THE IMPACTS OF CARBON TAX ON THAI ECONOMY: THE ANALYSIS USING COMPUTABLE GENERAL EQUILIBRIUM MODEL

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF ECONOMICS
FACULTY OF ECONOMICS
THAMMASAT UNIVERSITY
ACADEMIC YEAR 2024

THAMMASAT UNIVERSITY
FACULTY OF ECONOMICS

THESIS

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ENTITLED

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was approved as partial fulfillment of the requirements for
the degree of Master Degree of Economics

on July 18, 2025

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Thesis Title	THE IMPACTS OF CARBON TAX ON THAI ECONOMY: THE ANALYSIS USING COMPUTABLE GENERAL EQUILIBRIUM MODEL
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Academic Year	2024

ABSTRACT

Climate change mitigation has become a critical global priority, and in response, Thailand initiated a 200-baht carbon tax in 2025. Understanding the macroeconomic, distributional, and environmental impacts of such a policy is therefore essential for designing effective and sustainable climate strategies. This study develops a Computable General Equilibrium (CGE) model tailored to the Thai economy, incorporating carbon emissions and carbon taxation to evaluate the nationwide impacts of the carbon tax and explore alternative revenue-recycling strategies. The model simulates the economy using a Social Accounting Matrix (SAM) based on the 2010 input-output table and energy-related emissions data. Three tax base designs—narrow (gasoline only), moderate (liquid fuels), and broad (all fuels)—are assessed under two emission pathways: the Business-as-Usual (BAU) scenario and Thailand's Nationally Determined Contribution (NDC) scenario. To evaluate policy trade-offs, three revenue-recycling mechanisms are analyzed under both equity and efficiency considerations: direct transfers to households, income tax reductions, and increased government spending. The study yields several key findings that provide insights for carbon tax policy design in Thailand.

First, the implementation of a carbon tax across different tax bases reveals that a broader tax base results in greater emission reductions but also imposes higher economic costs. Despite these reductions, the overall level remains relatively low, indicating that Thailand is still far from meeting its national targets—underscoring the need for more stringent climate policies. On the macroeconomic front, the 200-baht carbon tax has a modest impact on GDP and stimulates investment but places pressure on household consumption.

Second, the effectiveness of revenue-recycling strategies depends largely on policy objectives. Increased government spending emerges as the most efficient option in terms of supporting GDP growth. In contrast, progressive transfers are the most effective in enhancing equity, particularly for lower-income households, though they may come at the expense of economic growth. Income tax reductions tend to benefit higher-income groups and may exacerbate income inequality.

Lastly, while both emission pathways—BAU and NDC—exhibit similar directional results, the NDC pathway produces more balanced outcomes due to embedded structural reforms. In comparison, the BAU scenario shows greater marginal improvements under revenue-recycling, primarily due to higher initial welfare losses and more regressive tax effects.

The findings emphasize that the design of revenue-recycling mechanisms should be aligned with specific policy objectives—whether prioritizing equity or efficiency. A key policy implication is that the observed increase in gross fixed capital formation indicates the need for the government to prioritize investment in relevant sectors to support long-term sustainable growth. Furthermore, to improve the effectiveness of increased government spending, public expenditures should be more precisely targeted to enhance policy outcomes. Finally, future research should consider hybrid or mixed revenue-recycling strategies, as they may offer a balanced approach that promotes both economic efficiency and social equity—providing a practical and inclusive path forward for Thailand's climate and economic development goals.

Keywords: CGE model, carbon tax, revenue-recycling

ACKNOWLEDGEMENTS

The success of this study is made possible by the support of many individuals. First and foremost, I would like to express my deepest gratitude to thesis advisor, *Assoc. Prof. Dr. Nattapong Pattanapong*, for his detailed guidance and support throughout every stage of this research. This study, which started as a personal interest without a clear path forward, was brought to completion through his dedicated mentorship. Throughout the entire process, he consistently offered insightful guidance, shared his expertise, and provided encouragement whenever challenges arose. His support not only deepened my understanding of the CGE model's structure and mechanisms but also helped shape the overall direction of the study through his thoughtful academic perspectives. I am also sincerely grateful for the opportunities he extended to me—particularly the chance to participate in both Thai and international conferences—which allowed me to grow academically and gain valuable experience beyond the classroom.

In addition, I would like to sincerely thank *Asst. Prof. Dr. Anin Aroonruengsawat and Assoc. Prof. Dr. Jaruwan Chontanawat*, thesis committee, for their thoughtful comments, suggestions, and critical insights. Their feedback was essential in improving the quality and clarity of this study.

I am deeply grateful to my family for their mentally support and for always being my warmest source of comfort throughout the journey of this thesis. Special thanks go to my friends—Ploy, who has been with me every step of the way, as well as Dream and Third, whose presence consistently brought joy and vivid energy into my life during the most challenging moments. Lastly, heartfelt appreciation to 4EVE, my daily and hourly source of energy—their music has been a constant source of motivation and has served as a powerful emotional boost throughout this process.

I would also like to thank the faculty members and staff of the graduate program for their support throughout the thesis process, including assistance with administrative procedures and coordination with the committee for each examination during the academic year.

Panchanok Siripanich

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

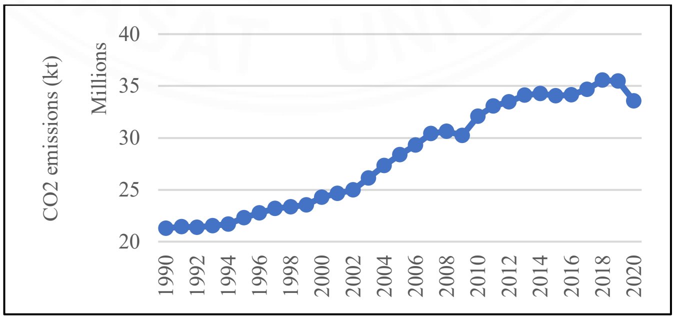
CHAPTER 1
INTRODUCTION

1.1 Statement of Problem

Climate change is a significant global trend characterized by long-term alterations in the Earth's climate. According to emission data from World Bank, human activities play a major role in leaving carbon footprint for generation through generation significantly after the industrial revolution in the late eighteenth century where the emission keep exponentially raised through time as shown in Figure 1.1. The accumulation of greenhouse gases (GHGs) in the Earth's atmosphere has trapped heat, leading to climate change and pushing us into an era of extreme weather events. These changes profoundly impact the environment, economy, and society. According to the International Energy Agency (IEA), carbon emission as a representative of human activities continued to rise 1.1% in 2023 and making a new record of 37.4 billion tons, globally, where NASA also revealed that the global surface temperature in 2023 was 1.2 degrees Celsius warmer than the average of NASA's baseline period which make it a hottest year on record.

Figure 1.1

The Annual Carbon Emissions from 1990-2020



Note. From World Bank, 2024, (https://data.worldbank.org/indicator/EN.ATM.CO2E.KT) and author's compilation.

The link between economic growth and climate change has been discuss over decades. Evidences from papers shows that economic growth is a cause of climate change and climate change also impacts economic activity, (Dobes et al., 2014). Due to the cause from climate change, the economic growth and emission paths do not change significantly at the global level, but relevant differences at the regional and sectoral level where developing countries or those in low-income countries who contribute least to climate change are the most vulnerable to these effects, (Tol, 2009).

In case of ASEAN, the top five nations with largest economies, including Thailand, also shows the positive relationship between the carbon emission and the economic growth, (Tu et al., 2022) . For the low-income countries, there is empirical evidence that shows climatic change, especially weather-related events, negatively impacts the economic growth in the long-run, (Shabir et al., 2022). In boarder scale, the middle-low-income countries with hot temperature characteristic got affected by direct and indirect(spillover) effects in both short- and long-run, while the cold countries with cold weather do not have evidence of these effects, (Benhamed et al., 2023). These papers highlighted the necessity of the impacts and pointed out that ignoring the spillover effect can lead to underestimating macroeconomics consequences where the international cooperation is needed.

As there are growing concern over climate change and the potential impact of carbon emissions on the environment which can be traced back to the late nineteenth and early twentieth centuries. In response to these problems, the international community has collaboratively signed international agreements such as the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and the Paris Agreement. In developed countries, the carbon pricing has been one of the most widely accepted tools in dealing with climate change by internalize the cost of carbon emission, which consists of two main approaches: carbon taxes and carbon credit trading (or cap-and-trade systems). The first implementer was the Nordic countries who are the role model for European countries in introducing a variety of environmental taxes in the 1990s. By the statistics from World Bank, there is a total of 75 instruments implemented by Emission Trading Scheme (ETS) and carbon tax which can cover 19% and 6% of global carbon emission, respectively. Despite that another reason is to meet the international “net zero” goal of reducing GHG emissions to a net zero level by the specified date which most goals are set for 2050 in order to mitigate climate change and limit global warming to 1.5 Celsius above pre-industrial levels as outlined by the Intergovernmental Panel on Climate Change(IPCC).

At the global level, Thailand has not made a binding commitment to emission reductions. However, the Kyoto Protocol and Nationally Appropriate Mitigation Actions (NAMA) have encouraged Thailand to voluntarily reduce emissions to a level that helps keep the global temperature rise below 2 degrees Celsius compared to pre-industrial levels. According to the Fourth Biennial Update Report (BUR), NAMA's target to reduce GHG emission by 7-20% from Business as Usual (BAU) by 2020 and the second updated NDC to UNFCCC of aligns with an ambitious pledge to reduce GHG emissions by 30% from BAU level by 2030. Furthermore, Thailand will continue efforts to meet the long-term goals of carbon neutrality by 2050 and net-zero GHG emissions by 2065.

According to UNDP report on Climate Change Adaptation Thailand was ranked ninth on the Global Climate Risk Index in 2021, indicating significant impacts from climate hazards in terms of both fatalities and economic losses. In response to growing environmental concerns, the Excise Department implemented a carbon tax, as announced in the Royal Thai Government Gazette on 28 March 2025. The tax is levied at a rate of 200 baht per ton of carbon dioxide equivalent. This policy aims to support Thailand's commitment to achieving carbon neutrality by 2050 and net-zero greenhouse gas emissions by 2065. It also serves as a preparatory measure for Thai exporters ahead of the enforcement of the Carbon Border Adjustment Mechanism (CBAM), thereby strengthening incentives for producers to consider carbon emissions in their production processes.

Beyond the carbon tax, Thailand has adopted a range of carbon pricing strategies, including environmental taxes on fuels and vehicles based on emission intensities, as well as the development of carbon credit mechanisms. One such initiative is the Voluntary Emission Reduction Program, launched in 2014, which currently accounts for less than one percent of the country's total carbon emissions.

The existing research on the effects of a carbon tax in Thailand remains limited. Most studies focus on how the country can prepare to meet its commitment to achieving net-zero emissions by 2050, as pledged to the UN. These studies typically adopt two approaches: a bottom-up analysis of the energy system and a top-down approach using Computable General Equilibrium (CGE) models. The bottom-up approach assesses the costs and potential for emission reductions, while the top-down approach estimates welfare impacts based on theoretical models.

On the energy system side, the results indicate that significant carbon removal from land use and forestry sectors can provide substantial benefits, even without CCS (Carbon Capture and Storage) technology. However, the findings strongly recommend a combination of measures, including energy efficiency, behavior change, electrification, renewable energy, hydrogen-based fuels, bioenergy, and CCUS (Carbon Capture, Utilization, and Storage). These measures require substantial cumulative investment in technological improvements to address changes in both energy demand and supply, ((Limmeechokchai et al., 2022) ; (Chaichaloempreecha et al., 2022) ; (Pradhan et al., 2024)).

Nevertheless, the recursive dynamic CGE as a representative from the top-down approach also supportively highlights the adoption of additional technologies or measures for flexible power generation, deploying carbon capture and storage, improve the energy efficiency, and encourage the behavioral changes which are the key identified pillars of decarbonization to drive Thailand toward the pathways of net-zero emission. In this case, they give more view of the economic impacts due to these actions or social implications of GHG reduction scenarios which illustrated a dramatic effects of GDP loss of 7.7%-8.5% in 2050 without economic and energy system transformation, Thailand would face high costs in reducing GHG emissions, ((Rajbhandari et al., 2019) ; (Lorm & Limmeechokchai, 2024); (Muangjai et al., 2023); (Rajbhandari et al., 2023)). Moreover, some paper directly mentioned the carbon pricing or carbon tax which they analyzed the effects of carbon tax policies using a Monte-Carlo Dynamic CGE model and found that such policies lead to lower real GDP and consumption of households but higher unemployment and inflation, (Puttanapong et al., 2015).

However, specific research on the effects of climate change mitigation through carbon taxation in Thailand remains scarce. Given concerns about changes in economic structure and the lack of studies addressing environmental effects and distributional impacts, further research is necessary. Such studies would benefit policy planning and the development of measures to address climate change mitigation. This paper will analyze the macroeconomic consequences, environmental effects, trade competitiveness, distributional impact, and the achievement of international goals.

1.2 The Objective of Study

The primary objective of this research is to evaluate the effects of a carbon tax on the Thai economy using a computable general equilibrium (CGE) model. In line with this goal, the study focuses on three key research objectives. First, it aims to develop a CGE model tailored to the Thai economy that integrates the implications of carbon emissions and carbon taxation. Second, the study seeks to assess the nationwide impact of a carbon tax, with particular attention to how variations in tax bases and emission pathways result in different in macroeconomic and environmental outcomes. Finally, the study analyzes alternative revenue recycling strategies to provide a comprehensive understanding of their implications for both economic efficiency and social equity.

In order to address the two key questions: first, evaluating the impact of carbon tax implementation on economic and environmental outcomes under different tax bases and emission pathways. Second, examining how different revenue recycling strategies influence the distributional and macroeconomic impacts of the carbon tax.

1.3 Scope of Study

This paper aims to study the economic-wide effects of carbon tax implementation by pricing the carbon emission through taxation. The goal is to address the negative externality and create the cost to each economic activities in different fields. The analysis relies on the SAM table. This table is constructed from the Input-Output Table by the Office of the National Economic and Social Development Council (NESDC).

1.4 Organization of the Study

The rest of this thesis is organized as follows. Chapter 2 reviews carbon tax implementation, its effects, related theories, and the use of CGE models in climate policy analysis. Chapter 3 illustrates carbon tax theory, theoretical framework, and methodology, describing the background of the CGE model the background of CGE model and its coefficient parameters. Furthermore, this discusses the data sets and variables that used to investigate the model. Chapter 4 provides the empirical results and consequent analysis derived from the study. Lastly, chapter 5 presents the conclusions of the study along with policy implications derived from the findings.

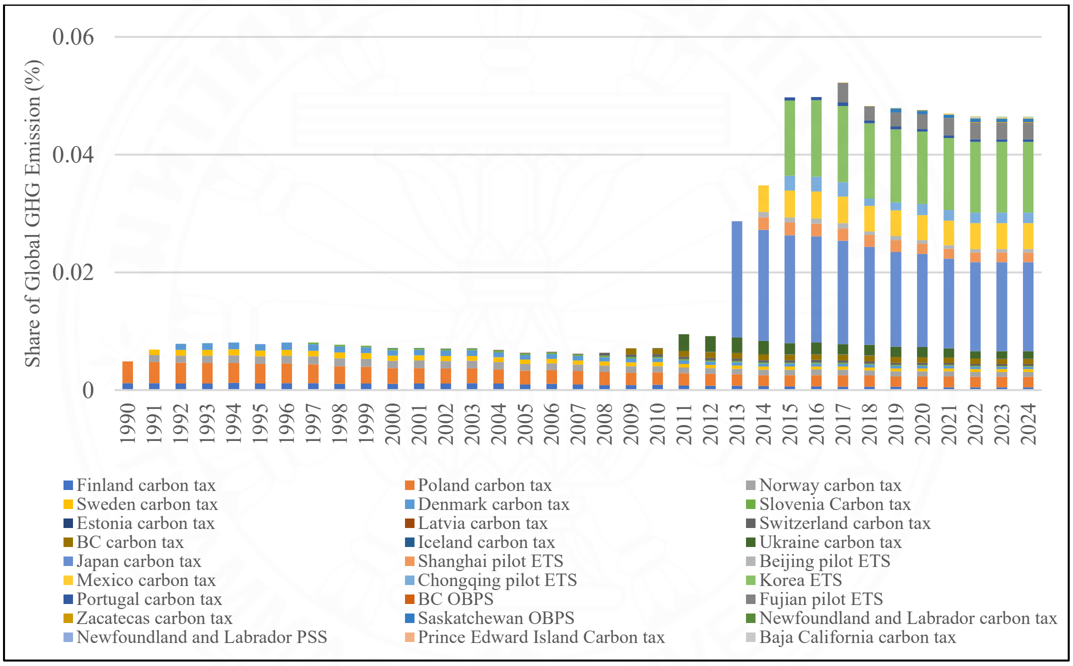
CHAPTER 2
REVIEW OF LITERATURE

2.1 Overview of Carbon Tax

2.1.1 The Situation of Carbon Tax Implementation

Figure 2.1

Share of Global Emission Covered at National Level of Carbon Taxation, 1990-2024



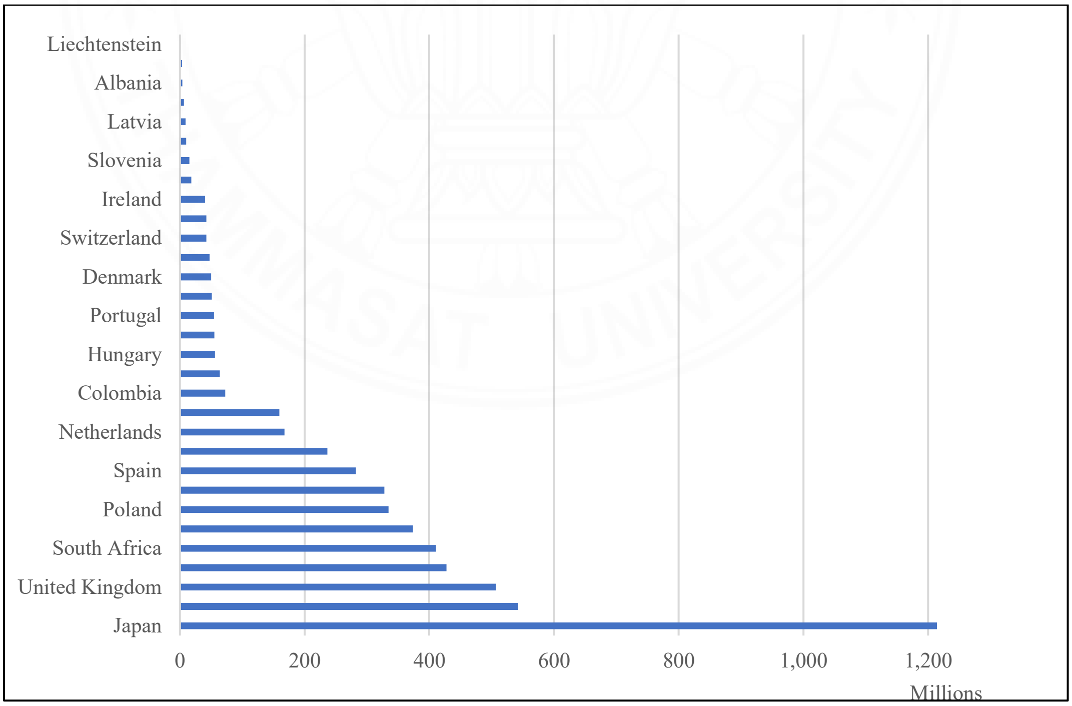
Note. From World Bank, 2024, (https://carbonpricingdashboard.worldbank.org/about#download-data) and author's calculation.

As mentioned earlier about the carbon taxation, Nordic countries are the first implementor as role model of European countries. According to data carbon pricing dashboard from World Bank, Figure 2.1, in the 1990, Finland is the world first implementor of carbon tax, followed by Poland that hold more covered share of global emission which together can covered approximately around 0.005% of the global emission. The period from 1990 until 2004, shows a slow growth of carbon tax implementation where only a few countries such as Finland, Poland, Norway, Sweden, and Denmark. After that in the period between 2005 to 2012, the number of countries adopting carbon taxes slowly increased where countries like Iceland and Switzerland began to join but the share of global emission was still limited.

Although, the significant expansion started in next period during 2013 to 2016 where the new comers like Japan, Mexico, and various Canadian Province have introduced carbon tax that is the reason of reaching around 4-5% of global emission covered in 2016. The current period between 2017 until 2024 hold the peaked period of reaching 5-6% with the additional jurisdictions like South Africa, Colombia, and Taiwan in 2017. But after 2018, the share of emission stabilized and contributed a slight fluctuation in the global coverage which reflects that there might be few countries left to implement similar policies other than carbon tax.

Figure 2.2

The Average Annual Carbon Emissions in Countries with Implemented Carbon Tax Policies, 1990-2022.



Note. From World Bank, 2024, (https://data.worldbank.org/indicator/EN.ATM.CO2E.KT) and author's calculation.

Along with Figure 2.2 and supported data from World Bank's Carbon Pricing Dashboard, this also support the previous part where we can see that Japan, Canada, and Mexico as the top polluter among the countries with implemented carbon tax that hold high share of jurisdiction emissions covered around 80%, so that when they joined, the global emission coverage significantly increased. On the other hand, in the case of Finland, Poland, Norway, and Sweden that have lower carbon emission and lower jurisdiction emission share, they have a slow growth in the first period.

For more detail for price rate classification, we can divide them into 2 groups of single prices and multiple prices. Whereas single price hold proportion of 78% among countries with implemented carbon tax which led by Denmark who is the only one among the Nordic countries who used this approach for carbon taxation, started in 1992. While another 22% of multiple pricing are among Nordic countries who are the models for carbon taxation around the world which started in the 1990s and led by Finland, Sweden, and Norway, respectively. Their multiple prices collected among the inputs, material, and activities such as transport fuels, heating fuels, waste incineration, petroleum industry, LPG and natural gas used in greenhouses, jet fuel, and coal.

Normally, carbon taxation has been collected from high-income countries due to their historically emitted more carbon dioxide as account of their earlier and more intense industrialization, high energy consumption, and consumer lifestyles which these are the key part of the debate on climate justice where it required a call upon responsibility for mitigating climate change. Other than global pressure in meeting targets as a part of international commitments, high-income countries have a stronger environmental movement, higher level of public awareness about the climate change, more ability to shift technological and infrastructural resources to greener alternatives.

In terms of emission coverage, different countries have different levels of jurisdictional coverage where the variety of fuels taxed suggests a broad approach to reducing carbon emissions and targeting multiple energy sources. There are only few countries that has covered share of jurisdiction emissions higher than 65% which are Japan, Singapore, Taiwan, Norway, Liechtenstein, Luxembourg, Albania, British Columbia, Northwest Territories, and South Africa which are from both high-and upper-middle income countries. On the average, the upper-middle income countries have higher share of jurisdiction emission coverage than the high-income countries.

2.1.2 Effects of Carbon Taxation

The implementation of carbon is to price the carbon where it creates a cost to the whole economy which numerous studies illustrated the related effects for post-carbon tax period can be investigated into mainly 4 aspects which are environmental effectiveness, macroeconomic effects, trade competitiveness and innovation, and income distributional implications.

Firstly, the environmental effectiveness pointed out that carbon taxes can reduce carbon emission though their effectiveness varies by region and sector, and achieving significant reductions to meet international targets remains challenging due to low tax rates and frequent exemption, (Köppl & Schratzenstaller, 2022). Another paper also in line as the result show a positive correlation between environmental protection and environmental quality, but conversely, a negative correlation with economic growth. The implementation of a carbon tax can increase production costs, leading to clear downward trends in output, capital, investment, and consumption. This pressure forces enterprises to reduce their desired investment and physical capital accumulation, while lower wages reduce household income and, consequently, consumption., (Tu et al., 2022).

Moreover, the implementation of a carbon tax significantly impacts macroeconomic indicators, particularly the labor markets of high carbon-intensive industries, light industries, construction, and advanced manufacturing, (Chua & She, 2023). Revenue recycling has been discussed as a strategy to mitigate the potential adverse economic effects of carbon pricing, which should be considered alongside sectoral composition and the strength of pass-through effects, (Känzig & Konradt, 2023). Regarding public acceptance, one study highlighted the importance of addressing pessimistic beliefs about tax collection, as aversion to the carbon tax can exacerbate output losses, (Frankowski et al., 2024).

Third, in terms of productivity and innovation, carbon pricing has a small and positive effect but most of these assessments find no statistically significant carbon pricing on competitiveness. However, when there has been found statistically significant relation between them, the magnitude of such effect is small, (Venmans et al., 2020). In some cases, mitigating the competition effects of the carbon tax can be potentially reduced by allowing the firm to adjust their energy efficiency levels, (Dorsey-Palmateer & Niu, 2020). In boarder view, the effects of carbon tax imposed on the import product can cause a reduction in trade welfare in terms of real income and carbon leakage due to the unilateral measure in the international trade while carbon emissions are shifted as expected from countries with low carbon taxes to the country with high carbon taxes, (Larch & Wanner, 2014).

Lastly, since carbon tax implementation has driven up the costs of energy and other goods, there is also a concern on their negative effects on low-income households and income inequality. Most of the evidences show a regressive effect of carbon tax in both urban and rural areas where the increase in price cause more effects in rural area more than the urban areas, which they further highlighted the possibility of having double-dividend hypothesis if the government can diminish the regressive effects of carbon by tax revenue redistribution where there should be focused on adjusting consumption structures and narrowing the income gap by recycling the revenues through lump-sum transfer or individual income tax return to low-income household in order to reduce the distortions in the economy and enhance the redistributive effects of individual income taxes, ((Rausch et al., 2011) ; (Guo et al., 2022); (Antosiewicz et al., 2022) ; (Zhao et al., 2022)). However, in few cases, there is also possibility of having progressive effects of carbon pricing on income distribution and heterogenous effect on the income of rural and urban workers as the middle- and high-income labors have higher income loss in case of urban areas, while the low-income labors in rural areas have experienced a greater income loss, (Zhang et al., 2023). Apart from the narrowing the income gap, there is another aspect of analyzing the relationship between carbon pricing and income inequality which they found that the high-income countries have significant progress effects of the relationship between revenue recycling and income inequality whereas it indicates that it could help reducing income inequality while it tends to be a regressive in the cases of middle- and low-income countries, (Nguyen & Song, 2021).

2.2 Related Theory

To address the negative externality of carbon emissions, a carbon tax is not the only approach used. There are a variety of tools implemented, which can be broadly categorized into two main groups: market-based mechanisms and non-market-based approaches.

2.2.1 Market-based Mechanism

The market-based mechanisms are widely accepted and often view as one of the most effective and flexible approaches to address the negative externalities of carbon emission. Additionally, it benefits the revenue generation that can be used for further environmental projects, offsetting social impact, and reducing other taxes, together with gaining global acceptance as it can be integrated into a wide variety of political and economic system. Under this mechanism hold both direct pricing mechanism and other market-driven approaches as followed.

There are two major carbon pricing instruments based on market mechanisms which are carbon taxes and emissions trading. Carbon tax gets widely accepted for emission reduction and has been mostly discussed in terms of empirical effects on environmental effectiveness, macroeconomic effects, impacts on competitiveness and innovation, and income distributional implication where they will further discuss on the revenue recycling and its possibility of double dividend hypothesis, (Köppl & Schratzenstaller, 2022). In the recent period, there are two issues brought into attention which first is the comparison of carbon tax with other policy instruments such as tradable permits, R&D investment, and subsidies to clean technologies; and second issue on the distributional impacts of carbon taxes by household income level, (Timilsina, 2022).

Cap-and-trade system or carbon credit trading in term of environmental and economic performance, they have generally led to emission reduction and cost saving but at a varying degree of economic success due to uncontrolled external factors like market conditions and regulatory decisions, (Schmalensee & Stavins, 2017). The evaluation of research in this field related to carbon trading has shifted their focus from the design of carbon-trading schemes to carbon pricing and lastly passed through a deeper analysis of the interaction between carbon-trading schemes and the economy which emphasizing coordinated development, (Shen et al., 2020).

Additionally, there are other market-based instruments, such as tax incentives for carbon capture and storage (CCS), subsidies for clean technologies, renewable energy certificates (RECs), and carbon offset markets. Tax incentives, in the form of tax credits, directly reduce the amount of tax a company owes. CCS primarily focuses on capturing CO_2 emissions from industrial processes and power plants, addressing regional pressure dissipation, (Hawez & Asim, 2024) , and selecting the suitable CO_2 injection strategies to maximize carbon storage efficiency, (Eyitayo et al., 2024). Overall, the use of CCS has minimal environmental and climate impact, (Suditu et al., 2024).

Subsidies for clean technologies are funded through carbon tax revenues, aimed at promoting innovation and research. However, empirical evidence suggests that green production subsidies can be ineffective, as they may reduce the incentive for innovation, (Barrett, 2021). Regarding technological spillover, while increased subsidies may reduce emissions, the environmental efficiency of subsidies decreases as their intensity rises, (Yang & Nie, 2022). This is further supported by another study, which shows that government subsidy policies cannot guarantee green technology investment or total carbon emission reduction. The outcome depends on factors such as the cost of green investments, the emission reduction rate of green technologies, and the carbon intensity of manufacturers, (Li et al., 2021). Additionally, subsidies can act as a cue to encourage action, but they are less likely to fully eliminate financial barriers, (Valkengoed & Werff, 2022).

Renewable energy certificates (RECs) play a role in accounting for GHG emissions by serving as a report of emission reductions. However, the widespread use of RECs by companies has led to an overestimation of the effectiveness of their mitigation efforts, and they are still unlikely to align with the 1.5-degree Celsius goal, (Bjørn et al., 2022). In terms of emission reduction effectiveness, RECs show a positive correlation with GHG emission reduction, which is also linked to a decrease in temperature anomalies, (Abidi & Nsaibi, 2024).

Lastly, the voluntary carbon offset market aims to deploy technologies at the lowest abatement cost. However, in some regions, a significant increase in forestry carbon credits issued suggests ineffectiveness due to poor governance and questionable outcomes in terms of actual carbon reduction, (Fujii et al., 2024). In the case of a three-year panel study of the airline industry, no changes in credit ratings were observed, but the effect of social norms in encouraging aviation offsets grew stronger over time, (Ritchie et al., 2019).

However, the market-based mechanisms faced some challenges and limitations due to political acceptability as concerning on the increased costs for consumer, economic competitiveness, and potential job losses in carbon-intensive industries, the equity concerns for low-income households or vulnerable sectors, hardship of volatility for planning long-term investments, and lastly the uncoordinated market-based policies can lead to carbon leakage or disparities in economic impacts across countries.

2.2.2 Alternative Approaches

While market-based mechanisms are highly effective and widely accepted, there are also non-market mechanisms that complement or address specific limitations of market-based solutions. These tools are tailored to the particular economic, political, and social context. Examples include command-and-control regulations, subsidies and incentives for low-carbon technologies, and corporate social responsibility (CSR).

The command-and-control approach is a regulatory strategy that involves setting standards, enforcing penalties, and monitoring compliance. This approach requires strong regulatory competence, but it also encourages creative solutions and allows companies to align pollution control efforts with productive investments, (Bergquist et al., 2013). However, the regulatory response can vary depending on factors such as the integration of environmental strategies and communication within the supply chain, (Junquera & Del Brío, 2016).

The relationship between subsidies and low-carbon technology investment shows that factors such as the carbon tax rate, carbon trading price, cost subsidies, and product subsidy rates play a crucial role in investment decisions. Product subsidies tend to have a greater impact than cost subsidies, (Liu & Sun, 2023). Another study also found that investment strategies vary depending on pricing decisions, profit margins for ports and shipping companies, and overall investment levels, (Li et al., 2024). From a societal and consumer perspective, increasing incentives for green technology innovation through a hybrid policy of carbon taxes and subsidies leads to the highest social welfare, (Xia et al., 2024).

Lastly, corporate social responsibility (CSR) plays a role in enterprises' annual carbon emission reduction reporting. The results indicate significant potential for reducing CO2 emissions, (Kuzior et al., 2022). CSR also improves a firm’s social responsibility and helps mitigate its carbon footprint. In this context, CSR governance tends to prioritize social issues over environmental ones, (Saeed et al., 2021).

2.3 Overview of Computable General Equilibrium (CGE) Models

2.3.1 CGE Model Overview

The foundation of computable general equilibrium (CGE) models can be traced back to the work of Léon Walras, who developed the concept of general equilibrium in the early 20th century. This concept illustrates the interconnection between markets for goods, labor, and capital. As noted by Devarajan and Robinson (2013), the first CGE model was developed by Leif Johansen in 1960, which was employed for policy analysis and later applied to areas such as public finance, international trade, and environmental policy, as highlighted in the works of Shoven and Whalley (1972) and Jorgenson (1984). In developing countries, parallel analytical paths emerged using input-output and programming models, which were precursors to CGE models, all grounded in the core principles of neoclassical general equilibrium theory.

However, in the realms of policy analysis, the credibility, applicability, and realism of economic models are frequently debated. Particular concerns arise regarding the theoretical treatment of foreign trade, where foreign goods are considered imperfect substitutes for domestic products, and the role of exchange rates in CGE models. This critique stems from the fact that Walrasian general equilibrium model determines only relative prices, leaving no role for a financial exchange rate.

Furthermore, dynamic CGE models were developed in the late twentieth century, and these models have since gained widespread use by international organizations such as the World Bank, IMF, and OECD. They are employed to assess the impacts of trade policies, structural adjustments, environmental policies, and fiscal reforms, providing valuable insights into global economic policy. These models help shape understanding of economic growth, income distribution, and environmental sustainability.

2.3.2 CGE for Climate Change

The primary objective of conducting a computable general equilibrium (CGE) analysis in the context of economic, environmental, and climate change impacts is to evaluate how various policies or external shocks influence the entire economy, considering the interactions between different sectors and agents. Research in this field typically focuses on the economic consequences of climate change and the analysis of climate-related policies, such as carbon pricing, emission reduction measures, or the adoption of renewable energy, and their effects on economic performance, sectoral output, and income distribution.

The economic impacts of climate change are particularly evident in global GDP losses, with significant sectoral and regional variations. Agricultural sectors tend to bear the brunt of these effects in most regions, while damages from rising sea levels are expected to increase over time, (Bosello et al., 2012). When categorized by income groups, developing countries, especially in Africa, Asia, and Latin America, are projected to experience more dramatic declines in agricultural production and income due to climate change compared to high-income or advanced economies. For instance, Africa is expected to suffer the most severe income and production losses, with low-income households experiencing a significant drop in consumption, (Winters et al., 1998).

Several studies have also examined the effects of climate policies on economic performance, comparing the effectiveness of market-based tools. For example, a cap-and-trade regime has been shown to alter the transmission of growth shocks between regions, while a carbon tax facilitates substantial emission reductions at relatively low economic cost, with varying effects on economic performance and income distribution across sectors, (McKibbin et al., 2008). However, in term of accounting for climate change feedback from these policy tools, global emissions of greenhouse gases have been only slightly reduced. Additionally, climate change is expected to exacerbate inequalities and hinder income convergence globally, with some regions experiencing losses while others may gain, ultimately leading to divergent growth paths, (Eboli et al., 2010).

2.3.3 CGE for Carbon Tax and Revenue Recycling Strategies

To evaluate the effects of carbon taxation, Computable General Equilibrium (CGE) models are among the most widely utilized tools for analyzing the economic impact of carbon tax policies. These models are frequently employed to investigate how such policies affect key economic variables, with particular emphasis on employment, efficiency, and the redistribution of tax revenues.

As demonstrated in Table 2.1, different studies apply various forms of CGE model; such as static, dynamic, and multi-sector models, depending on the particular focus of the research. The primary factors of production typically include labor and capital, with some models incorporating land or sector-specific energy resources. Most models utilize constant elasticity of substitution (CES) production functions, with some adopting nested structures to capture more complex sectoral interactions.

With regard to revenue recycling, its role varies significantly across models. The recycling methods range from lump-sum transfers to households, tax reductions, or debt reduction, each applied through simulations based on specific policy scenarios.

Table 2.1

The Key Feature of CGE Model for Carbon Tax

Author (Year)	Purpose	Model	Primary Factors	Production function	Revenue-Recycling Roles
McKitrick (1997)	Examine the revenue-recycling of carbon tax	Static CGE model	Capital, labor	CES	Lump-sum transfer to household, goods and service tax reduction, corporate income tax reduction, personal income tax reduction, payroll tax reduction
Böhringer et al. (2000)	Assess whether integrating environmental tax reform with joint implementation (JI) yields greater employment and efficiency gains compared to standalone environmental tax reform (ETR).	Comparative-static multi-sector model	Capital, Labor, Sector-specific resource	Nested CES	Revenue-neutral way to lower labor costs
Meng (2012)	Simulates the effects of Australian carbon tax on the resources sectors	Static CGE model based on ORANI-G	Capital, labor, land and natural resources, and energy bundle	5-layer nested Leontief-CES function	Transferred in lump sum to the six poorest household
Tuladhar et al. (2015)	Compares the effects of using revenues from a carbon tax to either reduce the national debt or reduce federal personal or corporate income	Forward-looking dynamic CGE model	Capital, labor	CES	Lump sum revenue recycling, reduction in personal income tax, reduction in the Federal Debt
Mengistu et al. (2019)	Analyze various policy scenarios for a carbon tax on greenhouse gas emissions from petroleum fuels and kerosene in Ethiopia	Recursive dynamic CGE model	Capital, labor	CES, goods and services, imports, labor, land, capital	Through a uniform sales tax reduction, reduction of labor income tax, reduction of business income tax, direct transfer back to households, use by government to reduce debt
Jia et al. (2023)	Explore the validity of this assertion and proposes alternative approaches to enhance the efficiency of carbon tax without revenue recycling	Recursive dynamic CGE model	Capital, labor	CES	No revenue-recycling

Note. From the Author's compilation

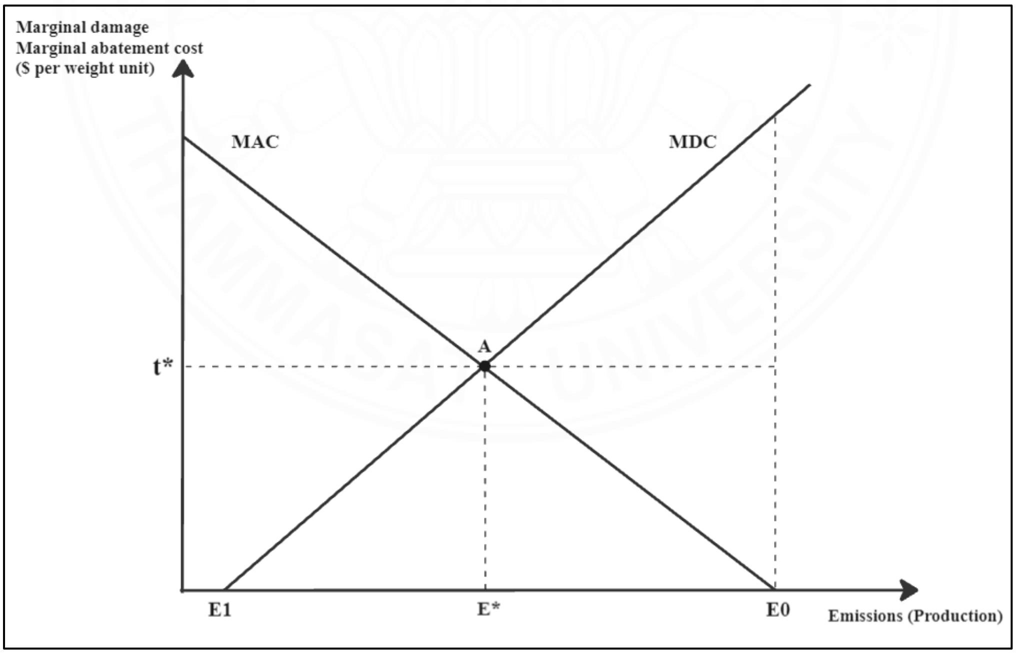
CHAPTER 3
THEORY AND RESEARCH METHODOLOGY

3.1 Carbon Tax Theory

Greenhouse emissions generate negative externalities for society and the environment. Without proper adjustment, the market price does not accurately reflect the social costs because producers and consumers consider only the private costs and ignore the external costs. Then, Pigou (1920), an economist who invented the "Pigouvian tax," proposed pollution taxes to internalize the negative externalities of carbon emissions, which later developed into a carbon tax representing tax calculations based on the amount of carbon emissions in each fossil fuel.

Figure 3.1

Carbon Tax and Emissions



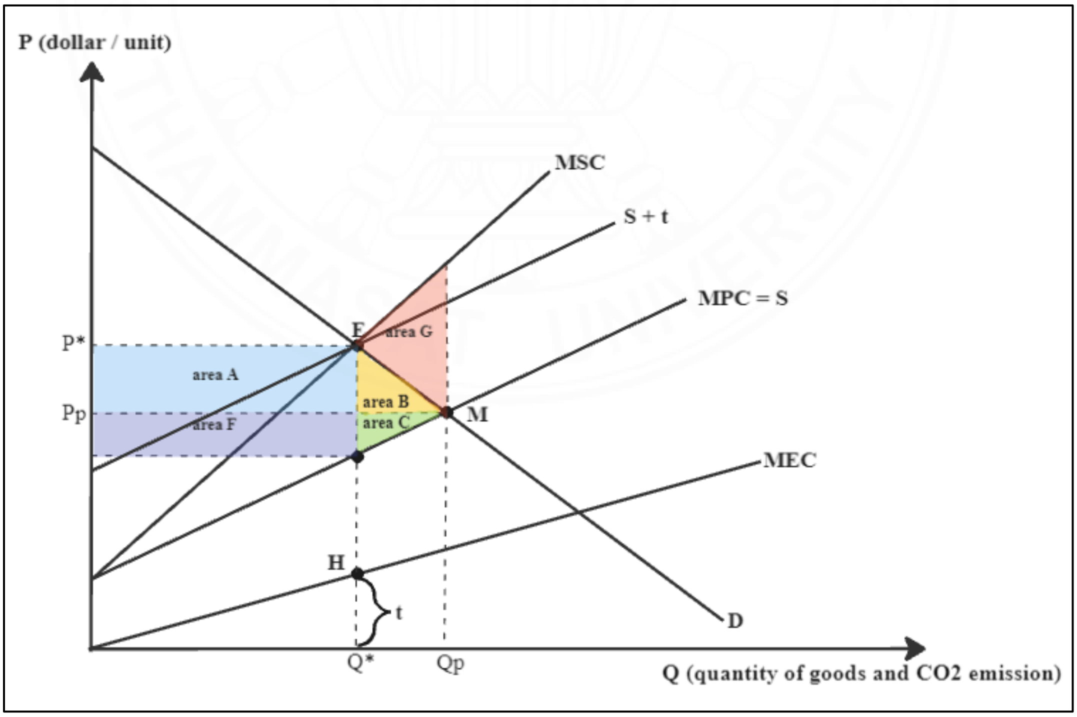
Note. Adapted from *Carbon Pricing: A Development and Trade Reality Check*, Edited by United Nations Conference on Trade and Development (UNCTD), 2022 (Original work Baumol and Oates, 1988).

According to material provided by UNCTAD (2022),based on economic theory, the optimal carbon tax can achieve a Pareto optimal outcome when the marginal abatement cost (MAC) equals the marginal damage cost (MDC), as illustrated in Figure 3.1. The MAC represents the economic cost of implementing measures to reduce emissions, while the social cost of carbon (SCC) is factored into decision-making. The SCC assigns a price to the negative externalities associated with carbon emissions. The MDC, on the other hand, reflects the additional economic damage or social cost caused by each incremental increase in emissions.

For each emission level (E), reducing emissions from E_0 to E_1 represents both higher abatement costs and lower social damage in terms of economic costs. When these costs converge at point A, it indicates that resources are being utilized efficiently to mitigate climate change, achieving a balance between the cost of emission reductions and the benefits of avoided damage.

Figure 3.2

Carbon Tax for Solving Market Failure.



Note. Adapted from *Carbon Pricing: A Development and Trade Reality Check*, Edited by United Nations Conference on Trade and Development (UNCTD), 2022 (Original work Pethig (1976) and Naegele & Zaklan (2019)).

Figure 3.2 explains how the government collects carbon tax to address market failure. So, starting at point M, which depicts the market equilibrium of both production and consumption in the absence of market failure, represented by the intersection of the demand (D) and supply curve (MPC=S), the market will produce output for Qp units at the price Pp. In order to account for the social cost as the negative externality from carbon emissions, we assume that 1 unit of output generates 1 unit of emission, and since the supply curve does not include the external cost as shown in the Marginal External Cost (MEC) curve. Therefore, the market equilibrium at point M does not reflect the marginal social cost.

If we include the external cost in consideration, the appropriate production cost of society should be represented as the Marginal Social Cost (MSC) curve, which is calculated from the summation of the supply curve (MPC) and the Marginal External Cost (MEC). Then, the appropriate market equilibrium will be adjusted to point E, where D = MSC. The producer will produce output for Q* units, which is less than Qp, and at a price of P*, which is higher than Pp. However, the appropriate quantity and price cannot be adjusted through the market mechanism alone; it requires government intervention to collect tax from the additional unit of external cost of production at Q*. Therefore, the government will collect tax for the area Q*H, represented as "t." The shift in the supply curve from S to S+t leads us to have a new market equilibrium at point E.

Collecting tax of t dollars per unit causes a decline in consumer welfare, as consumers can consume less at a higher price. This reduction in consumer welfare reflects a lower consumer surplus. Simultaneously, for producers, the net price after tax and the quantity of output will decrease, leading to a reduction in producer surplus. Together, the external costs will decrease due to the reduction in production and carbon emissions. This carbon tax increases government revenue. Therefore, the change in social welfare can be summarized as follows:

Change in consumer surplus = area A + B

Change in producer surplus = area F + C

Government revenue = area A + F

Change in external cost = area B + C + G

Change in welfare = G

In general, collecting tax from production creates distortions that cause negative externalities to society and lead to deadweight losses, which in this case equals the area B + C, as consumers can consume less at a higher price and producers can produce output and charge a price lower than in the case with no tax. Since the production of output releases carbon emissions that create negative externalities for society, a reduction in consumption and production will help reduce carbon emissions and the external cost, equaling area B + C + G, which has more value compared to the social deadweight losses (B + C). Therefore, the net social welfare of having a carbon tax will equal area G.

So, we can conclude that collecting carbon tax at the appropriate level might cause a decrease in consumer and producer welfare, but this will increase social welfare due to compensation from the government that earns higher revenue and a larger reduction in externality.

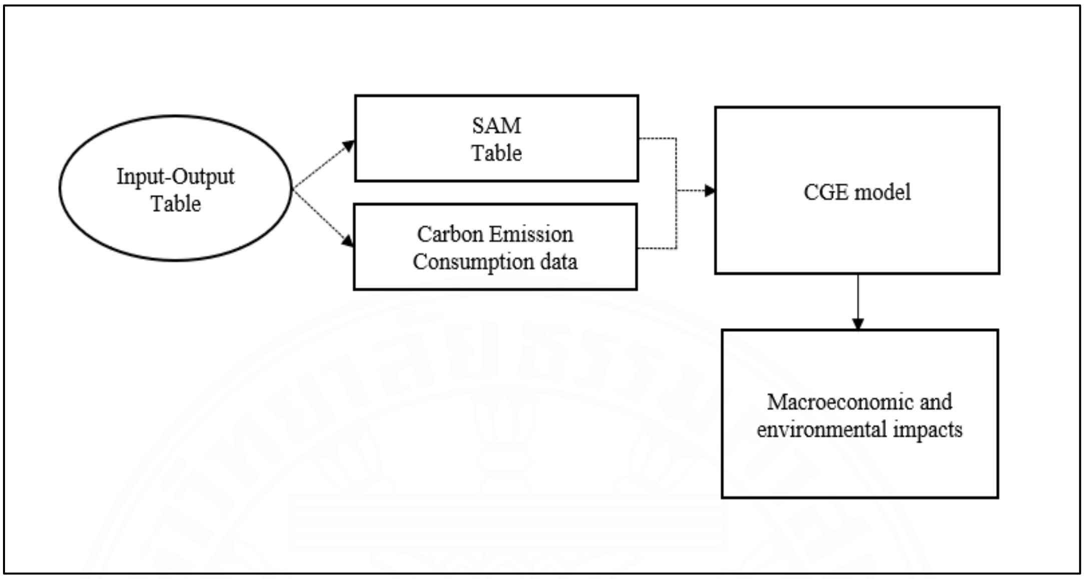
However, applying this partial equilibrium of carbon theory to the CGE model, there is the need to use the consumption of Walras's general equilibrium theory. Once the market is clear for at least one market the least of the market will be adjusted to the equilibrium.

3.2 Overview of the Methodology

The framework of this study outlines the analytical approach, as depicted in Figure 3.3. Initially, the primary data for analysis consists of input-output data, which is used to calculate the emissions and consumption for each economic sector. This data then serves as input for the Social Accounting Matrix (SAM) analysis. Next, the SAM data is integrated into the Computable General Equilibrium (CGE) model to simulate economy-wide impacts, with the GAMs program serving as the primary analytical tool. Finally, the simulation results across various scenarios are used to assess societal impacts and explore revenue recycling options.

Figure 3.3

The Framework of the Study



Note. From the author's compilation

3.3 Database

The data used in this study consists of two main parts as follows.

3.3.1 Carbon Emission Data

In this model, carbon emission data is derived using emission factors combined with external data on emissions from energy use provided by the Ministry of Energy. The emission factors are applied to the sectoral output quantities calculated by the CGE model, to Section 4.1.

3.3.2 The Structural of Social Accounting Matrix

The National SAM table was developed from Input-Output table of 2010, published by National Economic and Social Development Council (NESDC). The SAM table is prepared according to Phomsoda et al. (2021). This SAM is the main source of data, including 40 production activities, 49 commodities, the aggregate household, government, and the rest of the world, as exhibited in Appendix A.

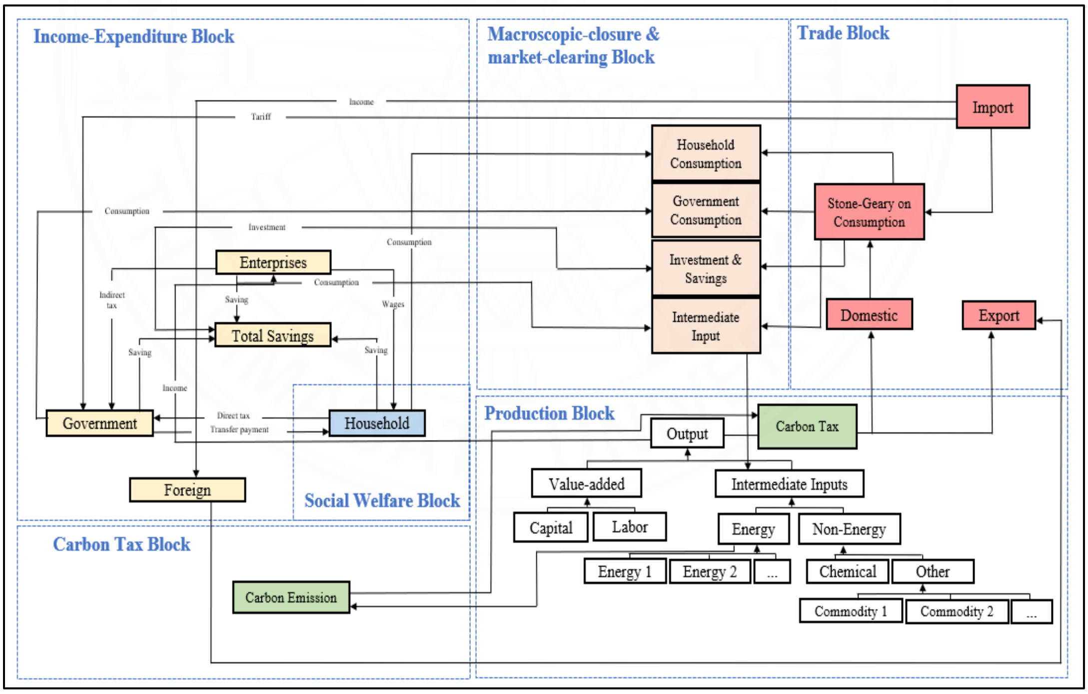
3.4 The Computable General Equilibrium (CGE) Model

3.4.1 Overview of CGE Model

The CGE model structure is based on PEP standard model 1-t, version 2.0 developed by members of Partnership for Economic Policy (PEP) research network, (Decaluwé et al., 2013). This version used in this study was revised in 2012. This PEP-1-t model is a recursive dynamic model that embedded the capital accumulation and economic mechanism into CGE model which enables adjustment of price and quantity of goods and input factor, and also allows simulations for both medium-term and long-term. The basic framework of CGE model is shown in Figure 3.4, shows the interaction mechanism exist in the model.

Figure 3.4

The Basic Framework of CGE Model



Note. Adapted from *Assessing the Impacts of Carbon Tax and Improved Energy Efficiency on the Construction Industry: Based on CGE Model*, by Du et al. (2022) and *Assessing Economic Impacts of Thailand's Fiscal Reallocation between Biofuel Subsidy and Transportation Investment: Application of Recursive Dynamic General Equilibrium Model*, by Phomsoda et al. (2021).

The mechanism and assumptions of the model are as follows Puttanapong et al. (2015), where each production sector is assumed to produce a single product, operating under the conditions of constant returns to scale and perfect competition. Producers aim to maximize their profits, driving their production behavior. Households, as representatives of consumers, seek to maximize their utility subject to budget constraints, earning income from their contributions to the factors of production. Their consumption behavior assumes a combination of both domestic and imported goods, and certain households receive transfers from the government.

The institutions in the model comprise five groups of households, firms, the government, and the rest of the world. Some household categories are subject to income tax and allocate portions of their income to savings. The government collects both direct and indirect taxes, and policy-related variables such as government revenue, interest rates, and subsidies are treated as exogenous within the model's equations.

All markets for goods and services are assumed to clear, with prices serving as equilibrating variables. Market equilibrium is characterized by several conditions: (a) aggregate demand for goods equals aggregate supply, (b) aggregate investment equals aggregate savings, (c) supply and demand for both labor and land are balanced, (d) no remaining income after tax is left unallocated, (e) government budgets are balanced, and (f) trade surpluses or deficits are adjusted by net inflows of foreign capital.

Finally, the model accounts for non-linear behavior in the frictional substitution mechanism between domestic and export products, as well as between domestic and imported goods. The behavior of imports and exports is derived from CES and constant elasticity of transformation (CET) equations, respectively. For more detail on economic impact mechanism, please see Appendix B.

3.4.2 The Structure of CGE Model

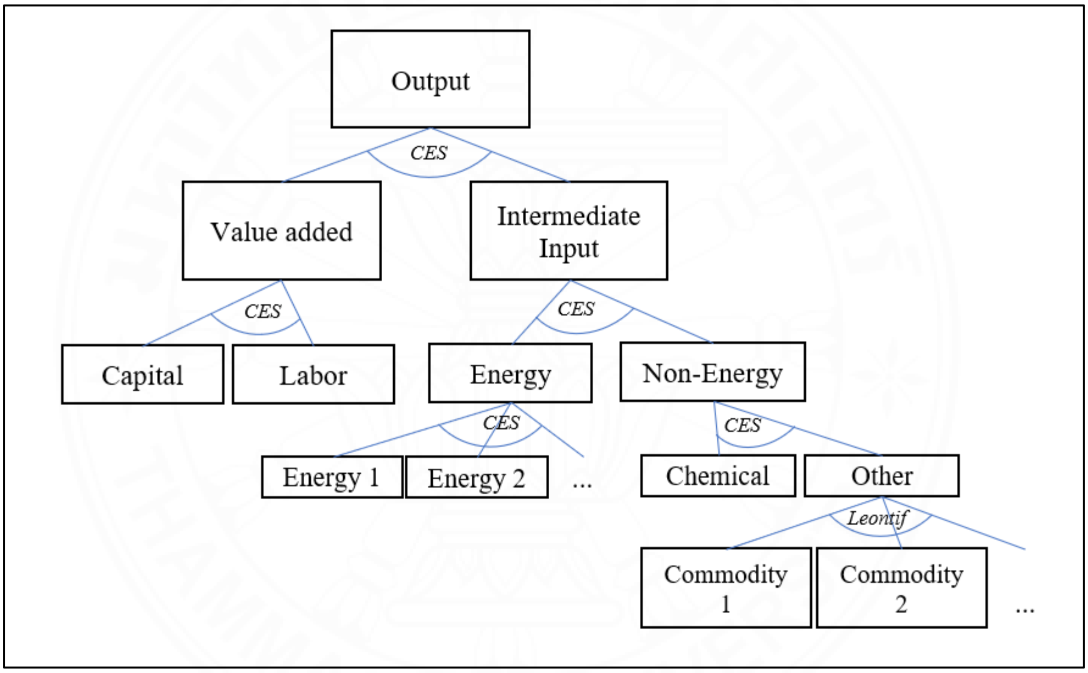
The structure of the CGE model can describe the transmission of effects with equations. These equations are illustrated in detail in Appendix C. The composition of the CGE model is divided into nine groups as follows.

3.4.2.1 Production Block

Under the assumption mentioned in the previous section, the firm operates in a perfectly competitive market. Producers in each sector maximize their profits based on their production technology, considering product and service prices alongside other relevant factors. The nested structure of the CGE model is illustrated in Figure 3.5.

Figure 3.5

The Nested Structural Production in CGE Model



Note. Adapted from *Assessing Economic Impacts of Thailand's Fiscal Reallocation between Biofuel Subsidy and Transportation Investment: Application of Recursive Dynamic General Equilibrium Model*, by Phomsoda et al. (2021).

The entire production function is divided into four layers, with output represented by multiple nested CES and Leontief functions. At the highest level, total output is composed of value-added and intermediate inputs. The second level is divided into two parts: the first part combines capital and labor into a bundle, while the second part represents intermediate inputs of energy and non-energy, both modeled through CES functions. The third level details the composition of energy as a bundle of composite energy elements, while non-energy inputs consist of chemicals and other components, also modeled using CES functions. The final level illustrates the use of energy and non-energy inputs for each commodity through Leontief functions. For example, at the top level, the CES function is applied to integrate value-added and intermediate inputs into the output, as shown in equation 3.1.

$$XST_{j,t} = B_j^{XST}[\beta_j^{XST} VA_{j,t}^{-\rho_j^{XST}} + (1-\beta_j^{XST}) CI_{j,t}^{-\rho_j^{XST}}]^{-\frac{1}{\rho_j^{XST}}} \qquad (3.1)$$

Where $XST_{j,t}$ is the gross output of industry j, $CI_{j,t}$ is the intermediate input usage of industry j, and $VA_{j,t}$ is the value-added of industry j, while B_j^{XST}, β_j^{XST}, and ρ_j^{XST} are the scale parameter, share parameter, and elasticity parameter of aggregate output, respectively. Together with equation C.2, it shows that value-added of industry j is calculated based on the scale proportion to the intermediate input with respect to their price index of value-added and the intermediate consumption of industry j. Furthermore, equation C.3 represents the resource allocation of capital and labor of firm along with the CES function to embed the value of value-added of industry j with respect to demand for capital and labor of industry j, which linked to equation C.4 that determine the primary production sector of demand for capital and labor according to rental rate of capital, wage rate, and the elasticity of transformation.

On the side of intermediate inputs, the demand for both energy and non-energy products is determined by the CES technology function. This reflects the assumption of constant elasticity of substitution through Extended-A and Extended-B, which illustrate the industry's use of intermediate inputs in relation to the consumption of both energy and non-energy products. Additionally, Extended-C represents the demand for composite energy. Under the assumption of perfect competition and profit maximization, firms will choose the composite energy demand that maximizes their profits, as outlined in Extended-D. This section represents the simultaneous zero-profit condition, or the first-order condition of energy demand.

Similarly, the demand for non-energy products is also determined by the CES function, as represented in Extended-E and Extended-F. These account for the demand for chemical products and the demand for other non-energy products excluding chemicals. Furthermore, due to imperfect substitution among primary production factors, firms maximize their profits under the CES technology function, as shown in equations C.5 to C.8. Lastly, the demand for intermediate production factors is determined by the fixed coefficients of Leontief's technology, as illustrated in equation C.9, which represents the intermediate inputs for non-energy products, excluding chemical inputs.

3.4.2.2 Income and Saving Block

This mainly represents the income and saving behavior of three economic agents used in this model which are household, firm, and government.

(1) Household

Household income, in its broad dimension, is referred to as total income. This income is derived from capital, labor, and transfers, as represented in equation C.10. Specifically, income sources include the rental rate of capital, wages, and transfers received from other agents, as detailed in equations C.11 to C.13, respectively. Capital income is based on the share of capital income received by agents, while labor income is based on the share received by households.

Household behavior determines that disposable income, or income after taxes, is allocated for consumption according to a linear expenditure system. Any remaining income, after consumption, is saved, as shown in equations C.14 to C.16.

(2) Firm

In contrast, the income of firms or enterprises is calculated based on income after capital allocation and transfers to other economic sectors, as shown in equations C.17 to C.19. The total business income is the difference between capital income and transfer income. In terms of expenses or liabilities, firms are also required to pay income taxes to the government. Their savings depend on income after taxes, or disposable income, minus transfer income, as illustrated in equations C.20 and C.21.

(3) Government

Government income comprises tax revenue, which includes both direct and indirect taxes. Examples of direct taxes are personal income tax and business income tax. Indirect taxes include customs duties (tariffs collected on import-export products) and excise taxes. Equation C.22 represents the total government income as a summation of government capital income, revenue from household and business income tax, revenue from others tax on production, revenue from export tax on products and imports, and government transfer income, whereas these components can be extended in detail for each tax collection through equation C.23 to C.39.

This study focuses on the sales tax, which plays a central role, as the carbon tax will be implemented through this channel as a tax on products subject to excise tax. This is represented as government revenue from indirect taxes on products, as shown in equation 3.40:

$$TIC_{m,t} = tticm_{m,t}[\left(PL_{m,t} + \sum_i PC_{i,t}\, tmrg_{i,m}\right) DD_{m,t} + ((1 + ttim_{m,t}) PWM_{m,t} e_t + \sum_i PC_{i,t} tmrg_{i,m}) IM_{m,t}] \tag{3.40}$$

where $TIC_{m,t}$ represents government revenue from indirect taxes on domestic products ($DD_{m,t}$) and imported products ($IM_{m,t}$), adjusted by $ttic_{m,t}$, the tax rate on commodities. This equation reflects the government's indirect tax revenue before carbon tax collection. Once the carbon tax is implemented, equation 3.40 is transformed into equation 3.41:

$$TIC_{m,t} = \left(ttic_{m,t} + tco2_t ttico2_{m,t}\right)[\left(PL_{m,t} + \sum_i PC_{i,t}\, tmrg_{i,m}\right) DD_{m,t} + ((1 + ttim_{m,t}) PWM_{m,t} e_t + \sum_i PC_{i,t}\, tmrg_{i,m}) IM_{m,t}] \tag{3.41}$$

where $tco2_t$ (carbon tax rate in baht per ton) and $ttico2_{m,t}$ (carbon emitted per unit) are added into the indirect tax revenue. This adjustment represents a product tax based on the carbon emissions of each sector. Furthermore, taxes on imported and exported products are represented by equations C.41 and C.42, respectively. Lastly, government savings are the remaining amount of total government revenue after accounting for transfers and expenditures on goods and services, as shown in equation C.43. For more detail related on carbon tax please see Appendix D.

(4) Income from Others Sector

The current account balance for other sectors is represented by equations C.44 to C.46, which reflect the rest-of-the-world income and savings. Rest-of-the-world savings are calculated as the remainder of its income after accounting for the value of exported products and transfers.

(5) Transfer

In a CGE model, transfers between economic sectors—including households, government, businesses, and the rest of the world—are determined primarily by fixed external variables rather than behavioral equations, as shown in equations C.47 to C.51.

3.4.2.3 Aggregated Demand Block

The demand for goods and services includes household demand, investment demand, and intermediate demand. For households, it is assumed that there is a minimum level of consumption for each commodity, following the Stone-Geary utility function, as represented by equation C.52. Household demand is expressed as the multiplication of the purchase price of a composite commodity and the household's consumption budget, which reflects the household's total consumption expenditure. On the other side of the equation, it shows how households aim to minimize their consumption budget.

In the case of investment demand, or gross fixed capital formation (GFCF), equilibrium between total investment expenditures and savings is adjusted based on changes in inventory investment. Any shortfall in domestic investment is offset by foreign savings to maintain equilibrium, as represented in equation C.53. The final investment demand for both the private and public sectors is calculated through equations C.54 to C.56. Additionally, government demand for goods and services is represented by public consumption expenditures, as shown in equation C.57.

Lastly, the demand for intermediate products in the industry reflects the typical inter-industry relationships. This is illustrated through the total intermediate demand, as well as trade margins and transport services for commodities, as represented by equations C.58 and C.59, respectively.

3.4.2.4 Aggregated Supply and International Trade Block

The supply side concentrated on producer decision on their product management to serve the market both domestic and abroad whereas this model employed the CET technology that reflect the production allocation with constant elasticity of transformation, as shown in equation C.60. Producers aim to maximize their profit by choosing the optimal level of production, as determined by equation C.61. At equilibrium, production supply balances the allocation between domestic and international markets, as represented in equation C.62.

At the same time, the supply could be adjusted for the export market as well, along with managing the domestic production supply, as outlined in equation C.63. While, the world demand for export product is based on export level at the base year, adjusted according to the growth rate of demand for export demand, as shown in equation C.64.

For domestic-imported market, the quantity demanded for composite commodity is determined through equation C.65, using the CES technology. At the equilibrium, adjustments are made according to equation C.66 which considers the price of local product, price of imported product, and the elasticity of substitution between them.

3.4.2.5 Price Block

After the market adjusted for aggregate demand and aggregate supply, the price will also be adjusted accordingly whereas the different prices and price index depend on the hypotheses and functional form.

(1) Producer Price

In the case of producer prices, the price is defined as the weighted average of primary production costs per unit, based on the value-added of primary and intermediate production factors, as shown in equation C.67. The basic price of output is adjusted according to industry unit costs and production taxes, as represented in equation C.68. The intermediate consumption price for the industry is calculated as the weighted average of the purchase price of intermediate products relative to intermediate input usage, as shown in equation C.69. Similarly, the price of industry value-added is determined by the weighted average of total production costs related to the two primary factors, capital and labor, in relation to the industry's value-added, as per equation C.70. The wage rate and rental rate of capital are further adjusted through equations C.71 to C.74.

(2) Prices of Imported and Exported Goods

The basic price of exported products is derived from the weighted average of the total value of domestic and exported products relative to total gross output, as expressed in equations C.75 to C.77. For the domestic-import market, there are some distinctions: the price of domestic products is determined by the producer price, which maximizes profit after accounting for indirect taxes, while the price of imported products is based on the global price in Thai baht, including taxes and tariffs, as shown in equations C.78 and C.79. The composite price of domestic and imported products is then calculated as the weighted average of the total value of domestic and imported products relative to the quantity demanded for the composite commodity, as presented in equation C.80.

(3) Price Index

The price indices used in this model include the GDP deflator, consumer price index, public investment, private investment, and public expenditure. The model employs both the Fisher index and the Laspeyres index to adjust base-period quantities, allowing for a more accurate reflection of consumer behavior, as represented in equations C.81 to C.85.

3.4.2.6 Equilibrium Conditions Block

Equilibrium conditions exist in every market of production, with adjustments occurring in savings-investment, the labor market, and the capital market. The equilibrium quantity of composite goods demanded is derived from aggregate household consumption, public consumption, final investment demand, inventory changes, total intermediate demand, and trade margins and transport services, as represented in equation C.86. In the labor and capital markets, equilibrium is adjusted for supply, as shown in equations C.87 and C.88, respectively. Total investment expenditure is calculated as the sum of household savings, business savings, government savings, and rest-of-the-world savings, as shown in equation C.89. Private investment expenditure is determined by subtracting public investment expenditure and the value of inventory changes from total investment expenditure, as defined by equation C.90. The equilibrium for domestic and export markets is represented in equations C.91 and C.92.

3.4.2.7 Computation of GDP Block

From one perspective, GDP (Gross Domestic Product) at basic prices is the sum of value-added and indirect taxes on production, as shown in equation C.93. In contrast, GDP at market prices is determined by adding indirect taxes to GDP at basic prices, as presented in equation C.94. GDP at market prices, based on the income approach, is calculated by aggregating labor value, capital value, and government revenue from taxes on products, as identified by equation C.95. Using the expenditure approach, GDP at market prices is measured by revenue and final demand, known as gross domestic expenditure, as defined in equation C.96.

3.4.2.8 Capital Accumulation and Dynamic Growth

The dynamic growth of the Thai economy is shaped by capital accumulation, where the future outlook for investment in Thailand is critical, both in terms of overall trends and the capital intensity structure of each industry as they adjust according to capital allocation. Equation C.97 represents future demand for capital, which is derived from the sum of capital depreciation and new capital investment. New capital investment is divided into public and private sectors. Public investment is calculated as the product of the price of new public capital and the aggregate volume of new public capital, reflecting overall public sector investment, as shown in equation C.98. Similarly, private investment is determined by multiplying the price of new private capital by the aggregate volume of new capital in the business sector, as represented in equation C.99.

Balancing new capital accumulation in both the public and private sectors requires careful adjustment, with the policy interest rate being a key factor. This rate influences the cost of capital, and equations C.100 to C.104 outline the conditions for adjusting the price of new capital, the volume of new capital, and the cost of capital for both the public and private sectors.

3.4.2.9 Carbon Emissions by Industry Sector

(1) Carbon Emissions of Intermediate Demand and Final Demand

To account for carbon emissions from production factors, these can be divided into emissions from intermediate demand and those from final demand. Equation C.104 represents carbon emissions from intermediate products, calculated by multiplying the quantity of intermediate inputs by the carbon emissions per unit and dividing by the factor price of the intermediate product. This reflects the amount of carbon emissions each intermediate product generates. For final demand, carbon emissions are calculated by aggregating household consumption, public consumption, and final investment demand, multiplying by carbon emissions per unit, and dividing by the factor price, as outlined in equation C.105.

(2) Carbon Emissions of Agricultural Sector

This model focuses on emissions from paddy cultivation, livestock production, and fertilizer use, while emissions from land use, land-use change, and forestry (LULUCF) are excluded. The decision to omit LULUCF is due to its unique relevance to the economic policies of the NESDC. Instead, the model emphasizes carbon mitigation in sectors such as energy use, agriculture (economic crops and livestock), industry, and services. Equation C.106 represents emissions from the paddy and livestock sectors, calculated based on methane emissions from agriculture at the final output level. For fertilizer, emissions are determined by the chemical composition of the fertilizers used, as outlined in equation C.107.

(3) Carbon Emissions of Industrial Sector

In addition to emissions from fossil fuel combustion, the industrial sector also generates significant carbon emissions through its production processes. High emissions are particularly associated with the use of intermediate inputs such as cement, limestone, glass, and carbonates, as well as the production processes in the chemical industry, especially in cement manufacturing. Equation C.108 outlines the carbon emissions from intermediate commodities that release methane.

(4) Overall Carbon Emissions

The total carbon emission from using fossil fuel combustion for production process and the releases of emission from other activity can be presented by equation C.109. Lastly, the total carbon emission from all activity is defined, as shown in equation C.110.

3.4.3 Closure Rules

In general, the initial structure of CGE model has more variables than equations where there is the need to set exogenous and endogenous variables in order to obtain a unique solution and satisfy the Walras law. In some cases, the model needs to determine the closure rules by specifying the exogenous variables and requiring an equal number of endogenous variables and equations in the model. The closure choice depends on the objective of the modeling. This model specified current account, household minimum consumption, current government expenditure, capital investment, demand for capital, wage rate, world price of imported-exported products, inventory change, household saving, household transfer to government, business income tax, household income tax, tax rate on commodity, capital, import-export, production of industry, worker compensation, emission factor coefficient, and carbon tax, as exogenous variables. Furthermore, the exchange rate was set as numeraire to satisfy the relative price mechanism. At the same time, the calibration technique of generating the value of scale, share, and exponential parameters followed the conventional approach of the numerical computation process.

3.4.4 Scenarios

3.4.4.1 Carbon Tax Rate and Tax Base

According to the Royal Thai Government Gazette dated 28 March 2025, the Excise Department began collecting a carbon tax at a rate of 200 baht per ton of carbon dioxide equivalent, applied specifically to petroleum products such as gasoline, jet fuel, liquefied petroleum gas (LPG), diesel, and gasohol. However, in the original setting of the Computable General Equilibrium (CGE) model used in this study, emissions from energy use were calculated based on a broader tax base. This broader base includes additional fuels such as coal, natural gas, and biodiesel, which are not currently covered under the Excise Department's carbon tax policy.

Table 3.1

Details of the Fuels Included in Each Tax Base

Tax Base	Fuel Covered
All fuel base	Coal, natural gas, gasoline, jet fuel, LPG, diesel, fuel oil, gasohol, biodiesel
Liquid fuel base	Gasoline, jet fuel, LPG, diesel, fuel oil, gasohol
Gasoline base	Gasoline

Note. From the Author's compilation

To provide insights for future carbon tax policy design, this study maintains the 200-baht tax rate but examines three alternative tax base scenarios, as summarized in Table 3.1: (1) all fossil fuels (the original model base), (2) only liquid fuel base (aligned with the current Excise Department's base), and (3) only gasoline. These scenarios are implemented in the model as Simulations 1 to 3, as shown in Table 3.2. The all-fuels scenario reflects the potential for future expansion of the carbon tax base, while the gasoline-only scenario explores the implications of narrowing the scope to a minimal emissions base.

3.4.4.2 Role of Carbon Tax Revenue-Recycling

According to Carbon Tax Guide of World Bank, the use of carbon tax revenue can be categorized into two main strategies: revenue neutrality where the government budget remains unaffected and increased spending to support government initiatives, (Conway et al., 2017). In the case of revenue neutrality, revenues are either redistributed directly or offset by reductions in other taxes. Examples include redistributing revenue to low-income households or reducing taxes on labor, capital, and sales. On the other hand, increased government spending often supports climate-related initiatives, such as subsidies for renewable energy.

Table 3.2

All Simulations

Simulations	Detail
Based case	Imposing a carbon tax at 200 baht/tCO2e
Simulation 1	Imposing a carbon tax at 200 baht/tCO2e – All fossil fuels
Simulation 2	Imposing a carbon tax at 200 baht/tCO2e – Only liquid fuels
Simulation 3	Imposing a carbon tax at 200 baht/tCO2e – Only gasoline
Simulation 4	Direct government transfers to low-income households
Simulation 5	A reduction in household income taxes
Simulation 6	Increase government spending

Note. Author's elaboration

In more detail, according to Table 3.2, revenue-recycling strategies adopted in this paper are designed based on Conway et al. (2017), which outlines two main approaches: revenue neutrality and expanded spending. Under the revenue-neutral strategy, the core objective is to ensure that the government's overall budget remains unchanged, with carbon tax revenues directly offset by transfer in simulation 4 and income tax reduction in simulation 5. In contrast, the expanded spending approach allocates carbon tax revenues to increased government expenditures through the general budget, in line with a broader fiscal policy framework under simulation 6.

To evaluate the implications of these strategies, the three revenue-recycling options considered in this study are assessed through the lenses of equity and efficiency. Specifically, the first option—direct transfers to households—is examined in terms of equity, with two transfer schemes analyzed: regressive and progressive. This follows the framework proposed by Zhao et al. (2022), which helps determine the most appropriate transfer mechanism that maximizes benefits for low-income households. The selected transfer approach is then used as a benchmark to compare with the other two strategies in terms of efficiency outcomes, thereby allowing an assessment of potential trade-offs. This comparative analysis draws on the framework of Combet et al. (2025), emphasizing the balance between distributional fairness and economic efficiency in carbon tax revenue allocation.

Therefore, to address the core research questions, specifically how carbon taxation under different tax bases and emission pathways leads to varying economic and environmental outcomes, and how alternative revenue recycling strategies influence both distributional effects and overall macroeconomic performance, the details of all simulation scenarios are summarized in Table 3.3.

For further information on the emission pathways used in this study, please refer to Chapter 4, Section 4.1.2, under the future emission projection of the model.

Table 3.3

Details of All Simulation Scenarios

Simulations	Detail	Emission Path
Section 1: Impact of carbon tax implementation		
Simulation 1	Imposing a carbon tax at 200 baht/tCO_2e – All fossil fuels	BAU path and NDC path
Simulation 2	Imposing a carbon tax at 200 baht/tCO_2e – Only liquid fuels	
Simulation 3	Imposing a carbon tax at 200 baht/tCO_2e – Only gasoline	
Section 2: Carbon tax revenue recycling strategies		
Section 2.1: Equity Considerations		
Simulation 4	Regressive transfer to low-income households	BAU path and NDC path
Simulation 5	Progressive transfer to low-income households	
Section 2.2: Efficiency Considerations		
Simulation 6	Progressive transfer to low-income households	BAU path and NDC path
Simulation 7	A reduction in household income taxes	
Simulation 8	Increase government spending	

Note. From the Author's compilation

CHAPTER 4
RESULTS AND DISCUSSION

This chapter is organized into six subsections. The first section assesses the reliability of the model and outlines future projections. The next four subsections provide an in-dept analysis of the effects on macroeconomics, government, households, and carbon emission trends, respectively. Lastly, the chapter concludes with a discussion of the overall results of implementing carbon tax.

4.1 Model Reliability

As mentioned earlier, this CGE model operates within the economic mechanism and enables simulations for both the medium and long term. To align the CGE model with real-world economic conditions, its parameters were adjusted through calibration, ensuring that the model's economic indicators matched observed data for both macroeconomic and emission variables. Additionally, designing future projections was crucial for evaluating forward-looking impacts.

This section primarily examines how effectively the CGE model can reflect real economic dynamics through parameter adjustments. By definition, a parameter is a constant variable that influences the behavior of an output function or equation. In this context, parameters interact with closure rules and exogenous variables to capture the nature and behavior of economic indicators. Since the model follows a recursive dynamic framework, it simulates how an economy evolves over time by solving for each period sequentially, with parameters being set differently at each stage. However, a major challenge arises when validating the model during periods of economic disruption, such as the pandemic. During such times, economic activity deviates significantly from normal conditions, potentially leading to inaccurate predictions. This occurs because some variables are exogenously determined outside the model, find it difficult to fully capture economic fluctuations. Moreover, the complex interactions among macroeconomic variables where changes in one variable trigger chain effects on others that further complicate accurate predictions, making it difficult to precisely capture-real world complexity.

4.1.1 Model Validation

4.1.1.1 Validation for Macroeconomic Variables

Validating data was performed through the root mean square error (RMSE) of each variable which measures the differences between the model estimated value and official data. In the case of macroeconomic variables, the primary source of the official data is from office of the National Economic and Social Development Council (NESDC) which provided national accounts of Thailand 2023, a comprehensive record of real gross domestic product, consumption expenditure, government expenditure, and other economic indicators. This dataset enables a reliability test of model performance from 2010 to 2023.

Table 4.1

Comparison of Model Macro Estimates and Official Data (2010-2023)

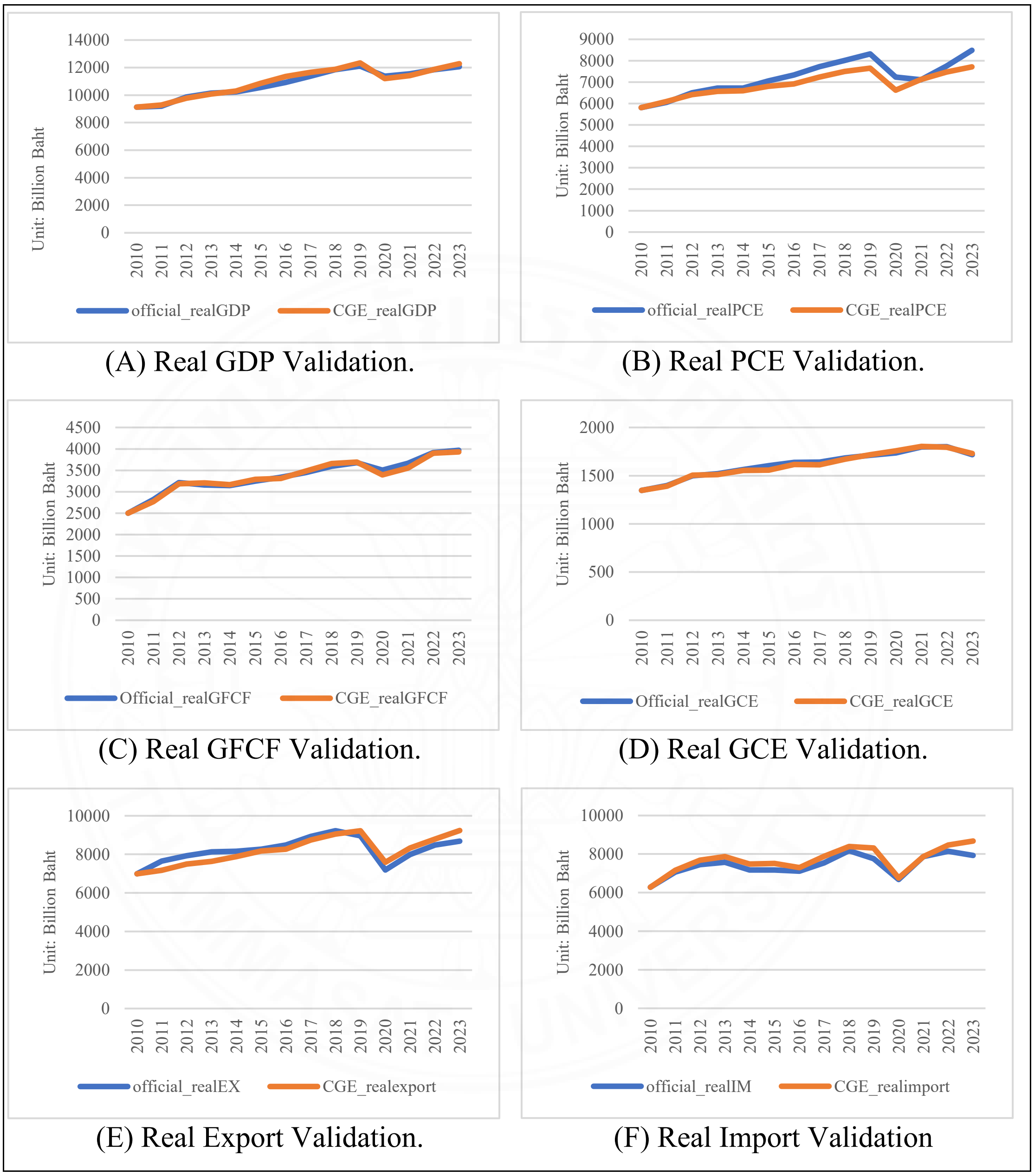
	RMSE
Real GDP	0.78%
Private Consumption Expenditure (PCE)	-3.95%
Real Gross Fixed Capital Formation (GFCF)	-0.33%
Government Consumption Expenditure (GCE)	-0.39%
Real Export	-0.44%
Real Import	3.44%

Note. From the Author's calculation.

From Table 4.1, the results show the high predictability performance due to their relatively small percentage deviations, indicating a good fit between the model and observed data. Especially, real gross domestic product (GDP), real gross fixed capital formation(GFCF), real government consumption expenditure(GCE), and real export, exhibit small percentage errors of 0.78%, -0.33%, -0.39%, and -0.44%, respectively, suggesting the model perform well in simulating these key macroeconomic indicators. As supported by (A) and (C-E) in Figure 4.1 that show small how well CGE could capture behavior of these variables.

Figure 4.1

Validation for Macroeconomic Variables



(A) Real GDP Validation.

(B) Real PCE Validation.

(C) Real GFCF Validation.

(D) Real GCE Validation.

(E) Real Export Validation.

(F) Real Import Validation

Note. From author's calculation

While private consumption expenditure (PCE) from (B) in Figure 4.1 and real import from (F) in Figure 4.1 show the largest discrepancy, with an RMSE of -3.95% and 3.44%, respectively, which indicate challenges in accurately capturing dynamic change, especially during the pandemic periods that may cause difficulty for adjusting parameter to reflect the situation. Therefore, there is a possibility of underestimate household consumption and overestimate import.

4.1.1.2 Validation for Emission Variables

In case of validating emission data, remains the primary tool to measure differences. The source of data is from Energy Policy Planning Office, operating under Ministry of Energy which provided data collection of carbon emission by energy type and sector that enables a reliability test of model performance from 2010 to 2022. For further details on grouping sectors, please refer to Appendix E.

Table 4.2

Comparison of Model Emission Estimates and Official Data (2010-2022)

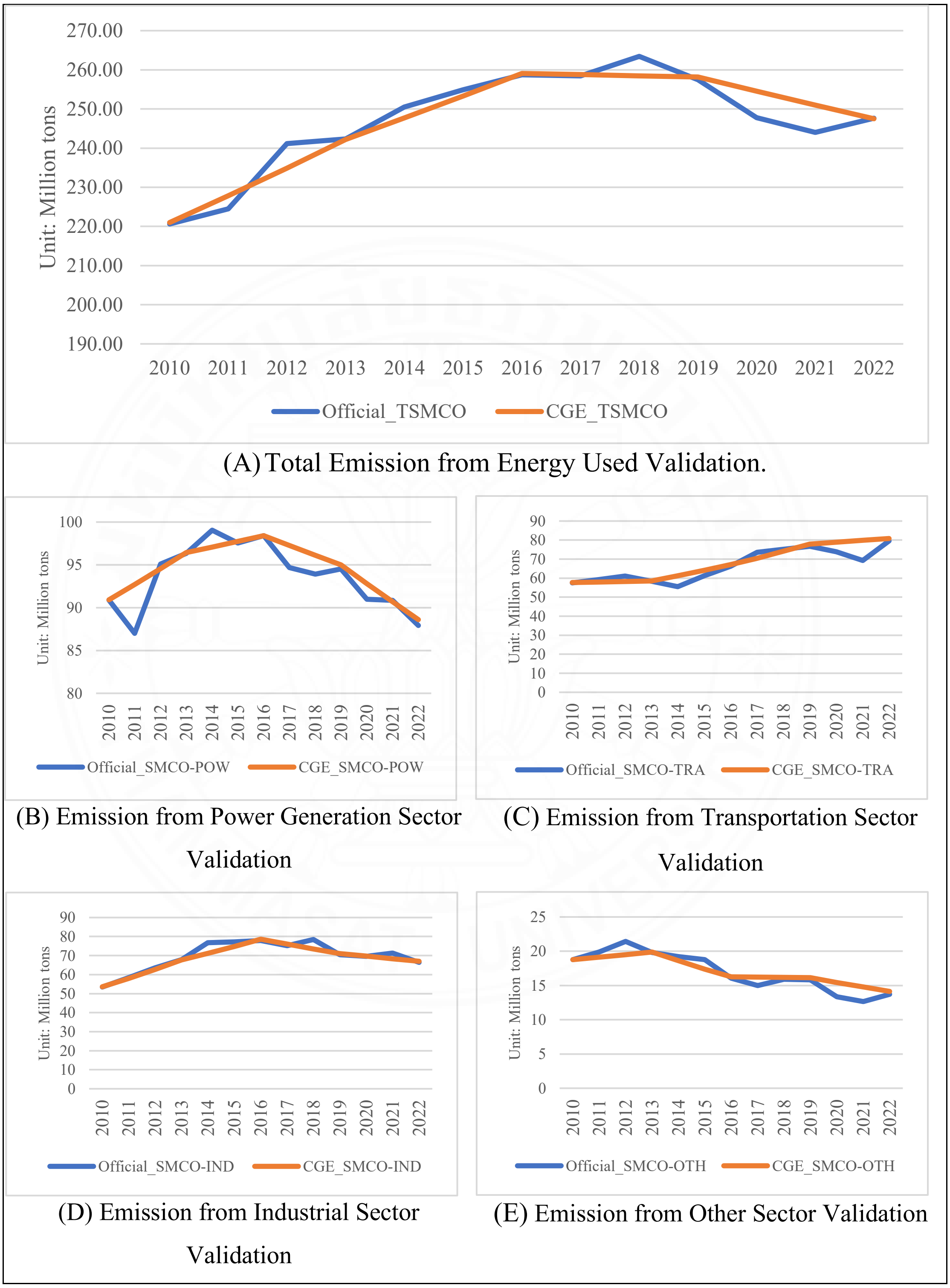
CO_2 Emission from Activity j (SMCO)	RMSE
Power Generation	0.96%
Transportation	2.25%
Industry	-1.44%
Others	1.98%
Total SMCO	0.11%

Note. From the Author's calculation.

Table 4.2 illustrated the strong forecasting performance of the emission variables, with total carbon emissions from economic sectors showing a low RMSE of 0.11% and a well-predicted trend in CGE_TSMCO, as illustrated in graph A from Figure 4.2. Furthermore, this accuracy extends to the four subsectors—power generation, transport, industry, and other sectors—with similarly low RMSE values of 0.96%, 2.25%, -1.44%, and 1.98%, respectively, as shown in graph B-E from Figure 4.2.

Figure 4.2

Validation for Emission Variables



(A) Total Emission from Energy Used Validation.

(B) Emission from Power Generation Sector Validation

(C) Emission from Transportation Sector Validation

(D) Emission from Industrial Sector Validation

(E) Emission from Other Sector Validation

Note. From author's calculation

4.1.2 Future Projections from the Model

Beyond validating the past trends, the model also offers crucial insights into future projections. Its design has incorporated interrelated factors from historical data, present conditions, and future national forecasts to generate reliable and meaningful results.

4.1.2.1 Economic Growth Trends and Baseline Projections

According to the past trends, data from NESDC revealed Thai GDP growth averaged 2.88%-3% annually over the past decade while post pandemic recovery lagging regional peer countries due to structural change in tourism, export, and productivity. Forward-looking viewed from IMF and World Bank report, "2024 Article IV Consultation – Press Release; Staff Report; and Statement by the Executive Director for Thailand", re-estimated Thai GDP growth after the pandemic as previous prediction has large hit to tourism and increase in private debt explained the lower post-pandemic potential output from 3% to 2.7%. Specifically, they projected 2.7% in 2024 and 2.9% in 2025 due to rebound in public investment and recovery in both private consumption and tourism, while in 2026, GDP growth would decline to 2.6% as a consequence of stimulus withdrawal and return to its potential rate estimated at 2.7% for 2027-2030.

In the mid-term horizon, this paper projects GDP growth to range between 2.5% and 3%, assuming that accelerated decarbonization investments will tighten both public and private budgets. Additionally, a World Bank report highlights the potential for downward pressure from carbon pricing, which could reduce GDP by 0.5% to 1.0% annually. Therefore, after 2023—the final year of validation—GDP is expected to grow at an average annual rate of 2.88%. Other macroeconomic variables are also projected to grow within the 2.5% to 3% range for the period between 2024-2050.

4.1.2.2 Emission Projections

Regarding future emission trends, this paper establishes two emission pathways. One followed the Business-As-Usual (BAU) and another path is set to align with Thailand's 2nd updated Nationally Determined Contribution (NDC), released in November 2022.

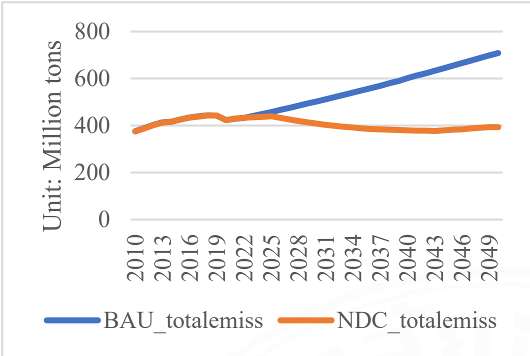
The emission level of BAU scenario projected from the reference year 2005 in the absence of major climate change policy which predicted to release carbon dioxide approximately at 555 million tons of carbon equivalent in 2030. While the second NDC report has mentioned 2 new emission reduction targets which are unconditional reduction for 30% and a conditional reduction for 40% where at 2030, they will release carbon emission at 385 and 333 million ton of carbon equivalent, respectively. However, this paper set to align with the conditional reduction at 40% due to the available data that go along with Thailand's 2065 net zero which this data reported on the Thailand's Long-Term Low Greenhouse Gas Emission Development Strategy (LT-LEDs), published by the Office of Natural Resources and Environmental Policy and Planning in 2022.

Accordingly, the model is calibrated to stimulate two district carbon pathways, each based on projected annual emission growth rates. The BAU scenario assumes an average annual emissions increase of 1.78%, while the NDC conditional scenario follows a declining trajectory, with emissions decreasing at an average rate of 0.33% per year, where NDC reflects the assumption that energy consumption shifts away from fossil fuels toward renewable energy and biofuels. Graph A in Figure 4.3 presents a comparative illustration of total emission trends under the BAU and NDC scenarios projected through 2050.

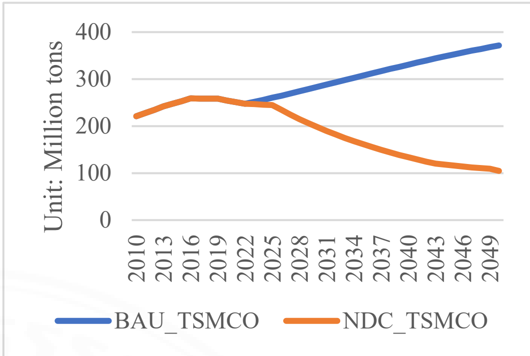
Moreover, emissions from energy use, a subset of total emissions, are based on reference values from the LT-LEDs report. The 2065 net-zero pathway projects a declining trend in energy sector emissions, with an average annual reduction of 3.01% after 2022. In the BAU scenario, energy sector emissions follow the same assumption as total emissions, growing at a rate of 1.46%, annually. Graph B in Figure 4.3 shows the different energy used emission trends of BAU and NDC paths projected until 2050. Therefore, the sub-sector of energy used can be proportionally decrease as shown in graph C-F from Figure 4.3.

Figure 4.3

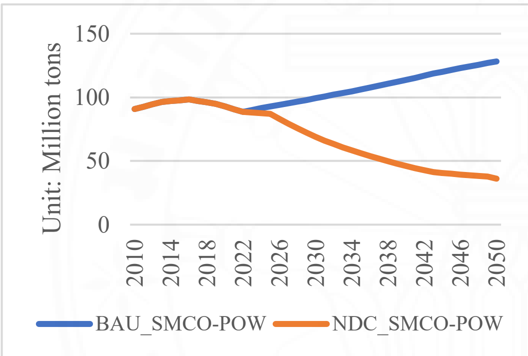
Reference Emission Paths



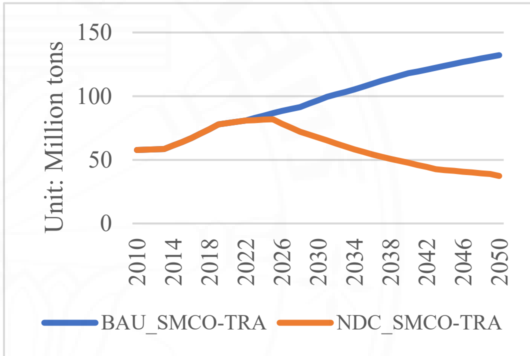
(A) Reference Emission Paths



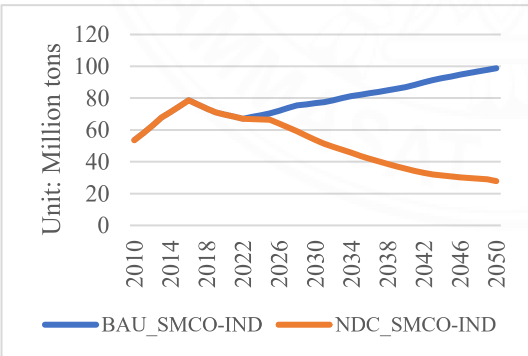
(B) Reference of Energy Used Emission Trends



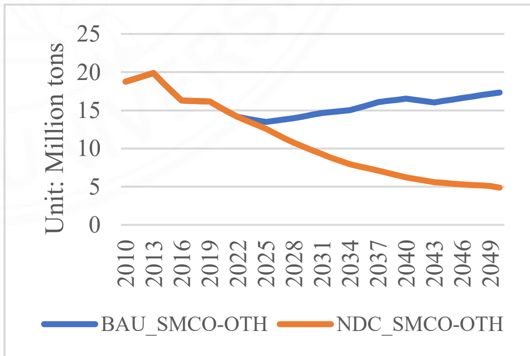
(C) Trends of Emission from Power Generation Sector



(D) Trends of Emission from Transport Sector



(E) Trends of Emission from Industrial Sector



(F) Trends of Emission from Others Sector

Note. From author's calculation

4.2 Impacts of Carbon Tax Implementation

4.2.1 Impacts of Carbon Tax under BAU Path

Table 4.3 presents the macroeconomic impacts of implementing a carbon tax at a rate of 200 Baht per ton of CO_2, applied from 2025 to 2050 under three distinct tax base scenarios: an all-fuel base (SIM1_ALL), a liquid fuel base (SIM2_LIQ), and a gasoline-only base (SIM3_GSL). The narrower the tax base, the milder the resulting economic effects, due to its more limited coverage of emissions. This is evident in the progressively smaller impacts observed from SIM1_ALL to SIM3_GSL. For a visual representation of the dynamic trends across all periods, please refer to Appendix F, Figures F.1-2, under the first section on the impacts of carbon tax implementation.

Table 4.3

Impacts of Carbon Tax under the BAU Path on Macroeconomic Variables

	SIM1_ALL	SIM2_LIQ	SIM3_GSL
Real GDP_BP	-0.10%	-0.05%	-0.01%
Real PCE	-1.52%	-0.89%	-0.22%
HH1_welfare	-3.04%	-1.77%	-0.43%
HH2_welfare	-3.33%	-1.94%	-0.47%
HH3_welfare	-3.65%	-2.12%	-0.52%
HH4_welfare	-3.95%	-2.30%	-0.56%
HH5_welfare	-3.97%	-2.31%	-0.56%
Real GFCF	4.60%	2.75%	0.69%
Real GCE	0.39%	0.24%	0.06%
Real Export	0.36%	0.23%	0.06%
Real Import	0.29%	0.18%	0.05%

Note. From the Author’s calculation.

In the long run, the carbon tax introduces a modest regressive effect on GDP, with real GDP declining by approximately 0.10%, 0.05%, and 0.01% under the SIM1_ALL, SIM2_LIQ, and SIM3_GSL scenarios, respectively. The most pronounced adverse impacts are observed among households, as indicated by the decline in both real private consumption expenditure (PCE) and household welfare across all income groups. These indicators reflect household consumption levels and suggest that carbon taxation reduces household purchasing power. Interestingly, the pattern of welfare loss reveals a stronger negative effect on higher-income households, consistent with their relatively higher energy consumption. Welfare losses range between 3–4% for SIM1_ALL, 1.7–2.3% for SIM2_LIQ, and 0.43–0.56% for SIM3_GSL.

On the other hand, the carbon tax generates positive effects on several macroeconomic variables. Notably, real GFCF increases substantially across all scenarios—by 4.60%, 2.75%, and 0.69%, respectively—indicating a significant rise in investment activity. Smaller but positive effects are also observed in government consumption expenditure (GCE), exports, and imports. These results suggest that while the carbon tax imposes a burden on household consumption, it simultaneously stimulates investment and certain sectors of aggregate demand.

Table 4.4

Impacts of Carbon Tax under the BAU Path on Emission Variables

	SIM1_ALL	**SIM2_LIQ**	**SIM3_GSL**
Total emission	-4.39%	-2.57%	-0.63%
SMCO_total	-5.36%	-3.14%	-0.77%
• Power Generation	-6.93%	-4.09%	-1.01%
• Transportation	-5.21%	-3.04%	-0.74%
• Industry	-3.25%	-1.89%	-0.46%
• Others	-6.65%	-3.94%	-0.98%

Note. From the Author's calculation.

In addition to macroeconomic outcomes, the implementation of carbon tax also leads to a noticeable reduction in emission across all scenarios, as shown in Table 4.4. The extent of emission reduction is directly related to the scope of tax base, the wider tax base leads to higher reduction amount where the total emission decrease for 4.39% of SIM1_ALL, 2.57% of SIM2_LIQ, and 0.63% of SIM3_GSL. By 2050, this translates to total emission levels of approximately 682 $MtCO_2e$ in SIM1_ALL, 693 $MtCO_2e$ in SIM2_LIQ, and 705 $MtCO_2e$ in SIM3_GSL.

Focusing specifically on the emission from energy used (SMCO_total), the results highlight that power generation sector experiences the most substantial reductions. Emissions from this sector decrease by 6.93% under SIM1_ALL, 4.09% under SIM2_LIQ, and 1.01% under SIM3_GSL. This suggests that carbon tax has strong influence on sectors heavily reliant on fossil fuels, due to its high emissions intensity and sensitivity to the price signals.

4.2.2 Impacts of Carbon Tax under NDC Path

Table 4.5

Impacts of Carbon Tax under the NDC Path on Macroeconomic Variables

	SIM1_ALL	SIM2_LIQ	SIM3_GSL
Real GDP_BP	0.04%	0.03%	0.01%
Real PCE	-1.37%	-0.80%	-0.19%
HH1_welfare	-2.64%	-1.53%	-0.37%
HH2_welfare	-2.89%	-1.67%	-0.41%
HH3_welfare	-3.13%	-1.82%	-0.44%
HH4_welfare	-3.39%	-1.97%	-0.48%
HH5_welfare	-3.41%	-1.98%	-0.48%
Real GFCF	4.46%	2.67%	0.67%
Real GCE	0.44%	0.27%	0.07%
Real Export	0.40%	0.26%	0.07%
Real Import	0.30%	0.19%	0.05%

Note. From the Author's calculation.

Under the NDC pathway, the macroeconomic outcomes remain broadly consistent with those observed in the BAU pathway, particularly in terms of household consumption, investment, and other key indicators, as shown in Table 4.5. However, the impact on GDP turns marginally positive, with increases of 0.04% in the

SIM1_ALL scenario, 0.03% in SIM2_LIQ, and 0.01% in SIM3_GSL. For a visual representation of the dynamic trends across all periods, please refer to Appendix F, Figures F.3-4, under the first section on the impacts of carbon tax implementation.

Real private consumption expenditure (PCE) experiences smaller declines compared to the BAU case, indicating a milder impact on households. The welfare losses are also less pronounced across all income groups: ranging from 2.64% to 3.41% in the all-fuels scenario, 1.53% to 1.98% in the liquid fuel base, and 0.37% to 0.48% in the gasoline base. Although investment slightly decreases, other components such as real government consumption expenditure (GCE), exports, and imports show modest increases compared to the BAU pathway.

Table 4.6

Impacts of Carbon Tax under the NDC Path on Emission Variables

	SIM1_ALL	**SIM2_LIQ**	**SIM3_GSL**
Total emission	-3.97%	-2.33%	-0.57%
SMCO_total	-5.38%	-3.15%	-0.77%
• Power Generation	-6.92%	-4.08%	-1.01%
• Transportation	-5.32%	-3.11%	-0.76%
• Industry	-3.23%	-1.87%	-0.45%
• Others	-6.62%	-3.92%	-0.97%

Note. From the Author's calculation.

In addition, the effects on emission-related variables align with the trends observed in the macroeconomic indicators, showing comparatively smaller reductions in emissions under the NDC pathway, as presented in Table 4.6. Total emissions decline by 3.97% in SIM1_ALL, 2.33% in SIM2_LIQ, and 0.57% in SIM3_GSL. The power generation sector remains the most significantly affected, reflecting its high emissions intensity. By 2050, the total emissions levels are projected to reach 382 $MtCO_2e$ under SIM1_ALL, 387 $MtCO_2e$ under SIM2_LIQ, and 392 $MtCO_2e$ under SIM3_GSL.

In conclusion, the choice of emission pathway substantially influences the outcomes. The BAU pathway, which assumes the absence of major climate policies, demonstrates greater economic and environmental sensitivity to the carbon tax. This results in more pronounced impacts across all key dimensions. In contrast, the NDC pathway incorporates behavioral adjustments such as fuel switching and reductions in fossil fuel consumption, leading to more moderate effects.

Furthermore, the scope of the tax base plays a critical role in determining the magnitude of the impact. A broader tax base captures a larger share of emissions, generating stronger price signals that are transmitted throughout the economy. Among all sectors, households are the most significantly affected by these changes. Despite differences in the results, both emission pathways point to a common conclusion that Thailand must strengthen its climate policies and implement additional measures to stay on course toward achieving its national emission reduction targets.

4.3 Carbon Tax Revenue Recycling Strategies

As shown in Section 4.2, the results indicate negative impacts on household consumption and welfare, with a decline in GDP under the BAU pathway, reflecting economic inefficiency. However, the increase in government revenue from carbon tax collection presents an opportunity to enhance public welfare and improve the overall efficiency of the tax system. Therefore, this section 4.3 explores revenue-recycling strategies, focusing on two key policy considerations: equity and efficiency. The analysis is conducted using revenue generated from the liquid fuel tax base, as it most closely aligns with the current carbon tax base employed by the Excise Department. Further details on tax revenue estimates for each tax base are provided in Appendix G.

4.3.1 Equity Considerations

In the context of equity considerations within a revenue-recycling scheme, the main focus is on the well-being, welfare, and consumption of households, with particular attention to the distributional impacts across different income groups. The increase in the cost of living resulting from a carbon tax raises concerns about distributional fairness and household welfare. It is essential to ensure that the burden of the tax does not disproportionately fall on low-income households. The direct transfer through revenue recycling presents an opportunity to protect or even enhance household well-being, especially for those more vulnerable to rising relative costs.

To address these concerns, two main approaches to direct transfers are considered in this study, with the objective of determining which is more suitable for adoption in the current policy context. The first is proportional transfers, which allocate revenue based on each income group's level of consumption. The second is progressive transfers, which are specifically designed to provide greater support to lower-income households, aiming to offset the regressive effects of the carbon tax.

4.3.1.1 Direct Transfers under the BAU Path

Table 4.7

Direct Transfers under the BAU Path: Impacts on Macroeconomic Variables

	SIM2_LIQ	SIM4_regressiveRR-TR	SIM5_progressiveRR-TR
Real GDP_BP	-0.05%	-0.09%	-0.10%
Real PCE	-0.89%	-0.77%	-0.76%
HH1_welfare	-1.77%	-0.41%	0.91%
HH2_welfare	-1.94%	-1.03%	-1.04%
HH3_welfare	-2.12%	-1.34%	-1.75%
HH4_welfare	-2.30%	-2.36%	-2.37%
HH5_welfare	-2.31%	-2.36%	-2.37%
Real GFCF	2.75%	2.49%	2.47%
Real GCE	0.24%	0.20%	0.19%
Real Export	0.23%	0.17%	0.16%
Real Import	0.18%	0.14%	0.14%

Note. From the Author's calculation.

In case of BAU pathway, according to Table 4.7, the overall impacts on macroeconomic variables indicate that revenue recycling through direct transfers, under both proportional and progressive approaches, results in a further decline in GDP, investment, and other macro indicators, with the exception of household consumption. In both cases, real private consumption expenditure (PCE) improves, reflecting higher overall household consumption. Specifically, real PCE increases from –0.89 percent in the no-transfer case to –0.77 percent under the proportional transfer scenario and –0.76 percent under the progressive transfer scenario. For a visual representation of the dynamic trends across all periods, please refer to Appendix F, Figure F.5-6, under the second section on carbon tax revenue recycling strategies (equity considerations).

At the disaggregated level, the progressive approach performs better in terms of equity. The welfare of the lowest-income household group (HH1) shifts from a regressive outcome of –1.77 percent under SIM2_LIQ to a progressive gain of 0.91 percent under the progressive transfer scenario. Although households in the second- and third- income groups (HH2 and HH3) continue to experience regressive impacts, their welfare losses are reduced compared to the no-transfer case.

In contrast, the regressive or proportional transfer approach, which is based on the principle that households contributing more in tax should receive higher transfers, results in regressive outcomes across HH1 to HH3. However, it provides relatively greater welfare improvements for HH2 and HH3 when compared to the progressive scenario, though this comes at the expense of HH1.

Furthermore, the impacts on emission-related variables are notable. Both total emissions and emissions from energy use show slight additional reductions, reflecting the co-benefits of direct transfer schemes. These transfers not only address equity concerns but also contribute to enhanced emission mitigation, as presented in Table 4.8.

Table 4.8

Direct Transfers under the BAU Path: Impacts on Emission Variables

	SIM2_LIQ	SIM4_regressiveRR-TR	SIM5_progressiveRR-TR
Total emission	-2.57%	-2.59%	-2.59%
SMCO_total	-3.14%	-3.18%	-3.19%
• Power Generation	-4.09%	-4.10%	-4.10%
• Transportation	-3.04%	-3.09%	-3.09%
• Industry	-1.89%	-1.97%	-1.98%
• Others	-3.94%	-3.92%	-3.91%

Note. From the Author's calculation.

4.3.1.2 Direct Transfers under the NDC Path

In the case of the NDC pathway, both direct transfer approaches result in a near GDP-neutral outcome, in contrast to the marginally negative GDP observed under the BAU pathway, as shown in Table 4.9. However, other macroeconomic variables—such as investment, real government consumption expenditure (GCE), exports, and imports—still show declines relative to the SIM2_LIQ scenario, similar to the BAU case. Nevertheless, the magnitude of these declines is smaller under the NDC pathway. For a visual representation of the dynamic trends across all periods, please refer to Appendix F, Figures F.7-8, under the second section on carbon tax revenue recycling strategies (equity considerations).

Table 4.9

Direct Transfers under the NDC Path: Impacts on Macroeconomic Variables

	SIM2_LIQ	SIM4_regressiveRR-TR	SIM5_progressiveRR-TR
Real GDP_BP	0.03%	0.00%	-0.01%
Real PCE	-0.80%	-0.74%	-0.74%
HH1_welfare	-1.53%	-0.74%	0.04%
HH2_welfare	-1.67%	-1.15%	-1.16%
HH3_welfare	-1.82%	-1.37%	-1.62%
HH4_welfare	-1.97%	-2.01%	-2.02%
HH5_welfare	-1.98%	-2.03%	-2.03%
Real GFCF	2.67%	2.52%	2.50%
Real GCE	0.27%	0.24%	0.24%
Real Export	0.26%	0.21%	0.21%
Real Import	0.19%	0.17%	0.16%

Note. From the Author's calculation.

For instance, under the BAU scenario, real GFCF decreases from 2.75 percent to 2.49 percent under the proportional transfer approach, and to 2.47 percent under the progressive transfer, representing approximate reductions of 0.06 and 0.07 percentage points, respectively. In the NDC case, investment decreases from 2.67 percent to 2.52 percent under the proportional transfer and to 2.50 percent under the progressive transfer, showing smaller declines of approximately 0.05 percentage points in both cases.

When examining distributional outcomes, the progressive transfer approach demonstrates stronger performance in terms of equity. It effectively offsets the regressive burden of the carbon tax for the lowest-income household group (HH1), shifting their welfare impact from a loss of –1.53 percent under SIM2_LIQ to a modest gain of 0.04 percent. While households in the second- and third- income groups (HH2 and HH3) continue to face negative welfare effects, these losses are notably smaller compared to the case without transfers.

On the other hand, the proportional transfer approach results in continued regressive effects for all lower-income groups (HH1 to HH3), though HH2 and HH3 experience relatively better outcomes compared to the progressive scenario. Despite this trade-off, household consumption levels under the NDC framework remain more stable, indicating that the adverse distributional effects of the carbon tax can be mitigated more effectively when policy design considers both efficiency and equity dimensions.

Table 4.10

Direct Transfers under the NDC Path: Impacts on Emission Variables

	SIM2_LIQ	SIM4_regressiveRR-TR	SIM5_progressiveRR-TR
Total emission	-2.33%	-2.34%	-2.34%
SMCO_total	-3.15%	-3.18%	-3.19%
• Power Generation	-4.08%	-4.09%	-4.10%
• Transportation	-3.11%	-3.14%	-3.14%
• Industry	-1.87%	-1.93%	-1.93%
• Others	-3.92%	-3.91%	-3.91%

Note. From the Author's calculation.

On the other hand, the impact on emission-related variables, as shown in Table 4.10, also highlights the dual benefit of both transfer approaches. Each lead to a slight additional reduction in total emissions compared to the SIM2_LIQ scenario.

These findings on equity, observed under both emission pathways, underscore that the progressive transfer approach is more effective in offsetting the regressive impacts of carbon taxation on the lowest-income households, whereas the proportional transfer yields milder improvements relative to the no-transfer case. This suggests a reinforcement of the carbon price signal, as direct transfers help sustain household purchasing power without undermining the overall effectiveness of the tax in reducing emissions.

Moreover, if inequality is considered a central concern within the broader equity objective, the progressive transfer emerges as the more appropriate strategy. This conclusion is supported by prior studies, which emphasize the role of targeted transfers in enhancing both social acceptability and fairness of climate policy. These studies will be discussed further in the following section. Given its demonstrated advantages in promoting equity while maintaining environmental effectiveness, the progressive transfer is selected as the baseline scheme for comparison with alternative revenue-recycling strategies focused on efficiency outcomes in the subsequent analysis.

4.3.2 Efficiency Considerations

In the context of efficiency considerations, revenue recycling is evaluated not only based on its long-term impact on GDP but also on how effectively it sustains overall economic performance while achieving emission reductions. This section presents a comparison among three main revenue-recycling schemes: direct household transfers, reductions in household income tax, and increases in government spending. The objective is to identify which scheme provides the most efficient use of carbon tax revenue.

4.3.2.1 Revenue-Recycling Comparison under BAU Path

Under the BAU pathway, the effects on macroeconomic variables vary across the different revenue-recycling options, as shown in Table 4.11. The impacts on GDP from direct transfers and income tax reductions are similar, each resulting in a decline of approximately 0.10 percent, which is 0.05 percentage points lower than the GDP level in SIM2_LIQ. Although the effects on real gross fixed capital formation (GFCF), government consumption expenditure (GCE), exports, and imports show slight variation, the most notable differences appear in household consumption and welfare outcomes. For a visual representation of the dynamic trends across all periods, please refer to Appendix F, Figures F.9-10, under the second section on carbon tax revenue recycling strategies (efficiency considerations).

Table 4.11

Comparative Impacts of Revenue Recycling Options under BAU Pathway: Effects on Macroeconomic Variables

	SIM2_LIQ	SIM6_RR-TR	SIM7_RR-HHtax	SIM8_RR-G
Real GDP_BP	-0.05%	-0.10%	-0.10%	-0.06%
Real PCE	-0.89%	-0.76%	-0.81%	-0.89%
HH1_welfare	-1.77%	0.91%	-1.83%	-1.77%
HH2_welfare	-1.94%	-1.04%	-2.00%	-1.93%
HH3_welfare	-2.12%	-1.75%	-2.19%	-2.11%
HH4_welfare	-2.30%	-2.37%	-2.36%	-2.28%
HH5_welfare	-2.31%	-2.37%	-1.76%	-2.29%
Real GFCF	2.75%	2.47%	2.50%	2.48%
Real GCE	0.24%	0.19%	0.20%	1.01%
Real Export	0.23%	0.16%	0.17%	0.16%
Real Import	0.18%	0.14%	0.13%	0.14%

Note. From the Author's calculation.

Direct transfers provide clear benefits to low-income households, while income tax reductions primarily favor the highest-income group. In contrast, the recycling scheme through increased government spending yields the most favorable macroeconomic results. Under this SIM8_RR-G scenario, GDP declines by only 0.06 percent, and overall household consumption remains stable. At the disaggregated level, households in income groups 2 through 5 experience a slight increase in consumption of approximately 0.01 percent compared to SIM2_LIQ.

In terms of investment, SIM8_RR-G shows a modest decline in real GFCF from 2.75 percent in SIM2_LIQ to 2.48 percent. However, since this scenario is specifically designed to increase government spending, it leads to a significant rise in real GCE compared to the other revenue-recycling options. According to Table 4.12, all revenue-recycling schemes result in a further reduction in carbon emissions compared to the SIM2_LIQ scenario.

Table 4.12

Comparative Impacts of Revenue Recycling Options under BAU Pathway: Effects on Emission Variables

	SIM2_LIQ	SIM6_RR-TR	SIM7_RR-HHtax	SIM8_RR-G
Total emission	-2.57%	-2.59%	-2.60%	-2.59%
SMCO_total	-3.14%	-3.19%	-3.18%	-3.17%
• Power Generation	-4.09%	-4.10%	-4.12%	-4.06%
• Transportation	-3.04%	-3.09%	-3.07%	-3.10%
• Industry	-1.89%	-1.98%	-1.97%	-1.98%
• Others	-3.94%	-3.91%	-3.95%	-3.86%

Note. From the Author's calculation.

4.3.2.2 Revenue-Recycling Comparison under NDC Path

Under the NDC pathway, as shown in Table 4.13, the effects on macroeconomic variables are generally consistent with those observed under the BAU pathway. The revenue recycling schemes through direct transfers and income tax reductions produce similar outcomes, with relatively minor impacts. Direct transfers continue to benefit low-income households, while income tax reductions mainly favor the highest-income group. Among the three approaches, the increased government spending scheme in SIM8 yields the most favorable results across key economic indicators. For a visual representation of the dynamic trends across all periods, please refer to Appendix F, Figures F.11-12, under the second section on carbon tax revenue recycling strategies (efficiency considerations).

Notably, the GDP impacts under the NDC pathway indicate a near GDP-neutral outcome. GDP changes are recorded at –0.01 percent for SIM6, 0.00 percent for SIM7, and a slight increase of 0.01 percent for SIM8. These results further support the conclusion that increased government spending (SIM8) represents the most efficient revenue-recycling approach. It achieves the only positive change in GDP following revenue redistribution. Although household consumption and welfare show little to no improvement in SIM8, investment performance is stronger compared to the direct transfer scenario, reinforcing the efficiency gains of this approach.

Table 4.13

Comparative Impacts of Revenue Recycling Options under NDC Pathway: Effects on Macroeconomic Variables

	SIM2_LIQ	SIM6_RR-TR	SIM7_RR-HHtax	SIM8_RR-G
Real GDP_BP	0.03%	-0.01%	0.00%	0.01%
Real PCE	-0.80%	-0.74%	-0.76%	-0.80%
HH1_welfare	-1.53%	0.04%	-1.58%	-1.54%
HH2_welfare	-1.67%	-1.16%	-1.72%	-1.68%
HH3_welfare	-1.82%	-1.62%	-1.87%	-1.82%
HH4_welfare	-1.97%	-2.02%	-2.02%	-1.97%
HH5_welfare	-1.98%	-2.03%	-1.67%	-1.98%
Real GFCF	2.67%	2.50%	2.52%	2.51%
Real GCE	0.27%	0.24%	0.25%	0.69%
Real Export	0.26%	0.21%	0.22%	0.21%
Real Import	0.19%	0.16%	0.16%	0.16%

Note. From the Author's calculation.

Table 4.14

Comparative Impacts of Revenue Recycling Options under NDC Pathway: Effects on Emission Variables

	SIM2_LIQ	SIM6_RR-TR	SIM7_RR-HHtax	SIM8_RR-G
Total emission	-2.33%	-2.34%	-2.35%	-2.34%
SMCO_total	-3.15%	-3.19%	-3.18%	-3.18%
• Power Generation	-4.08%	-4.10%	-4.10%	-4.08%
• Transportation	-3.11%	-3.14%	-3.13%	-3.14%
• Industry	-1.87%	-1.93%	-1.93%	-1.93%
• Others	-3.92%	-3.91%	-3.93%	-3.88%

Note. From the Author's calculation.

Similar to the BAU case, the impact on emission-related variables under the NDC pathway across all revenue-recycling strategies demonstrates a dual benefit. Each approach contributes to a slight additional reduction in emissions compared to the SIM2_LIQ scenario, as shown in Table 4.14.

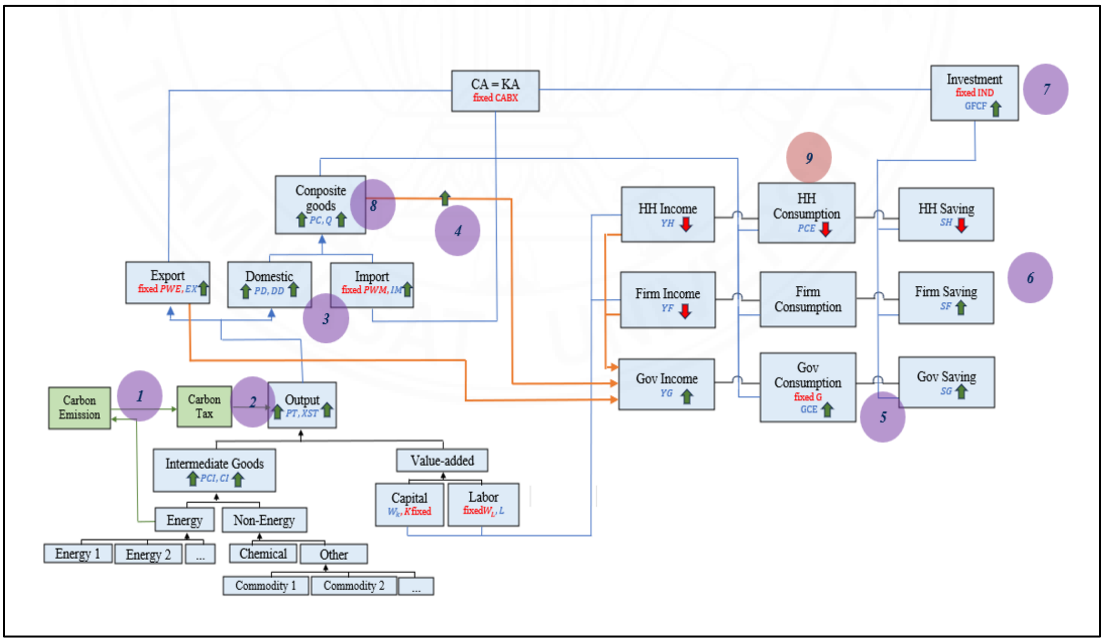
The findings on efficiency, observed under both emission pathways, highlight that revenue recycling through increased government spending is the relatively most efficient approach. This strategy results in the smallest long-term impact on GDP, avoids placing a direct tax burden on any specific household group, and maintains only a modest decline in investment. In contrast, direct transfers primarily benefit low-income households but are associated with negative effects on both GDP and investment. Similarly, reducing household income tax provides advantages mainly to the highest-income group, while leaving lower-income households with a disproportionate share of the burden.

4.4 Result Discussion

4.4.1 Discussion of Carbon Tax Impacts

Figure 4.4

Sequential Economic Impact Propagation under a Carbon Tax.



Note. From the Author’s compilation.

The impact of a carbon tax on the economic circulation is illustrated in Figure 4.4. The mechanism begins at point 1, where the carbon tax is imposed on products based on the carbon emissions embedded in intermediate inputs used during production. This taxation results in increased production costs, as shown at point 2, subsequently leading to higher prices and changes in output levels over time. At point 3, the model captures how these cost increases are transmitted through the economy, influencing export volumes as well as domestic production and imports. As a consequence, the overall supply of composite goods expands. Finally, at point 4, the imposition of the carbon tax generates substantial government revenue, contributing to fiscal resources available for redistribution or investment.

At point 5, the rise in government revenue enhances the fiscal balance through an increase in government savings. In parallel, at point 6, total national savings also increase, which supports a higher level of investment in the form of gross fixed capital formation. This investment contributes to capital stock expansion at point 7. The accumulation of capital leads to higher output levels in the long term, as illustrated at point 8 , potentially contrasting with findings from previous studies that suggest contractionary effects of carbon taxation. However, at point 9, the increase in output prices results in a decline in private consumption, indicating a potential long-term adverse impact of the carbon tax on household expenditure.

The previous diagram in Figure 4.18 illustrates the mechanism through which a carbon tax influences various components of the economy. Building upon these results, it is useful to compare the findings of this study with existing literature from other developing countries to identify key similarities and differences, as shown in Table 4.15. These comparisons focus on four main aspects: tax rate and base, tax revenue, impacts on GDP, and household consumption.

First, regarding the tax based, other studies often rate carbon tax per ton of CO_2 rather than per energy unit where the rates are considerably var, ranging from low levels of \$1-10 per ton of CO_2 in countries such as Vietnam and Indonesia, high levels of approximately \$700 per ton in Mexico by 2050. Most studies define the tax based on carbon emission from energy used, fossil fuel consumption and combustion.

Table 4.15

The Relation to Existing Literature

Author (Year)	Country	Tax rate	Tax base	Tax revenue (proportion to GDP)	Effect on GDP	Effect on household consumption
This paper finding	Thailand	200 baht per ton	Energy used	0.21% (BAUpath), 0.11% (NDCpath)	-0.05% (BAU), 0.03% (NDC)	-0.89% (BAU), 0.80% (NDC)
Puttanapong et al. (2015)	Thailand	227.75, 445.49, 683.23 baht per ton	Energy used		-0.56%, -1.02%, -1.47%	-0.47%, -1.02%, -1.58%
Mengistu et al. (2019)	Ethiopia	Increase from $5 per ton in 2018 to $30 per ton in 2030	Energy used		-0.38%	Urban (-0.16%), rural (-0.013%)
Jia et al. (2023)	China	Increase from 31.1 to 133.7 CNY/tCO_2	Energy type		-1.6%, -1.610%, -1.616%, -0.729%	urban (-4.71%), rural (-4.87%),
Alonso and Kilpatrick (2022)	China	$50 per ton	Energy used	1.70%		-3.4%
	Indonesia			1.70%		-7%
	Mongolia			4.50%		-10%
	India			2.50%		3.4%
	Kiribati			0.70%		2.7%
	Myanmar			1%		1.2%
	Philiphines			0.90%		2.1%
Octaviano et al. (2016)	Brazil	$10/$tCO_2$, $50/$tCO_2$	Fossil fuel combustion and industrial sources		Loss 0-4%	
	Mexico				Loss 1-11%	
Landa Rivera et al. (2016)	Mexico	US$100(in 2030), US$700 (in 2050)		5-6% in 2050	Decline more than 4% after 2040	-10% by 2050
Calderón et al. (2016)	Columbia	$50/$tCO_2$ (growth at 4%/year)	Fossil fuel combustion		Loss 2.3-3.4% by 2050	Loss 2.2-4.7% by 2050
Alton et al. (2014)	South Africa	$3/$tCO_2$ in 2012	Fossil fuel combustion		-1.2% by 2025	-0.63% by 2025

Table 4.15

The Relation to Existing Literature (Cont.)

Author (Year)	Country	Tax rate	Tax base	Tax revenue (proportion to GDP)	Effect on GDP	Effect on household consumption
Nong (2018)	Vietnam	33.33%, 50% increase in tax rate	Fossil fuel used	3.91% (Petroleum) , 1.98% (Coal)	-1.99% (Petroleum) , -0.51% (Coal)	-0.5% (Petroleum) , -0.51% (Coal)
Nguyen (2023)	Vietnam	\$1, \$5, and \$10 per ton of tCO_2	Fossil fuel used		Loss 0.247%-2.306%	Loss 0.51%-4.772%
Nurdianto and Resosudarmo (2016)	Vietnam	\$10/tCO_2	Energy used	0.69%	-5.77%	-1.58%
	Thailand			0.68%	-2.33%	-0.75%
	Singapore			0.42%	-0.95%	-0.22%
	Philippines			0.64%	-2.99%	-0.63%
	Malaysia			0.82%	-4.06%	-1.12%
	Indonesia			0.75%	-3.76%	-1.11%

Note. From the Author's compilation.

Second, the share of tax revenue as a percentage to GDP differs significantly across countries. For example, revenue size ranges from 0.42 percent in Singapore to 6 percent in Mexico by 2050, depending on tax rate, tax base, and economic structure.

Third, the effects on GDP are straight regressive where Thailand from this paper aligned with other studies that report negative or regressive impacts. Most models from developing countries indicate a stronger decline effect, particularly in economies heavily reliant on carbon-intensive sectors.

Lastly, the distributional effects on household consumption also vary. This study finds that carbon taxation in Thailand has a regressive effect on consumption which aligns with findings in Vietnam (-0.5 percent), Singapore (-0.22 percent), and Philippines (-0.63 percent). In contrast, some countries such as India, Myanmar, and Kiribati report more progressive effects, likely due to different consumption patterns. Across all cases, household consumption tends to decline, particularly in energy-intensive sectors such as petroleum and coal. In Brazil, for instance, consumption losses are projected to reach up to 10 percent by 2050.

Overall, these comparisons suggest that the economic impacts of carbon taxation are highly dependent on tax design, the structure of the economy, and the level of fossil fuel dependency. Countries with higher tax rates generally achieve greater revenue generation but also face more pronounced negative effects on GDP and household welfare. On the other hand, evidence from a joint report by the IMF and World Bank (2020), Implications of the Global Economic Crisis for Carbon Pricing, provides useful insights from countries with carbon tax implementation. According to the report, a \$75 per ton of carbon dioxide equivalent tax could reduce 28 percent of total emission while generating 1.1 percent of government revenue to GDP. To compare this study's result with their findings, the tax rate of \$75 could lead to emission reduction around 22.59 percent of total emissions while generating 2.69 percent of government revenue to GDP. Therefore, the results suggest that a higher carbon tax could achieve greater emission reductions and fiscal benefits compared to global benchmarks.

4.4.2 Discussion of Revenue Recycling Schemes

The primary objective of implementing revenue recycling is to evaluate the advantages and disadvantages of each strategy and to offer critical insights for policymakers on how to allocate carbon tax revenues in a way that enhances both equity and efficiency.

From an equity perspective, when the analysis centers on household welfare and consumption, proportional transfers tend to produce milder impacts on welfare across all income groups compared to a no-transfer scenario. Moreover, this approach results in more favorable outcomes for GDP and investment relative to the progressive transfer scheme. However, progressive transfers demonstrate a stronger capacity to mitigate the regressive impacts of carbon taxation, particularly for the lowest-income households. In these cases, even the second- and third- income quintiles experience less adverse effects than under the no-transfer scenario. Nevertheless, the macroeconomic impacts—especially on GDP and investment—are more negative under progressive transfers than under proportional or no-transfer cases.

Furthermore, evidence from Zhao et al. (2022) that regressive transfers tend to widen income inequality, whereas progressive transfers are more effective at narrowing the income gap across different household groups. Therefore, when inequality is another key policy consideration, progressive transfers emerge as the more suitable option, as they provide meaningful support to low-income households without imposing excessive burdens on the broader economy.

From an efficiency perspective, progressive transfers to low-income households are consistent with the findings of Turner et al. (2022) and Combet et al. (2025). These targeted transfers are more effective at addressing the regressive effects of carbon taxation on low-income groups. However, they exhibit lower efficiency in terms of GDP performance over the long term under both emission pathways.

In the case of income tax reduction, the comparative results underscore the importance of aligning revenue-recycling strategies with the characteristics of each emission pathway. Under the BAU scenario, where no major climate policy is implemented, income tax cuts produce negative macroeconomic impacts, similar to the direct transfer approach. In contrast, under the NDC pathway, which incorporates behavioral changes such as fuel switching, the same income tax reductions become GDP-neutral. This shift reflects improved economic efficiency in the long run, aligning with the literature presented in Table 4.16. These studies emphasize that reducing income tax can mitigate tax distortions and enhance overall economic efficiency, particularly when supported by broader structural changes in the economy.

The effects of revenue recycling through government spending exhibit a similar divergence depending on the emission pathway. Under the BAU scenario, government spending results in milder negative macroeconomic impacts compared to the other two strategies. Under the NDC pathway, however, it leads to a positive-neutral effect on GDP, avoids imposing a direct tax burden on any specific household group, and is associated with only a modest decline in investment. Although general government spending is a common recycling strategy in several countries—such as Chile, Finland, Iceland, Mexico, Sweden, and the United Kingdom (Conway et al., 2017)—it is less frequently examined in the literature compared to transfers or tax cuts. This study therefore provides valuable insight, aligning with findings from Turner et al. (2022), which suggest that well-targeted public spending has the potential to mitigate negative economic effects, though care must be taken to avoid inefficiencies.

Table 4.16

Related Literature for Revenue Recycling Strategies

Author(Year)	Country	Revenue-Recycling Roles	Results
McKitrick (1997)	Canada	(1) Payroll tax reduction (2) Lump-sum transfer	Double dividend is possible when revenue reduces distortionary taxes. Lump-sum transfer causes GDP and welfare losses
Timilsina and Shrestha (2007)	Thailand	(1) Lump-sum transfer to households (2) Labor tax cut (3) Indirect tax cut on non-energy goods	Carbon tax is more efficient under tax-cut schemes
Tuladhar et al. (2015)	United States	(1) Reduce federal personal income tax (2) Reduce corporate tax (3) Debt reduction	Revenue recycling mitigates economic costs, but doesn't fully offset them
Beck et al. (2015)	Canada	Revenue-neutral design: (1) Low-income tax credits (2) Personal income tax cuts	Revenue recycling further increases progressivity. Wealthy households bear more burden due to labor income structure.
Mengistu et al. (2019)	Ethiopia	(1) Direct transfers to households (2) Sales tax reduction (3) Labor or business income tax cuts (4) Debt repayment'	Carbon tax has limited macroeconomic impact where labor income tax cut and direct transfer are most efficient option. Distributional effects small, urban households more impacted.
Zhao et al. (2022)	China	(1) Individual income tax returns: - Proportional - Progressive (2) General transfer to local governments	Carbon pricing worsens inequality unless paired with progressive recycling. Progressive income tax returns reduce Gini index.
Turner et al. (2022)	United Kingdom	(1) Income tax adjusts (2) All gov. spend adjusts (3) Lump sum transfer to households	Government spending can reduce negative economic impacts if well-targeted. A recommended approach is hybrid revenue recycling—combining tax cuts with targeted support—to balance efficiency and equity.
Combet et al. (2025)	France	(1) Lump-sum transfer (uniform or targeted) (2) Cutting distortionary taxes (3) Hybrid options	Trade-off depends on macro context (e.g. wage flexibility). Lump-sum transfers preferred for equity but less efficient. Suggests case-by-case hybrid designs.

Note. From the Author's compilation.

Overall, while most studies focus on comparing transfers and tax reductions, recent literature has increasingly acknowledged that there is no universal solution. Instead, hybrid or mixed policy approaches—for example, combining tax reductions with targeted transfers—may offer a more balanced trade-off between economic efficiency and social equity. Furthermore, these findings reinforce the importance of coordinated climate-fiscal policy design, where behavioral adaptation under the NDC pathway serves as a catalyst for achieving both environmental and economic objectives.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study aims to examine the economic and environmental impacts of carbon taxation in Thailand, with a particular focus on identifying the most effective revenue recycling strategy. A Computable General Equilibrium (CGE) model is employed to evaluate the effects on key macroeconomic indicators, including household consumption, investment, government expenditure, and carbon emissions. The analysis considers three tax base scenarios—all fuels, liquid fuels, and gasoline—across two emission pathways: the Business-as-Usual (BAU) scenario and the Nationally Determined Contribution (NDC) scenario, which reflects Thailand's conditional target of a 40% emissions reduction by 2030. Additionally, three revenue-recycling mechanisms are assessed: direct household transfers, income tax reductions, and increased government spending.

The results of implementing a 200-baht carbon tax indicate that a broader tax base captures a larger share of emissions and generates higher carbon tax revenues, leading to more pronounced impacts on both macroeconomic and environmental outcomes. Among the scenarios, the liquid fuel tax base most closely reflects the current structure used by Thailand's Excise Department, and is therefore selected as the reference case for further analysis of revenue recycling strategies.

The choice of emission pathway significantly influences the results. Under the Business-as-Usual (BAU) pathway, the economy exhibits greater sensitivity to the carbon tax, with GDP declining by 0.05%, household consumption falling by 1.77% to 1.98%, and investment increasing by 2.75%. In contrast, the Nationally Determined Contribution (NDC) pathway shows more moderate effects, with a slight increase in GDP of 0.03%, a reduction in household consumption by 1.53% to 1.98%, and an investment rise of 2.67%. Additionally, total carbon emissions are reduced by 2.57% under BAU and 2.33% under the NDC pathway.

This study finds that the effectiveness of revenue recycling strategies under carbon taxation depends on the policy objective—whether the priority is economic efficiency or social equity. Proportional transfers yield milder welfare impacts across all income groups and are associated with more favorable macroeconomic outcomes. In contrast, progressive transfers more effectively reduce inequality, particularly for low-income households, but tend to generate more negative effects on GDP and investment.

The efficiency of income tax reductions varies by emission pathway. Under the Business-as-Usual (BAU) scenario, such reductions have adverse macroeconomic effects. However, under the NDC scenario, which incorporates behavioral adjustments, the same policy becomes GDP-neutral, suggesting improved long-term efficiency when embedded within broader climate efforts.

Government spending emerges as a robust revenue recycling option, particularly under the NDC pathway. It delivers neutral-to-positive GDP effects of 0.01%, imposes no direct burden on specific household groups, and involves only a modest investment decline of 0.16%. While general in nature, this approach demonstrates the potential to balance macroeconomic stability with inclusive outcomes.

In summary, this study finds that carbon taxation in Thailand delivers both environmental and economic impacts that vary by tax base, emission pathway, and revenue recycling strategy. While a broader tax base enhances emission reduction and revenue potential, the liquid fuel base offers a practical reference aligned with current policy. The NDC pathway moderates negative economic effects through behavioral adjustments. Among recycling options, none is universally optimal—each involves trade-offs between equity and efficiency—highlighting the need for careful policy design tailored to national priorities and emission targets.

5.2 Policy Implications

The results suggest several key policy implications.

1) Investment in clean technology should be prioritized. Since, there is significant increase in GFCF which suggests that carbon taxation can drive green investment where in this case government incentives can enhance these effects by

subsidize for renewable energy and efficiency improvement. This approach would further accelerate the transition to a low-carbon economy.

2) Since government spending demonstrates the most balanced strategy—delivering near-neutral GDP effects without imposing direct burdens on households—policymakers could consider this channel for carbon tax revenue recycling. To enhance its effectiveness, the use of public spending could be more narrowly targeted, such as through investment in energy efficiency programs or other low-carbon public infrastructure.

3) Hybrid or mixed strategies could be considered, as adopted in many countries, to balance both equity and efficiency objectives. A flexible policy framework that integrates elements from multiple recycling approaches—for example, combining tax reductions with targeted transfers—may provide a more resilient and adaptive path. Such an approach can offer a more balanced trade-off between promoting economic efficiency and ensuring social equity.

5.3 Limitations

The limitations of this study can be categorized into two key areas that warrant further investigation. First, the Social Accounting Matrix requires updating to better reflect the current economic structure. Ensuring that the SAM incorporates the most recent data would enhance the accuracy and relevance of the analysis, particularly in capturing shifts in sectoral dynamics and economic trends. Second, the exclusion of technological innovation presents a limitation. While the model accounts for investment responses, it does not explicitly simulate future technological advancements, which could significantly influence long-term economic and environmental outcomes. Incorporating technological progress into the model would provide a more comprehensive assessment of carbon taxation effects over time.

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APPENDICES

APPENDIX A
LIST OF SECTORS AND COMMODITIES

Table A.1

List of Sectors and Commodities

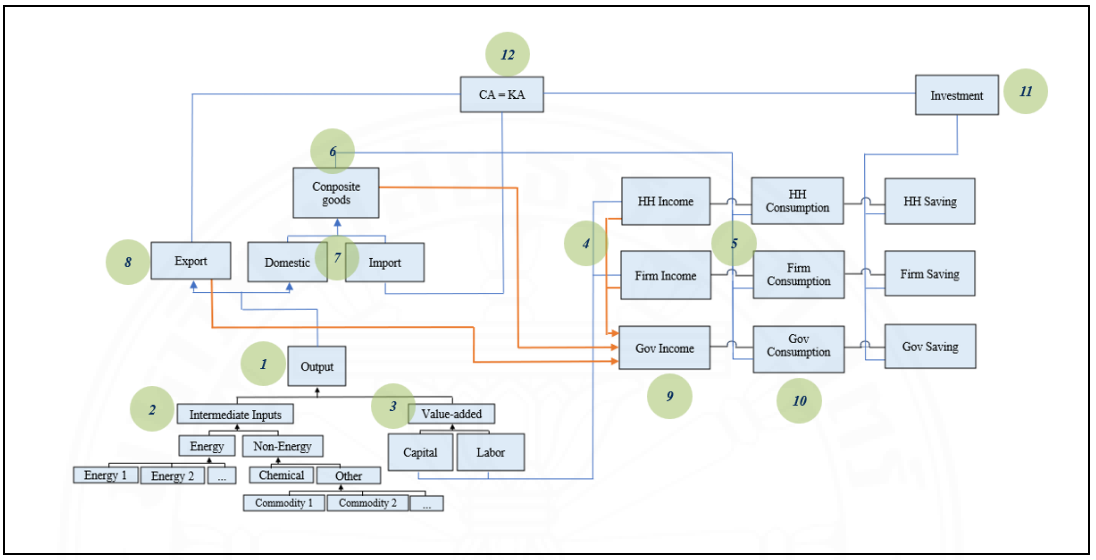
Sec	Activity	Sec	Activity	Com	Commodities	Com	Commodities
1	Paddy	21	Paper	1	Paddy	26	Gasoline
2	Corn	22	Ethanol	2	Corn	27	Jet fuel
3	Cassava	23	Chemical	3	Cassava	28	LPG
4	Cane	24	Refinery	4	Cane	29	Diesel
5	Oil palm	25	Rubber	5	Oil palm	30	Fuel oil
6	Livestock	26	NonMetal	6	Livestock	31	Other refinery
7	Chcoal	27	Iron	7	Chcoal	32	Gasohol
8	Fishery	28	Metal	8	Fishery	33	Biodiesel
9	Residue agriculture	29	Motor	9	Other agriculture	34	Rubber
10	Coal	30	Machine	10	Coal and lignite	35	NonMetal
11	Oil Gas	31	Other industry	11	Crude oil	36	Iron
12	Mining	32	Electricity	12	Natural Gas	37	Metal
13	Food	33	Construction	13	Mineral	38	Motor
14	Palmoil	34	Trade	14	Food	39	Machine
15	Rice	35	Rail transport	15	Palm oil	40	Other industry
16	Starch	36	Road transport	16	Rice	41	Electricity
17	Maize	37	Water transport	17	Starch	42	Construction
18	Sugar	38	Air transport	18	Maize	43	Trade
19	Textile	39	Other transport	19	Sugar	44	Rail transport
20	Wood	40	Service	20	Molas	45	Road transport
				21	Textile	46	Water transport
				22	Wood	47	Air transport
				23	Paper	48	Other transport
				24	Ethanol	49	Service
				25	Chemical product		

Note. From the Author's elaboration.

APPENDIX B
ECONOMIC IMPACT FRAMEWORK

Figure B.1

Economic Impact Framework



Note. From the Author's compilation.

Figure 3B.1 illustrates the economic mechanisms within the CGE model. The circular flow begins at Point 1, where production takes place using intermediate inputs (Point 2) based on fixed input-output coefficients, along with labor and capital inputs from Point 3. In return (Point 4), households and firms receive income through wages and returns on capital, which is then used for consumption (Point 5). This consumption generates total demand for goods and services, represented as composite goods in Point 6. These composite goods are sourced from both domestic production and imports, linking the demand and supply sides of the economy at Point 7. As part of this linkage, producers also have the option to export (Point 8), thereby completing the circular flow of production.

In addition, the model integrates the role of the government at Point 9, where it collects revenue from direct taxes on household income and indirect taxes on goods and services. This revenue is allocated for government spending and savings at Point 10. Finally, as an open economy, the model incorporates investment and savings alongside international trade at Point 11, with these external transactions captured through the current and capital accounts to ensure macroeconomic balance at Point 12.

APPENDIX C
THE CGE MODEL STRUCTURE

C.1 Notation of Set

C.1.1 Industries and Commodities

All industries: $j, jj \in J = \{J_1, \ldots, J_j, \ldots\}$

All industries: $i, ij \in I = \{I_1, \ldots, I_j, \ldots\}$

Public sectors: $pub \in PUB \subset J = \{PUB_1, \ldots, PUB_{pub}, \ldots\}$

Private sectors: $bus \in BUS \subset J = BUS_1, \ldots, BUS_{bus}, \ldots, BUS \cap PUB = \emptyset$

Where $j = \{AGR, MIN, MUC, SER,\}$ and

$i = \{NENERGY, ENERGY\}$

AGR = Agricultural sector

MIN = $Mining\ Sector$

MUC = $Manufacturing\ sector$

SER = $Service\ sector$

$NENERGY$ = $All\ non-energy\ commodities$

$ENERGY$ = $Petroleum\ product$

C.1.2 Production Factors

Labor categories: $l \in L = \{L_1, \ldots, L_l, \ldots\}$

Capital categories: $k \in K = \{K_1, \ldots, K_k, \ldots\}$

C.1.3 Agents

All industries:

$ag, agj \in H \cup F \cup \{GVT, ROW\} = \{H_1, \ldots, H_h, \ldots, F_1, \ldots, F_f, \ldots, GVT, ROW\}$

Where H = Household

F = Firms, Enterprises

GOV = Government

RoW = Rest of the World

$Agng$ = Non-government agents

AGD = All domestic agents

AGG = government

$AGDG$ = All domestic agents except government

C.2 List of Parameters

$aij_{i,j}$	Input output coefficient
A_k^{PRI}	Scale parameter (private investment funtion)
B_j^{XST}	Scale parameter (CES – Aggregate Output)
β_j^{XST}	Share parameter (CES – Aggregate Output)
ρ_j^{XST}	Elasticity parameter (CES – Aggregate Output): $-1< \rho_j^{XST}<\infty$
B_j^{VA}	Scale parameter (CES – value added)
β_j^{VA}	Share parameter (CES – value added)
ρ_j^{VA}	Elasticity parameter (CES – value added) : $-1<\rho_j^{VA}<\infty$
B_j^{KD}	Scale parameter (CES – composite capital)
B_j^{LD}	Scale parameter (CES – composite labor)
$\beta_{k,j}^{KD}$	Share parameter (CES – composite capital)
$\beta_{l,j}^{LD}$	Share parameter (CES – composite labor)
ρ_j^{KD}	Elasticity parameter (CES – composite capital): $-1<\rho_j^{KD}<\infty$
ρ_j^{LD}	Elasticity parameter (CES – composite labor): $-1<\rho_j^{LD}<\infty$
σ_j^{KD}	Elasticity parameter (CES – composite labor): $-1<\sigma_j^{KD}<\infty$
σ_j^{LD}	Elasticity parameter (CES – composite labor): $-1<\sigma_j^{LD}<\infty$
η	Price elasticity of indexed transfers and parameters
$\lambda_{agng,h}^{TR}$	Share parameter (transfer functions)
B_j^{XT}	Scale parameter (CET – total output)
$\beta_{j,i}^{XT}$	Share parameter (CET – total output)
ρ_j^{XT}	Elasticity parameter (CET – total output) : $1<\rho_j^{XT}<\infty$
$B_{j,i}^{X}$	Scale parameter (CET – exports and local sales)
$\beta_{j,i}^{X}$	Share parameter (CET – exports and local sales)

$\rho_{j,i}^{X}$	Elasticity parameter (CET – exports and local sales) : 1<$\rho_{j,i}^{X}$<∞
B_{i}^{M}	Scale parameter (CES – composite commodity)
β_{i}^{M}	Share parameter (CES – composite commodity)
ρ_{i}^{M}	Elasticity parameter (CES – composite commodity): 1<ρ_{i}^{M}<∞
A^{K_PRI}	Scale parameter (price of new private capital)
A^{K_PUB}	Scale parameter (price of new public capital)
$\emptyset_{k,bus}$	Scale parameter (allocation of investment to industries)
σ_{j}^{VA}	Elasticity of transformation (CES-value added) : 0 <σ_{j}^{VA}<∞
σ_{j}^{KD}	Elasticity of substitution (CES – composite capital): 0 <σ_{j}^{KD}<∞
σ_{j}^{LD}	Elasticity of substitution (CES – composite labor): 0 <σ_{j}^{LD}<∞
σ_{j}^{XT}	Elasticity of transformation (CET – total output) : 0<σ_{j}^{XT}<∞
$\sigma_{j,i}^{X}$	Elasticity of transformation (CET – exports and local sales): 0<$\sigma_{j,i}^{X}$<∞
σ_{i}^{XD}	Price-elasticity of the world demand for exports of product i
σ_{i}^{M}	Elasticity of substitution (CES – composite commodity) 0<σ_{i}^{M}<∞
$\sigma_{k,bus}^{INV}$	Elasticity of private investment demand relative to Tobin's q
$\lambda_{h,k}^{RK}$	Share of type k capital income received by agent ag
$\lambda_{h,l}^{WL}$	Share of type l labor income received by type h households
$\gamma_{i,h}^{LES}$	Marginal share of commodity i in type h household consumption budget
γ_{i}^{GVT}	Share of commodity i in total current public expenditures on goods and services
$\gamma_{i,h}^{INVPRI}$	Share of commodity i in total private investment expenditure
γ_{i}^{INVPUB}	Share of commodity i in total public investment expenditure
$tmrg_{i,m}$	Rate of margin i applied to commodity ij
$tmrg_{ij,i}^{X}$	Rate of margin ij applied to export i
pop_{t}	Population index

C.3 List of Variables

C.3.1 Rates, Intercepts, and Other Variable Parameters

$sh0_{h,t}$	Intercept (type h household savings)
$sh1_{h,t}$	Slope (type h household savings)
$ttdh0_{h,t}$	Intercept (income taxes of type h households)
$ttdh1_{h,t}$	Marginal income tax rate of type h households
$ttdf0_{f,t}$	Intercept (income taxes of type f businesses)
$ttdf1_{f,t}$	Marginal income tax rate of type f businesses
$tr0_{h,t}$	Intercept (transfers by type h households to government)
$tr1_{h,t}$	Marginal rate of transfers by type h households to government
$ttiw_{l,j,t}$	Tax rate on type l worker compensation in industry j
$ttik_{k,j,t}$	Tax rate on type k capital used in industry
$ttip_{j,t}$	Tax rate on the production of industry j
$ttic_{m,t}$	Tax rate on commodity i
$ttix_{i,t}$	Export tax rate on exported commodity i
$ttim_{i,t}$	Rate of taxes and duties on imports of commodity i

C.3.2 Volume Variables

$C_{i,h,t}$	Consumption of commodity i by type h households
$C_{i,h,t}^{MIN}$	Minimum consumption of commodity i by type h households
$CG_{i,t}$	Public consumption of commodity i (volume)
$KDC_{j,t}$	Industry j demand for capital
$LDC_{j,t}$	Industry j demand for labor
$KD_{k,j,t}$	Demand for type k capital by industry j
$LD_{k,j,t}$	Demand for type l labor by industry j
$DD_{m,t}$	Domestic demand for commodity i produced locally
$INV_{i,t}$	Final demand of commodity i for investment purposes

$INV_{i,t}^{PRI}$ Final demand of commodity i for private investment purposes

$INV_{i,t}^{PUB}$ Final demand of commodity i for public investment purposes

$DIT_{i,t}$ Total intermediate demand for commodity i

$EXD_{i,t}$ World demand for exports of product i

$Q_{i,t}$ Quantity demanded of composite commodity i

C.3.3 Price Variables

$PVA_{j,t}$ Price of industry j value added (including taxes on production directly related to the use of capital and labor)

$PCI_{j,t}$ Intermediate consumption price index of industry j

$PIXCON_t^{\eta}$ Consumer price index

e_t Exchange rate: price of foreign currency in terms of local currency

$PC_{i,t}$ Purchaser price of composite commodity i (including all taxes and margins)

$PL_{m,t}$ Price of local product i (excluding all taxes on products)

$PE_{i,t}$ Price received for exported commodity i (excluding export taxes)

$PWM_{m,t}$ World price of imported product i (expressed in foreign currency)

$PE_{i,t}^{FOB}$ FOB price of exported product i (in the national currency)

$P_{j,i,t}$ Basic price of industry j's production of commodity i

$PWX_{i,t}$ World price of export product i (expressed in foreign currency)

$PD_{i,t}$ Price of local product i sold on the domestic market (including all taxes and margins)

$PM_{i,t}$	Price of imported product i (including all taxes and margins)
$PT_{j,t}$	Basic price of industry j's output
$PVA_{j,t}$	Price of industry j value added (including taxes on production directly related to the use of capital and labor)
$PCI_{j,t}$	Intermediate consumption price index of industry j
$PIXINV_t^{PRI}$	Private investment price index
$PIXINV_t^{PUB}$	Public investment price index
$PIXGVT_t$	Public expenditure price index
PK_t^{PUB}	Price of new public capital
PK_t^{PRI}	Price of new private capital
PF_i	Factor price of intermediate product i (Billion baht/Ktoe)
$PF2_i$	Factor price of chemical fertilizer
$RC_{j,t}$	Rental rate of capital in industry j
$RTI_{k,j,t}$	Rental rate of type k capital, including capital taxes paid by industry j
$R_{k,j,t}$	Rental rate of type k capital in industry j
$WC_{j,t}$	Wage rate of industry j
$WTI_{l,j,t}$	Wage rate of type l labor, including payroll taxes paid by industry j
$W_{l,t}$	Wage rate of type l labor

C.3.4 Nominal Variables

CAB_t	Current account balance
$CTH_{h,t}$	Consumption budget of type h households
G_t	Current government expenditures on goods and services
IT_t	Total investment expenditures
IT_t^{PRI}	Total private investment expenditures
IT_t^{PUB}	Total public investment expenditures
GDP_t^{BP}	GDP at basic prices

GDP_t^{MP}	GDP at market prices
GDP_t^{IB}	GDP at market prices (income-based)
GDP_t^{FD}	GDP at purchasers' prices from the perspective of final demand
$GFCF_t$	Gross fixed capital formation
$SH_{h,t}$	Savings of type h households
$SF_{f,t}$	Savings of type f businesses
SG_t	Government savings
$SROW_t$	Rest-of-the-world savings
$YROW_t$	Rest-of-the-world income
$TDH_{h,t}$	Income taxes of type h households
$TDF_{f,t}$	Income taxes of type f businesses
$TDFT_t$	Total government revenue from business income taxes
$TDHT_t$	Total government revenue from household income taxes
$TIC_{i,t}$	Government revenue from indirect taxes on product i
$TICT_t$	Total government receipts of indirect taxes on commodities
$TIK_{k,j,t}$	Government revenue from taxes on type k capital used by industry j
$TIKT_t$	Total government revenue from taxes on capital
$TIM_{i,t}$	Government revenue from import duties on product i
$TIMT_t$	Total government revenue from import duties
$TIP_{j,t}$	Government revenue from taxes on industry j production (excluding taxes incurred on the use of capital and labor)
$TIPT_t$	Total government revenue from production taxes (excluding taxes directly incurred on the use of capital and labor)
$TIW_{l,j,t}$	Government revenue from payroll taxes on type l labor in industry j
$TIWT_t$	Total government revenue from payroll taxes

$TIX_{i,t}$	Government revenue from export taxes on product i
$TPRCTS_t$	Total government revenue from export taxes, on product and imports
$TPRODN_t$	Total government revenue from other taxes on production
$TR_{h,ag,t}$	Transfers from agent ag to type h households
$YH_{h,t}$	Total income of type h households
$YHL_{h,t}$	Labor income of type h households
$YHK_{h,t}$	Capital income of type h household
$YHTR_{h,t}$	Transfer income of type h households
$YDH_{h,t}$	Disposable income of type h households
$YF_{f,t}$	Total income of type f businesses
$YFK_{f,t}$	Capital income of type f businesses
$YFTR_{f,t}$	Transfer income of type f businesses
$YDF_{f,t}$	Disposable income of type f businesses
YG_t	Total government income
YGK_t	Government capital income
$YGTR_t$	Government transfer income

C.4 Equations

C.4.1 Production Module

$$XST_{j,t} = B_j^{XST}[\beta_j^{XST} VA_{j,t}^{-\rho_j^{XST}} + (1-\beta_j^{XST}) CI_{j,t}^{-\rho_j^{XST}}]^{-\frac{1}{\rho_j^{XST}}} \quad \text{(C.1)}$$

$$VA_{j,t} = [\frac{B_j^{XST}}{1-B_j^{XST}} \frac{PCI_{j,t}}{PVA_{j,t}}]^{\sigma_j^{XST}} CI_{j,t} \quad \text{(C.2)}$$

$$VA_{j,t} = B_j^{VA}[\beta_j^{VA} LDC_{j,t}^{-\rho_j^{VA}} + (1-\beta_j^{VA}) KDC_{j,t}^{-\rho_j^{VA}}]^{-\frac{1}{-\rho_j^{VA}}} \quad \text{(C.3)}$$

$$LDC_{j,t} = [\frac{B_j^{VA}}{1 - B_j^{VA}} \frac{RC_{j,t}}{WC_{j,t}}]^{\sigma_j^{VA}} KDC_{j,t} \tag{C.4}$$

$$LDC_{j,t} = B_j^{LD} \left[\sum_l \beta_{l,j}^{LD} LD_{l,j,t}^{-\rho_j^{LD}}\right]^{-\frac{1}{\rho_j^{LD}}} \tag{C.5}$$

$$LD_{l,j,t} = [\frac{\beta_{l,j}^{LD} WC_{j,t}}{WTI_{l,j,t}}]^{\sigma_j^{LD}-1} LDC_{j,t} \tag{C.6}$$

$$KDC_{j,t} = B_j^{KD}[\sum_k \beta_{k,j}^{KD} KD_{k,j,t}^{-\rho_j^{KD}}]^{-\frac{1}{\rho_j^{KD}}} \tag{C.7}$$

$$KD_{k,j,t} = [\frac{\beta_{k,j}^{KD} WC_{j,t}}{RTI_{k,j,t}}]^{\sigma_j^{KD}} (B_j^{KD})^{\sigma_j^{KD}-1} KDC_{j,t} \tag{C.8}$$

$$DI_{nenergyc,j,t} = aij_{nenergyc,j} DICC_{j,t} \tag{C.9}$$

C.4.2 Income and Savings

C.4.2.1 Households

$$YH_{h,t} = YHL_{h,t} + YHK_{h,t} + YHTR_{h,t} \tag{C.10}$$

$$YHL_{h,t} = \sum_l \lambda_{h,l}^{WL}[W_{l,t} \sum_j LD_{l,j,t}] \tag{C.11}$$

$$YHK_{h,t} = \sum_k \lambda_{h,k}^{RK}[\sum_j R_{k,j,t} KD_{k,j,t}] \tag{C.12}$$

$$YHTR_{h,t} = \sum_{ag} TR_{h,a,g,t} \tag{C.13}$$

$$YDH_{h,t} = YH_{h,t} - TDH_{h,t} + TR_{gvt,h,t} \tag{C.14}$$

$$CTH_{h,t} = YDH_{h,t} - SH_{h,t} + \sum\nolimits_{agng} TR_{agng,h,t} \tag{C.15}$$

$$SH_{h,t} = PIXCON_t^{\eta} sh0_{h,t} + sh1_{h,t} YDH_{h,t} \tag{C.16}$$

C.4.2.2 Enterprise

$$YF_{f,t} = YFK_{f,t} - YFTR_{f,t} \tag{C.17}$$

$$YFK_{f,t} = \sum\nolimits_{k} \lambda_{h,k}^{RK} \left[\sum\nolimits_{j} R_{k,j,t} KD_{k,j,t}\right] \tag{C.18}$$

$$YFTR_{f,t} = \sum\nolimits_{ag} TR_{f,a,g,t} \tag{C.19}$$

$$YDF_{f,t} = YF_{f,t} - TDF_{f,t} \tag{C.20}$$

$$SF_{f,t} = YDF_{f,t} - \sum\nolimits_{ag} TR_{ag,f,t} \tag{C.21}$$

C.4.2.3 Government

$$YG_t = YGK_t + TDHT_t + TDFT_t + TPRODN_t + TPRCTS_t + YGTR_t \tag{C.22}$$

$$YGK_t = \sum\nolimits_{k} \lambda_{gvt,k}^{RK} \left[\sum\nolimits_{j} R_{k,j,t} KD_{k,j,t}\right] \tag{C.23}$$

$$TDHT_t = \sum\nolimits_{h} TDH_{h,t} \tag{C.24}$$

$$TDFT_t = \sum\nolimits_{f} TDF_{f,t} \tag{C.25}$$

$$TPRODN_t = TIWT_t + TIKT_t + TIPT_t \quad (C.26)$$

$$TIWT_t = \sum_{l,j} TIW_{l,j,t} \quad (C.27)$$

$$TIKT_t = \sum_{k,j} TIK_{k,j,t} \quad (C.28)$$

$$TIPT_t = \sum_{j} TIP_{j,t} \quad (C.29)$$

$$TPRCTS_t = TICT_t + TIMT_t + TIXT_t \quad (C.30)$$

$$TICT_t = \sum_{i} TIC_{i,t} \quad (C.31)$$

$$TIMT_t = \sum_{i} TIM_{i,t} \quad (C.32)$$

$$TIXT_t = \sum_{i} TIX_{i,t} \quad (C.33)$$

$$YGTR_t = \sum_{agng} TR_{gvt,agng,t} \quad (C.34)$$

$$TDH_{h,t} = PIXCON_t^{\eta} ttdh0_{h,t} + ttdh1_{h,t} YD_{h,t} \quad (C.35)$$

$$TDF_{h,t} = PIXCON_t^{\eta} ttdf0_{f,t} + ttdf1_{f,t} YFK_{f,t} \quad (C.36)$$

$$TIW_{l,j,t} = ttiw_{l,j,t} W_{l,t} LD_{l,j,t} \quad (C.37)$$

$$TIK_{k,j,t} = ttik_{k,j,t} R_{k,j,t} KD_{k,j,t} \quad (C.38)$$

$$TIP_{j,t} = ttip_{j,t}PP_{j,t}XST_{j,t} \tag{C.39}$$

$$\begin{aligned} TIC_{m,t} = {} & ttic_{m,t}[\left(PL_{m,t} + \sum\nolimits_i PC_{i,t}tmrg_{i,m}\right)DD_{m,t} \\ & + (\left(1 + ttim_{m,t}\right)PWM_{m,t}e_t \\ & + \sum\nolimits_i PC_{i,t}tmrg_{i,m})IM_{m,t}] \end{aligned} \tag{C.40}$$

$$TIM_{i,t} = ttim_{i,t}PWM_{i,t}e_tIM_{i,t} \tag{C.41}$$

$$TIX_{i,t} = ttix_{i,t}(PE_{i,t} + \sum\nolimits_i PC_{ij,t}tmrg^X_{ij,i})EXD_{i,t} \tag{C.42}$$

$$SG_t = YG_t - \sum\nolimits_{agng} TR_{agng,gvt,t} - G_t \tag{C.43}$$

C.4.2.4 Other Sectors

$$\begin{aligned} YROW_t = {} & e_tPWM_{i,t}IM_{i,t} + \sum\nolimits_k \lambda^{RK}_{row,k}\,[\sum\nolimits_j R_{k,j,t}KD_{k,j,t}] \\ & + \sum\nolimits_{agd} TR_{row,agd,t} \end{aligned} \tag{C.44}$$

$$SROW_t = YROW_t - \sum\nolimits_i PE^{FOB}_{i,t}EXD_{i,t} - \sum\nolimits_{agd} TR_{agd,row,t} \tag{C.45}$$

$$SROW_t = -CAB_t \tag{C.46}$$

C.4.3 Transfer

$$TR_{agng,h,t} = \lambda^{TR}_{agng,h}\,YDH_{h,t} \tag{C.47}$$

$$TR_{gvt,h,t} = PIXCON^{\eta}_t tr0_{h,t} + tr1_{h,t}YH_{h,t} \tag{C.48}$$

$$TR_{agng,f,t} = \lambda_{ag,f}^{TR}\, YDF_{f,t} \tag{C.49}$$

$$TR_{agng,gvt,t} = PIXCON_t^{\eta} TR_{agng,gvt}^{0} pop_t \tag{C.50}$$

$$TR_{agng,row,t} = PIXCON_t^{\eta} TR_{agd,row}^{0} pop_t \tag{C.51}$$

C.4.4 Aggregate Demand

$$PC_{i,t}C_{i,h,t} = PC_{i,t}C_{i,h,t}^{MIN} + \gamma_{i,h}^{LES}(CTH_{h,t} + \sum_i PC_{ij,t}C_{i,j,h,t}^{MIN}) \tag{C.52}$$

$$GFCF_t = IT_t - \sum_i PC_{i,t}VSTK_{i,t} \tag{C.53}$$

$$PC_{i,t}INV_{i,t}^{PRI} = \gamma_{i,h}^{INVPRI} IT_t^{PRI} \tag{C.54}$$

$$PC_{i,t}INV_{i,t}^{PUB} = \gamma_{i}^{INVPUB} IT_t^{PUB} \tag{C.55}$$

$$INV_{i,t} = INV_{i,t}^{PRI} + INV_{i,t}^{PUB} \tag{C.56}$$

$$PC_{i,t}CG_{i,t} = \gamma_i^{GVT} G_t \tag{C.57}$$

$$DIT_{i,t} = \sum_j DI_{i,j,t} \tag{C.58}$$

$$\begin{aligned} MRGN_{i,t} = {} & \sum_{i,j} tmr_{i,ij} DD_{ij,t} + \sum_{i,j} tmrg_{i,ij} IM_{ij,t} \\ & + \sum_{i,j} tmrg_{i,ij}^{X} DD_{ij,t} \end{aligned} \tag{C.59}$$

C.4.5 Aggregated Supply and International Trade Block

$$XST_{j,t} = B_j^{XT}[\sum_i \beta_{j,i}^{XT} XS_{j,i,t}^{\rho_j^{XT}}]^{\frac{1}{\rho_j^{XT}}} \tag{C.60}$$

$$XS_{j,i,t} = \frac{XST_{j,t}}{B_j^{XT^{1+\sigma_j^{XT}}}}[\frac{P_{j,i,t}}{B_{j,i}^{XT} PT_{j,t}}]^{\sigma_j^{XT}} \tag{C.61}$$

$$XS_{j,i,t} = B_{j,i}^X[\beta_{j,i}^X EX_{j,i,t}^{\rho_{j,i}^X} + (1-\beta_{j,i}^X) DS_{j,i,t}^{\rho_{j,x}^X}]^{\frac{1}{\rho_{j,i}^X}} \tag{C.62}$$

$$EX_{j,i,t} = [\frac{1-\beta_{j,i}^X}{\beta_{j,i}^X}\frac{PE_{i,t}}{PL_{i,t}}]^{\sigma_{j,i}^X} DS_{j,i,t} \tag{C.63}$$

$$EXD_{i,t} = EXD_t^0 pop_t [\frac{e_t PWX_{i,t}}{PE_{i,t}^{FOB}}]^{\sigma_i^{XD}} \tag{C.64}$$

$$Q_{i,t} = B_i^M[\beta_i^M IM_{i,t}^{-\rho_i^M} + (1-\beta_i^M) DD_{i,t}^{-\rho_j^M}]^{\frac{-1}{\rho_i^M}} \tag{C.65}$$

$$IM_{i,t} = [\frac{B_i^M}{(1-B_i^M)}\frac{PD_{i,t}}{PM_{i,t}}]^{\sigma_i^M} DD_{i,t} \tag{C.66}$$

C.4.6 Price Block

C.4.6.1 Producer Price

$$PP_{j,t} = \frac{PVA_{j,t}VA_{j,t} + PCI_{j,t}CI_{j,t}}{XST_{j,t}} \tag{C.67}$$

$$PT_{j,t} = (1 + ttip_{j,t}) * PP_{j,t} \tag{C.68}$$

$$PCI_{j,t} = \frac{\sum_i PC_{i,t}DI_{i,j,t}}{CI_{j,t}} \tag{C.69}$$

$$PVA_{j,t} = \frac{WC_{j,t}LDC_{j,t} + RC_{j,t}KDC_{j,t}}{VA_{j,t}} \tag{C.70}$$

$$WC_{j,t} = \frac{\sum_i WTI_{l,j,t}LD_{i,j,t}}{LDC_{j,t}} \tag{C.71}$$

$$WTI_{l,j,t} = W_{l,j,t}\left(1 + ttiw_{l,j,t}\right) \tag{C.72}$$

$$RC_{j,t} = \frac{\sum_i RTI_{k,j,t}KD_{k,j,t}}{KDC_{j,t}} \tag{C.73}$$

$$RTI_{l,j,t} = R_{k,j,t}\left(1 + ttik_{k,j,t}\right) \tag{C.74}$$

C.4.6.2 Price of Imported and Exported Goods

$$PT_{j,t} = \frac{\sum_i P_{j,i,t}XS_{j,i,t}}{XST_{j,t}} \tag{C.75}$$

$$P_{j,i,t} = \frac{PE_{i,t}EX_{j,i,t} + PL_{i,t}DS_{j,i,t}}{CS_{j,i,t}} \tag{C.76}$$

$$PE_{i,t}^{FOB} = [PE_{i,t} + \sum\nolimits_{i,j} PC_{ij,t}tmrg_{ij,i}^{X}]\left(1 + ttix_{i,t}\right) \tag{C.77}$$

$$PD_{i,t} = \left(1 + ttic_{i,t}\right)\left[PL_{i,t} + \sum\nolimits_{ij} PC_{ij,t}tmrg_{ij,i}\right] \tag{C.78}$$

$$\begin{aligned} PM_{i,t} = \left(1 + ttic_{i,t}\right)\Big[&\left(1 + ttim_{i,t}\right)e_tPWM_{i,t} \\ &+ \sum\nolimits_{ij} PC_{ij,t}tmrg_{ij,i}\Big] \end{aligned} \tag{C.79}$$

$$PC_{i,t} = \frac{PM_{i,t}IM_{j,i,t} + PD_{i,t}DD_{i,t}}{Q_{i,t}} \tag{C.80}$$

C.4.6.3 Price Index

$$PIXGDP_t = \sqrt{\frac{\sum_j PVA_{j,t}VA_j^0}{\sum_j PVA_{j,t}^0 VA_j^0} \frac{\sum_j PVA_{j,t}VA_j}{\sum_j PVA_{j,t}^0 VA_j}} \tag{C.81}$$

$$PIXCON_t = \frac{\sum_i PCA_{i,t} \sum_h C_{i,h}^0}{\sum_{ij} PVA_{j,t}^0 \sum_h C_{ij,h}^0} \tag{C.82}$$

$$PIXINV_t^{PRI} = \prod_i \left[\frac{PC_{i,t}}{PC_i^0}\right] \gamma_i^{INVPRI} \tag{C.83}$$

$$PIXINV_t^{PUB} = \prod_i \left[\frac{PC_{i,t}}{PC_i^0}\right] \gamma_i^{INVPUB} \tag{C.84}$$

$$PIXGVT_t = \prod_i \left[\frac{PC_{i,t}}{PC_i^0}\right] \gamma_i^{GVT} \tag{C.85}$$

C.4.7 Equilibrium Conditions Block

$$Q_{i,t} = \sum_h C_{i,h,t} + CG_{i,t} + INV_{i,t} + VSTK_{i,t} + DIT_{i,t} + MRGN_{i,t} \tag{C.86}$$

$$\sum_j LD_{l,j,t} = LS_{l,t} \tag{C.87}$$

$$\sum_j KD_{k,j,t} = KS_{k,t} \tag{C.88}$$

$$IT_t = \sum_h SH_{h,t} + \sum_f SF_{f,t} + SG_t + SROW_t \tag{C.89}$$

$$IT_t^{PRI} = IT_t - IT_t^{PUB} - \sum_i PC_{i,t} VSTK_{i,t} \tag{C.90}$$

$$\sum_j DS_{j,i,t} = DD_{i,t} \tag{C.91}$$

$$\sum_j EX_{j,i,t} = EXD_{i,t} \tag{C.92}$$

C.4.8 Computation of GDP Block

$$GDP_t^{BP} = \sum_j PVA_{j,t} VA_{j,t} + TIPT_t \tag{C.93}$$

$$GDP_t^{MP} = GDP_t^{BP} + TPRCTS_t \tag{C.94}$$

$$\begin{aligned} GDP_t^{IB} = & \sum_{l,j} W_{l,t} LD_{l,j,t} + \sum_{k,j} R_{k,j,t} KD_{k,j,t} + TPRODN_t \\ & + TPRCTS_t \end{aligned} \tag{C.95}$$

$$\begin{aligned} GDP_t^{FD} = & \sum_i PC_{i,t} \left[\sum_h C_{i,h,t} + CG_{i,t} + INV_{i,t} + VSTK_{i,t} \right] \\ & + \sum_i PE_{i,t}^{FOB} EXD_{i,t} - \sum_i e_t PWM_{i,t} IM_{i,t} \end{aligned} \tag{C.96}$$

C.4.9 Capital Allocation and Dynamic Growth

$$KD_{k,j,t+1} = KD_{k,j,t}(1 - \delta_{k,j}) + IND_{k,j,t} \tag{C.97}$$

$$IT_t^{PUB} = PK_t^{PUB} \sum_{k,pub} IND_{k,pub,t} \tag{C.98}$$

$$IT_t^{PRI} = PK_t^{PRI} \sum_{k,bus} IND_{k,bus,t} \tag{C.99}$$

$$PK_t^{PRI} = \frac{1}{A^{K\_PRI}} \prod_i \left[\frac{PC_{i,t}}{\gamma_i^{INVPRI}}\right]^{\gamma_i^{INVPRI}} \tag{C.100}$$

$$PK_t^{PUB} = \frac{1}{A^{K\_PUB}} \prod_i \left[\frac{PC_{i,t}}{\gamma_i^{INVPUB}}\right]^{\gamma_i^{INVPUB}} \tag{C.101}$$

$$IND_{k,bus,t} = \emptyset_{k,bus} \left[\frac{R_{k,bus,t}}{U_{k,bus,t}}\right]^{\sigma_{k,bus}^{INV}} KD_{k,bus,t} \tag{C.102}$$

$$U_{k,bus,t} = PK_t^{PRI}(\delta_{k,bus} + IR_t) \text{ and}$$
$$U_{k,pub,t} = PK_t^{PUB}(\delta_{k,pub} + IR_t) \tag{C.103}$$

C.4.10 Carbon Emission by Industry Sector

C.4.10.1 Carbon Emission of Intermediate Demand and Final Demand

$$MCO_{i,j,t} = (DI_{i,j,t} * EFCO_i)/PF_i \tag{C.104}$$

$$MCOFF_{i,t} = ((\sum_h C_{i,h,t} + CG_{i,t} + INV_{i,t}) * EFCO_i)/PF_i \tag{C.105}$$

C.4.10.2 Carbon Emission of Agricultural Sector

$$MAGRI_{i,t} = (XS_{i,j,t} * EFCH4_i) * PF_i \tag{C.106}$$

$$SOIL_{i,j,t} = (DI_{i,j,t} * EFSOIL_i) * PF2_i \tag{C.107}$$

C.4.10.3 Carbon Emission of Industrial Sector

$$MCOINDUS_{i,j,t} = (DI_{i,j,t} * EFINDUS_i) * PF2_i \tag{C.108}$$

C.4.10.4 Overall Carbon Emission

$$SMCO_{j,t} = MCO_{i,j,t} \tag{C.109}$$

$$\begin{aligned} Total_{emiss_t} = \sum_j SMCO_{j,t} + \sum_i MCOFF_{i,t} + \sum_i MAGRI_{i,t} \\ + \sum_{ij} SOIL_{i,j,t} + \sum_{ij} MCOINDUS_{i,j,t} \end{aligned} \tag{C.110}$$

APPENDIX D
CARBON TAX CALCULATION

Carbon tax embedded inside indirect tax on product (TIC) as shown in this equation D.41:

$$TIC_{m,t} = (ttic_{m,t} + tco2_t ttico2_{m,t})[\left(PL_{m,t} + \sum_i PC_{i,t}\, tmrg_{i,m}\right) DD_{m,t} + ((1 + ttim_{m,t}) PWM_{m,t} e_t + \sum_i PC_{i,t}\, tmrg_{i,m}) IM_{m,t}] \tag{D.41}$$

$TIC_{m,t}$ denotes government revenue from indirect taxes on both domestically produced ($DD_{m,t}$) and imported ($IM_{m,t}$) commodities. The base tax on commodities is captured by $ttic_{m,t}$, while the carbon tax component is incorporated through $tco2_t$* $ttico2_{m,t}$, where $tco2_t$ is the carbon tax rate (in baht per ton of CO_2), and $ttico2_{m,t}$ represents the emission factor per unit of commodity, acting as a converter that translates carbon emissions into monetary value.

The carbon tax revenue is thus primarily calculated from $tco2_t$* $ttico2_{m,t}$, where emission coefficients are assigned to each commodity based on the carbon content of the energy sources used in their production—such as coal, natural gas, gasoline, jet fuels, LPG, diesel, fuel oil, other fossil fuels, gasohol, and biodiesel. These estimated emissions reflect how much each activity sector utilizes these carbon-intensive inputs. This study focuses solely on Scope 1 emissions, which represent direct emissions from production activities, and does not account for upstream or downstream (Scope 2 or 3) emissions. In this model, emissions are monetized once per unit of commodity through an embedded emission coefficient. The tax is imposed on the final commodity only, meaning the upstream fuel inputs are not taxed separately. As a result, each ton of CO_2 is taxed only once, effectively avoiding any double taxation.

APPENDIX E
EMISSION GROUPS BY SECTOR

Table E.1

Emissions Grouped by Sector

Power Generation (SMCO_POW)			Others (SMCO_OTH)	
Sec	**Activity**		**Sec**	**Activity**
10	Coal		1	Paddy
11	Oil Gas		2	Corn
32	Electricity		3	Cassava
			4	Cane
Transportation (SMCO_TRA)			5	Oil palm
Sec	**Activity**		6	Livestock
35	Rail transport		7	Chcoal
36	Road transport		8	Fishery
37	Water transport		9	Residue agriculture
38	Air transport		12	Mining
39	Other transport		13	Food
			14	Palmoil
Industry (SMCO_IND)			15	Rice
Sec	**Activity**		16	Starch
21	Paper		17	Maize
22	Ethanol		18	Sugar
23	Chemical		19	Textile
24	Refinery		20	Wood
25	Rubber		40	Service
26	NonMetal			
27	Iron			
28	Metal			
29	Motor			
30	Machine			
31	Other industry			
33	Construction			
34	Trade			

Note. From the Author's compilation.

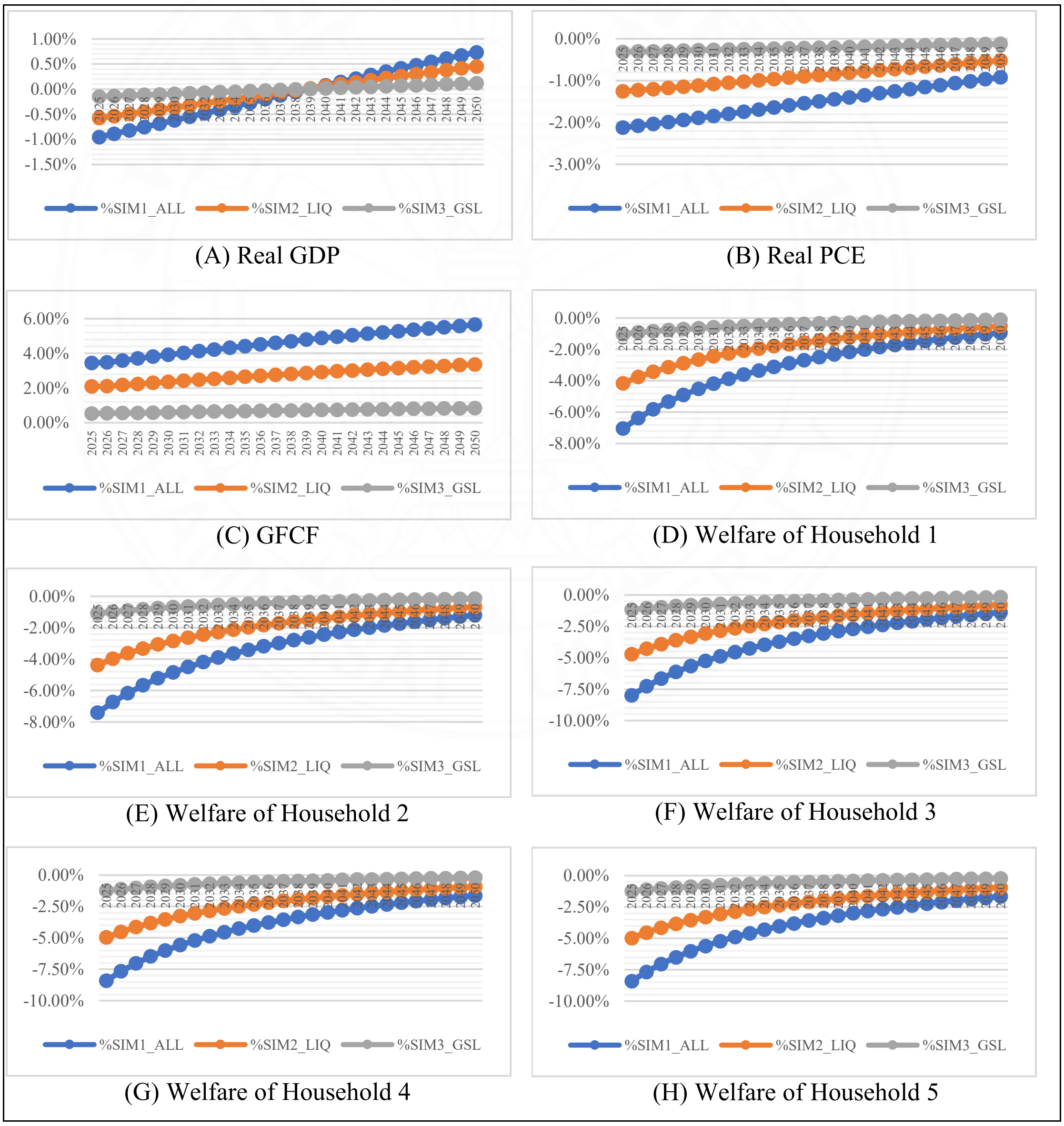
APPENDIX F
DYNAMIC TRENDS ACROSS SCENARIOS

F.1 Impacts of Carbon Tax Implementation

F.1.1 Results under BAU Path

Figure F.1

Carbon Tax Impacts on Macroeconomic Variables (BAU Path)



(A) Real GDP (B) Real PCE

(C) GFCF (D) Welfare of Household 1

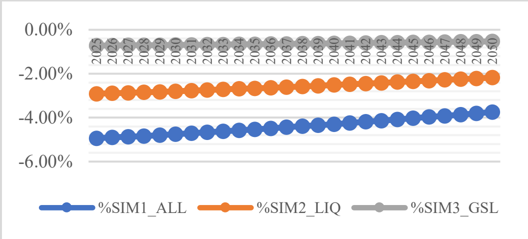
(E) Welfare of Household 2 (F) Welfare of Household 3

(G) Welfare of Household 4 (H) Welfare of Household 5

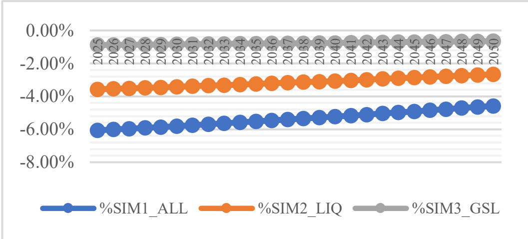
Note. From the Author's calculation.

Figure F.2

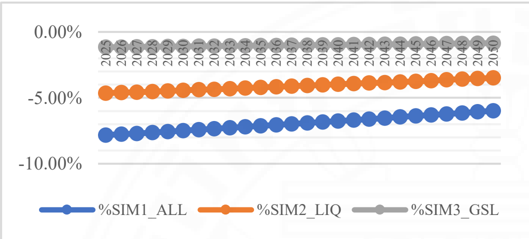
Carbon Tax Impacts on Emission Variables (BAU Path)



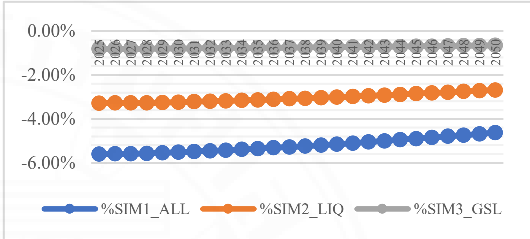
(A) Total Emission



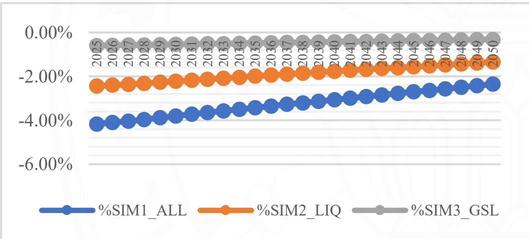
(B) Emission from Energy Used



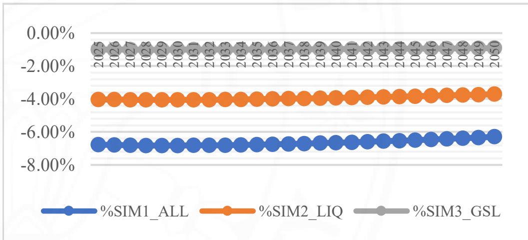
(C) Energy Used Emission from Power Generation Sector



(D) Energy Used Emission from Transportation Sector



(E) Energy Used Emission from Industrial Sector



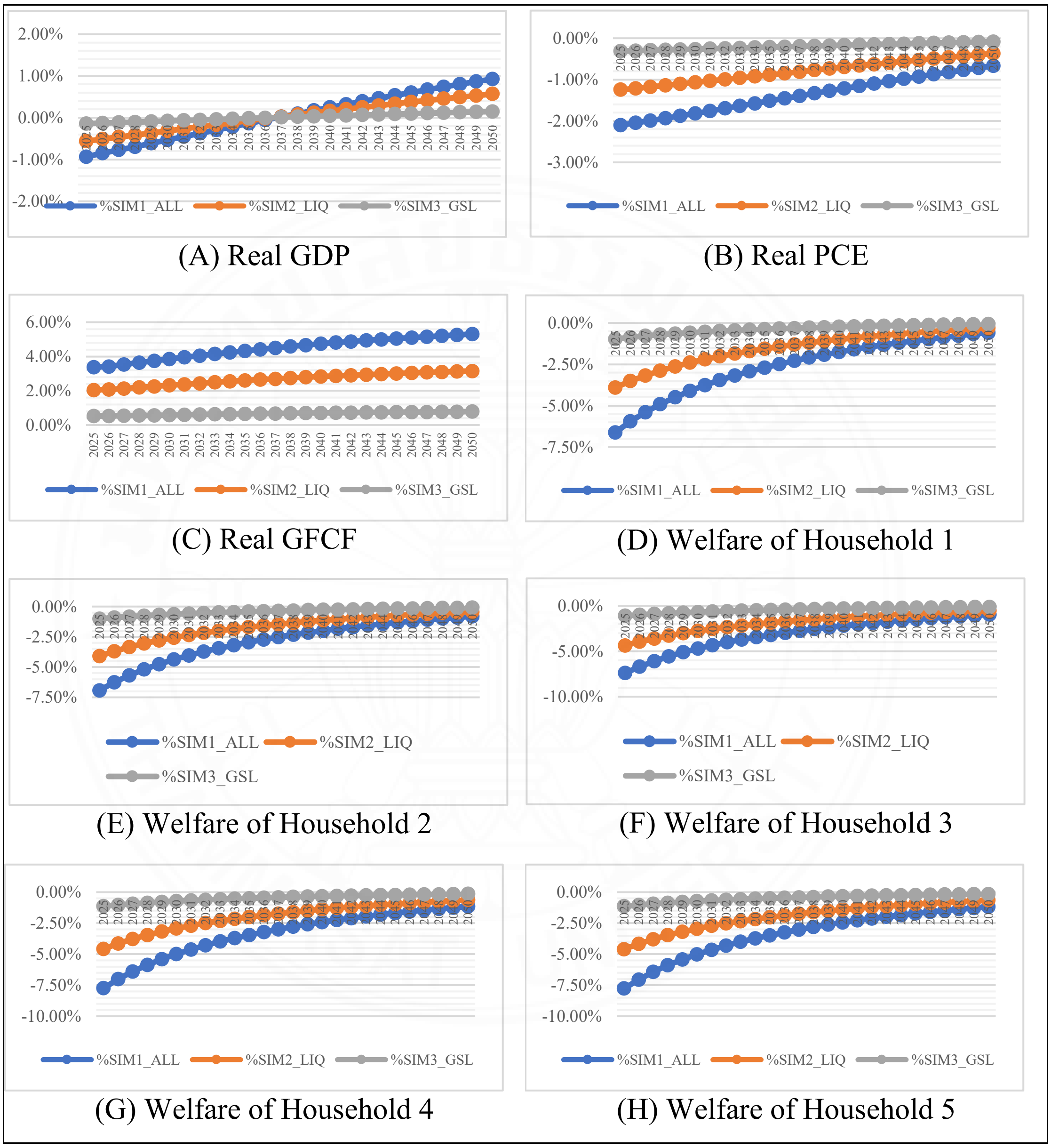
(F) Energy Used Emission from Other Sector

Note. From the Author's calculation.

F.1.2 Results under NDC Path

Figure F.3

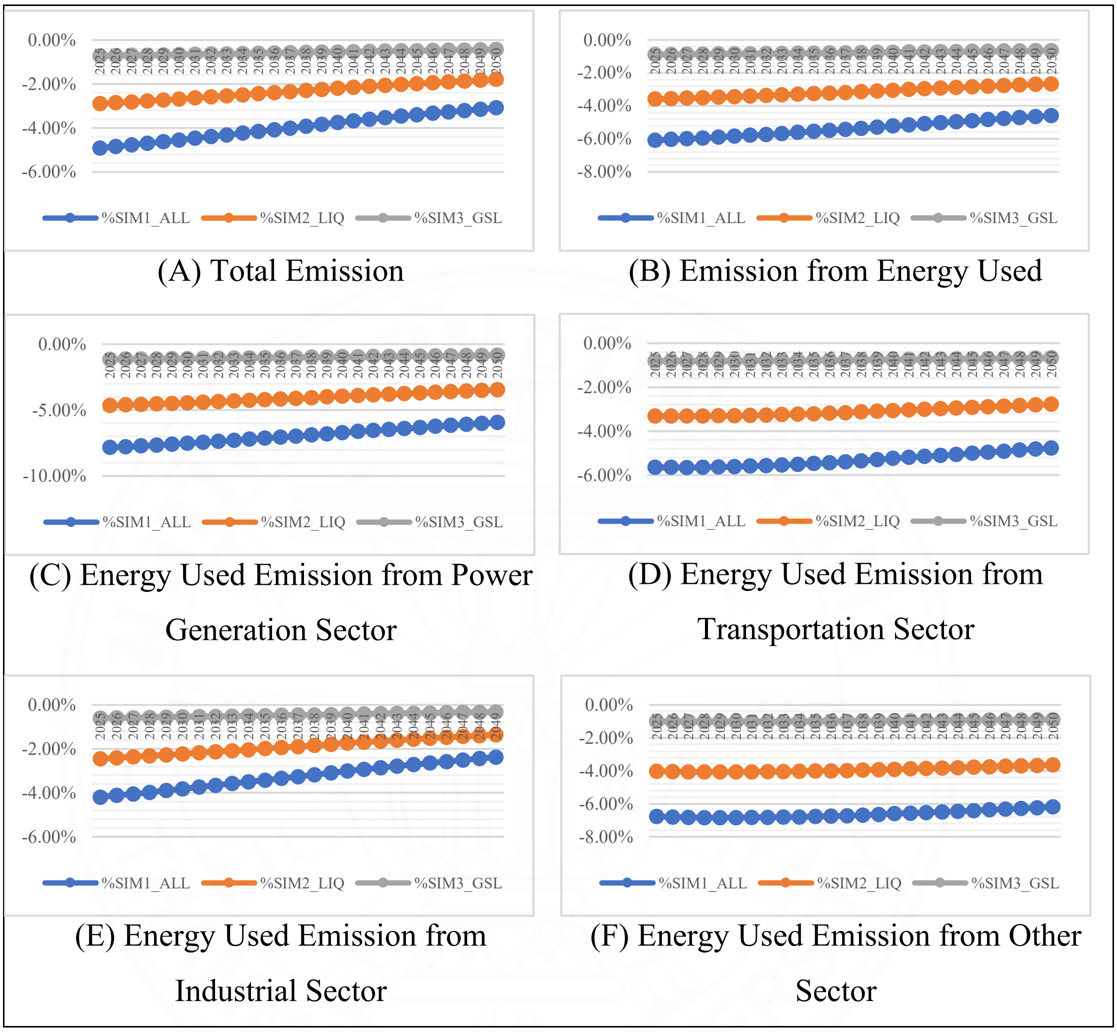
Carbon Tax Impacts on Macroeconomic Variables (NDC Path)



Note. From the Author's calculation.

Figure F.4

Carbon Tax Impacts on Emission Variables (NDC Path)



(A) Total Emission

(B) Emission from Energy Used

(C) Energy Used Emission from Power Generation Sector

(D) Energy Used Emission from Transportation Sector

(E) Energy Used Emission from Industrial Sector

(F) Energy Used Emission from Other Sector

Note. From the Author's calculation.

F.1.3 Comparative Analysis of Carbon Tax Effects under Both Pathway

Overall, the dynamic trends associated with carbon tax implementation indicate that a broader tax base generates larger short-term economic shocks but results in stronger long-term gains in real GDP and gross fixed capital formation (GFCF). In contrast, real private consumption expenditure (PCE), a proxy for household consumption, experiences a deeper initial decline, reflecting a higher early burden on households. Household welfare trajectories, as illustrated in the accompanying graphs, support the results presented in Tables 4.3 and 4.5, showing that high-income households (HH4 and HH5) experience larger absolute welfare losses than lower-income households (HH1–HH3). However, in relative terms, low-income households may bear more severe impacts due to their limited economic resilience.

In terms of emissions, the strongest reduction effects are observed in the early years and gradually diminish over time. The power generation and transport sectors respond most significantly to carbon taxation, due to their high carbon intensities and greater price sensitivity. In contrast, emissions from industrial activities decline more moderately, suggesting that carbon pricing alone may be insufficient to drive deep decarbonization in the absence of complementary structural reforms.

The comparison between the BAU and NDC pathways reveals that the BAU scenario generates slightly stronger responses in key macroeconomic indicators, including real GDP, GFCF, and household consumption. This is primarily attributed to the absence of accompanying climate policy measures—such as fuel switching or improvements in energy efficiency—that are embedded in the NDC scenario. Consequently, economic burdens are more directly transmitted under BAU.

Moreover, in the absence of structural transition incentives, real GDP under BAU experiences a steeper initial contraction and slower recovery. While investment reacts more strongly under BAU, household consumption and welfare are more persistently affected, reflecting higher cost pass-throughs without behavioral or structural adjustments to mitigate the burden. The regressive nature of these impacts is more pronounced in the BAU scenario, potentially widening welfare disparities across household groups. On the emissions side, BAU results in a greater magnitude of reduction, largely due to higher baseline emissions.

This first set of simulations suggests that a broader tax base reinforces economy-wide price signals but also imposes a greater burden on households, particularly in the early stages. Despite differences in emission pathways, both scenarios underscore the need for integrated climate policy frameworks that combine carbon pricing with structural measures in order to meet Thailand’s emission targets while safeguarding macroeconomic stability and equity.

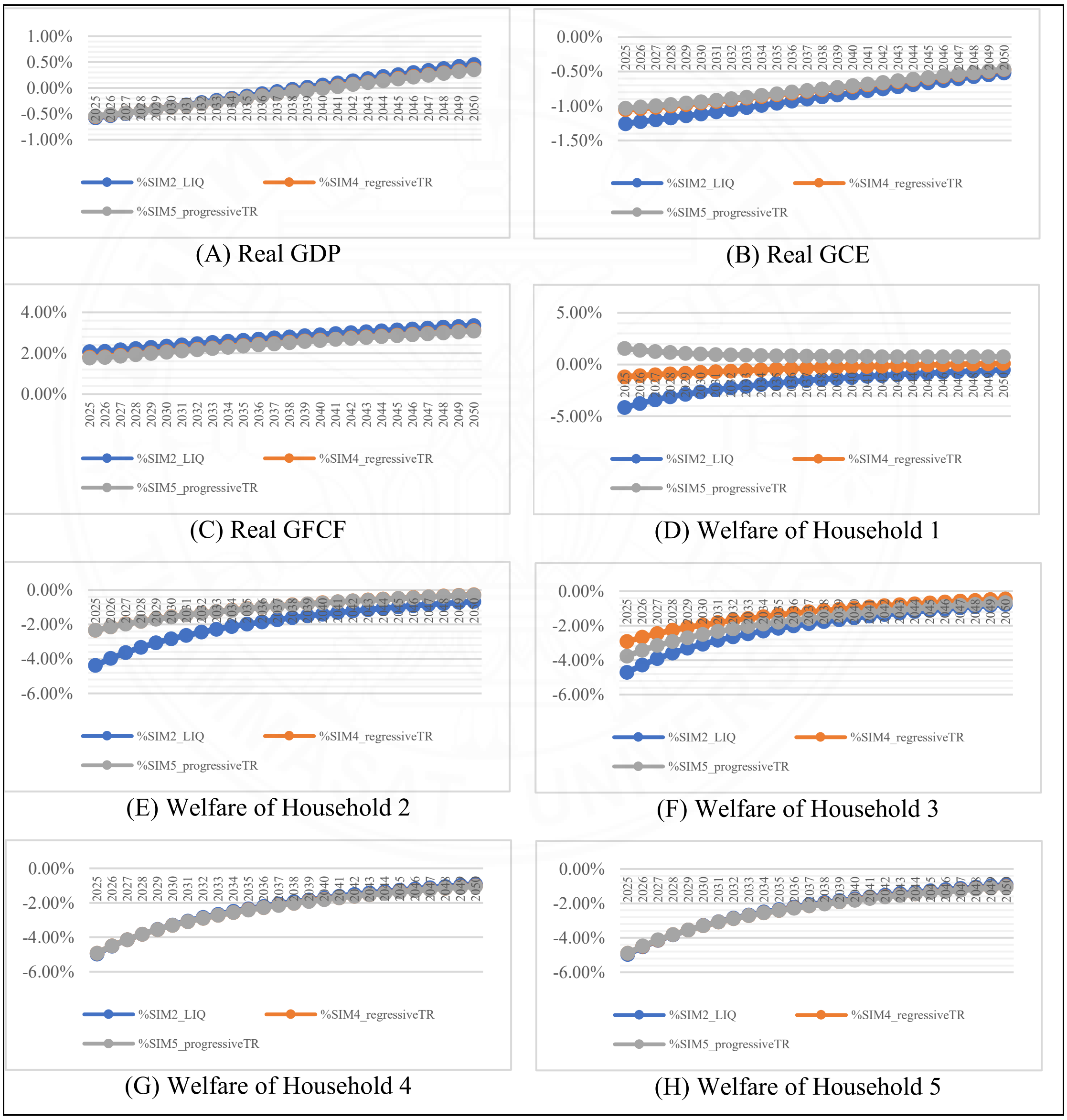
F.2 Carbon Tax Revenue Recycling Strategies

F.2.1 Equity Considerations

F.2.1.1 BAU path

Figure F.5

Direct Transfer Impacts on Macroeconomic Variables (BAU Path)



(A) Real GDP (B) Real GCE

(C) Real GFCF (D) Welfare of Household 1

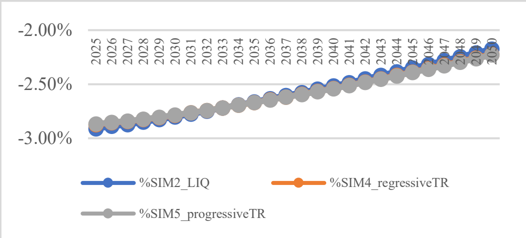
(E) Welfare of Household 2 (F) Welfare of Household 3

(G) Welfare of Household 4 (H) Welfare of Household 5

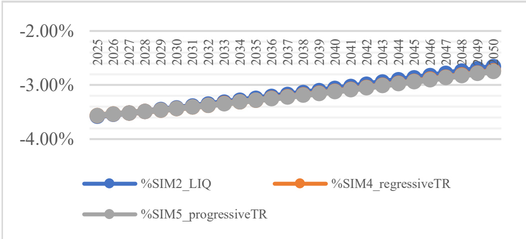
Note. From the Author's calculation.

Figure F.6

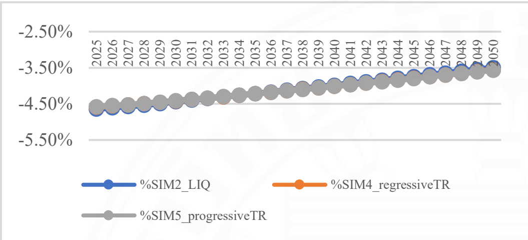
Direct Transfer Impacts on Emission Variables (BAU Path)



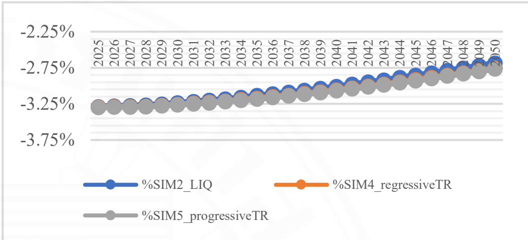
(A) Total Emission



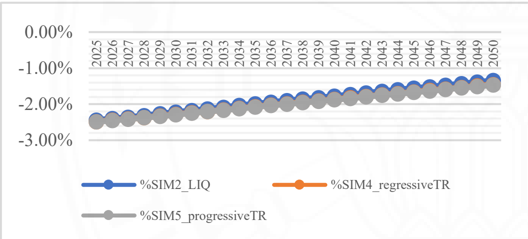
(B) Emission from Energy Used



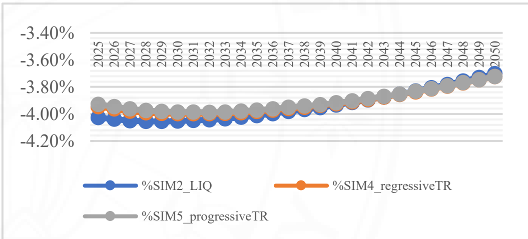
(C) Energy Used Emission from Power Generation Sector



(D) Energy Used Emission from Transportation Sector



(E) Energy Used Emission from Industrial Sector



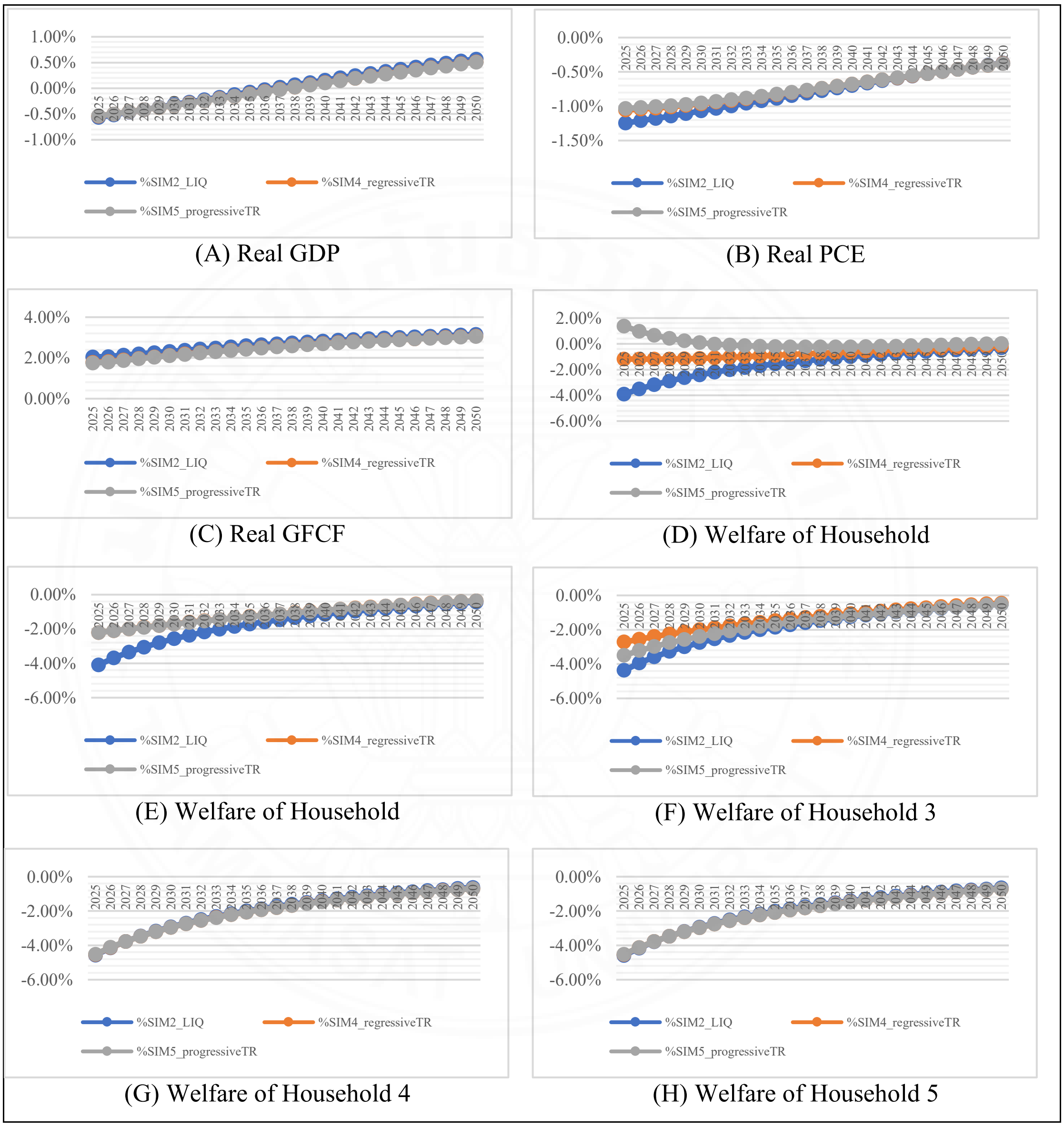
(F) Energy Used Emission from Other Sector

Note. From the Author’s calculation.

F.2.1.2 NDC path

Figure F.7

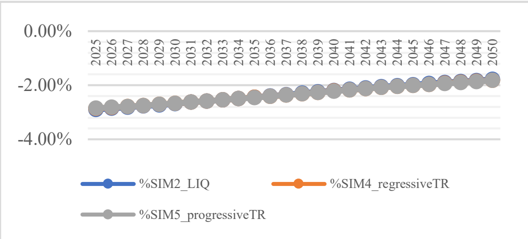
Direct Transfer Impacts on Macroeconomic Variables (NDC Path)



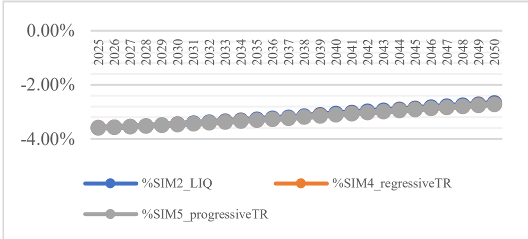
Note. From the Author's calculation.

Figure F.8

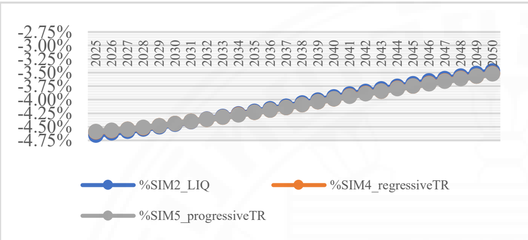
Direct Transfer Impacts on Emission Variables (BAU Path)



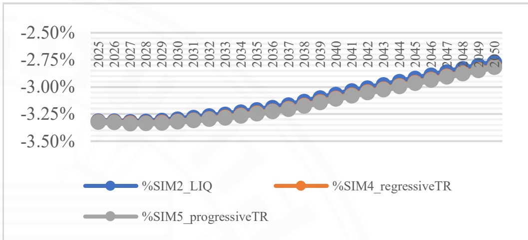
(A) Total Emission



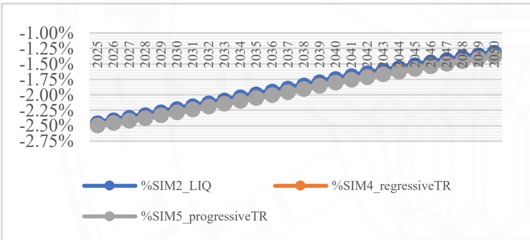
(B) Emission from Energy Used



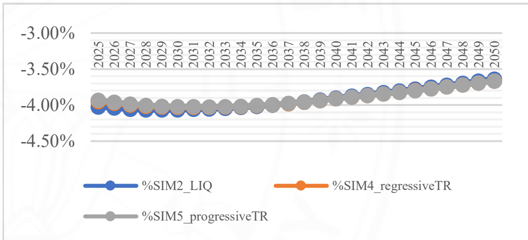
(C) Energy Used Emission from Power Generation Sector



(D) Energy Used Emission from Transportation Sector



(E) Energy Used Emission from Industrial Sector



(F) Energy Used Emission from Other Sector

Note. From the Author's calculation.

F.2.1.3 Comparative Analysis of Direct Transfer Effects under Both Pathways

Under equity considerations, the graphical results confirm the findings presented in Chapter 4. Both types of direct transfers—progressive and regressive—lead to slight declines in real GDP and GFCF compared to the no-transfer case. However, real private consumption expenditure (PCE) improves in both scenarios, with the progressive transfer yielding slightly higher gains, indicating better protection of household consumption. While the overall PCE trend shows consumption gains under both schemes, the disaggregated results reveal that progressive transfers most benefit the lowest-income household group (HH1), whereas regressive transfers provide relatively greater gains to other low-income households (HH2 and HH3).

While the NDC pathway demonstrates superior performance in terms of overall macroeconomic stability and investment stimulation, the BAU pathway shows slightly greater marginal improvement in household welfare—measured in percentage point changes—relative to the no-recycling case. This higher marginal gain under BAU is primarily due to its larger initial welfare losses, absence of transition-related costs, and more concentrated regressive tax effects, which make welfare gains from revenue recycling appear more significant. Nevertheless, the inclusion of fuel switching and structural adjustments in the NDC scenario still contributes to mitigating economic distortions, stimulating long-term investment, and supporting more stable household consumption. In contrast, the BAU pathway, which lacks such transitional mechanisms, results in deeper initial macroeconomic contractions and more persistent regressive pressures—indicating a less adaptive policy environment overall.

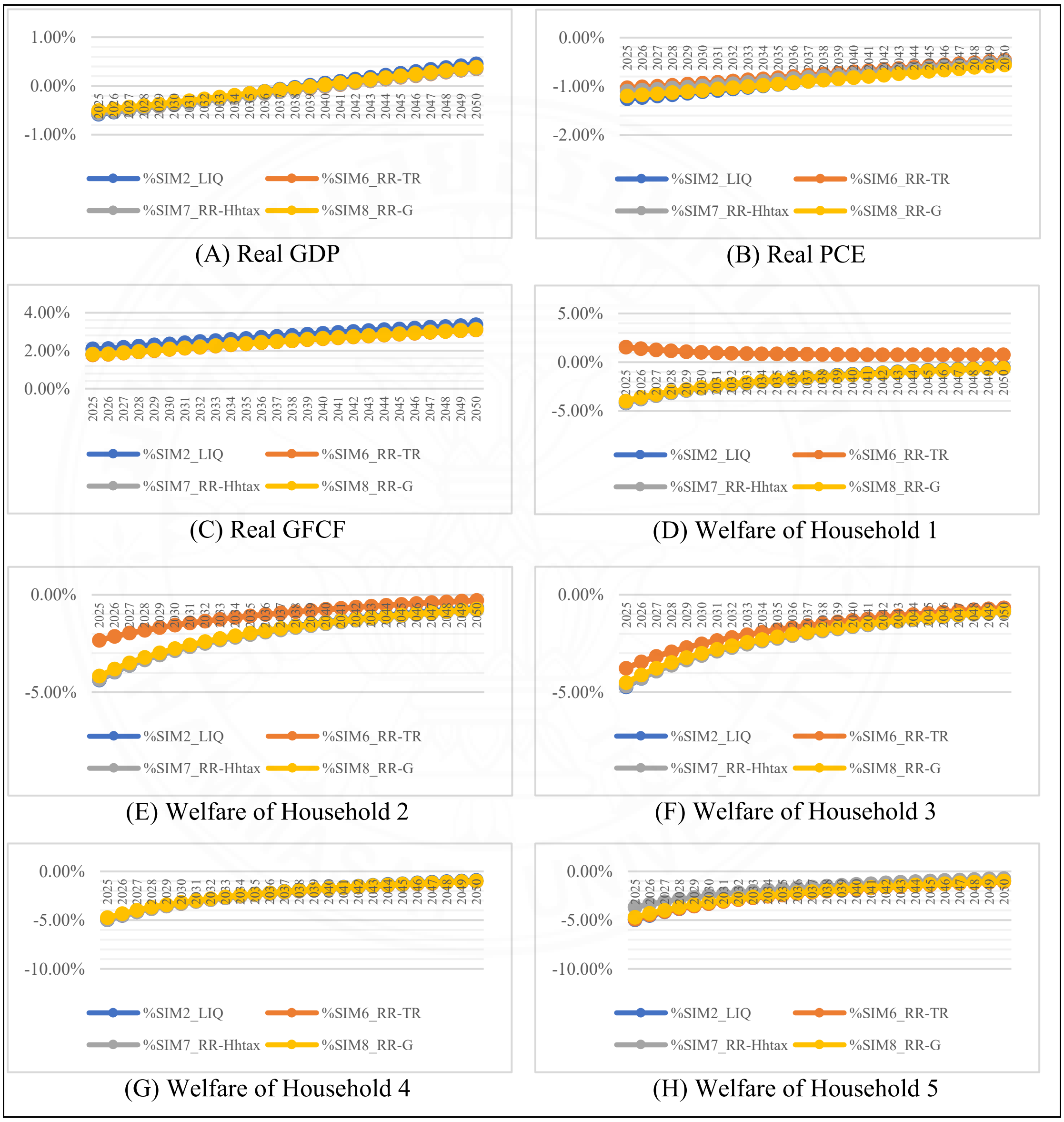
This equity-focused simulation confirms that progressive transfers better protect the poor, whereas regressive transfers strike a balance between equity and efficiency—However, progressive schemes remain the preferred option for reducing inequality and enhancing policy acceptance.

F.2.2 Efficiency Considerations

F.2.2.1 BAU path

Figure F.9

Direct Transfer Impacts on Macroeconomic Variables (BAU Path)



(A) Real GDP

(B) Real PCE

(C) Real GFCF

(D) Welfare of Household 1

(E) Welfare of Household 2

(F) Welfare of Household 3

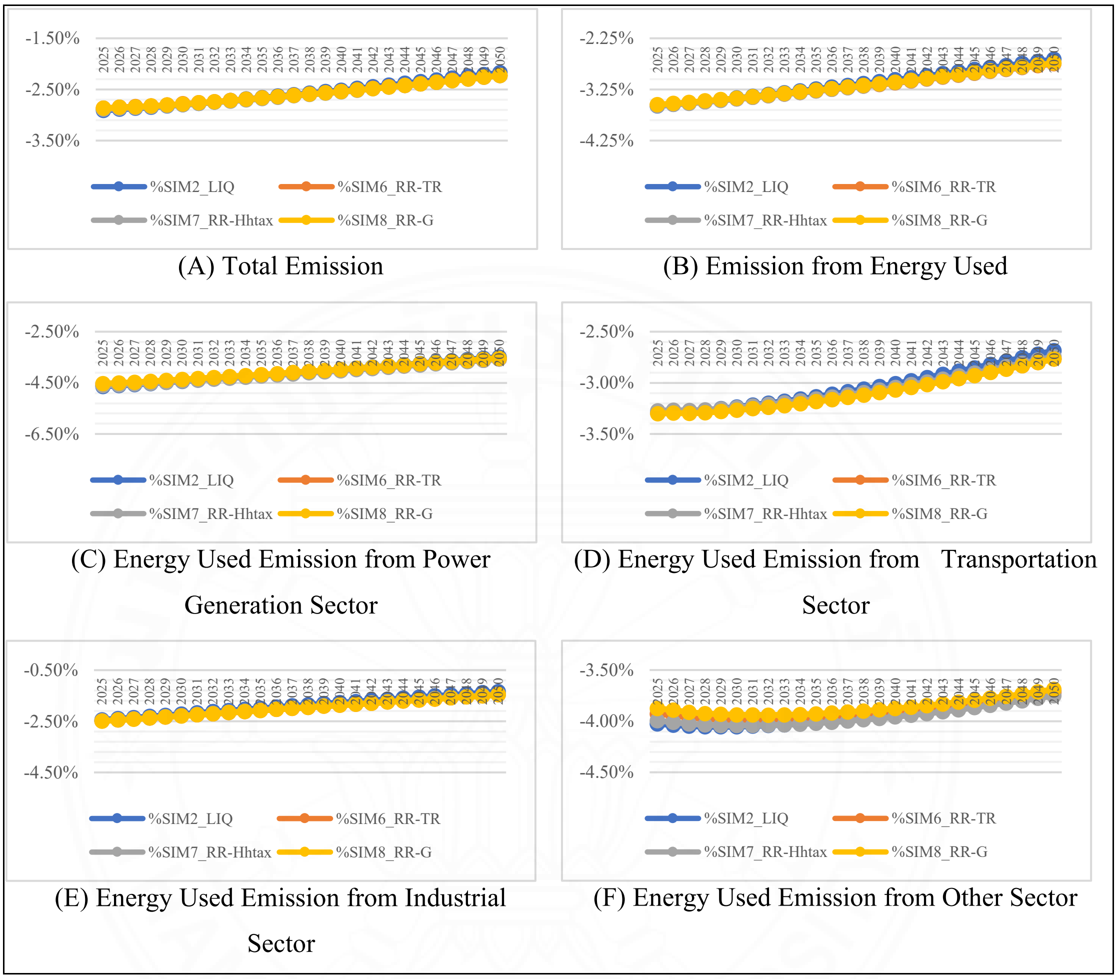
(G) Welfare of Household 4

(H) Welfare of Household 5

Note. From the Author's calculation.

Figure F.10

Direct Transfer Impacts on Emission Variables (BAU Path)



(A) Total Emission

(B) Emission from Energy Used

(C) Energy Used Emission from Power Generation Sector

(D) Energy Used Emission from Transportation Sector

(E) Energy Used Emission from Industrial Sector

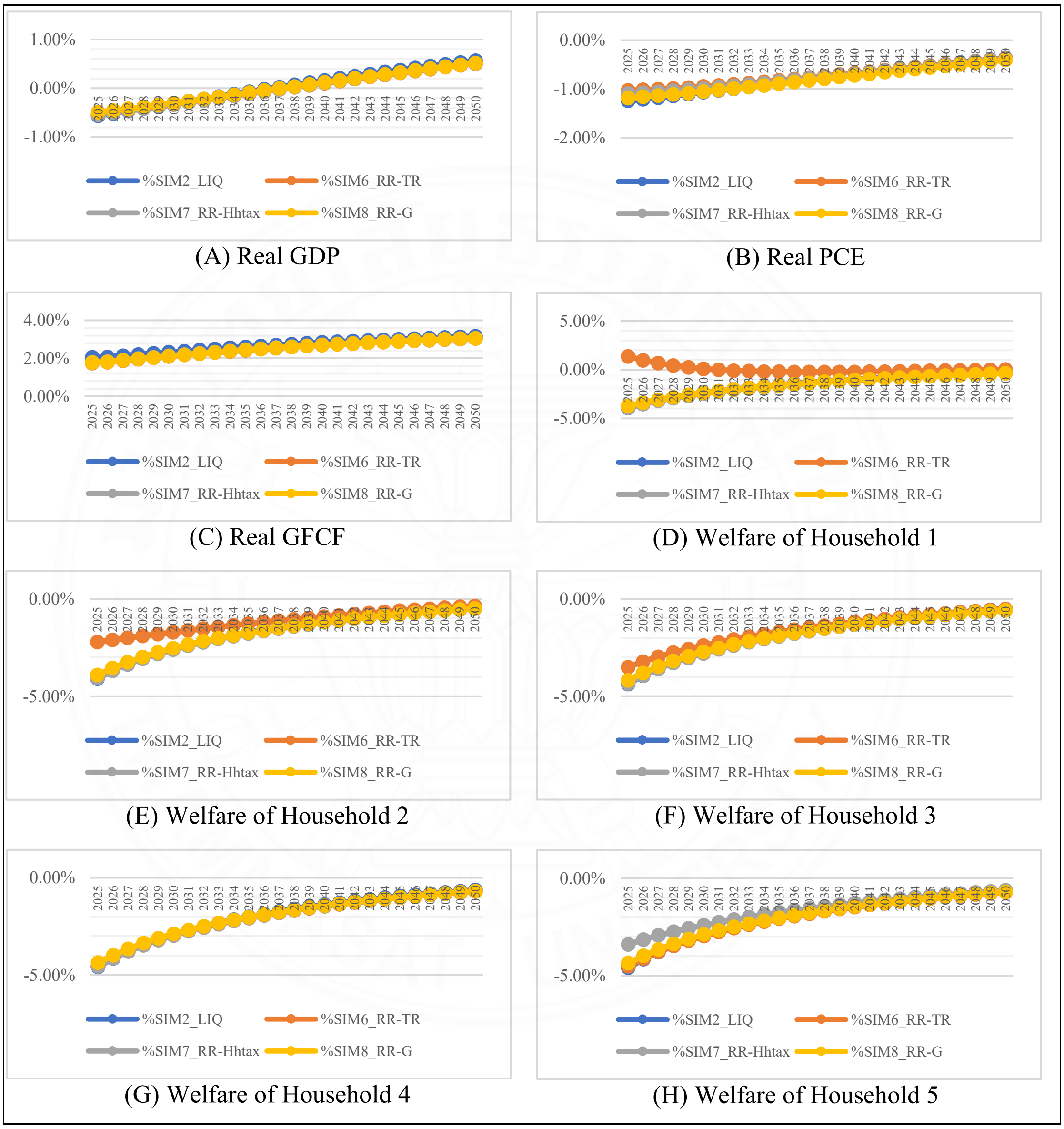
(F) Energy Used Emission from Other Sector

Note. From the Author's calculation.

F.2.2.2 NDC path

Figure F.11

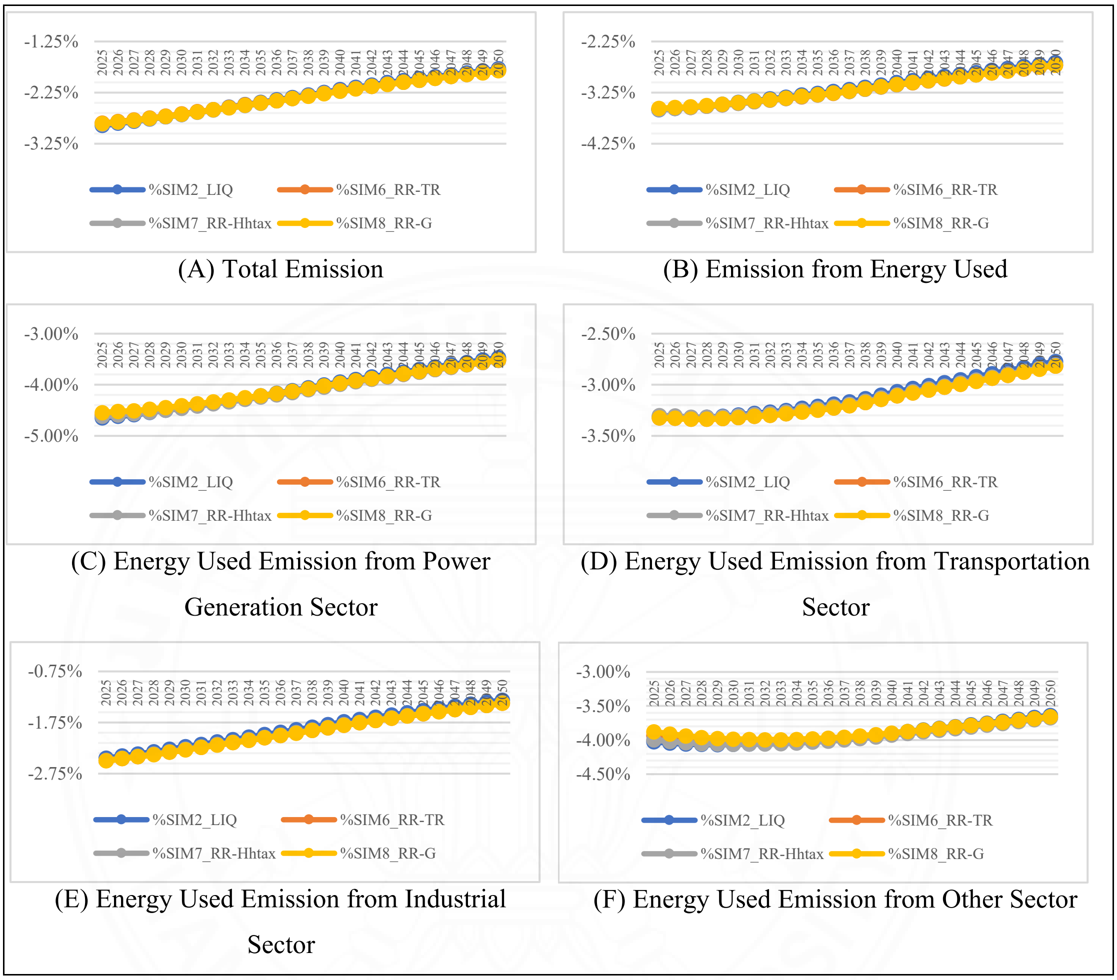
Direct Transfer Impacts on Macroeconomic Variables (NDC Path)



Note. From the Author's calculation.

Figure F.12

Direct Transfer Impacts on Emission Variables (NDC Path)



(A) Total Emission

(B) Emission from Energy Used

(C) Energy Used Emission from Power Generation Sector

(D) Energy Used Emission from Transportation Sector

(E) Energy Used Emission from Industrial Sector

(F) Energy Used Emission from Other Sector

Note. From the Author's calculation.

F.2.2.3 Comparative Analysis of Revenue Recycling Effects under Both Pathways

Across simulations, all revenue-recycling schemes under efficiency considerations contribute to long-term GDP recovery, with government spending delivering the strongest short-term boost. Investment increases under all options, though the levels remain below those observed in the no-transfer scenario. For households, real private consumption expenditure (PCE) shows earlier improvements—particularly during the first decade—while welfare outcomes vary considerably across income groups. Direct transfers provide the greatest benefits to lower-income households, especially Household 1, whereas income tax reductions tend to favor higher-income groups. Government spending offers moderate welfare improvements across all household groups.

These results are consistent across both the BAU and NDC pathways. However, the marginal improvements from revenue recycling are more pronounced under the BAU scenario. This is largely due to its higher initial welfare losses, the absence of structural transition costs, and more concentrated regressive tax effects, which make the gains from recycling appear larger in relative terms. In contrast, the NDC pathway, with embedded structural reforms, results in smaller initial losses and more balanced economic and distributional outcomes.

APPENDIX G
CARBON TAX REVENUE

G.1 Carbon Tax Revenue under BAU path

Table G.1

Carbon Tax Revenue under BAU Path (Unit: Billion Baht)

	CT-rev_ALL	CT-rev_LIQ	CT-rev_GSL
2025	52.32	29.91	7.15
2026	53.20	30.41	7.27
2027	54.09	30.92	7.40
2028	54.99	31.43	7.52
2029	55.93	31.97	7.65
2030	56.88	32.51	7.78
2031	57.85	33.07	7.91
2032	58.72	33.56	8.03
2033	59.59	34.06	8.15
2034	60.48	34.57	8.27
2035	61.40	35.10	8.40
2036	62.33	35.63	8.52
2037	63.29	36.18	8.65
2038	64.16	36.67	8.77
2039	65.04	37.18	8.89
2040	66.02	37.74	9.03
2041	66.96	38.28	9.16
2042	67.85	38.78	9.28
2043	68.72	39.28	9.40
2044	69.52	39.74	9.50
2045	70.29	40.18	9.61
2046	71.09	40.63	9.72
2047	71.78	41.03	9.81
2048	72.48	41.43	9.91
2049	73.18	41.83	10.01
2050	73.82	42.20	10.09
CTrev/GDP	0.38%	0.21%	0.05%

Note. From the Author's calculation.

G.2 Carbon Tax Revenue under NDC path

Table G.2

Carbon Tax Revenue under NDC Path (Unit: Billion Baht)

	CT-rev_ALL	CT-rev_LIQ	CT-rev_GSL
2025	49.58	28.34	6.78
2026	47.48	27.14	6.49
2027	45.47	25.99	6.22
2028	43.55	24.89	5.95
2029	41.75	23.87	5.71
2030	40.03	22.88	5.47
2031	38.38	21.94	5.25
2032	36.86	21.07	5.04
2033	35.40	20.24	4.84
2034	34.00	19.44	4.65
2035	32.72	18.70	4.47
2036	31.49	18.00	4.31
2037	30.30	17.32	4.14
2038	29.19	16.68	3.99
2039	28.11	16.07	3.84
2040	27.08	15.48	3.70
2041	26.13	14.94	3.57
2042	25.21	14.41	3.45
2043	24.33	13.91	3.33
2044	23.90	13.66	3.27
2045	23.48	13.42	3.21
2046	23.07	13.19	3.15
2047	22.76	13.01	3.11
2048	22.45	12.83	3.07
2049	22.15	12.66	3.03
2050	21.23	12.13	2.90
CTrev/GDP	0.20%	0.11%	0.03%

Note. From the Author's calculation.