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Simulation of Carbon Tax Impact on the Competitiveness of the Manufacturing Industry in Indonesia Using a System Dynamics Approach

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ABSTRACT

This study investigates the impact of carbon tax on the competitiveness of Indonesia's manufacturing sector using a System Dynamics (SD) approach. The analysis explores how different carbon tax levels—0, 30, and 200 IDR/kg CO_2e—affect production inputs, outputs, and added value. The results show that manufacturing inputs remain low and stable at 0 IDR/kg CO_2e due to the lack of financial pressure to reduce fossil fuel consumption. However, input costs increased slightly at 30 IDR/kg CO_2e, prompting industries to adopt energy-efficient technologies to manage costs. The highest tax level, 200 IDR/kg CO_2e, significantly raises input costs, compelling manufacturers to invest in low-carbon technologies to mitigate the cost burden. The study also assesses the impact of carbon taxes on output and value-added in the manufacturing sector. While carbon taxes initially reduce value added due to increased input costs, investments in green technologies can help companies recover and improve productivity over time. Higher tax rates, such as 200 IDR/kg CO_2e, push industries towards significant technological shifts, potentially enhancing long-term competitiveness. The research highlights the importance of supportive policies, including subsidies for renewable energy and efficiency incentives, to facilitate the transition to greener production methods. Overall, the study concludes that well-designed carbon tax policies can drive industrial sustainability while maintaining economic growth in Indonesia.

Keywords: Carbon Tax, Competitiveness, System Dynamics, Simulation, Carbon Pricing
JEL Classifications: C61, H23, Q52, L60, Q58

1. INTRODUCTION

Climate change has emerged as one of the most urgent and pressing global challenges of the 21st century. The scientific consensus is clear: Human activities, notably the burning of fossil fuels, have significantly increased the concentration of greenhouse gases (GHGs) in the atmosphere, contributing to global warming and climate instability. According to the Intergovernmental Panel on Climate Change (IPCC), human-induced activities have caused the Earth's surface to warm by approximately 1.0°C above pre-industrial levels, with the potential for further temperature increases if decisive actions are not taken (IPCC, 2022). Among these activities, carbon emissions from energy, transportation, and industrial manufacturing sectors are the most significant contributors to GHG accumulation. As researchers, policymakers, and industry professionals in environmental economics and industrial development, your role in addressing this issue is crucial and urgent.

The rising concerns over climate change have led to calls for more robust policies aimed at reducing carbon emissions, one of which is carbon pricing. Economists argue that current market systems fail to account for the "social cost" of carbon emissions, which includes the economic damages from climate-related disasters, health issues, and agricultural losses (Nordhaus, 2014). This externality—where industries do not pay for the societal damage caused by their emissions—has been identified as a critical market failure. Carbon pricing mechanisms, such as carbon taxes, have been proposed as an effective policy tool to correct these market distortions and align economic activities with sustainable development goals (Stern, 2022). These policies' potential benefits are significant and promising, offering a path towards a more sustainable and resilient future.

1.1. Carbon Taxes and Their Role in Reducing Emissions

A carbon tax directly imposes a price on CO_2 emissions, typically by charging per ton of carbon from fossil fuel consumption. The primary objective of a carbon tax is to internalize the social cost of carbon, incentivizing businesses and consumers to reduce their carbon footprint by shifting to cleaner energy sources and adopting more efficient production processes (Pigou, 2006). The underlying economic rationale is that by reflecting the actual cost of carbon in prices, market actors will make more rational, environmentally friendly decisions, ultimately reducing emissions (Tol, 2011). Understanding the role of carbon taxes is not just crucial but a matter of utmost importance in our collective efforts to combat climate change.

Several countries have implemented carbon taxes internationally, demonstrating their efficacy in reducing emissions without hampering economic growth. For example, Sweden introduced a carbon tax in 1991, which led to a 25% reduction in GHG emissions while the country's GDP grew by more than 60% during the same period (Andersson, 2019). Similarly, Finland and Canada have implemented carbon taxes with positive outcomes, illustrating that well-designed carbon tax policies can reduce emissions without causing significant economic disruptions. These success stories should reassure us about the potential effectiveness of carbon taxes in our collective efforts to combat climate change.

However, carbon taxes remain contentious, particularly in developing countries and industries that are energy-intensive and trade-exposed (EITE). These industries, such as manufacturing, steel production, and cement, rely heavily on fossil fuels, and imposing a carbon tax could significantly raise operational costs. This could lead to a loss of competitiveness in countries that do not impose similar environmental taxes, potentially resulting in "carbon leakage." Carbon leakage refers to the situation where production and emissions shift to regions with weaker environmental regulations, effectively "leaking" the problem of carbon emissions from one region to another (Verde, 2020).

1.2. The Indonesian Context

As the fourth-most populous country and one of the largest emitters of GHGs, Indonesia faces unique challenges in its climate policy. The country has committed to reducing GHG emissions by 29% (up to 41% with international assistance) by 2030, as outlined in its Nationally Determined Contribution (NDC) under the Paris Agreement. The NDC is a critical component of the Paris Agreement, where each country outlines its climate action plan and contributions to global efforts to combat climate change (Matemilola et al., 2020). However, despite these ambitious goals, Indonesia remains heavily reliant on fossil fuels, particularly coal, for electricity generation and industrial production. The manufacturing sector, which contributes approximately 22% to Indonesia's GDP, is one of the largest energy consumers and a significant source of national GHG emissions (BPS, 2020).

Recognizing the need for carbon pricing to meet its climate targets, Indonesia introduced carbon pricing as part of the Harmonized Tax Law No. 7 in 2021 (Kementerian Keuangan Republik Indonesia, 2021). This law, which aims to harmonize various tax regulations in the country, initially planned to impose a carbon tax on coal-fired power plants by 2022. However, implementation has been delayed due to concerns over its potential impact on energy prices and industrial competitiveness. The proposed tax, set at Rp 30,000 per ton of CO_2 equivalent (approximately \$2 per ton), is much lower than the carbon taxes implemented in developed countries, raising questions about its effectiveness in driving substantial emissions reductions.

While introducing carbon pricing represents a positive step, several challenges remain. First, the relatively low carbon tax rate may not incentivize industries to transition to low-carbon technologies. Second, there are concerns about how the tax will affect Indonesia's manufacturing sector, which is a critical economic growth and employment driver. If not carefully designed, the carbon tax could raise production costs, reduce industrial competitiveness, and lead to carbon leakage as industries relocate to countries with less stringent environmental regulations (Cohen et al., 2017).

1.3. Research Gap

Despite the growing interest in carbon taxes as a tool for reducing emissions, there is a significant research gap in understanding the impact of these taxes on the competitiveness of energy-intensive industries, particularly in developing countries like Indonesia. Studies in developed nations such as Sweden, Finland, and Canada have shown that carbon taxes can effectively reduce emissions while maintaining economic growth. For instance, Andersson (2019) Sweden's carbon tax reduced GHG emissions and contributed to significant GDP growth. Similarly, the Meijer (2021) highlighted Finland's success in implementing a carbon tax without significant disruptions to industrial competitiveness.

However, the context of these high-income nations is vastly different from that of Indonesia. Developed countries generally have more diversified energy portfolios and robust policy frameworks facilitating the transition to cleaner technologies. The research by Coste et al. (2018) and Martin (2023) highlighted that carbon taxes may disproportionately affect energy-intensive and trade-exposed industries, which is critical in developing economies like Indonesia. While their research addresses the general risks of carbon leakage and industrial competitiveness, there has been little focus on how these dynamics play out specifically in Indonesia's manufacturing sector.

In Indonesia, previous studies, such as those by Rokhmawati et al. (2024) and Rokhmawati (2023), focus on the potential environmental benefits of carbon pricing mechanisms but do not sufficiently address the economic impacts on crucial industries. Cohen et al. (2017) raised concerns about Indonesia's proposed low carbon tax rate, arguing that it may not be enough to drive significant changes in industrial practices. Furthermore, while several studies discuss the environmental benefits of carbon pricing, they often overlook the long-term economic consequences, particularly for the manufacturing sector, which plays a pivotal role in Indonesia's economic growth.

Most notably, there is a lack of quantitative studies that model the long-term effects of carbon taxes on the Indonesian manufacturing sector. Existing research in Indonesia tends to be more descriptive. It lacks the depth to understand how various carbon tax scenarios will impact production costs, industrial competitiveness, and emissions over time. Studies like Coste et al. (2018) emphasize the importance of harmonizing environmental and economic objectives in carbon tax policies. However, there has been little empirical work on achieving this balance in Indonesia.

1.4. Novelty of the Research

This study seeks to fill these research gaps by employing system dynamics (SD) modeling, which offers a more comprehensive approach to understanding the long-term effects of carbon taxes on Indonesia's manufacturing sector. Unlike traditional static models, SD modeling allows researchers to capture the complex feedback loops and interactions between subsystems, such as production costs, energy consumption, and investment in clean technologies. This approach is particularly well-suited for the Indonesian context, where fossil fuel dependence and economic growth are tightly intertwined.

Previous studies have shown the potential of system dynamics modeling in understanding the impact of carbon taxes. For example, Liu et al. (2022) applied a combination of SD and the STIRPAT model in China to analyze the effects of carbon taxes on emissions and economic growth. Their findings demonstrated that higher carbon taxes could significantly reduce emissions without causing major economic disruptions, provided tax revenues were reinvested in green technologies. Similarly, Rokhmawati et al. (2024) applied system dynamics to assess the impact of carbon taxes on Indonesia's manufacturing sector, offering valuable insights into the trade-offs between emissions reductions and industrial competitiveness.

The goal of this research is to evaluate the potential impact of carbon taxes on the competitiveness of Indonesia's manufacturing sector. The research uses system dynamics modeling to simulate different carbon tax scenarios and assess how these taxes may affect production costs, industrial competitiveness, and carbon emissions over time. Ultimately, the study seeks to provide evidence-based insights to guide policymakers in designing a carbon tax policy that balances environmental sustainability with economic growth.

The research problem is how the implementation of a carbon tax will affect the competitiveness of Indonesia's manufacturing sector. How will different carbon tax scenarios impact production costs and carbon emissions in the manufacturing sector?

The novelty of this research lies in its application of system dynamics modeling to explore various carbon tax scenarios and their potential impacts on the Indonesian manufacturing sector. By simulating different tax rates, industrial responses, and government interventions, such as revenue recycling and subsidies for clean technologies, this study aims to provide policymakers with data-driven insights to design a carbon tax policy that balances emissions reductions with economic growth. This approach addresses the research gap related to the lack of quantitative studies on carbon taxes in Indonesia. It contributes to the broader discourse on how developing countries can implement carbon pricing mechanisms effectively.

2. METHODS

2.1. System Dynamics Approach

This study utilizes System Dynamics (SD) modeling to simulate the impact of carbon taxes on the competitiveness of Indonesia's manufacturing sector. System Dynamics is a robust methodology designed to capture and simulate the complex feedback loops and interactions between different variables in socio-economic systems. It is particularly well-suited for analyzing long-term trends in dynamic systems where relationships between components are non-linear and affected by time delays.

This study employs System Dynamics (SD) modeling integrated with an Input-Output (I-O) model to simulate the impact of carbon taxes on the competitiveness of Indonesia's manufacturing sector. The I-O model captures the flow of goods and services between different sectors of the economy, providing a detailed framework for understanding how carbon taxes affect production costs, energy consumption, and economic outputs across the manufacturing value chain.

The I-O model maps out the interdependencies between industries, allowing for a more comprehensive understanding of how a carbon tax on one sector (e.g., energy) influences other sectors, such as manufacturing, by increasing input costs. By incorporating the I-O model into the SD framework, this study simulates how changes in production inputs—such as energy prices—affect the outputs of various manufacturing industries in Indonesia over time.

The SD model is structured around three primary subsystems:

- The input-output subsystem tracks the flow of inputs (raw materials, energy) into manufacturing processes and outputs (goods, emissions) industries produce. This subsystem directly links changes in energy prices due to carbon taxes to production costs in the manufacturing sector.
- The corporate operations subsystem captures business dynamics, including production, added value, and industrial investments. This subsystem helps simulate how firms may respond to increased operational costs caused by carbon taxation by adjusting production levels or investing in clean technologies.
- The consumer demand subsystem includes variables related to market demand for manufactured goods, influenced by economic growth, disposable income, and global competition. This allows the model to project how shifts in demand, driven by changes in production costs and energy prices, will affect the sector's overall performance.

Once these interactions are mapped using causal loop diagrams, they are further translated into stock-flow diagrams that simulate the dynamics of carbon emissions, production costs, and sectoral competitiveness under different carbon tax scenarios.

2.2. Simulation Scenarios

To assess the potential impact of carbon taxes, the study employs scenario-based simulations using the Input-Output and System Dynamics framework. The following three scenarios are examined:

1. Baseline Scenario: No carbon tax is imposed, and the manufacturing sector continues its current trajectory.
2. Low Tax Scenario: A carbon tax of Rp 30,000 per ton of CO_2 equivalent is applied, reflecting the initial policy proposal.
3. High Tax Scenario: A more aggressive carbon tax of Rp 100,000 per ton of CO_2 equivalent is implemented to explore its potential impact on emissions and competitiveness.

Each scenario forecasts critical outcomes such as production costs, energy consumption, carbon emissions, and overall value-added in the manufacturing sector. The model allows for a detailed comparison of how different levels of carbon taxation may affect the competitiveness of Indonesia's manufacturing sector, both domestically and in the global market.

2.3. Experimentation with Ex-Ante Data

Given the absence of historical data on the impact of carbon taxes in Indonesia, the study uses ex-ante data through simulation-based forecasting. Ex-ante data provide insights into the potential outcomes of policies prior to their implementation, making this approach suitable for evaluating Indonesia's carbon tax policy. By leveraging the Input-Output model, which includes detailed sectoral interactions, the study can forecast how a carbon tax will alter the structure of manufacturing costs and emissions profiles.

The simulation model iteratively adjusts variables such as energy prices, carbon tax rates, and industrial investment in green technologies to forecast outcomes. These projections are particularly valuable in understanding how the increased costs of inputs like energy and raw materials will ripple through the manufacturing value chain and affect competitiveness.

2.4. Validation and Sensitivity Analysis

Validation and sensitivity analysis are performed to ensure the model's reliability. The validation process involves comparing the model's outputs with known sectoral behavior patterns in Indonesia, mainly focusing on energy consumption and industrial growth trends. This helps ensure that the model accurately represents the real-world dynamics of Indonesia's manufacturing sector.

Sensitivity analysis tests the model's responsiveness to changes in key variables, such as carbon tax rates, energy prices, and production levels. By analyzing how sensitive the model's outputs are to variations in these inputs, the study assesses the robustness of its findings and the degree of uncertainty in its projections.

Additionally, the Input-Output framework is tested for its ability to capture sectoral interdependencies, ensuring that any changes in one industry (e.g., energy) are accurately reflected in related industries (e.g., manufacturing). This allows for a holistic assessment of the impact of carbon taxes on Indonesia's entire economy, mainly focusing on the manufacturing sector.

2.5. Measuring the Variables

The system dynamics approach simulates the development trend of all selected variables. Based on the SD model, this study can estimate future carbon emissions and added value (competitiveness) in Indonesia from the manufacturing sector. The equations in the system dynamics model can be seen in Table 1.

2.6. System Dynamics Modeling

Economic modeling is based on data on Indonesia's input-output economic indicators obtained from microstatistical data of the manufacturing industry from 2014 to 2020. The input-output table illustrates the relationship between sales and purchases between producers and consumers in an economy.

This graph shows how energy sources (consisting of 9 types of energy consumed by the manufacturing sector) contribute to carbon emissions, and green tech contributes to reducing carbon emissions. Combining the two will obtain a net GHG value and be the basis for determining the carbon tax. Furthermore, expenditures on energy costs, carbon taxes, labor, and fixed assets contribute to inputs. Finally, how fixed assets also contribute to added value, namely through increased productivity. The added value is calculated from the output value minus the input value. Output itself is measured from the contribution of the manufacturing industry sector to GDP (manufacturing sector GDP to national GDP), which reflects how much industrial demand produces final output.

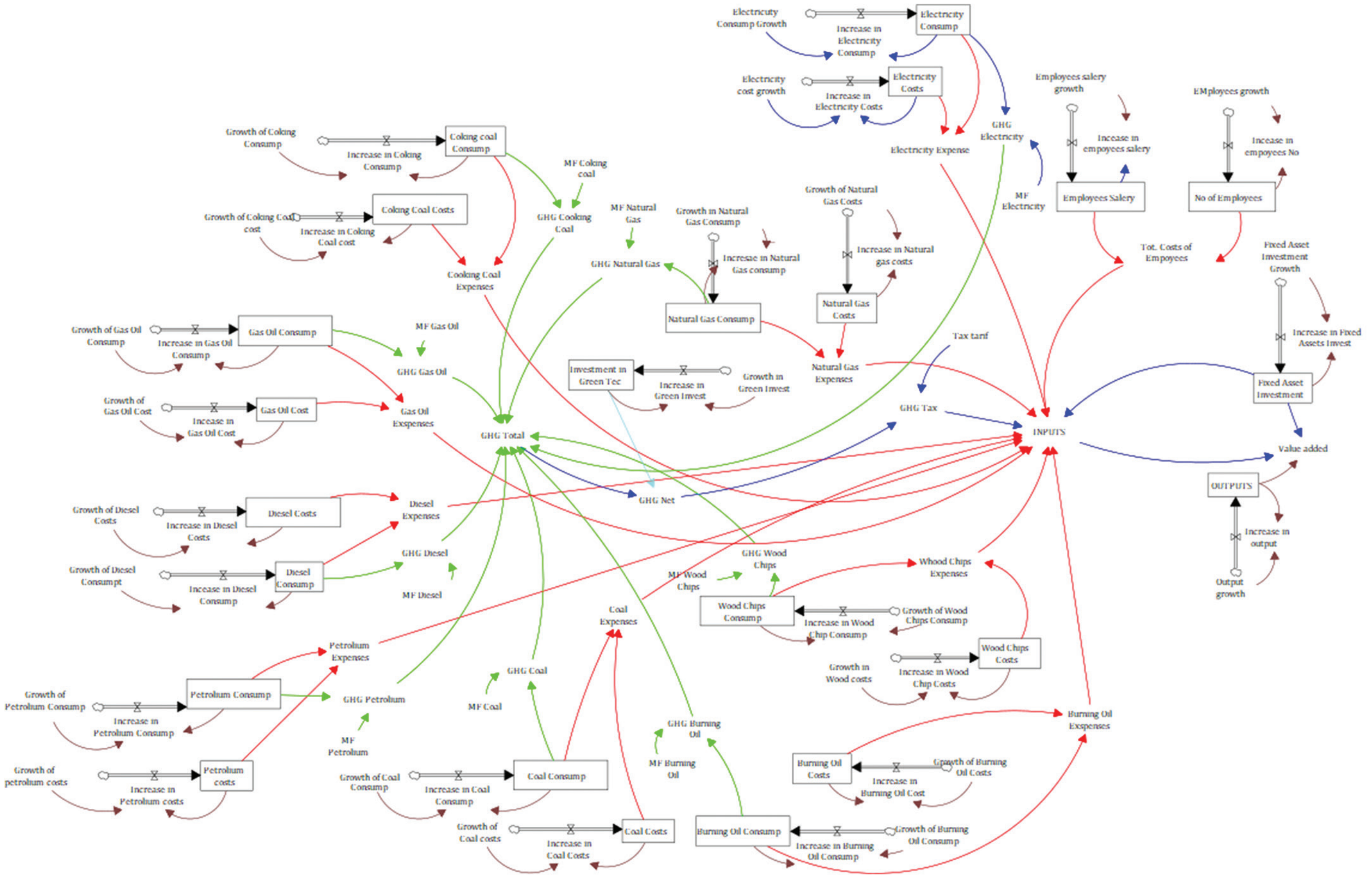
3. RESEARCH RESULTS

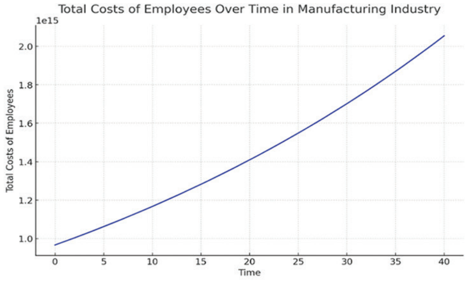
Based on the SD model, the results of the estimates of various types of energy consumed are shown in Figure 1. The baseline for time is in 2015 for year 0, and the 40th time is in 2055.

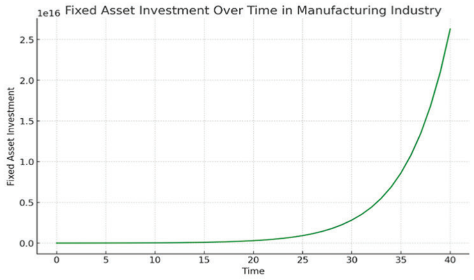
The data shows a consistent upward trend in energy expenditure from the nine main variables over time. Spending on Coking Coal, Gas Oil, Diesel, and Petroleum all increased, reflecting increased energy consumption in heavy industry sectors. Similarly, the cost of Coal and Burning Oil continues to rise as the use of these fuels remains high in various industries. Wood Chips Expenses related to biomass also increased, although it was more varied. Spending on Natural Gas and Electricity reflects a significant spike, indicating a shift to cleaner energy sources and increased electricity consumption in several sectors of the economy. Overall, the observed trend illustrates a sustained rise in energy costs, which indicates growth in energy consumption across various industrial sectors.

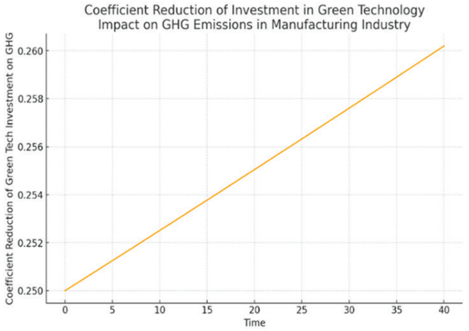
3.1. Projection Results of Employee Costs, Fixed Asset Investment, Contribution of Green Tech Investment to GHG Emission Reduction, and Total GHG Emissions

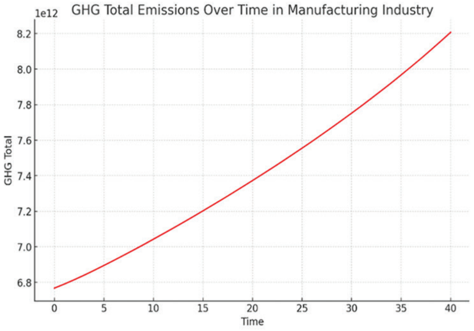
This section will thoroughly discuss the projection results for employee costs, fixed asset investment, the contribution of green tech investment to GHG emission reduction, and total GHG emissions.











First, the projected employee costs will be outlined, reflecting labor expenses across various sectors over a specified period. Next, the analysis will cover fixed asset investment, which plays a crucial role in infrastructure development, production capacity, and its impact on economic growth. The contribution of green tech investment to reducing greenhouse gas (GHG) emissions, an essential strategy for achieving global climate targets, will also be explored. Additionally, total GHG emissions will be analyzed to provide insights into the effectiveness of policies and technologies in mitigating the environmental impacts of industrial activities. Each part will offer critical insights into how investment and technological policies influence economic efficiency and environmental sustainability.

3.2. Scenarioizing

This study developed three scenarios to investigate the increase and decrease of carbon emissions in Indonesia's manufacturing

Table 1: Equations in system dynamics model

No.	Name	Equation	Variable type	Initial value
1	Growth of Coking Consump	0.00628	Constant	
2	Increase in Coking Consump	Coking coal Consump*Growth of Coking Consump	Auxiliary	
3	Coking coal Consump	Increase in Coking Consump	Level	1.4979e+09
4	Growth of Coking Coal cost	0.00628	Constant	
5	Increase in Coking Coal cost	Coking Coal Costs*Growth of Coking Coal cost	Auxiliary	
6	Coking Coal Costs	Increase in Coking Coal cost	Level	33056.1
7	Cooking Coal Expenses	Coking Coal Consump*Coking Coal Costs	Auxiliary	
8	MF Coking coal	3563	Constant	
9	GHG Cooking Coal	Coking Coal Consump*MF Coking coal	Auxiliary	
10	Growth of Gas Oil Consump	-0.00103269	Constant	
11	Increase in Gas Oil Consump	Gas Oil Consump*Growth of Gas Oil Consump	Auxiliary	
12	Gas Oil Consump	Increase in Gas Oil Consump	Level	6.3751e+08
13	Growth of Gas Oil Cost	0.03	Constant	
14	Increase in Gas Oil Cost	Gas Oil Cost*Growth of Gas Oil Cost	Auxiliary	
15	Gas Oil Cost	Increase in Gas Oil Cost	Level	856.477
16	Gas Oil Expenses	Gas Oil Consump*Gas Oil Cost	Auxiliary	
17	MF Gas Oil	3.5477	Constant	
18	GHG Gas Oil	Gas Oil Consump*MF Gas Oil	Auxiliary	
19	Growth of Diesel Costs	0.0351	Constant	
20	Increase in Diesel Costs	Diesel Costs*Growth of Diesel Costs	Auxiliary	
21	Diesel Costs	Increase in Diesel Costs	Level	6542.95
22	Growth of Diesel Consumpt	−0.0006741	Constant	
23	Increase in Diesel Consump	Growth of Diesel Consumpt*Diesel Consump	Auxiliary	
24	Diesel Consump	Increase in Diesel Consump	Level	3.675e+09
25	Diesel Expenses	Diesel Costs*Diesel Consump	Auxiliary	
26	MF Diesel	3.1787	Constant	
27	GHG Diesel	Diesel Consump*MF Diesel	Auxiliary	
28	Growth of Petroleum Consump	−0.258895	Constant	
29	Petroleum Consump	Increase in Petroleum Consump	Level	7.47797e+09
30	Growth of petroleum costs	0.410809	Constant	
31	Increase in Petroleum costs	Growth of petroleum costs*Petroleum costs	Auxiliary	
32	Increase in Petroleum costs	Growth of petroleum costs*Petroleum costs	Constant	
33	Petroleum costs	Increase in Petroleum costs	Level	2257.48
34	Petrolium Expenses	Petrolium Consump*Petrolium costs	Auxiliary	
35	MF Petrolium	2.7329	Constant	
36	GHG Petrolium	MF Petrolium*Petrolium Consump	Auxiliary	
37	Growth of Coal Consump	−0.0050321	Constant	
38	Increase in Coal Consump	Coal Consump*Growth of Coal Consump	Auxiliary	
39	Coal Consump	Increase in Coal Consump	Level	5.00933e+08
40	Growth of Coal costs	0.09	Constant	
41	Increase in Coal Costs	Coal Costs*Growth of Coal costs	Auxiliary	
42	Coal Costs	Increase in Coal Costs	Level	25683.8
43	Coal Expenses	Coal Consump*Coal Costs	Auxiliary	
44	MF Coal	2718	Constant	
45	GHG Coal	Coal Consump*MF Coal	Auxiliary	
46	Growth of Burning Oil Consump	−0.00505048	Constant	
47	Increase in Burning Oil Consump	Burning Oil Consump*Growth of Burning Oil Consump	Auxiliary	
48	Burning Oil Consump	Increase in Burning Oil Consump	Level	3.08288e+08
49	Growth of Burning Oil Costs	0.0357245	Constant	
50	Increase in Burning Oil Cost	Burning Oil Costs*Growth of Burning Oil Costs	Auxiliary	
51	Burning Oil Costs	Increase in Burning Oil Cost	Level	107093
52	Burning Oil Expenses	Burning Oil Consump*Burning Oil Costs	Auxiliary	
53	MF Burning Oil	3.0121	Constant	
54	GHG Burning Oil	Burning Oil Consump*MF Burning Oil	Auxiliary	
55	Growth in Wood costs	0.062666	Constant	
56	Increase in Wood Chip Costs	Growth in Wood costs*Wood Chips Costs	Auxiliary	
57	Wood Chips Costs	Increase in Wood Chip Costs	Level	16514.3
58	Growth of Wood Chips Consump	0.100326	Constant	
59	Increase in Wood Chip Consump	Growth of Wood Chips Consump*Wood Chips Consump	Auxiliary	
60	Wood Chips Consump	Increase in Wood Chip Consump	Level	165143
61	Wood Chips Expenses	Wood Chips Consump*Wood Chips Costs	Auxiliary	
62	MF Wood Chips	1372	Constant	
63	GHG Wood Chips	MF Wood Chips*Wood Chips Consump	Auxiliary	
64	Growth in Natural Gas Consump	0.119044	Constant	

(Contd...)

Table 1: ***(Continued)***

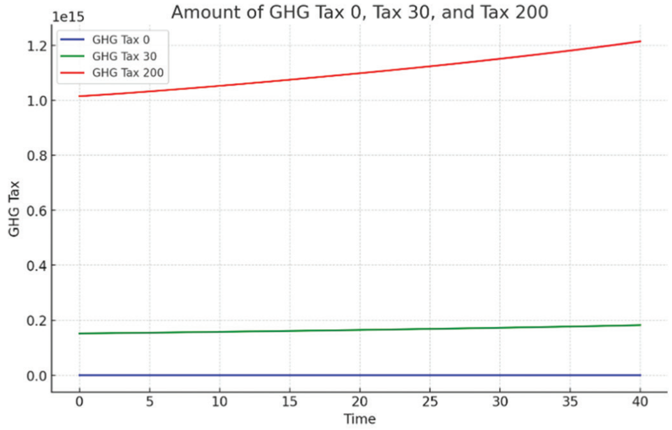
No.	Name	Equation	Variable type	Initial value
65	Increase in Natural Gas consump	Growth in Natural Gas Consump*Natural Gas Consump	Auxiliary	
66	Natural Gas Costs	Increase in Natural gas costs	Level	17566.3
67	Growth in Natural Gas Consump	0.119044	Constant	
68	Increase in Natural Gas consump	Growth in Natural Gas Consump*Natural Gas Consump	Auxiliary	
69	Natural Gas Consump	Increase in Natural Gas consump	Level	3.11614e+08
70	Whood Chips Expenses	Wood Chips Consump*Wood Chips Costs	Auxiliary	
71	MF Natural Gas	2.224	Constant	
72	GHG Natural Gas	MF Natural Gas*Natural Gas Consump	Auxiliary	
73	Growth in Natural Gas Consump	0.119044	Constant	
74	Incresae in Natural Gas consump	Growth in Natural Gas Consump*Natural Gas Consump	Auxiliary	
75	Natural Gas Consump	Incresae in Natural Gas consump	Level	3.11614e+08
76	Growth of Natural Gas Costs	0.016856	Constant	
78	Increase in Natural gas costs	Growth of Natural Gas Costs*Natural Gas Costs	Auxiliary	
79	Natural Gas Costs	Increase in Natural gas costs	Level	17566.3
80	Natural Gas Expenses	Natural Gas Consump*Natural Gas Costs	Auxiliary	
81	MF Natural Gas	2.224	Constant	
82	GHG Natural Gas	MF Natural Gas*Natural Gas Consump	Auxiliary	
83	Electricity Consump Growth	0.039385	Constant	
84	Increase in Electricity Consump	Electricity Consump*Electricity Consump Growth	Auxiliary	
85	Electricity Consump	Increase in Electricity Consump	Level	5.67582e+10
86	Electricity cost growth	0.035637	Constant	
87	Increase in Electricity Costs	Electricity cost growth*Electricity Costs	Auxiliary	
88	Electricity Costs	Increase in Electricity Costs	Level	839.247
89	Electricity Expense	Electricity Consump*Electricity Costs	Auxiliary	
90	MF Electricity	0.571	Constant	
91	GHG Electricity	Electricity Consump*MF Electricity	Auxiliary	
92	GHG Total	GHG Burning Oil+GHG Coal+GHG Cooking Coal+GHG Diesel+GHG Electricity+GHG Gas Oil+GHG Petrolium+GHG Natural Gas+GHG Wood Chips		
93	Growth in Green Invest	0.04	Constant	
94	Increase in Green Invest	Growth in Green Invest*Investment in Green Tec/100	Auxiliary	
95	Investment in Green Tec	Increase in Green Invest	Level	0.25
96	Tax tariff	0; 30; 200	Constant	
97	GHG Tax	GHG Net*Tax tariff	Auxiliary	
98	GHG Net	GHG Total - (Investment in Green Tec*GHG Total)	Auxiliary	
99	Employees salary growth	0.00333	Constant	
100	Increase in employees salary	Employees salary growth*Employees Salary	Auxiliary	
101	Employees Salary	Increase in employees salary	Level	3.04347e+07
102	Employees growth	0.015645	Constant	
103	Increase in employees No	Employees growth*No of Employees	Auxiliary	
104	No of Employees	increase in employees No	Level	3.17653e+07
105	"Tot. Costs of Employees"	(Employees Salery*No of Employees)	Auxiliary	
106	Fixed Asset Investment growth	0.25	Constant	
107	Increase in Fixed Assets Invest	Fixed Asset Investment*Fixed Asset Investment Growth	Auxiliary	
108	Fixed Asset Investment	Increase in Fixed Assets Invest	Level	0.18*(1.94163e+13)
109	INPUTS	Burning Oil Exspenses+Coal Expenses+Cooking Coal Expenses+Diesel Expenses+Electricity Expense+Gas Oil Exspenses+GHG Tax+Natural Gas Expenses+Petrolium Expenses+Whood Chips Expenses+ "Tot. Costs of Empoyees"+(Fixed Asset Investment/8)	Auxiliary	
110	Output growth	0.1	Constant	
111	Increase in output	Output growth*OUTPUTS	Auxiliary	
112	OUTPUTS	Increase in output	Level	1.7592e+15
113	Value added	(((1e+15*OUTPUTS)+(0.1*Fixed Asset Investment)-1e+16)-((8e+14*INPUTS) - 9e+15))^0.5	Auxiliary	

Source: Authors' analysis

sector. Scenario 0 represents a baseline or business-as-usual condition without implementing a carbon tax. In Scenario 1, the carbon tax is set at Rp30 per kilogram of CO_2e; in Scenario 2, the tax is increased to Rp200 per kilogram of CO_2e. These three scenarios are designed to evaluate the impact of carbon taxes on greenhouse gas (GHG) emissions in the manufacturing sector and their impact on industrial operating costs.

3.3. GHG Tax in the Manufacturing Industry: Carbon Tax Amount at Tax Levels 0, 30, and 200

Based on the data analyzed, the influence of carbon tax on GHG emissions in the manufacturing industry can be seen from the variation in GHG Tax 0, GHG Tax 30, and GHG Tax 200 levels. The carbon tax encourages companies to reduce emissions by applying green technology.



In Scenario 0, companies have no incentive to reduce emissions without implementing a carbon tax. As a result, there has been no significant change in the number of emissions, and the rate of growth in emissions remains flat. This shows that without financial incentives such as taxes, companies tend to maintain the status quo without making investments in greener technologies. In contrast, implementing a carbon tax of Rp30 per kilogram in Scenario 1 shows a gradual reduction in emissions with an average annual growth rate of 0.33%. Taxes at this rate incentivize companies to invest in green technologies, although the impact is still relatively slow. In Scenario 2, with a tax of Rp200 per kilogram, the emission reduction rate remains at 0.33%. Although higher taxes put more pressure on companies to reduce emissions, the pace of adoption of green technology is still not significant enough to provide more drastic reductions. Research by Liu et al. (2021) indicates that a higher carbon tax can accelerate the transition to clean energy. However, its effectiveness is highly dependent on the industry's speed of adoption of low-carbon technologies. Similarly, Wang et al. (2023) point out that although higher carbon taxes encourage more significant investment in renewable energy, tangible results in emission reductions may take longer.

The introduction of a carbon tax also impacts operational costs in the manufacturing industry. This tax is intended to reduce emissions by charging a fee on greenhouse gas emissions, thus forcing companies to invest in cleaner technologies. However, this also means increased operating costs, especially for companies that depend on fossil energy, such as coal and petroleum. Under the no-tax scenario, operating costs remain stable as there is no penalty for emissions. Companies can continue using traditional fuels without additional financial costs related to emissions. However, in Scenario 1, with a tax of Rp30, operational costs start to increase along with penalties for emissions. While companies can start investing in cleaner technologies to reduce the tax burden, operating costs continue to increase as the industry adjusts. In Scenario 2, with a tax of Rp200, operational costs increase significantly. Higher tax burdens force companies to transition to green technologies more quickly, but investments in these new technologies will take time before the financial benefits can be felt. This leads to increased costs in the short term before the efficiency and long-term savings of green technology are realized. Manufacturing industries that rely heavily on fossil fuels are more vulnerable to rising costs under the carbon tax scenario. Companies that rely on coal, for example, face sharper cost increases compared to those that use cleaner energy sources such as natural gas or renewables. In addition to the direct fines from the carbon tax, these companies also have to bear the indirect costs associated with the transition to clean energy, which could include capital expenditures on new infrastructure and technologies.

In the long term, implementing a carbon tax creates challenges and opportunities for the manufacturing industry. The main challenge is the increase in operating costs that can weigh on profitability, especially for companies that are slow to transition to green technology. However, for companies that invest early in clean technology, there is an opportunity to make long-term profits. This investment will reduce the impact of carbon taxes and provide a competitive advantage in a market that prioritizes sustainability. Wang et al. (2023) concluded that higher carbon taxes correlate with increased operating costs in energy-intensive industries. However, companies transitioning faster to clean energy can reap long-term financial benefits, such as reduced energy costs and potential revenue from selling excess renewable energy back to the grid. Liu et al. (2019) also, carbon taxes create strong incentives for companies to switch to renewable energy, although this transition period is critical to addressing high capital costs. Rokhmawati et al. (2024) although carbon taxes increase costs in the short term, they encourage innovation in green technologies that ultimately reduce emissions and operational costs, facilitating a more sustainable manufacturing sector.

3.4. Effect of Carbon Tax on Inputs in the Manufacturing Industry at Tax Levels 0, 30, 200

An analysis of inputs in the manufacturing industry at various levels of carbon taxes (0, 30, and 200) shows how carbon pricing policies affect resource use by producers. Inputs in this context represent a wide range of resources, including energy, raw materials, and technologies used in production. Variations in the use of inputs under different scenarios reflect the industry's response to financial pressures from implementing carbon taxes.

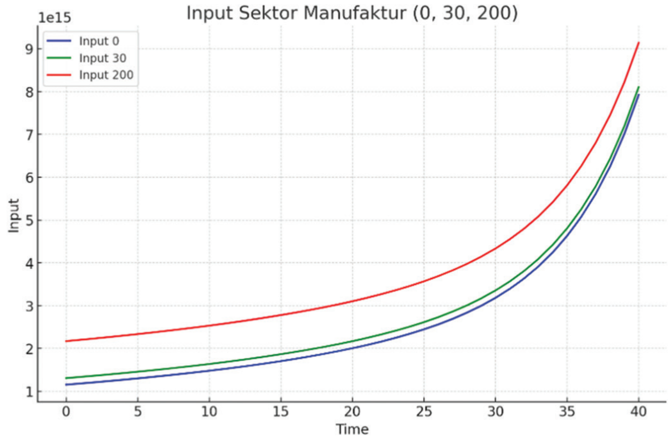
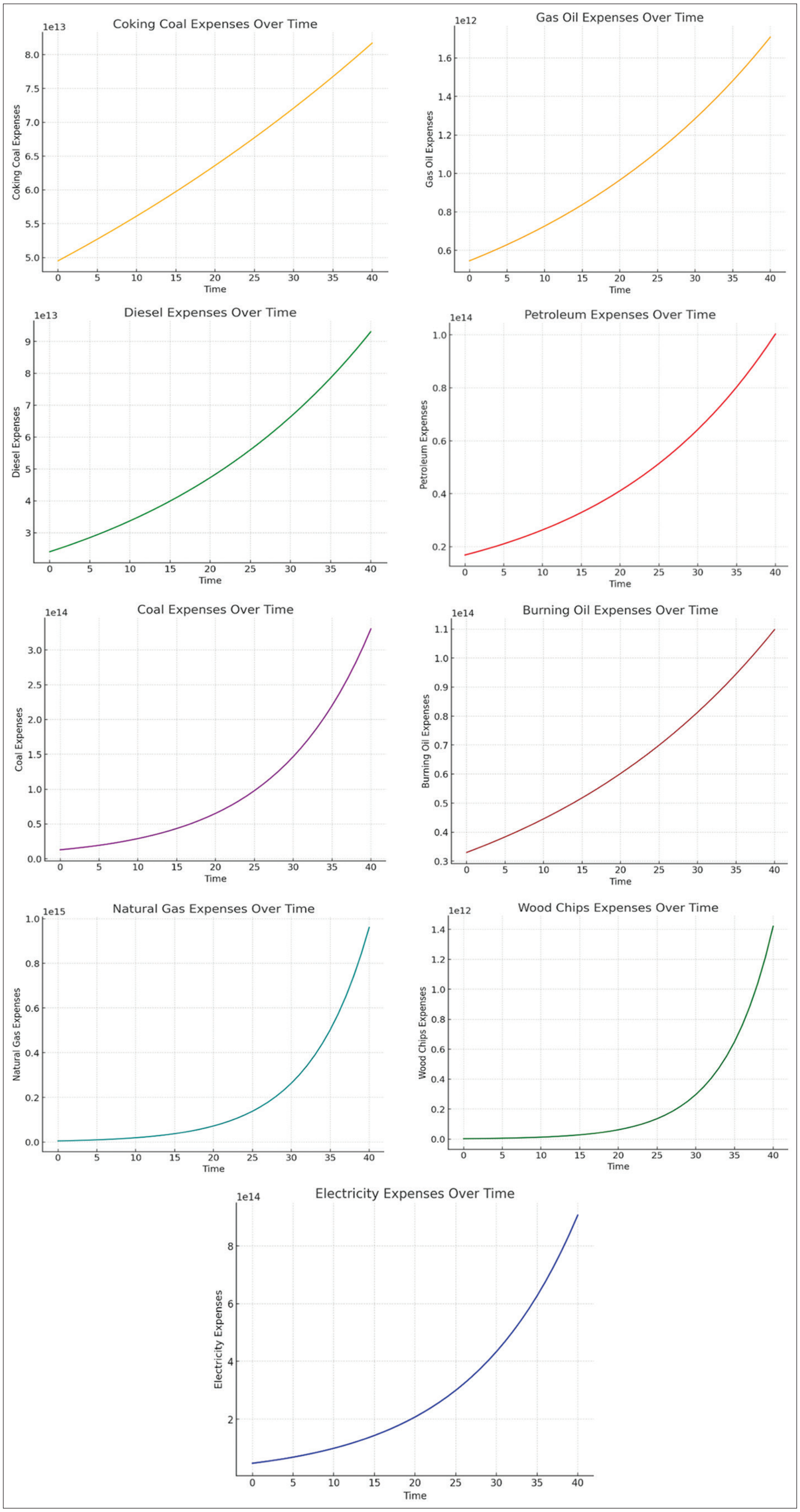


Figure 1: Graph of energy consumption forecast of manufacturing industry sub-sector based on SD model 2015-2055



Source: Authors' analysis

At input level 0, where no carbon tax is applied, the rate of input use grows at a compound annual growth rate (CAGR) of 2.39% per year. This reflects a typical growth pattern in input consumption in the manufacturing industry. Producers do not face financial incentives to reduce their carbon footprint, so they tend to maintain conventional production practices that pay less attention to energy efficiency and environmental sustainability. As a result, inputs continue to increase as production increases without significant adjustments to reduce the environmental impact or long-term operating costs associated with carbon emissions.

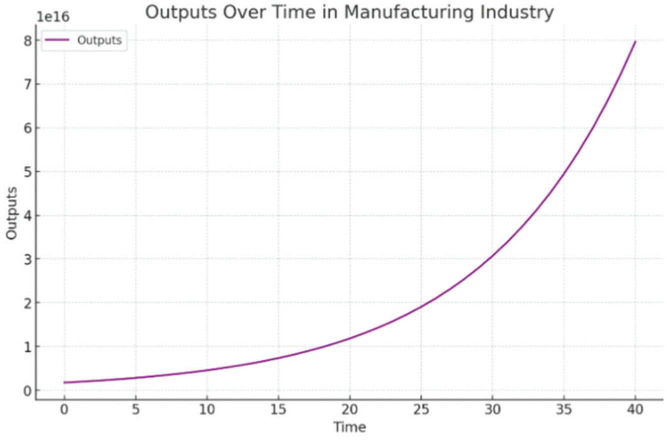
However, at input level 30, when a carbon tax of Rp30 per kilogram of CO_2e was implemented, there was a noticeable change. Input growth decreased to a CAGR of 2.16% per year. This decline shows that producers are starting to respond to the additional cost pressures of carbon taxes by optimizing resource use. They began to invest in more efficient technologies and adopt more energy-efficient production processes. A carbon tax at this level encourages companies to reevaluate their operational efficiency and start making adjustments, although the changes are not too drastic. A study by Liu et al. (2019) supports these findings, suggesting that a moderate carbon tax rate, such as Rp30, motivates companies to optimize resource use gradually without causing significant changes in their production patterns.

At the input level of 200, where the carbon tax reaches Rp200 per kilogram of CO_2e, there is a significant decline in input growth, with the CAGR dropping to 1.45% per year. This reflects a much more aggressive response from the industry to higher taxes. Manufacturers must substantially reduce resource consumption and switch to more efficient and sustainable technologies. Financial pressures become so intense at this tax rate that producers invest in more advanced technologies, such as renewable energy and sustainable production processes. They are also likely to reduce their reliance on emissions-intensive fossil fuels like coal and petroleum and switch to cleaner and greener energy sources. Rokhmawati et al. (2024) found that companies facing high carbon taxes, such as the 200 tariffs, tend to switch to renewable energy and sustainable inputs, reducing environmental impact and resulting in cost savings in the long run.

Overall, the impact of carbon taxes on input use in the manufacturing industry shows that the higher the tax, the greater the incentive for producers to reduce their resource consumption. Introducing a carbon tax is forcing companies to adopt more efficient and environmentally friendly technologies, which can ultimately improve economic and environmental sustainability in the long run. While lower taxes encourage more gradual change, higher taxes force companies to take more drastic steps to reduce their energy consumption and carbon footprint. Wang et al. (2021) emphasized that higher carbon taxes force companies to significantly reduce resource consumption by switching to greener and more energy-efficient technologies.

3.5. Manufacturing Industry Outputs

In the manufacturing industry, output represents the total production of goods.



Output in the manufacturing industry reflects the total production of goods and services, the primary indicator of the sector's performance. Based on the data analyzed, the manufacturing sector is experiencing an impressive compound annual growth rate (CAGR) of 10% per year. This steady growth reflects a significant upward trend in production, likely driven by high market demand and improved operational efficiency in the manufacturing industry. This consistent output growth shows that the manufacturing sector continues to grow despite facing various economic and policy challenges, such as implementing a carbon tax.

One of the critical factors driving output growth is energy efficiency. Adopting energy-efficient technologies, primarily driven by policies such as carbon taxes, allows companies to increase their output with more efficient energy use. This technology reduces energy consumption without sacrificing production rates, so companies can save costs and stay competitive. In addition, technological innovation plays a crucial role in output growth. Investments in automation and digitalization have increased productivity in the manufacturing sector. The new technology allows manufacturers to scale production while controlling costs, which is critical to maintaining output growth. Zhang et al. (2018) highlighted that technological innovation is vital in driving output growth, especially in developing countries where the manufacturing sector is booming.

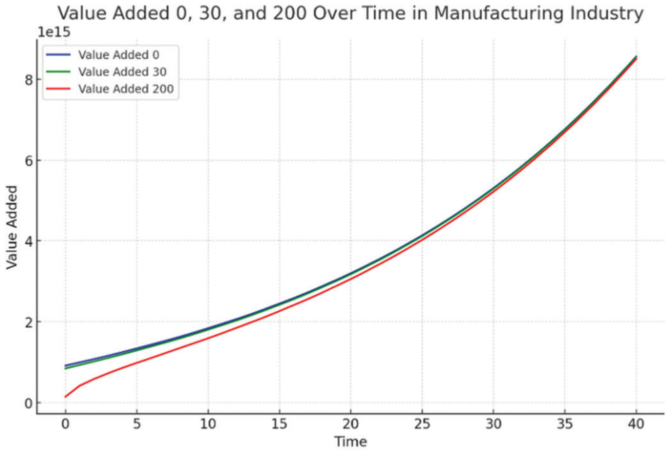
In addition, the transition to cleaner energy sources, such as natural gas and renewable energy, is also essential in maintaining stable output. Companies that switch from heavy carbon-based fuels to greener energy sources meet stringent environmental regulations and reduce the potential cost burden arising from carbon taxes. According to Ahmadi et al. (2022), this transition is crucial in mitigating the negative impact of carbon tax policies on output growth, thus allowing companies to maintain stable production.

A study by Liu et al. (2019) found that the manufacturing sector's ability to sustain output growth despite facing increased operating costs is due mainly to the adoption of green technologies and energy-efficient practices. Wang et al. (2023) also emphasized that sectors that make initial investments in renewable energy are better able to withstand fluctuations in fossil fuel prices, which are often volatile. They noted that companies investing in renewable energy can enjoy more resilient and sustainable output growth.

Steady output growth across the manufacturing sector reflects the industry's ability to adapt to new changes and challenges, including carbon taxes and the shift to clean energy. By investing in more advanced and environmentally friendly technologies, as well as by optimizing production processes, manufacturers are not only able to maintain high output levels but also reduce their environmental footprint. This adaptation shows that sustainability and economic growth can go hand in hand in the manufacturing industry, especially in the transition era to a low-carbon economy.

3.6. The Impact of Carbon Tax on the Added Value of the Manufacturing Sector

The value-added analysis in the manufacturing sector provides insights into how different carbon inputs and taxation levels affect the industry's overall economic contribution.



Based on the data analyzed, the effect of implementing a carbon tax on added value in Indonesia's manufacturing sector varies depending on the amount of tax applied. In the scenario without a carbon tax (carbon tax 0), value-added grows at a compound annual growth rate (CAGR) of 8.13% annually. This CAGR is a measure of the average annual growth of a value over a period of time, calculated by the CAGR formula as follows:

$$\text{CAGR} = \left(\frac{\text{Final value}}{\text{Starting value}}\right)^{\frac{1}{\text{Periods}}} - 1$$

We need the initial value (at time 0, year 2015), the final value (at the end time, year 2019), and the number of periods analyzed to calculate CAGR.

1. Starting value (t = 0): 450
2. Final value (t = 4): 617

$$\text{CAGR} = \left(\frac{617}{450}\right)^{\frac{1}{4}} - 1 = 8.13\%$$

With an initial value of 450 and a final value of 617 over 4 years, the resulting CAGR is 8.13%. This growth reflects a situation in which the industry continues to operate without any financial incentives to reduce carbon emissions or adopt green technologies. In this scenario, manufacturing still heavily depends on cheap fossil fuels such as coal and petroleum, so value-added growth runs without considering long-term environmental sustainability. This is a reflection of the reality that is happening in Indonesia, where the industry still faces significant challenges in the transition to renewable energy.

However, when a carbon tax of Rp30 per kilogram of CO_2e is applied (carbon tax 30), there is an increase in added value with a CAGR of 9.16% per year. The industry is starting to respond to the carbon tax by investing in low-emission technologies to reduce the impact of tax costs. This shows that a low carbon tax policy can motivate the manufacturing sector to improve energy efficiency and adopt more environmentally friendly production processes without sacrificing economic competitiveness. Research conducted by Köppl and Schratzenstaller (2023) shows that a moderate carbon tax can provide a strong enough incentive for companies to invest in green technologies, ultimately increasing productivity and economic output. In Indonesia, this policy can significantly drive the industry to innovate and abandon dependence on fossil fuels.

In a scenario with a higher carbon tax, namely Rp200 per kilogram of CO_2e (carbon tax 200), the added value growth increased significantly with a CAGR of 12.78% per year. In this scenario, industries are encouraged to radically change their production processes, including massive investments in low-emission and energy-efficient technologies. The added value increased from 100 to 1558 in the same period, suggesting that implementing a high carbon tax forces companies to adapt faster using green technologies. In the Indonesian context, this scenario could trigger an industrial revolution towards sustainability by switching from fossil fuels to renewable energy, such as solar and wind power. However, the biggest challenge in implementing a high carbon tax is its impact on production costs, especially for the small and medium industry (SME) sector, which often lacks the resources to make expensive technology investments. Therefore, the rapid transition to green energy needs to be supported by government policies that provide technology incentives and subsidies for SMEs so that they can participate in the transformation towards a more sustainable industry.

Overall, depending on the level, carbon taxes can catalyze improving energy efficiency in the manufacturing sector. Carbon taxes force industries to adopt cleaner technologies and optimize production processes, increasing their economic added value. At higher levels of taxation, industries that successfully transition to more energy-efficient operations can benefit from reduced energy costs, increased productivity, and higher added value in the long run. Ahmadi et al. (2022) assert that companies that invest early in renewable energy and energy efficiency will reap significant benefits in the long run, including cost savings and increased global competitiveness.

Technological advancements also play an essential role in increasing added value in the manufacturing sector. The implementation of automation, digitalization, and renewable energy not only helps companies reduce emissions but also increases their productivity. Research by Liu et al. (2021) emphasizes that companies that invest in green technologies and innovation are better positioned to capitalize on the opportunities generated by carbon taxes, allowing them to achieve higher growth while reducing environmental impact. However, the more considerable initial absolute value can explain the difference in value-added graph visualizations in the IDR 200 tax scenario, which appears lower despite having higher geometric growth. In the IDR 200 carbon tax scenario, a higher initial value makes the growth graph look lower, even though it shows higher growth in terms of percentages.

4. CONCLUSION, IMPLICATIONS AND LIMITATIONS

This study evaluates the impact of implementing a carbon tax on inputs, outputs, and value-added in Indonesia's manufacturing sector at three tax levels: 0, 30, and 200 IDR/kg CO_2e. This analysis focuses on how carbon taxes affect production costs, particularly related to fossil-based energy, labor, and fixed asset investment.

In the scenario without a carbon tax (0 IDR/kg CO_2e), input costs in the manufacturing sector are relatively low and stable. Without the burden of carbon taxes, companies have no incentive to switch to clean energy or energy efficiency technologies. They tend to maintain the use of fossil-based energy such as coal, petroleum, and natural gas, which contributes to low input costs. Under these conditions, the manufacturing sector can maintain low production costs, so there is no tremendous pressure to adopt green technology. As a result, the input cost structure remains stable, but it does not support innovation or the switch to renewable energy.

When a carbon tax of 30 IDR/kg CO_2e was implemented, there was a moderate increase in input costs. Implementing this tax increases the cost of fossil-based energy, so companies are starting to respond by investing in energy efficiency technologies and cleaner energy sources to reduce the increase in input costs. Despite rising production costs, companies investing in green technologies can mitigate the impact of this carbon tax, keeping their cost structure under control. Investments in more efficient energy technologies help companies reduce fossil-based energy consumption, gradually reducing the carbon tax burden.

In a higher carbon tax scenario, 200 IDR/kg CO_2e, input costs experience a significant spike. The high tax burden on fossil-based energy forces companies to invest in low-emission and energy-efficient technologies. These cost spikes are difficult to avoid in the short term, but in the long term, investments in green technologies can help reduce energy costs and keep cost structures efficient. Companies that are quick to switch to low-carbon technologies can better mitigate the impact of high carbon taxes, while companies that are slow to adapt will face more significant cost pressures.

This study also assesses the manufacturing sector's output through its contribution to Gross Domestic Product (GDP). With low input costs in the no-carbon tax scenario, the manufacturing sector can maintain high production levels, positively impacting its contribution to GDP. However, companies face challenges maintaining productivity at higher tax rates due to rising energy costs.

Regarding value-added, the no-carbon tax scenario shows steady growth as low input costs allow companies to maximize output. However, in the 30 IDR/kg CO_2e carbon tax, the value-added experienced a slight decrease due to increased input costs. After adaptation, investments in energy efficiency technologies help stabilize value-added and sustain long-term growth. The 200 IDR/kg CO_2e carbon tax scenario led to a sharper decline in value added in the early stages. However, significant investments in green technology and energy efficiency helped to recover value-added gradually. Despite the sharp decline initially, companies investing in low-emission technologies can recover their value-added and approach pre-tax levels.

Carbon taxes significantly impact inputs, outputs, and added value in the manufacturing sector. While a carbon tax can increase input costs and lower added value in the short term, investing in green technology allows companies to mitigate those adverse impacts in the long run.

4.1. Research Implications

This research has implications for various economic policies, corporate management, and environmental strategies. The policy implications suggest that carbon taxes such as 30 IDR/kg CO_2e can encourage companies to invest in green technologies, while higher taxes, such as 200 IDR/kg CO_2e, force drastic changes. Therefore, carbon tax policies should be supported by renewable energy subsidies and energy efficiency incentives to help companies adapt. The implications for companies emphasize the importance of investing in green technology to reduce the impact of rising production costs due to carbon taxes. Companies that are slow to adapt face lower profitability risks. The economic implications highlight that carbon taxes can affect the growth of the manufacturing sector. However, with the transition to clean technologies, the sector's contribution to GDP could increase in the long run. Environmental implications support the transition to a low-carbon economy by reducing greenhouse gas emissions. The implications of investment and innovation show that carbon taxes drive the growth of the clean technology sector, creating investment opportunities in renewable energy and energy efficiency technologies. Future research should classify industries to ensure effective carbon tax policies without compromising the competitiveness of companies.

4.2. Research Limitations

This study has following weaknesses: First, the model used is based on historical data with a system dynamics (SD) approach, which relies on assumptions regarding the development of economic and energy variables. Reliance on these assumptions can lead to bias in long-term predictions, especially given the uncertainty of environmental policy changes or technological innovations. Second, the study does not consider variations in the elasticity of energy substitutions in the face of carbon taxes, so it is assumed that the increased input costs will be fully passed on to consumers without considering the possibility of industrial adaptation through efficiency or clean energy. These limitations limit accurate predictions about the industry's response to climate policy in the long term. Third, the limited scope of data on the manufacturing and energy sectors excludes other significant sectors, such as transportation and agriculture, so the study's results may not fully reflect the overall state of Indonesia's economy. Fourth, the model relies on many variables calibrated from past data, so it may not be able to capture new dynamics or sudden changes, such as fluctuations in commodity prices or energy crises. Finally, the study relies on a simulation model without field trials. Hence, the results need to be further validated through empirical data to assess the effectiveness of carbon tax policies in actual practice.

5. ACKNOWLEDGMENT

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