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POLICY STRATEGIES FOR REDUCING CARBON EMISSIONS IN THE TRANSPORTATION SECTOR

Muhammad Syamil Fadlillah[1], Erma Suryani[2*]

Institut Teknologi Sepuluh Nopember,
Sukolilo, Surabaya 60111, Indonesia

ABSTRACT
This study uses system dynamics modeling to explore policy strategies for reducing carbon emissions in the transportation sector by adopting electric vehicles (EVs). It addresses global warming and climate change, aligning with the 13th Sustainable Development Goal on climate action. The research focuses on transitioning from fossil-fuel-powered vehicles to EVs, with governments worldwide implementing incentives and tax benefits to promote this shift. The study develops a dynamic system model to assess both the economic and environmental impacts of EV adoption, considering international and national policy factors. By evaluating government incentives, infrastructure development, and public acceptance, the research aims to provide policy recommendations that optimize environmental and economic benefits, facilitating a smoother transition to EVs and contributing to sustainable development goals.

KEYWORDS : Vehicles, Renewable, Carbon Emission Reduction, System Dynamics Modeling, Sustainable.

1. INTRODUCTION.

Global warming and the climate crisis are recognized as urgent global issues, addressed under the 13th Sustainable Development Goal (SDG) which emphasizes climate action (United Nation, 2015). These issues are interconnected with other SDGs, suggesting that effectively addressing climate change is crucial for broader sustainable development achievements. The primary cause of climate change is identified as the excessive emission of carbon, predominantly from the use of fossil fuels in transportation (Suryani, Hendrawan, Eka Adipraja, *et al.*, 2022).

In Indonesia, the transportation sector significantly contributes to carbon emissions, necessitating strategic interventions to reduce its environmental impact. Various policies and measures are being implemented to address these challenges. The Indonesian government is promoting the use of public transportation, improving fuel efficiency, and encouraging the adoption of cleaner fuels. Strategies include regulatory measures, economic incentives, and investments in infrastructure to support sustainable transportation systems.

A thorough review of existing literature reveals a growing body of research focused on reducing emissions in the transportation sector. Studies emphasize the need for comprehensive strategies that address both environmental and economic challenges. These strategies include regulatory incentives, tax benefits, and the development of sustainable public transportation infrastructure (Hsiao et al., 2018; J. Liu et al., 2022).

The proposed study will use system dynamics modeling to analyze the comprehensive impacts of transportation policies on the environment and the economy in Indonesia. It will evaluate how various strategies contribute to reducing carbon emissions and improving air quality, while also considering broader economic implications such as job creation and shifts in the energy and transportation sectors (Wen & Wang, 2023)

The study will create scenarios to assess the effectiveness of different transportation policies, including government incentives, and the implementation of electric vehicles (Liu and Xiao, 2018; Pu, Jiang and Zhang, 2023). This research aims to provide policy recommendations that reduce carbon emissions, facilitating a smoother transition to sustainable transportation systems and contributing to Indonesia's sustainable development goals.

2. MATERIALS/METHODOLOGY.

This research employs the system dynamics method, a powerful tool for examining the behavior of intricate systems over time. By leveraging system dynamics, we can create models, conduct simulations, and analyze the interplay and feedback mechanisms within the system being investigated. This approach enables us to capture the evolving interconnections and temporal variations within the system, offering deep insights into its structure and functionality. The subsequent sections will outline the specific procedures and methodologies used in applying system dynamics to our study, including the construction, validation, and simulation of the model.

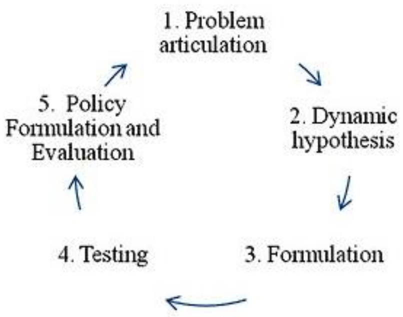


Fig. 1 System Dynamic Methodology

2.1. Problem Articulation.

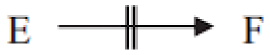
This initial stage involves clearly defining and articulating the problem to be addressed. It includes identifying the key issues, setting the boundaries of the system, and determining the main variables and stakeholders involved. The goal is to establish a clear understanding of the problem context and objectives.

2.2. Dynamic Hypothesis.

In this stage, a dynamic hypothesis is formulated to explain the causes of the problem behavior. This hypothesis is based on the understanding of the system's structure and feedback loops. It involves identifying the relationships between variables and hypothesizing how these relationships drive the behavior of the system over time. This stage is where the causal loop diagram (CLD) start to develop, CLD is a mapping form aimed at understanding cause-and-effect relationships between variables (Sterman, 2000).

Table 1. Causal Loop Diagram Symbols

Variable	Symbol	Description
Positive Links	A —(+)→ B	There is a positive/causal relationship from variable A to variable B.
Negative Links	C —(-)→ D	There is a negative/causal relationship from variable C to variable D.

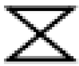
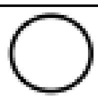
Delay Links		There is a time delay in the interaction between variable E and variable F.
Positive Loop		The effect of a positive/increasing influence among variables where its loop is named reinforcing. This loop occurs when the relationships among variables are the same (both + positive or both - negative).
Negative Loop		The effect of a negative/decreasing influence among variables where its loop is named balancing. This loop occurs when the relationships among variables are balancing (There is an odd number of variables with a - negative relationship).

After we find all the variables, define the characteristics of each variable in the model. Next, all the variables are modelled into a causal-loop diagram (CLD). The CLD model that has been developed can determine the cause and effect relationship between each variable in the system (Arishinta & Suryani, 2020).

2.3. Formulation.

During formulation, the dynamic hypothesis is translated into a formal model. This involves constructing stock-and-flow diagrams, defining equations, and specifying parameters. The model should capture the essential features of the system and allow for simulation and analysis. In this step is where the stock and flow diagram (SFD) being develop. In an SFD, stocks represent accumulations that can increase or decrease, while flows represent the processes that cause these changes in stocks (Suryani *et al.,* 2023). This structured classification enhances clarity and facilitates the creation of the stock and flow diagram. Following this, each variable is intricately linked based on their intrinsic relationships, ensuring that the final diagram provides a thorough and detailed depiction of the system's behavior over time (Chi et al., 2022).

Table 2. Stock and Flows Diagram Symbols

Variable	Symbol	Description
Stock (Level)		A variable that accumulates value over time based on rate changes.
Flow (rate)		A variable that influences the change in value of a stock.
Auxiliary		A variable that is influenced by other variables and contains calculation formulas.

Subsequently, dynamic systems utilize simulation processes to construct models that reflect real-world conditions. These models are rigorously tested to gain insights into the system's behavior (Shannon, 1998). Following testing, evaluations are performed to formulate operational strategies for the system. Simulations are invaluable for decision-making and designing solutions for intricate system issues, ultimately resulting in a framework that is free from assumptions (Chaharbaghi, 1990).

2.4. Testing.

The model is tested to ensure its validity and reliability. This involves comparing the model's behavior with real-world data, checking for consistency and plausibility, and performing sensitivity analysis. Testing helps to refine the model and improve its accuracy in representing the actual system. In this research testing are held in 2 ways, first is verification which to ensure the model do not have bug and error within (Mudjahidin *et al.,* 2019). Secondly there is validation which to to ensure that the model's behavior outputs accurately represent current conditions. If the model does not function correctly or the results do not represent the current conditions, then the model is considered invalid (Barlas, 1996). In validation we use: mean comparison (E1) which is comparing the average of real-historical data and simulation results from the model, error varriance (E2) which is the same but comparing the standart deviation.

$$E1 = \left(\frac{S-A}{A}\right) \qquad (1)$$

Where,

S= Average of simulation results

A= Average of real-historical data

The result will be considered valid if E1 < 5%.

$$E2 = \left(\frac{Ss-Sa}{Sa}\right) \qquad (2)$$

Where,

Ss = Standart Deviation of simulation results

As = Standart Deviation of real-historical data

The result will be considered valid if E2 < 30%.

2.5. Policy Formulation and Evalution.

In this final stage, the validated model is used to design and evaluate potential policies or interventions. The goal is to identify strategies that can effectively address the problem and achieve desired outcomes. Different scenarios and policy options are simulated to assess their impacts and to support decision-making. The scenarios are separated into policy strategy on electric vehicle implementation which has 2 different approach the strategy to increase with incentives that stop in 2025 and the extended until 2045. There is also scenario on technology policy so to see if there will be effect if transportation must use some sort of filter to reduce the carbon production.

2.6. Data Collection.

The data used in this study were meticulously gathered from a variety of sources to ensure comprehensive coverage and reliability. This section outlines the data collection methodologies employed, including the types of data collected, the sources from which the data were obtained, and the procedures followed to ensure data accuracy and integrity. By systematically collecting and analyzing relevant data, we aim to create a robust model that accurately represents the system under study and supports effective policy formulation and evaluation. The data used were obtained from reports by the Central Statistics Agency, databoks, worldometers, transportologi, and data.worldbank.

3. RESULT AND DISCUSSION.

In this chapter, we present the findings of our study and provide a comprehensive discussion on their implications. The results are derived from the analysis and simulations conducted using the system dynamics model outlined in the methodology section. Each key result is discussed in detail, highlighting how it contributes to our understanding of the system under study. We examine the behavior of various system variables, the impact of different policy scenarios, and the overall performance of the model in representing real-world conditions. Additionally, we interpret the significance of these findings in the context of existing literature and the practical implications for stakeholders. This discussion aims to provide a nuanced understanding of the complex dynamics at play and offer insights into potential strategies for effective system management.

3.1. Problem Articulation.

By establishing these variables, we lay the groundwork for the subsequent development of our system dynamics model, ensuring a comprehensive understanding of the intricate relationships and feedback loops that drive the system's behavior. This foundational step is crucial for accurately modeling the system and deriving meaningful insights into its operation and potential interventions. It is found that all the variables are categorized as below:

Table 3. Endogenous Variables from the system

Endogenous Variables
Amount of Passenger Cars, Freight Car Carbon Emissions, Carbon Quota Price, Broken Passenger Cars, Amount of Motorcycles, Average Car CO2 Produce, Used Passenger Cars Purchases, Average Motorcycle CO2 Produce, Transportation Sector Carbon Emissions, Passenger Cars Purchases, Used Motorcycles Purchases, Broken Motorcycles, Car Carbon Emissions, Motorcycles Purchases, Carbon Quota Revenues, Amount of Freight Cars, Motorcycle Carbon Emissions, Freight Cars Purchases, Broken Freight Cars, Carbon Emissions, Used Freight Cars Purchases.

Table 4. Exogenous Variables from the system

Exogenous Variables
Other Sector Carbon Emissions, Carbon Quota

3.2. Dynamic Hypothesis.

Having categorized the key variables influencing our system into endogenous and exogenous types, we now proceed to develop the Causal Loop Diagram (CLD). This step is critical as the CLD visually represents the complex interrelationships and feedback loops among the variables. The CLD will help elucidate how these variables interact over time, highlighting the reinforcing and balancing loops that drive system behavior. By constructing the CLD, we aim to capture the essence of the system's structure, providing a clear and detailed map of the causal relationships that will inform subsequent modeling and analysis stages.

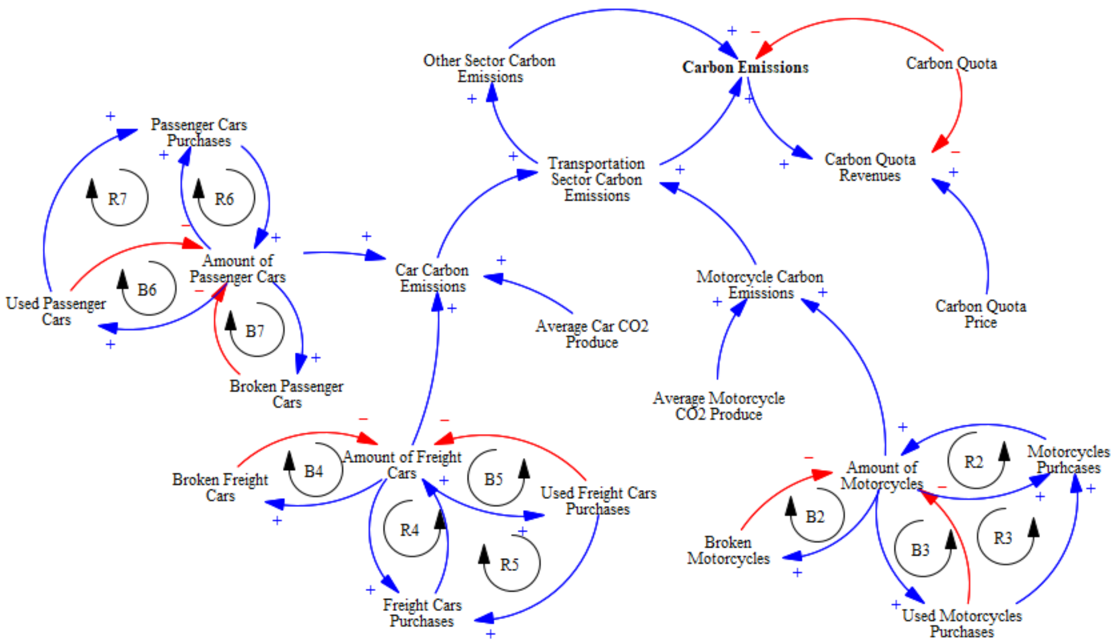


Fig. 2 Causal Loop Diagram

3.3. Formulation.

The model is divided into four sub-models, each with its respective name: Sub-model Cars Amount, Sub-model Motorcyles Amount, and Sub-model Carbon Emissions. A Stock and Flow Diagram (SFD) will be developed to create and give the results for analysis in Carbon Emissions from transportation sector. The SFD is to observe the relationships and interactions between variables, providing new information about the system's state. This knowledge will offer insights into the system and influence final decision-making. The developed SFD can be used for scenario testing simulations. Before conducting scenario testing, the model will undergo validation and verification.

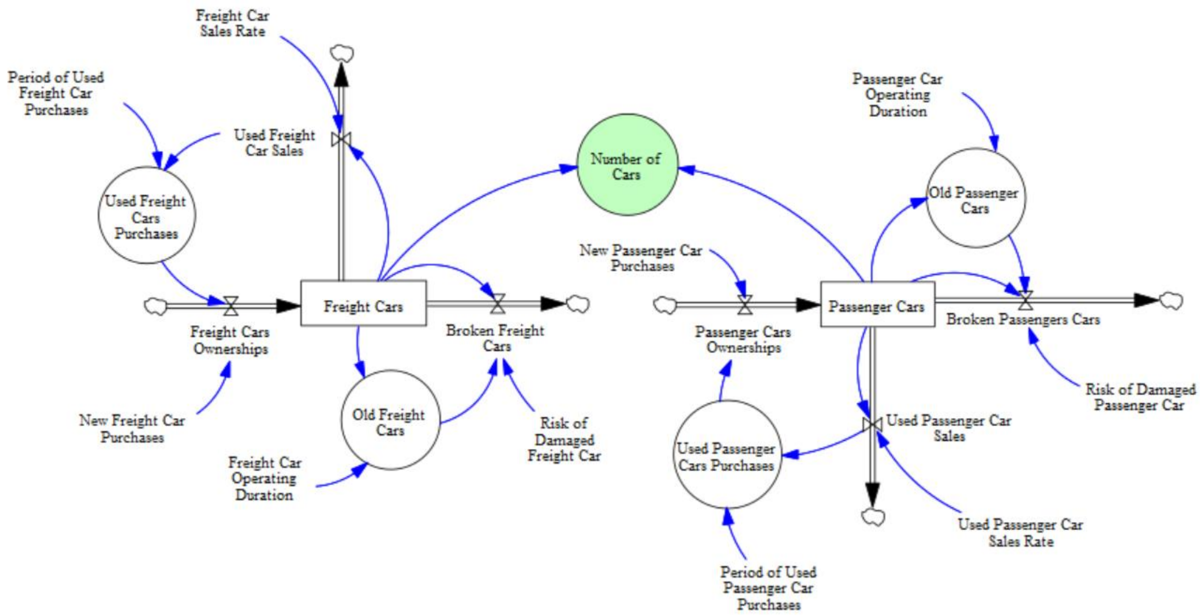


Fig. 3 SFD Sub-model Numbers of Cars

This diagram illustrates the dynamic system involving the number of passenger and freight cars in the transportation sector. It shows the flow from the purchase of new and used vehicles, their operation, to their eventual breakdown. The model highlights the interactions between new vehicle purchases, used vehicle transactions, and the attrition rate due to vehicle breakdowns, depicting how these factors collectively influence the total number of vehicles in operation over time.

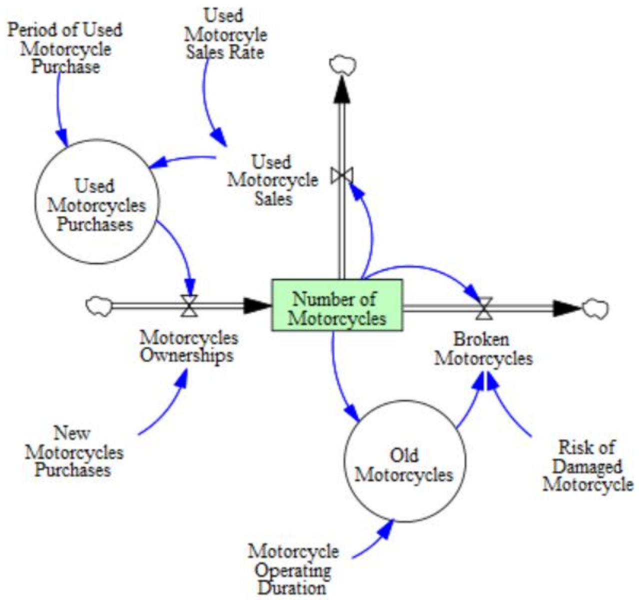


Fig. 4 SFD Sub-model Numbers of Motorcycles

This diagram depicts the dynamic interactions within the motorcycle sector, focusing on the number of motorcycles. It outlines the processes of purchasing new and used motorcycles, their sales, and their breakdown. The system dynamics model captures the lifecycle of motorcycles, including the purchase rates, operational duration, and the rate of breakdowns, providing a comprehensive view of how these elements affect the total motorcycle numbers.

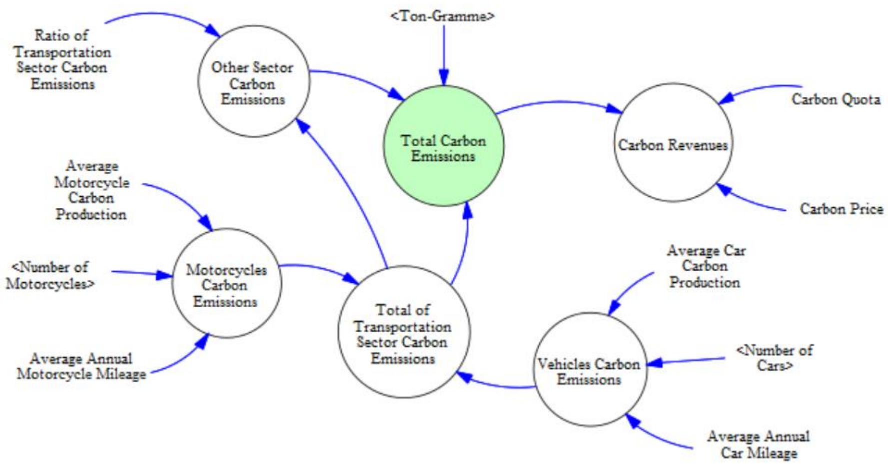


Fig. 5 SFD Sub-model Carbon Emissions

This diagram represents the dynamic system of total carbon emissions, focusing on contributions from the transportation sector and other sectors. It details the carbon emissions from vehicles and motorcycles, integrating them with overall carbon emissions. The model highlights the interactions between the number of vehicles, their average carbon production, and total transportation sector emissions, providing a detailed view of how these factors contribute to overall carbon emissions.

3.4. Testing.

The model has undergone thorough structural and unit verification to ensure its robustness and accuracy. Structurally, each component and feedback loop within the system has been meticulously reviewed to confirm that all logical relationships and causal links are correctly represented. This verification process involved structural and unit verifications.

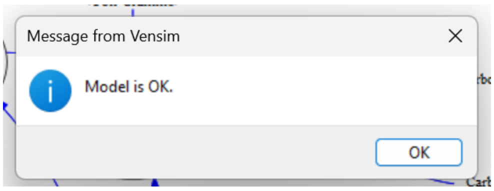


Fig. 6 Model Verification

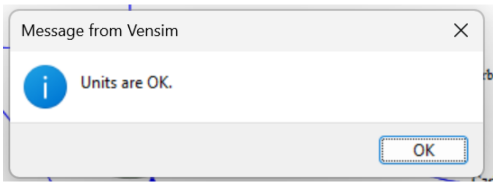


Fig. 7 Unit Verification

Model validation is conducted by comparing the average error rate and error variance stated as in 2.4 before. A model is considered valid if the error rate is ≤ 5% and the error variance is ≤ 30%. The results for the validation as shown below:

Table 5. Validation Results

Variables	Type of Validation	Results
Passenger Cars	Mean Comparison (E1)	3 %
	Error Variance (E2)	6 %
Freight Cars	Mean Comparison (E1)	3 %
	Error Variance (E2)	21 %
Number of Cars	Mean Comparison (E1)	4 %
	Error Variance (E2)	1 %
Number of Motorcycles	Mean Comparison (E1)	2 %
	Error Variance (E2)	7 %
Carbon Emissions	Mean Comparison (E1)	4 %
	Error Variance (E2)	29 %

3.5. Policy Formulation and Evalution.

In the dynamic system simulation model for the policy strategy for reducing carbon emissions in the transportation sector, scenarios were also implemented to understand the potential outcomes for the system. There are three types of scenarios that will applied in the model:

1. Existing Scenario: A scenario where the system or model operates under normal conditions without any additional factors altering the system to see what will happen in future (2045) under normal or no change circumstances.
2. Carbon Reduce Policy Scenario: A scenario where the system or model operates using technology and policy on the vehicles (both motorcycles and cars) so the carbon production from each vehicles is lesser than normal in hopes to reduce carbon emissions.
3. Electric Vehicle Poilcy Scenario: A scenario where the system or model try to implement electric vehicle promotion so the usage of electric vehicle increase and conventional vehicles decrease so the carbon emissions lessen. The program of incentives is started in 2021 therefore the effect of scenario would be seen around 2021-2022.

The sesults from each simulation can be seen as in figures below:

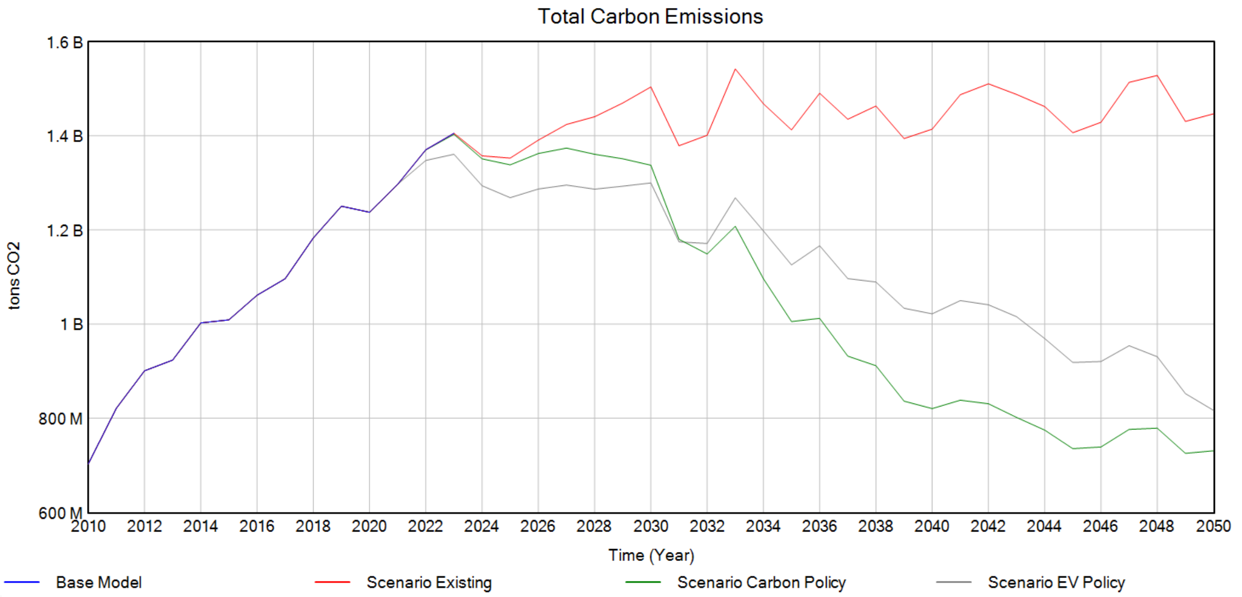


Fig. 8 Results Graph of Total Carbon Emissions

The provided graphs illustrate the trends in total carbon emissions and carbon revenues under four scenarios from 2010 to 2050: the Base Model, Scenario Existing, Scenario Carbon Policy, and Scenario EV Policy. The total carbon emissions graph shows the Base Model with a steady increase until 2025, then leveling off and gradually decreasing. The Scenario Existing continues to rise until 2030, then fluctuates slightly but remains high. The Scenario Carbon Policy indicates a significant decrease in emissions from 2025 onwards, reflecting effective policy impacts, while the Scenario EV Policy also shows a steady decline starting around 2025, though less aggressive than the Carbon Policy. The carbon revenues graph reveals that the Base Model experiences high revenues initially, followed by a sharp decline and remaining negative. The Scenario Existing shows a similar trend but stabilizes in negative territory. In contrast, the Scenario Carbon Policy and EV Policy show revenue improvements post-2025, with the Carbon Policy scenario achieving the most significant positive revenue gains by 2050. These graphs collectively highlight the environmental and economic impacts of different carbon management strategies.

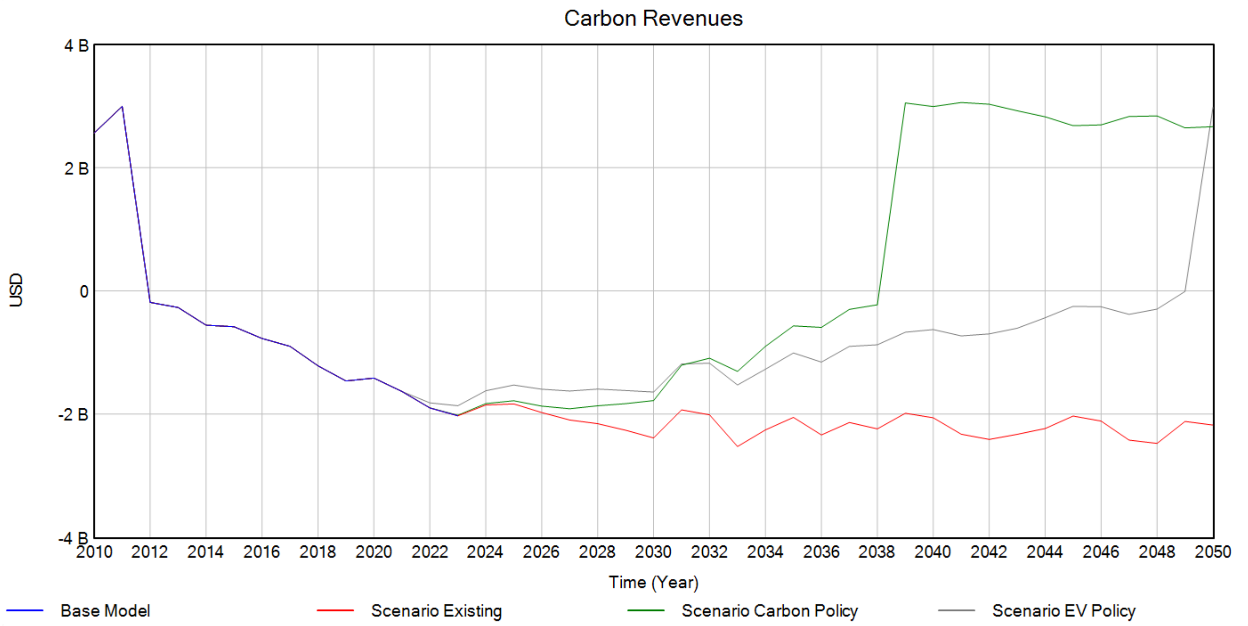


Fig. 9 Results Graph of Carbon Revenues

The provided graphs illustrate the trends in total carbon emissions and carbon revenues under four scenarios from 2010 to 2050: the Base Model, Scenario Existing, Scenario Carbon Policy, and Scenario EV Policy. The total carbon emissions graph shows the Base Model with a steady increase until 2025, then leveling off and gradually decreasing. The Scenario Existing continues to rise until 2030, then fluctuates slightly but remains high. The Scenario Carbon Policy indicates a significant decrease in emissions from 2025 onwards, reflecting effective policy impacts, while the Scenario EV Policy also shows a steady decline starting around 2025, though less aggressive than the Carbon Policy. The carbon revenues graph reveals that the Base Model experiences high revenues initially, followed by a sharp decline and remaining negative. The Scenario Existing shows a similar trend but stabilizes in negative territory. In contrast, the Scenario Carbon Policy and EV Policy show revenue improvements post-2025, with the Carbon Policy scenario achieving the most significant positive revenue gains by 2050. These graphs collectively highlight the environmental and economic impacts of different carbon management strategies.

4. CONCLUSION.

Based on the comprehensive analysis using system dynamics modelling, the study concludes that different transportation policies have significant impacts on both environmental and economic outcomes. The research highlights the following key points:

1. **Total Carbon Emissions**: The Base Model indicates a steady rise in carbon emissions until around 2025, followed by a gradual decline. The Scenario Existing continues to see rising emissions until 2030, with only minor reductions thereafter. The Scenario Carbon Policy and Scenario EV Policy both demonstrate substantial reductions in emissions starting around 2025, with the Carbon Policy scenario showing the most pronounced decrease. This underscores the effectiveness of robust carbon reduction policies in mitigating emissions.
2. **Carbon Revenues**: The analysis of carbon revenues reveals that the Base Model and Scenario Existing result in continued negative revenues, reflecting ongoing economic costs associated with high carbon emissions. Conversely, the Scenario Carbon Policy and Scenario EV Policy show notable improvements in revenues post-2025, with the Carbon Policy scenario achieving the highest

positive revenue gains by 2050. These findings suggest that strategic policy interventions not only contribute to environmental sustainability but also enhance economic benefits.

3. **Policy Effectiveness**: The study confirms that implementing strong carbon reduction policies and promoting electric vehicle adoption are critical strategies for reducing carbon emissions and improving economic outcomes. The success of these policies hinges on comprehensive approaches that include regulatory incentives, tax benefits, and the development of sustainable transportation infrastructure.
4. **Broader Implications**: The results align with the broader Sustainable Development Goals (SDGs), particularly the goal of climate action (SDG 13). By effectively addressing carbon emissions in the transportation sector, Indonesia can make significant strides towards achieving its sustainable development objectives, fostering a cleaner environment, and promoting economic growth.

In conclusion, the study provides robust evidence supporting the adoption of targeted transportation policies to reduce carbon emissions. These strategies not only help combat climate change but also offer substantial economic advantages, thereby contributing to Indonesia's sustainable development goals. The insights gained from this research can inform policymakers in designing and implementing effective interventions for a sustainable and economically resilient transportation sector. Further research could explore additional scenarios, such as the integration of renewable energy sources, regional and sectoral breakdowns, behavioural and social factors, technological innovations, economic impacts, climate adaptation, and international comparisons. These areas of further investigation would deepen our understanding and enhance the effectiveness of sustainable transportation policies.

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