nevertheless, there are also research findings that offer a different perspective. Zhang et al., (2025) noted that the impact of the carbon tax on electricity production costs is not very significant, because the cost structure of power plants still heavily depends on the relatively stable price of coal and the presence of government subsidies. Under these conditions, the additional fiscal burden from the carbon tax is not strong enough to noticeably change the total cost of electricity production. These differing findings indicate that the relationship between the carbon tax and production costs remains inconsistent. Based on a review of previous research, the hypotheses proposed in this study are as follows:
H1: Carbon tax payments are not significantly associated with electricity production costs in coal-fired power plants.

Carbon Tax and Carbon Emission Intensity

In addition to being associated with cost aspects, carbon tax is also designed as an instrument to control emissions. According to Pratama et al., (2022) the imposition of a carbon tax encourages companies to improve energy efficiency, implement more environmentally friendly technologies, and reduce emission volumes so that their fiscal obligations do not become larger. This shows that the carbon tax acts as a regulatory mechanism that can influence the reduction of carbon emission intensity. However, other studies provide different results. Asmoro, (2024) found a positive relationship between the carbon tax and emission intensity. This means that the higher the level of emissions produced, the greater the tax that companies have to pay. In other words, the carbon tax not only functions as a control tool but also represents the level of

emission intensity generated (Xu & Zhang, 2025). Based on the description, the hypothesis of this study is:
H2: Carbon tax payments are positively associated with carbon emission intensity due to emission-based tax calculation mechanisms.

Research Methods

This research uses a quantitative approach with descriptive-associative research design. The analysis focuses on statistical relationships between the independent variable (carbon tax) and the dependent variables (electricity production costs and carbon emission intensity). The quantitative approach was chosen because the results obtained can be processed statistically and provide an objective picture of the extent of the correlation of the carbon tax on the financial and environmental aspects of coal-fired power plants.

The data consist of post-implementation operational records from coal-fired power plants, including electricity output, fuel consumption, production costs, and carbon emissions. Carbon tax payments are calculated as the applicable tax rate multiplied by total carbon emissions. Electricity production costs are measured based on fuel consumption and coal prices, while carbon emission intensity is defined as total emissions per unit of electricity generated. The amount of the tax is calculated by multiplying the applicable carbon tax rate (Rp/ton CO_2) by the total carbon emissions generated.

Carbon Tax = Tax Rate (Rp/ton CO_2) X Total Emissions (ton CO_2)

The cost of electricity production includes all expenses required to generate electrical energy, covering fuel costs, operational costs, as well as additional burdens from carbon taxes. In this study, the calculation of production costs is carried out using a specific formula:

Electricity Production Cost = Specific Fuel Consumption (SFC) X Coal Price per Kg

Carbon emission intensity is a measure of the amount of carbon emissions produced during the electricity generation process per unit of electricity generated. This variable indicates the efficiency level of the power plant in producing electricity with lower emissions. The formula for measuring it is as follows:

Emission Intensity = (Total Emissions (ton CO_2)) / (Electricity Production (MWh))

This study does not aim to establish causal inference due to the inherent endogeneity and mechanical relationships between emission-based variables. Therefore, the analysis focuses on associative patterns and descriptive interpretation.

Results And Discussion

In Table 1, the research variables show a fairly significant difference between the minimum and maximum values. The carbon tax variable shows a wide range of variation, indicating differences in the tax burden borne by power plants during the observation period. For the electricity production cost variable, the average value obtained indicates a general tendency of the costs required to generate electricity, while the standard deviation illustrates how much cost deviations occur between periods. Meanwhile, the carbon emission intensity variable also shows a fairly wide range of values, indicating that emission efficiency varies among power plants, both in terms of the technology used and their production capacity. The average value of each variable provides a general overview of the condition of coal-fired power plants (PLTU), while the maximum and minimum values indicate significant differences among the plants. For example, there may be PLTUs with relatively low production costs but high emissions, or conversely, high production costs but better emission efficiency. The standard deviation of variables such as carbon tax and carbon emission intensity indicates a fairly large data dispersion, which means that the correlation of carbon tax policies is not uniform across all PLTUs. This suggests the presence of internal factors (such as machinery technology, production capacity, and fuel efficiency) as well as external factors (such as regulations or energy prices) that influence differences between units.

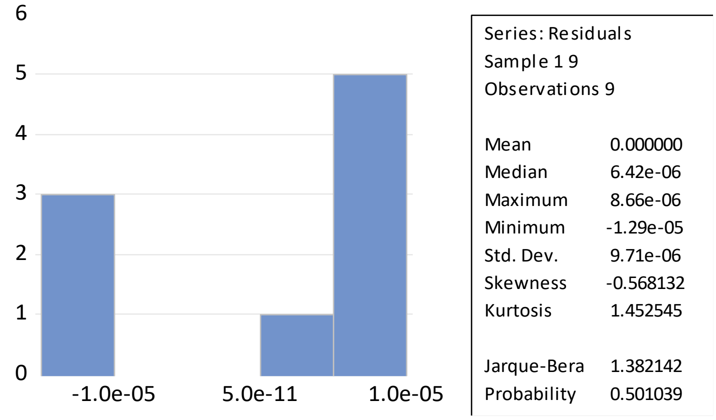
Table 1. Descriptive Statistics

	X	Y1	Y2
Mean	6.28E+10	542520.1	0.000367
Median	6.24E+10	541509.8	0.000365
Maximum	7.22E+10	557790.6	0.000425
Minimum	4.92E+10	528260.0	0.000293
Std. Dev.	7.26E+09	12809.56	4.21E-05
Skewness	-0.421170	0.124901	-0.340801
Kurtosis	2.484255	1.500000	2.236549
Jarque-Bera	0.365823	0.867151	0.392790
Probability	0.832842	0.648188	0.821688
Sum	5.65E+11	4882681.	0.003307
Sum Sq. Dev.	4.22E+20	1.31E+09	1.42E-08
Observations	9	9	9

Normality Test

The results of the classical assumption test on the residuals show that the research data follow a normal distribution. This is indicated by a Jarque-Bera value of 1.382142 with a probability of 0.501089, which is greater than the significance level of 0.05. Thus, the regression model used does not have a normality problem, so the residuals are considered to be evenly distributed around the mean. Meeting the normality assumption indicates that the regression model is suitable for further analysis, as the estimates obtained can be relied upon and are unbiased.

Table 2. Normality Test



Heteroskedasticity Test

The results of the heteroskedasticity test indicate that the regression model used does not have heteroskedasticity problems. This is shown by the Prob. F(2,6) value of 0.2201, Prob. Chi-Square(2) of 0.1681, and Prob. Chi-Square(2) scaled explained SS of 0.5977, all of which exceed the significance level of 0.05. Therefore, the residual variance can be considered constant or homogeneous, meaning the regression model meets the homoscedasticity assumption and is suitable for further analysis.

Table 3. Heteroscedasticity Test

F-statistic	1.968533	Prob. F(2,6)	0.2201
Obs*R-squared	3.565800	Prob. Chi-Square(2)	0.1681
Scaled explained SS	1.029481	Prob. Chi-Square(2)	0.5977

Autocorrelation Test

The results of the autocorrelation test show that the regression model does not have an autocorrelation problem. This is evident from the Prob. F(2,4) value of 0.2521 and the Prob. Chi-Square(2) value of 0.1064, both of which are greater than the 0.05 significance level. Therefore, the residuals between periods do not show correlation, indicating that the regression model meets the assumption of being free from autocorrelation and is suitable for further analysis.

Table 4. Autocorrelation Test

F-statistic	1.983682	Prob. F(2,4)	0.2521
Obs*R-squared	4.481567	Prob. Chi-Square(2)	0.1064

Correlation Coefficient

The results of the correlation coefficient test indicate that variable X (carbon tax) has a correlation of 0.093445 with Y1 (electricity production costs). This value, which is nearly close to zero, suggests that the relationship between the two is very weak and almost insignificant. Therefore, the implementation of a carbon tax does not have a significant correlation on changes in electricity production costs at the power plant, and fluctuations in the carbon tax do not directly affect the level of electricity production costs.

Table 5. Correlation Coefficient of X with Y1

	X	Y1
X	1.000000	0.093445
Y1	0.093445	1.000000

The results of the correlation coefficient test show that variable X (carbon tax) has a correlation value of 0.972325 with Y2 (carbon emission intensity). This value, which is nearly +1, indicates a very strong and positive relationship between the two. In other words, an increase in the carbon tax tends to be followed by a significant rise in carbon emission intensity. Therefore, it can be concluded that this study found a very strong positive linear relationship between the carbon tax and carbon emission intensity.

Table 6. Correlation Coefficient of X with Y2

	X	Y2
X	1.000000	0.972325
Y2	0.972325	1.000000

Coefficient of Determination

The results of the coefficient of determination test show an R-squared value of 0.008732, indicating that the carbon tax variable (X) can only explain about 0.87% of the variation in electricity production costs (Y1), while the remaining 99.13% is influenced by other factors outside the research model. In addition, the Prob(F-statistic) value of 0.811016, which is greater than 0.05, indicates that the carbon tax does not have a significant correlation on electricity production costs. This finding is consistent with the previous correlation test results, which showed a very weak relationship between the two variables.

Table 7. Coefficient of Determination of X on Y1

R-squared	0.008732	Mean dependent var	542520.1
Adjusted R-squared	-0.132878	S.D. dependent var	12809.56
S.E. of regression	13634.07	Akaike info criterion	22.07166
Sum squared resid	1.30E+09	Schwarz criterion	22.11549
Log likelihood	-97.32248	Hannan-Quinn criter.	21.97708
F-statistic	0.061662	Durbin-Watson stat	0.465682
Prob(F-statistic)	0.811016		

The results of the determination coefficient test show that the R-squared value is 0.945418, which means that the carbon tax variable (X) can explain about 94.54% of the variation in carbon emission intensity (Y2), while the remaining 5.46% is influenced by factors outside the model. In addition, the Prob (F-statistic) value is 0.000011, which is less than 0.05, indicating that the correlation of the carbon tax on carbon emission intensity is statistically significant. But the strong positive association between carbon tax payments and emission intensity should not be interpreted as evidence of policy ineffectiveness. Instead, it reflects the mechanical construction of emission-based fiscal instruments, where higher emissions directly result in higher tax obligations. This finding highlights a limitation of simple regression approaches in evaluating environmental policy effectiveness.

Table 8. Coefficient of Determination of X on Y2

R-squared	0.945416	Mean dependent var	0.000367
Adjusted R-squared	0.937619	S.D. dependent var	4.21E-05
S.E. of regression	1.05E-05	Akaike info criterion	-19.89576
Sum squared resid	7.73E-10	Schwarz criterion	-19.85193
Log likelihood	91.53090	Hannan-Quinn criter.	-19.99034
F-statistic	121.2432	Durbin-Watson stat	0.789466
Prob(F-statistic)	0.000011		

Simple Linear Regression

The results of the simple linear regression between the independent variable X and the dependent variable Y1 show that the constant (C) of 532,172.5 indicates that Y1 will be 532,172.5 when X is zero. The regression coefficient of X is 1.65×10^{-7}, which is positive, meaning that each 1-unit increase in X will raise Y1 by 0.000000165, although the association is very small. Based on the t-test, the t-statistic value of 0.248318 with a probability of 0.8110 (> 0.05) indicates that X has no significant association on Y1. Therefore, changes in X do not significantly explain the variation in Y1 in this regression model.

Table 9. Simple Linear Regression of X on Y1

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	532172.5	41918.04	12.69555	0.0000
X	1.65E-07	6.64E-07	0.248318	0.8110

Based on the results of the simple linear regression, the constant (C) has a value of 1.38E-05 with a probability of 0.6830. Since this probability value is greater than 0.05, the constant is considered insignificant, indicating that the presence of the constant does not have a meaningful association on variable Y2 when X is zero. Meanwhile, the variable X has a coefficient of 5.63E-15 with a t-statistic of 11.01105 and a probability of 0.0000. A probability value less than 0.05 indicates that X has a significant association on Y2. This suggests that an increase in X will positively correlation impact Y2, making the relationship between the two variables statistically significant.

Table 10. Simple Linear Regression of X on Y2

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.38E-05	3.23E-05	0.425836	0.6830
X	5.63E-15	5.12E-16	11.01105	0.0000

Based on the results of the simple linear regression, variable X has a coefficient of 1.65E-07 with a t-statistic of 0.248318 and a probability of 0.8110. Since the probability value is greater than 0.05, variable X does not have a significant correlation on Y1. This indicates that partially, X is unable to explain the variation in Y1, so changes in X do not have a meaningful correlation on Y1.

Table 11. t-test of X against Y1

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	532172.5	41918.04	12.69555	0.0000
X	1.65E-07	6.64E-07	0.248318	0.8110

R-squared	0.008732	Mean dependent var	542520.1
Adjusted R-squared	-0.132878	S.D. dependent var	12809.56
S.E. of regression	13634.07	Akaike info criterion	22.07166
Sum squared resid	1.30E+09	Schwarz criterion	22.11549
Log likelihood	-97.32248	Hannan-Quinn criter.	21.97708
F-statistic	0.061662	Durbin-Watson stat	0.465682
Prob(F-statistic)	0.811016		

Based on the results of the simple linear regression, the variable X has a coefficient of 5.63E-15 with a t-statistic = 11.01105 and a probability of 0.0000. Since the probability value is less than 0.05, X has a significant correlation on Y2. This indicates that, partially, X is able to explain changes in Y2. Therefore, it can be concluded that X has a positive and significant correlation on Y2, meaning that any increase in X will be followed by an increase in Y2, and this relationship is statistically significant.

Table 12. t-test of X against Y2

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.38E-05	3.23E-05	0.425836	0.6830
X	5.63E-15	5.12E-16	11.01105	0.0000

R-squared	0.945416	Mean dependent var	0.000367
Adjusted R-squared	0.937619	S.D. dependent var	4.21E-05
S.E. of regression	1.05E-05	Akaike info criterion	-19.89576
Sum squared resid	7.73E-10	Schwarz criterion	-19.85193
Log likelihood	91.53090	Hannan-Quinn criter.	-19.99034
F-statistic	121.2432	Durbin-Watson stat	0.789466
Prob(F-statistic)	0.000011		

The empirical results show no statistically significant association between carbon tax payments and electricity production costs. This finding suggests that production cost structures at coal-fired power plants remain primarily influenced by coal prices, fuel efficiency, and operational factors, rather than by the relatively low carbon tax rate. In contrast, a strong positive association is observed between carbon tax payments and carbon emission intensity. This relationship should not be interpreted as evidence that the carbon tax increases emissions. Instead, it reflects the mechanical construction of emission-based fiscal instruments, where higher emissions directly translate into higher tax payments. The high coefficient of determination observed in the regression model indicates mathematical linkage rather than explanatory power regarding environmental policy effectiveness. These findings underscore the limitations of simple regression approaches in evaluating emission-based fiscal policies and highlight the need for more robust empirical strategies to assess environmental outcomes.

Conclusion, Implications, Suggestions, and Limitations

This study was conducted to analyze the correlation of carbon tax on electricity production costs and carbon emission intensity at coal-fired power plants (PLTU). This study provides a post-implementation assessment of carbon tax payments, electricity production costs, and emission indicators in Indonesian coal-fired power plants. The results indicate that the current carbon tax is not significantly associated with production cost changes and primarily functions as a fiscal and emission-reporting mechanism rather than a demonstrably effective environmental control tool within the scope of this analysis. Policy implications suggest that carbon taxation should be complemented by stronger regulatory measures, technological incentives, and efficiency improvements to achieve meaningful emission reductions. For academic research, this study highlights the importance of addressing endogeneity and mechanical relationships when evaluating emission-based policies. This study is subject to several limitations, including the use of post-implementation data only, the absence of a counterfactual scenario, and the reliance on simple associative methods. Future research should employ panel data, pre- and post-policy comparisons, and additional control variables to enable causal inference and more comprehensive policy evaluation.

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