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Contribution of Mitigation Actions to Decarbonization in Laos

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Abstract

This study assesses the economic and environmental impact of introducing decarbonization policies in Lao. The main assessment was done on the transport and waste sectors of the country. The explanation is divided into several chapters as described as follows.

Chapter one explains the background and general socioeconomic and environmental situation in Lao. The average economic growth during the last five years (2016-2020) is around 5.8% per year. But the growth in the year 2021 dropped to 3.5%. The GDP per capita, also presented in this chapter, in 2020 was USD 2,660, and the gross national income (GNI) per capita was USD 2,100. The export value increased by 23% of the national growth rate during 2015-2020. Even though Laos is rich in forest and biodiversity, forest cover decreased from 70% in 1940 to 40% in 2015. At the same time, the city's air pollution is getting worse due to the growing number of motor vehicles and the rapid urbanization in Laos. The total number of registered private vehicles has been increased at an average growth rate of 9.4% since 2010. Vehicles running on traditional fuels will result in extensive vehicular pollution and worsen the urban environment. The increase of solid waste in urban areas and unappropriated handling can also affect city air pollution.

Although Laos has developed a series of policies to mitigate GHG emissions, based on the literature review, the number of peer-review research papers are still limited. Therefore, this chapter also mentions the main objective of this study, which is to measure the impacts of emission mitigation policies in Laos by considering the emission reduction countermeasures in road transport and solid waste treatment.

The second chapter describes the projection of GHG emissions, including emissions from the transportation and waste sectors. The average GDP growth was estimated at 4% during 2021-2025. This chapter also shows the trend of vehicle growth that Laos will have around 6.5 million vehicles by 2050, resulting in emissions from this sector of around 12,000 ktCO_2. The population is projected to grow slower at 0.7% in 2040. The national GHG emissions from the latest national inventory and the ambition to reduce GHG emissions are explained here. The history of GHG emissions is mentioned, in which the main source of GHG emission was from the AFOLU sector, accosting for 78% of the total emission in 2014. However, emission from the transport sector has remarkably increased. Emission from improper solid waste treatment also contribute to pollution since the waste collection rate is relatively low. It is also because the waste is disposed unproperly by households. The related mitigation technologies are provided with some detailed descriptions. Those mitigation countermeasures are also listed in Nationally Determined Contribution (NDC). And the updated NDC 2020 has set an ambitious target to reduce GHG emissions, 2030 target of 60% GHG emission reduction compared to the base year, and target 2050 net zero emissions, for examples.

The third chapter explains the methodology and data used in this study. The AIM/CGE [Laos] model was developed by Asia-Pacific Integrated Model (AIM) team is applied to assess the introduction of new technologies for the potential emission reduction and impacts to the economy, especially the Lao GDP. The primary data to develop the

AIM/CGE [Laos] model are based on the Laos input-output (IO) table in 2014. For this study, the Laos IO table 2014 with 35 sectors is used. The base year is selected as 2014 due to the availability of the latest national greenhouse gas inventory that was estimated through a survey in 2014. Additional input socio-economic data to set a future scenario are potential gross domestic product (GDP), the trade balance, capacity of power generation, and population growth.

In chapter 4, the simulation result of the assessment of the transportation and waste sectors are presented. The simulation result is shown by comparing the result for each scenario, generally consisting of Business as usual (BaU) and Counter Measures (CM) scenarios. According to the results, to contribute to decarbonization in Laos, introducing EV penetration in road transport could contribute to reducing CO_2 emission from the transport sector by around 36% in 2050 compared to the BaU scenario. Subsidy for EV costs will also support EV promotion, reducing emissions by around 56% in 2050. However, introducing a carbon tax at USD 10/tCO_2 will have an insignificant impact on CO_2 reduction. But EV introduction will create a GDP loss of one per cent in 2050. Regarding the introduction of increasing solid waste recycling, The GHG emissions from MSW management, under the BaU scenario, will increase more than seven times in 2050. However, by introducing MSW recycling, GHG emissions can reduce to 93% in 2050 compared to the BaU scenario.

Finally, in chapter 5, the conclusion and some policy recommendations based on the simulation results are presented. Introducing EVs will have a significant on CO_2 emission reduction. However, the additional introduction of only carbon tax in the transport sector will not influence household behavior for energy consumption, resulting in no impact on CO_2 emission. Nevertheless, mitigation actions (EV and biofuel), carbon tax, and subsidy countermeasures can significantly affect their final energy consumption and CO_2 emission. With the introduction of mitigation countermeasures, except for introducing carbon tax only, the GDP growth will gradually decline. By introducing of MSW recycling, can influence GHG emissions reduction. With an increase in the recycling rate, GHG emissions in the sectors in which the recycled material is provided will decrease. But the recycling sector will increase energy-related CO_2. In order to achieve decarbonization in Lao, material recycling performed in an energy-efficient process will be important.

Table of Content

Table of Content i
List of Figure iv
List of Tables v
1. Introduction 1
1.1 Background 1
1.1.1 Road Transport and Waste Management Circumstances in Laos 1
1.1.2 Economic Situation 3
1.2 Previous Studies and the Importance of the Study 5
1.3 Novelty and Research Objective of Study 8
1.4 Organization of Study 8
2. GHG Emissions and The Emission Mitigation Targets 9
2.1 Laos GHG Emissions 9
2.1.1 GHG Emissions from Energy Sector 11
2.1.2 GHG Emissions from Waste Sector 12
2.2 GHG Emission Reduction Ambitions and Mitigation Technologies 13
2.2.1 Mitigation Technologies for Energy and Transport Sectors 15
2.2.2 Mitigation Technologies for Waste Sector 17
2.3 Goal of this Dissertation 20
4. Methodology 21
3.1 General CGE Framework 21
3.2 Model Structure 23
3.2.1 Overall Model Structure 23
3.2.2 Updated of CGE Model Structure in this Study 25
3.2.3 Formulation of CGE Model Structure 27
3.2.3.1.1 Activity based on existing capital 28
3.2.3.1.2 Activity for Sector Based on New Capital 31
3.1.2 Household sector 35
3.1.2.2 Composition of Non-Energy Goods 36
3.1.2.3 Energy Service Demand 36
3.3.2.4 Energy Service Using New Equipment 37
3.1.2.5 Energy Service Using Existing Equipment 38
3.1.3 Government Sector 39
3.1.4 Fix Capital Formation 40
3.1.5 Relationship between Output, Export, Import, and Domestic Market 41
3.1.6 Market equilibrium 43
3.1.6.1 Production Market 43

3.1.6.2 Market of Domestic Supply Goods 43
3.1.6.3 Market of labor 44
3.1.6.4 Market of Capital 44
3.1.6.5 Market of GHG 44
3.1.6.6 Household energy service 45
3.2 Recursive Dynamic Process 45
3.2.1 Labor Supply 45
3.2.2 Capital Stock Accumulation and Investment 46
3.2.3 Update of Parameter 47
3.3 Waste generation 48
3.4 Data 49
3.5 Scenarios Development 52
3.5.1 Business as Usual (BaU) 52
3.5.2 Countermeasure Scenarios 53
3.5.2.1 Introduction of EV Technology 53
3.5.2.2 Extension of Waste Recycle 54
4. Results 55
4.1 BaU Scenario 55
4.2 Assessing the Impacts of Introducing of Carbon Tax and Technologies for Road Transportation in Laos 58
4.2.1 Comparison of GDP 58
4.2.2 Comparison of Carbon Dioxide Emission in Transport Sector 59
4.2.3 Number of Private Vehicle 60
4.2.3 Comparison of Final Energy Consumption 61
4.2.4 Conclusion on simulation of Introducing of Carbon Tax and Technologies for Road Transportation. 62
4.3. Simulation Result on the Extension of Waste Recycle 63
4.3.1 Gross Domestic Product 63
4.3.2 GHG Emissions from MSW 64
4.3.3 Final Waste Disposal 65
4.3.4 Conclusion on the Simulation for the Solid Waste Management 66
4.4.1 Sensitivity Analysis for Elasticity of Substitution 67
4.4.2 Sensitivity Analysis for Income Elasticity 68
5. Conclusion and Future Works 71
5.1 Remarkable Findings 71
5.2 Conclusion 72
5.3 Policy Implications 73

5.4 Future Works ... 74
Acknowledgement ... 75
Appendix A ... 76
Appendix B ... 79
References ... 80

List of Figure

Fig 1.1. GDP based on constant prices 2016-2021 4
Fig 1.2. GDP growth rate during 2010-2021 5
Fig 2.1. Lao's GHG emissions proportion 1990-2014. 9
Fig 2.2. GHG emissions in 2014, unit: ktCO2eq. 11
Fig. 2.3. GHG emission from the energy sector, 1990-2014. 11
Fig. 2.5. Number of road vehicles and projection. 12
Fig. 2.6. Emission from the waste sector (unit: $ktCO_2eq$). 13
Fig. 2.7. Waste management hierarchy 18
Fig. 3.1. Outline of the study 21
Fig. 3.2. Simplified CGE model framework 22
Fig. 3.3 General CGE model structure 24
Fig. 3.4 CGE structure for production sector 24
Fig 3.5: CGE structure of energy consumption in household sector 26
Fig. 3.6. Flow of MSW in this model 27
Fig 3.7 Production sector using existing capital 28
Fig. 3.8 Structure of production using new capital 32
Fig. 3.9. Relationship between Output, Export, Import, and Domestic Markets 41
Fig. 4.1 GDP 55
Fig. 4.2 GHG emissions 56
Fig. 4.3 Number of private vehicle 56
Fig. 4.4 Final energy consumption 57
Fig. 4.5 Solid waste generation 57
Fig. 4.6. Comparison of GDP value in the BaU and countermeasure scenario 59
Fig. 4.7. Comparison of CO_2 emission in transport sector 60
Fig. 4.8 Number of vehicles in EV scenario 61
Fig. 4.9 Total final energy consumption 62
Fig. 4.11 GHG emissions from MSW management 64
Fig. 4.12 Total GHG 65
Fig. 4.13 Final waste disposal 66
Fig. 4.16 Waste generation 69
Fig. 4.17 GDP 70
Fig. 4.18 GHG emission 70

List of Tables

Table 2.1. Total GHG emission in 2014 10
Table 3.1. Modified Input-Output Table Commodity Classification 50
Table 3.2. GDP Growth Rate 51
Table 3.3 Number of Population 52
Table 3.4. Scenario in this analysis 54
Table 3.5 Ratio of waste collection and recycles 54

1. Introduction

Introduction starts with the background to show the emissions situation and economic condition in Laos. Next section will show literature review on the related matters. Having the literature review to identify the research gap, the research objectives and novelty of this study are informed. The last section will explain the structure of this study.

1.1 Background

1.1.1 Road Transport and Waste Management Circumstances in Laos

In order to achieve the target "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels" and as per Paris Agreement Article 4, UNFCCC parties agreed to update the NDC and Laos reviewed and updated its 2015 NDC with a view to enhancing its ambition through the introduction of three national level greenhouse gas (GHG) emissions scenarios, namely a baseline emissions scenario, an unconditional mitigation scenario to 2030, as well as a more ambitious conditional mitigation scenario to 2030 towards achieving net zero GHG emissions by 2050.

The number of motor vehicles is growing due to the rapid urbanization in Laos. The total number of registered private vehicles increased at an average growth rate of 9.4% since 2010; that accelerating number of vehicles increased from 2.3 million in 2020 to 2.9 million in 2021 (MPI, 2021), in which two-wheelers accounted for 75% of the total vehicle stock in 2021, while public transport only accounts for an estimated 0.6% of daily trips. On one hand, automobiles are boosting the Lao economy by creating employment opportunities, improvement in productivity as well as facilitating the consumers in travelling and other day-to-day activities, on the other hand, the significant increase in traffic volume has caused traffic congestion in the urban areas of Vientiane and other cities (GGGI, 2019b). Vehicles running on conventional fuels such as gasoline and diesel result in extensive vehicular pollution and worsening the urban environment. Additionally, tourism, which is one of the country's major economic drivers accounting for 15–20% of foreign exchange receipts, will likely suffer due to traffic congestion, noise, and air pollution. Moreover, since Laos depends entirely on imported fuel, this has implications on the country's foreign exchange receipts and has ramifications on the national financial and energy security (GGGI, 2018a).

Carbon tax is an effective mitigation tool for curtailment of emission, and several developed and developing countries have applied this mechanism globally. The state of the National Green Growth Strategy (NGGS) of Laos stated that carbon tax could be a significant measure to restrict the import and use of personal vehicles (NGGS secretariat, 2018). This was also consistent with the objective the Environmental Protection Law that aims to ensure balance between social and natural environment (Laos, 2013). But carbon tax has not been considered as a mitigation countermeasure in Laos, so in order to provide a scientific evidence for policy to spur green production and consumption in the country, there is a need to assess the impacts of carbon tax policy.

In developing world, the common waste problems facing is limited collection service. As a consequence, people usually dispose their household waste by open dumping and burning. However, most of the collected waste is disposed in the landfill, since this commonly practiced in developing countries due to low operational cost and unskilled workers needed, lack of technology as well (Kumar and Sharma, 2014).

Population and economic growth are the main factor influencing people migrate to settle and work in the main cities, resulting in rapid urbanization and households afford to consume more that driving the increase of waste generation, particularly municipal solid waste (MSW). When the MSW is treated unproperly, it can generate GHG emissions. Generally, the common challenges in developing countries are low rate of solid waste collection, and openly dumping and burning are common practices. In the developing world, due to budget constraints, low skill workers, and lack of technologies, landfill is ordinarily practiced for waste disposal (Kumar and Sharma, 2014).

The growth of population and rapid urbanization in Laos, in recent years, are influencing and challenging to capacity of the final disposal site in the main cities. The waste collection rate remains at a low level and waste treatment is facing the continuous expansion of the plastic waste fraction and over two-thirds of municipal waste could be recycled, but the current scale of recycling in Laos is still very modest (Vatthanamixay and Souvanna, 2020). In addition, hazardous management is unproperly managed, there are some cases, medical waste and hazardous waste are treated by dumping including in municipal waste disposal sites and vacant lots (JICA, 2021).

The increase of solid waste in urban areas and unappropriated handling has potential to affect not only city air pollution but also the quality of surface and groundwater. Enlargement of urban populations with detective solid waste management approach is accelerating the worsen of city pollution (GGGI, 2018). The main subject of waste treatment is poor design of waste collection storage. In most settlements, the main collected solid waste is deposited by open dumping that could harm the environmental and aesthetic cities, as well as health hazardous.

Nowadays, there are challenges to achieving the Lao government’s goal of a green economy and sustainability (JICA, 2021). Particularly the remaining capacity of final disposal sites in cities is becoming insufficient due to the impact of rapid urbanization in recent years. Waste collection rates remain low and vacant lots are without proper treatment. Even though there are final disposal sites for waste in main prefectures, due to lack of human resources, technology, equipment, and budget, environmentally sound landfills are not possible, and problems such as GHG emission is still apparent.

According to the Laos government plan 2021-2025 (MPI, 2021), there are three "priorities achievements" to achieve 2025 goal, one of which is effective conservation of the natural environment based on the green economy and sustainability. As activities to be undertaken between 2021 and 2025 to achieve this result, the following items related to the reduction of waste is mentioned, for example, promote green and sustainable development by establishing systems for waste management and reduction; apply mechanisms to manage, eliminate and reduce waste generation while facilitating the application of the 3Rs Principle in the main municipalities (GGGI, 2018). Therefore, it is recommended to strategically prepare for such a situation; to prioritize major cities for improvement according to the severity of the waste problem, to consider the similarity of problems such as low collection rate and improper disposal, and applicability of countermeasures to the problems of other cities.

Current solid waste management practices in Laos are primarily based on a "collect and dispose" approach that overlooks the enormous potential for converting waste into resources. The adoption of waste- to-resource approach has the potential of contributing to national development priorities, since this approach is at the top of the waste management hierarchy pyramid (Hoornweg and Bhada-Tata, 2012) and (UNEP, 2013). In this analysis, by introducing waste-to-resource approach in Laos, the effectiveness of GHG emissions from solid waste sector is assessed.

Adoption of waste-to-resource approach is recommended and being considered as a piloting for MSW management in Vientiane Capital, Laos. This approach has the potential reducing GHG emissions from the disposal sites. It is believed that this approach has an ability to ensure a certain level of segregation that can be converted into a product and energy (GGGI, 2018) and may introduce the indirect GHG emission reduction in other sectors.

1.1.2 Economic Situation

Over the five-year period 2016-2020, based on the result of the implementation of the Five-Year National Socio-Economic Development Plan 2016-2020, the national economy continued to grow steadily, with an average rate of 5.8% per year (MPI, 2021). The main driver of economic growth came from the industrial sector, particularly power and construction. The growth of GDP in 2021 was 3.5% which is higher than GDP 2020 which the growth was at 3.3%, and the industrial sector is till the key driver (LASES, 2022).

The GDP per capita increased from USD 2,025 in 2016 to USD 2,654 in 2019 and increased to USD 2,664 in 2020 (MPI, 2021a). While the Gross National Income (GNI) per capita reached USD 2,106 in 2020. The economic structure has not yet shifted towards industrialization and modernization, which can be noted in the share of the agricultural sector in the economic structure which has increased from 15.8% in 2016 to 16.6% in 2020; while the share of the industrial sector decreased from 33.7% to 33% and the share of the service sector decreased from 40.3% to 39.5% in the same period.

Export values of Laos have been dramatically increased with 23% of annual growth rate in the period of 2015-2020, the main market is China. Main export goods are minerals (45%), electricity (10%) and garments (13%), while main import goods are machineries and production equipment (47%) and vehicles (11%). The import of petroleum products accounted for 17% in the total amount of import value in 2020. More than 95% of the petroleum product (gasoline and diesel) was consumed by transport sector (MOIC, 2021).

Generally, industrial sector is the main driver of economic growth, specifically hydropower industry provides the highest contribution to Lao GDP, with an amount of 21 billion kip (around 1.4 million USD) in 2021, for example. However, most electricity product is exported to neighboring countries. Wholesale and retail trade; repair of motor vehicle and motorcycle are the second remarkable contributor, following by agriculture cropping and mining sectors (figure 1.1).

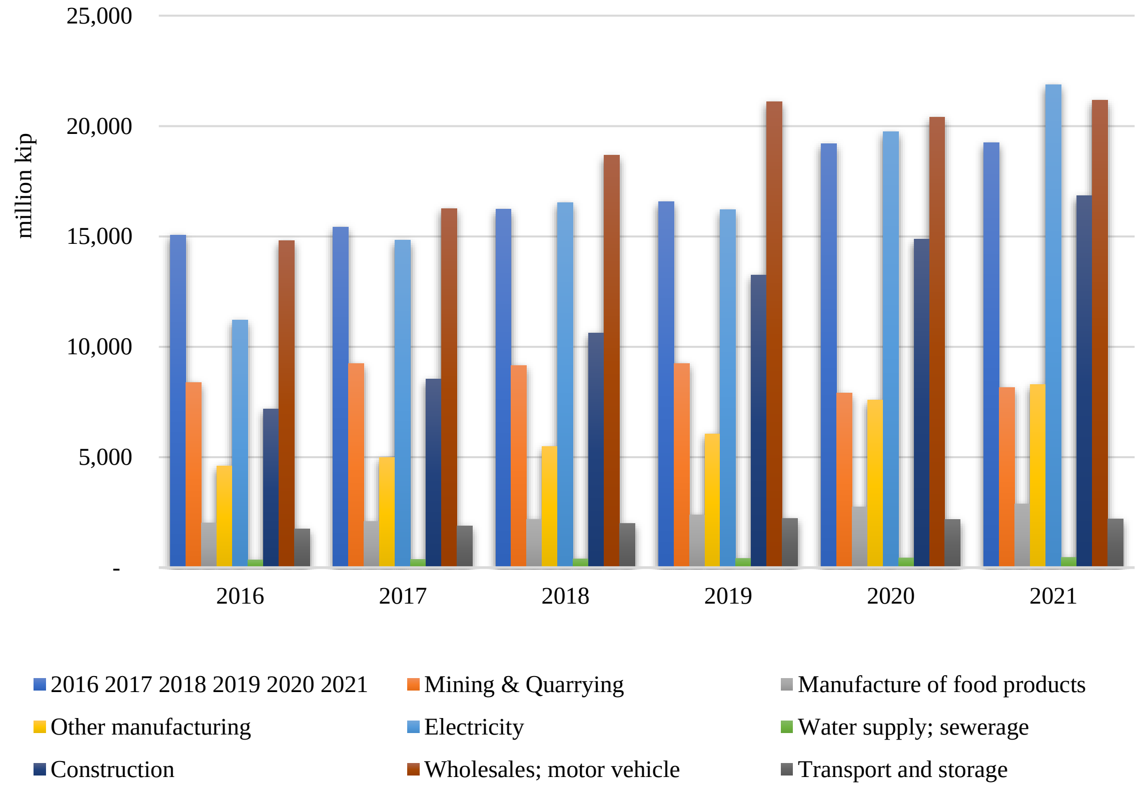


Fig 1.1. GDP based on constant prices 2016-2021.

Source; MPI, National Yearbook (2016-2021)

Even though industrial sector is the key driver of Lao economy, however, automobiles, specifically passenger transport, are boosting Lao economy by creating employment opportunities, improving productivity as well as facilitating the consumers in travelling and other day-to-day activities. On the other, most vehicles are conventional automobiles and running on imported fossil fuels such as gasoline and diesel result in extensive vehicular city pollution.

In case the current trend of vehicle growth continues will result in CO_2 emissions more serious consequences for humans and environment. Hence, in order to promote green growth, Laos can explore EV technology as one of the potential solutions to mitigate transport emissions and would also help cutting oil imports.

Service sector is an important contributor to the GDP growth, especially tourism plays its role creating employments, small-medium enterprise, for example. sustainable tourism directly dealing with proper waste handling. Particularly municipal solid waste, the tourism is now growing up after Laos-China high speed railway started operation. More tourists visit Laos and result in more demand for consumption and generate more waste. Thus, in order to overcome this challenge, "waste-to-resources" should be analyzed and promoted in Laos.

Figure 1.2 shows the GDP growth rate during 2010-2021. The growth steadily declined during 2010-2019, however, the growth rate was suddenly decreased in 2020 due to severe Covid-19 pandemic and globally lockdown. However, to achieve country's development goals, graduate from least developed country and become an upper-middle income country, for examples, Lao government targeted long-term economic growth at an average of 4% or more per year during 2021-2025 (PMI, 2021), in which this target is consistency with the latest report on the trend of economic growth in first quarter of 2022 was 4.5% (MPI, 2022). This projection also aligned with estimation of world bank (WB, 2022).

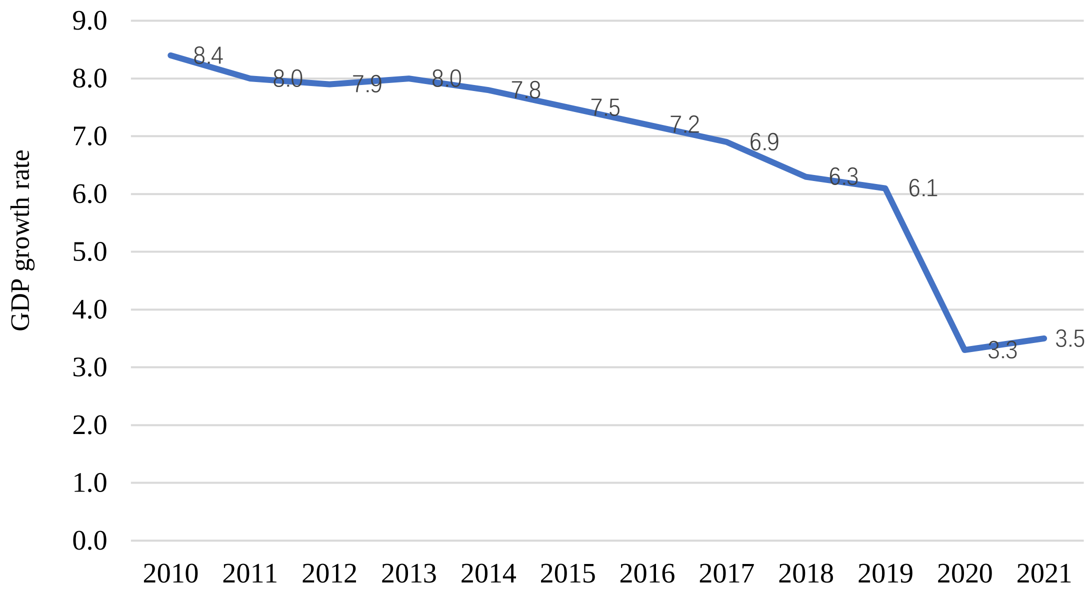


Fig 1.2. GDP growth rate during 2010-2021

Source: National Yearbook (2010-2021), MPI

1.2 Previous Studies and the Importance of the Study

There are limited studies related to GHG emission mitigation in Laos and those studies are not yet considering the mitigation actions based on the recent government's policy/strategic targets. Most recent analysis on low carbon emission technologies in road transport was introduced by Phoualavanh and Limmeechokchai in 2015, their academic paper was applied the Long-rang Energy Alternative Planning (LEAP) model to forecast energy consumption and CO_2 emission in transport sector in Laos by comparing introduction of fuel switching; advance technologies penetration at low and highly intensive levels; and modal shift in BaU and mitigation actions scenarios. Fuel switching action was categorized into two optional fuels as gasohol (gasoline blended with ethanol) and biodiesel (diesel blended with biodiesel). The advanced technologies include hybrid vehicle (HB), pug in hybrid vehicle (PHB) and battery electric vehicle (BEV) whilst, the modal shift included substitution of buses for motorcycle and passenger's cars.

Their analysis results shown that low level of mitigation countermeasure case, the energy consumption would be reduced by 4% when compared to the BaU scenario, while high level of countermeasures gave the highest energy saving with reduction of 9% of total energy consumption in the BaU in 2050. The cumulative mitigation of CO_2 emission from 2010 to 2050 in the low level scenario when compared to the BaU is approximately 8% and the high level scenario in the target year CO_2 reduction is approximately 20%.

In 2016, Phoualavanh and Limmeechokchai developed a research paper by also applied LEAP model to investigate the energy reduction and CO_2 mitigation potential from promoting the EV technology penetration in Lao road transportation. This paper focused on electric technology diffusion in different scenarios by assuming that switching to electric technology will start from 2020 and end in 2050 with maximum of EVs penetration at 15% for HEVs and 5% for PHEVs and BEVs, while switching with higher level of EVs implement at 25% for HEVs and 15% for PHEVs and BEVs in 2050. The results from this analysis shown that the energy consumption from low level of mitigation countermeasure scenarios would be reduced by 3% compared to the BAU scenario in 2050, while more intensive countermeasures would reduce about 5%.

However, those studies were not considered analyzing the impacts of technologies introduction on the GDP growth. In addition, the introduced technologic packages and assumption analysis were also considered differently.

According to this strategy, the Lao government sets the ambition of EV penetration targets, beginning at EV share of 0.1% in 2020 and growing to 14%, 30%, and 50% by 2025, 2030 and 2050, respectively (MEM, 2018). The targets only focus on battery electric vehicles, excludes HEVs and PHEVs. Through the introducing the EV technology, it could mitigate CO_2 emission by 23% cumulative reduction in road transport sector during 2020-2050.

Even thought the government defined the concerning policies to facilitate and promote decarbonization in Laos, for example, strategy on increase forest cover to 70% of land area, promote renewable energy development, decarbonization in road transportation, includes EV penetration targets. However, the scientific analysis to support implementing these policies is still limited. The policy side needs the scientific information on both perspectives, positive and negative scenarios, through policy implementation.

Study on municipal solid waste management at national scale is not available, but there are some assessment and survey reports for specific city, Vientiane Capital, for example. The assessment focused on how Vientiane Authority handling the waste collection and disposal. There are, however, some analysis on potential emission reduction for sub-nationals. The study illustrated the emission scenarios from the different assumptions, namely, expanding waste collection service and more waste diverted to be disposed at the landfill, composing, and materials recovery.

Study-related sustainable waste management in Laos is very limit. However, there are some academic papers developed emission scenarios at the sub-national. Estimation of the current situation of the GHG emission from municipal solid waste management (MSWM) in Vientiane is one of initiative research on waste management in Laos, and this paper analyzed the mitigation options to reduce the GHG emission and environmental impacts. The proposed alternative solutions for dealing with MSW in Vientiane include recycling and composting. Under countermeasure scenario would reduce emission from waste sector in Vientiane Capital about 37% comparing to BAU scenario (Vilaysouk and Babel, 2015).

Vilaysouk and Basbel, in 2017, examined the advantages from MSWM improvement in Luang Prabang city. Improvement of the MSW management by expanding MSW collection services, introducing waste composting and recycling, and avoiding open burning, can be considered as a significant mechanism to beat the current challenges of Luang Prabang municipal solid waste management. The result shows that the scenario of introducing and recycling can achieve lowest GHG emissions.

Currently, there are no concrete policies or regulations, either at the national or main cities level, on sustainable solid waste management, particularly in support of waste-to-resource approaches or the principles of 3Rs (Reduce, Reuse, Recycle). Since the “waste-to-resource” approach is aligned with the 3R principle and it is at the top of the waste management hierarchy pyramid (UNEP, 2013).

Lao government, in the long term, set three "priority achievements" to achieve the goal in 2025, one of which is "effective conservation of the natural environment based on the green economy and sustainability. Particularly activities-related to the reduction of waste and harmful substances such as promote green and sustainable development by establishing systems for waste, chemical, and toxic substance management and reduction, and integrated wastewater treatment at the local governments; apply mechanisms to manage, eliminate and reduce waste and hazardous substances while facilitating the application of the 3R Principles in the main municipalities. It is appeared, therefore, that “waste-to-resource” analysis is necessary to be carried out and provide the simulation results to illustrate the potential benefits from applying this approach.

In this study, regarding EV introduction analysis, aims to respond to the most recent government policy, particularly the Strategy on Clean Energy Use in Transport Sector (MEM, 2018). The EV technology, therefore, was selected as a countermeasure for mitigating emissions from road transportation. Additional mechanisms, carbon tax and subsidy policy, as well as biofuels, are taken into account. Which the existing studies emphasized on only EV technologies. Moreover, impact on GDP from EV introduction was also considered in this study.

Regarding the extension of waste recycle, this is first analysis for decarbonization in waste sector at national level. Based on existing studies found only the studies for sub-national. The impact from adoption of extension of waste recycle on GDP was examined.

1.3 Novelty and Research Objective of Study

One of the key determinants to drive an average 5.8% of economic growth during the last five-year 2015-2020 is energy sector (MPI, 2021). Following the urbanization and population increase, number of vehicles have been rapidly extended and resulted in more demand on fossil fuels of road transport and appearance of remarkable emission expansion in transport sector that can be seen from latest national GHG inventory in 2014, the total emission from energy sector was second largest emitter at 3,729 $KtCO_2eq$, accounting for 15% and emission from fuel combustion in transportation seized 62% of total emission from energy sector (MONRE, 2020). In addition, current global fuels crisis and high inflation are threatening national energy security, fuel demand in transport sector specifically. The policy on EV promotion could mitigate dependence too much on imported fossil fuels. Government, therefore, needs an analytical scientific information to support achieving EV penetration target.

In waste sector, Laos is similar to other developing countries, urbanization and population size have been steadily increased in the last decade; more people immigrated to urbanized areas and earn more incomes, resulting in generating more municipal solid waste, while waste management still faces with budget constraints, low skill workers and technologies to handle increasing waste generation. Waste generation is also directly link with tourism, after high speed Laos-China railway started the operation then more tourists visit Laos. The concept of "waste-to-resources" will not only ensure sustainable solid waste management but will also create value chain from recyclable waste and limit emission from the waste sector.

Emission reduction from both sectors, transport, and waste, will be a significantly contributor to achieve 60% of emission reduction target in 2030 and net zero emission in 2050 (NDC, 2021).

The main objective of this study is to measure the impacts of emission mitigation policies in Laos by considering the emission reduction countermeasures in road transport and solid waste treatment. The potential effects to be assessed from EV penetration are the energy consumption, CO_2 emission reduction and GDP value aspects. Whilst the influences from sustainable solid waste management are considered such as the possibility of lessened direct waste disposal, emission reduction and contribution to GDP. At the end, some policy implications will be recommended for the government to consider integrating into the concerning policies.

1.4 Organization of Study

This study is divided into five chapters. The study begins with the introduction and highlights emissions and economic situations, and some relevant previous studies in Chapter 1. Chapter 2, talking about GHG emissions and emission reduction ambitions, includes mitigation technologies are described in this chapter. Chapter 3 explains the methodology of this research which describes general structure of the Computable General Equilibrium (CGE), input data such as input-output table and scenario analysis. Chapter 4 shows the results of analysis. In last Chapter, there are conclusions, some recommendations, and suggestions for future studies.

2. GHG Emissions and The Emission Mitigation Targets

2.1 Laos GHG Emissions

Nowadays, Laos is a country with low greenhouse gas emissions and also a country with an absorption capacity higher than the emissions. The net greenhouse gas emissions in the Laos have slightly decreased from 50,700 kt$CO_{2\text{-}eq}$ in 2000 to 24,100 kt$CO_{2\text{-}eq}$ in 2014 (MONRE, 2013, 2021). Under the baseline scenario, the estimated GHG emission is projected to reach around 82,000 ktCO_2-eq in 2020 and 125,000 ktCO_2-eq in 2050 (MONRE, 2020). One of the drivers of this high expansion rate is the increase in vehicles. In 2014, energy-related emission sources were the second largest, at 3,700 kt$CO_{2\text{-}eq}$, accounting for 15% of national emissions. The emission from fuel combustion in transportation accounted for 62% of the energy-related emission (MONRE, 2021).

Lao national GHG inventory has been conducted four times and the latest survey was carried out in 2014 under Biennial Update Report (BUR). The GHG emissions and removals were from four sectors, namely energy, industrial process and product use (IPPU), agriculture, forestry and other land Use (AFOLU), and waste sector. From the historical emissions, most emissions were from AFOLU sector, and second emitter was energy sector (MONRE, 2013; 2021). Energy and waste sectors increased their emission share in 2010 and 2014 inventories comparing to the emissions in 1990 and 2000 (figure 3).

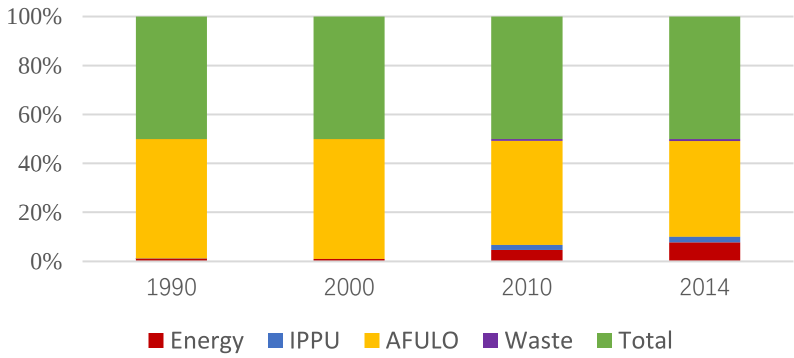


Fig 2.1. Lao's GHG emissions proportion 1990-2014.

Source: MONRE, 2013; 2021

Table 2.1 shows the detail of GHG emissions sources and removal from the latest 2014 national inventory, the main driver of emission in energy sector was from transport, while the IPPU was from mineral industry and the key emission source was from cropland. The net emission was 24,100 ktCO_2eq, while the removal was equivalent to about 13,000 ktCO_2eq (MONRE, 2021). The most emission released from AFOLU sector was about 18,800 GgCO_2eq, accounting for 78% of the total emissions. Second largest source of emissions was energy sector, which emitted 3,729 ktCO_2eq (15%). The rest, IPPU and Waste shared 5% (1,150 GgCO_2eq) and 2% (425 ktCO_2eq) of the national emissions, respectively (see figure 2.2).

Table 2.1. Total GHG emission in 2014

Categories	Emissions (Gg)			Emissions CO2 Equivalents (Gg)				Emissions (Gg)					Emissions (Gg)
	Net CO2 (1)(2)	CH4	N2O	HFCs	PFCs	SF6	Other halogenated gases with CO2 equivalent conversion factors (3)	Other halogenated gases without CO2 equivalent conversion factors (4)	NOx	CO	NMVOCs	SO2	CO2e
Total National Emissions and Removals	**15,441.035**	**300.562**	**7.571**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**24,099.98**
1 - Energy	**3,343.418**	**5.958**	**0.842**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3,729.42**
1.A - Fuel Combustion Activities	3,343.418	5.843	0.842	0	0	0	0	0	0	0	0	0	3,727.00
1.A.1 - Energy Industries	0	5.381	0.718						0	0	0	0	335.44
1.A.2 - Manufacturing Industries and Construction	27.042	0.001	0.000						0	0	0	0	27.16
1.A.3 - Transport	2,281.649	0.270	0.113						0	0	0	0	2,322.40
1.A.4 - Other Sectors	1,034.726	0.190	0.011						0	0	0	0	1,042.01
1.B - Fugitive emissions from fuels	0	0.115	0	0	0	0	0	0	0	0	0	0	2.41
1.B.1 - Solid Fuels	0	0.115	0						0	0	0	0	2.41
2 - Industrial Processes and Product Use	**1,151.890**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1,151.89**
2.A - Mineral Industry	1,090.245	0	0	0	0	0	0	0	0	0	0	0	1,090.24
2.A.1 - Cement production	1,087.294								0	0	0	0	1,087.29
2.A.2 - Lime production	2.951								0	0	0	0	2.95
2.B - Chemical Industry	0	0	0	0	0	0	0	0	0	0	0	0	-
2.C - Metal Industry	61.646	0	0	0	0	0	0	0	0	0	0	0	61.65
2.C.1 - Iron and Steel Production	61.646	0							0	0	0	0	61.65
2.D - Non-Energy Products from Fuels and Solvent Use	0	0	0	0	0	0	0	0	0	0	0	0	-
2.E - Electronics Industry	0	0	0	0	0	0	0	0	0	0	0	0	-
2.F - Product Uses as Substitutes for Ozone Depleting Substances	0	0	0	0	0	0	0	0	0	0	0	0	-
2.G - Other Product Manufacture and Use	0	0	0	0	0	0	0	0	0	0	0	0	-
3 - Agriculture, Forestry, and Other Land Use	**10,943.431**	**280.544**	**6.318**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**18,793.41**
3.A - Livestock	0	179.826	0.615	0	0	0	0	0	0	0	0	0	3,966.89
3.A.1 - Enteric Fermentation		152.914							0	0	0	0	3,211.19
3.A.2 - Manure Management		26.912	0.615						0	0	0	0	755.69
3.B - Land	9,093.245	0	0	0	0	0	0	0	0	0	0	0	9,093.25
3.B.1 - Forest land	(12,661.984)								0	0	0	0	- 12,661.98
3.B.2 - Cropland	19,314.621								0	0	0	0	19,314.62
3.B.3 - Grassland	8.148								0	0	0	0	8.15
3.B.4 - Wetlands	0		0						0	0	0	0	-
3.B.5 - Settlements	91.672								0	0	0	0	91.67
3.B.6 - Other Land	2,340.789								0	0	0	0	2,340.79
3.C - Aggregate sources and non-CO2 emissions sources on land	25.883	100.718	5.703	0	0	0	0	0	0	0	0	0	3,908.98
3.C.1 - Emissions from biomass burning		46.057	0						0	0	0	0	967.19
3.C.2 - Liming	1.731								0	0	0	0	1.73
3.C.3 - Urea application	24.152								0	0	0	0	24.15
3.C.4 - Direct N2O Emissions from managed soils			4.215						0	0	0	0	1,306.59
3.C.5 - Indirect N2O Emissions from managed soils			1.355						0	0	0	0	420.05
3.C.6 - Indirect N2O Emissions from manure management			0.133						0	0	0	0	41.37
3.C.7 - Rice cultivations		54.662							0	0	0	0	1,147.90
3.C.8 - Other (please specify)		0	0						0	0	0	0	-
3.D - Other	1,824.303	0	0	0	0	0	0	0	0	0	0	0	1,824.30
3.D.1 - Harvested Wood Products	1,824.303								0	0	0	0	1,824.30
3.D.2 - Other (please specify)	0	0	0						0	0	0	0	-
4 - Waste	**2.296**	**14.060**	**0.412**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**425.26**
4.A - Solid Waste Disposal	0	2.624	0	0	0	0	0	0	0	0	0	0	55.10
4.B - Biological Treatment of Solid Waste	0	0.005	0	0	0	0	0	0	0	0	0	0	0.10
4.C - Incineration and Open Burning of Waste	2.296	0	0	0	0	0	0	0	0	0	0	0	2.30
4.D - Wastewater Treatment and Discharge	0	11.431	0.412	0	0	0	0	0	0	0	0	0	367.76
4.E - Other (please specify)	0	0	0	0	0	0	0	0	0	0	0	0	-
5 - Other	0	0	0	0	0	0	0	0	0	0	0	0	-
5.A - Indirect N2O emissions from the atmospheric deposition of nitrogen in NOx and NH3	0	0	0	0	0	0	0	0	0	0	0	0	-
5.B - Other (please specify)	0	0	0	0	0	0	0	0	0	0	0	0	-
Memo Items (5)													-
International Bunkers	53.068	0.000	0.001	0	0	0	0	0	0	0	0	0	53.54
1.A.3.a.i - International Aviation (International Bunkers)	53.068	0.000	0.001						0	0	0	0	53.54
1.A.5.c - Multilateral Operations	0	0	0	0	0	0	0	0	0	0	0	0	-

Source: MONRE, 2021

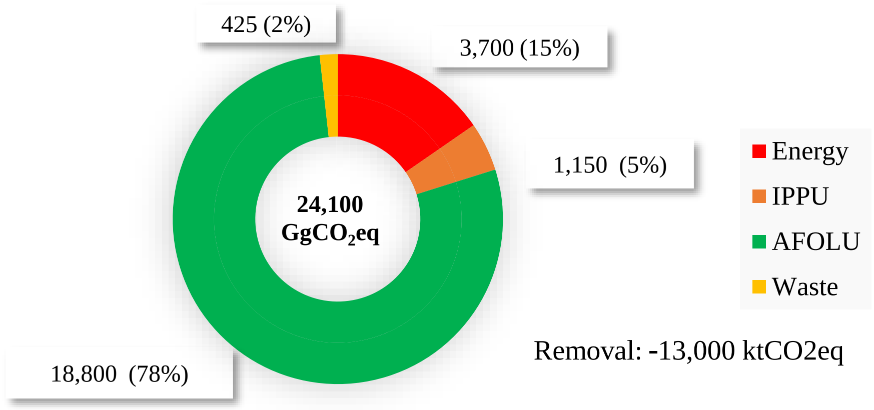


Fig 2.2. GHG emissions in 2014, unit: ktCO2eq.

Source: MONRE, 2021

2.1.1 GHG Emissions from Energy Sector

Even though the main emission sources were from the AFOLU sector, the emission from the energy sector has increased remarkably. If compared, the emission in 2014 which emitted more than one times of emission in 2010. The total emissions from this sector in 2014 were 3,700 ktCO_2eq, accounting for 15% of the total emissions (figure 2.3). In which emissions from fuel combustion seized 99.9 %, particularly from transportation had a share of about 62% (2,300 ktCO_2eq), followed by manufacturing and construction, the energy industry and other sectors, which shared 28 %; 9% and 0.7%, respectively (figure 2.2).

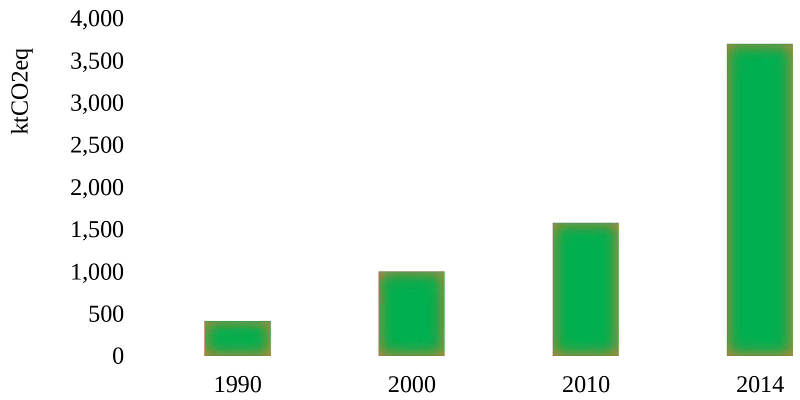


Fig. 2.3. GHG emission from the energy sector, 1990-2014.

Source: MONRE, 2021

The increase in emissions from the transport sector is consistent with a report on the pollution situation in Laos. The report reaffirmed that the high increase of PM 2.5 in the main cities is due to the increasing number of vehicles resulting in worse city pollution. The continued increase of road passenger vehicles (figure 2.5), particularly conventional vehicles, also resulted in an increase in fossil fuel, which means that Laos has spent more foreign currency to import fossil fuels.

Therefore, the emission from the transport sector needs to be analyzed for full-scale mitigation measures to limit the emissions from this sector. Otherwise, city air pollution will be worse in the near future. The EV is an option to mitigate emissions from the transport sector and to utilize existing local energy that generates from hydropower.

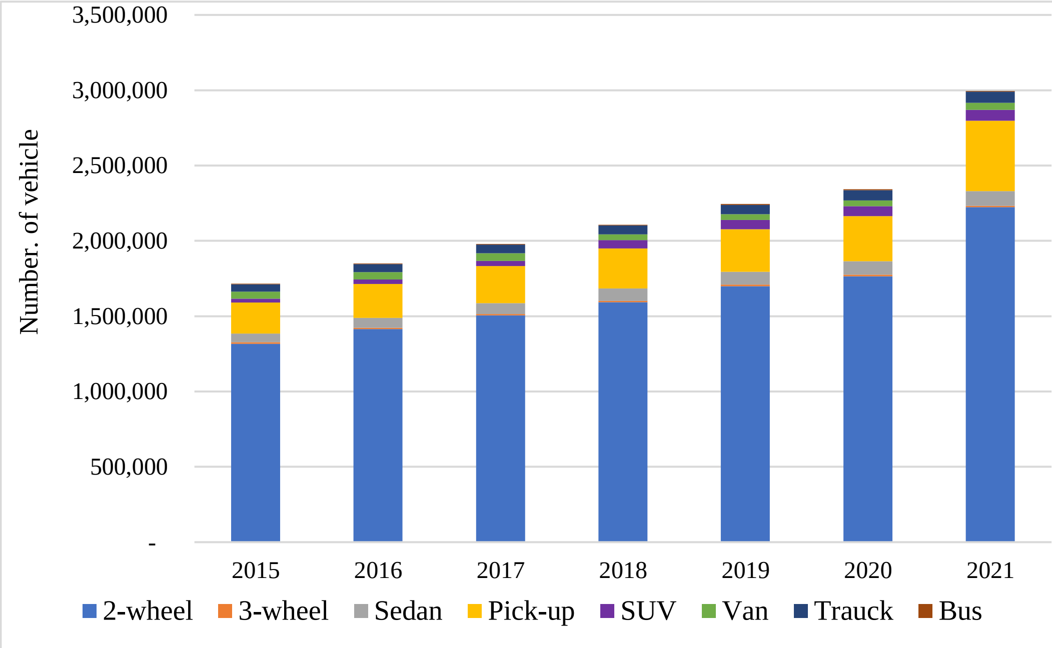


Fig. 2.5. Number of road vehicles and projection.

Source: National Statical Yearbook 2015-2021.

2.1.2 GHG Emissions from Waste Sector

Based on the national GHG inventory, the waste sector's emissions contributed the smallest amount to total national emissions. The small ratio of total emissions is believed to be due to the low waste collection rate. However, the survey result shows that emissions from the waste sector have increased gradually, extending from total emission of 280 $ktCO_2eq$ in the 2010 base year to 400 $ktCO_2eq$ of emission in 2014 (MONRE, 2022; MONRE, 2021). The low emission ratio from the waste sector could be due to the low waste collection rate, estimated at 30% in 2018.

The total mission from the waste sector released about 400 $ktCO_2eq$ in 2014, which 87% of the total emissions generated from wastewater treatment and discharge. However, solid waste which organic and plastic waste are the main element and cover more 65% of total waste generation, emitted around 13%, and the rest emissions were from solid waste incineration and open burning and biological treatment, which released 0.2% and 0.1% respectively (figure 2.6).

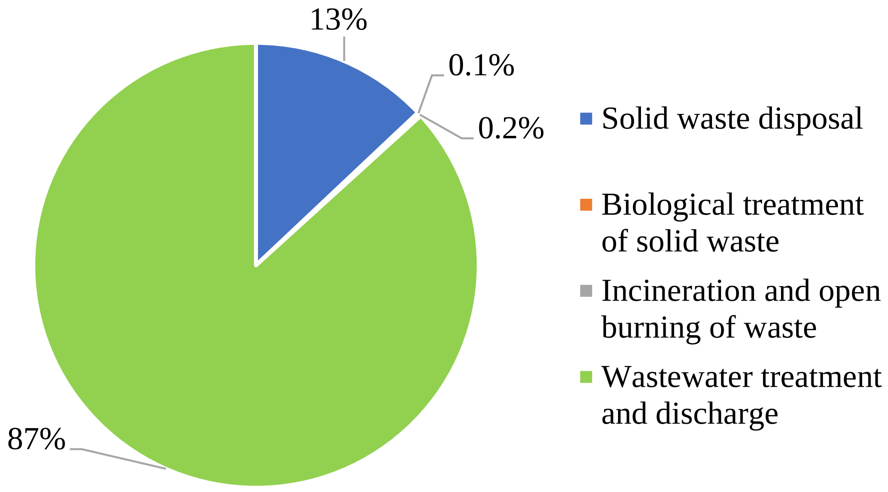


Fig. 2.6. Emission from the waste sector (unit: ktCO_2eq).

Source: MONRE, 2021

Emission from the waste sector, besides emission from industry and road transport, also significantly contributes to air pollution in big cities. Illegal waste disposal by open burning is common practice across the country. Solid waste treatment improperly also affects surface and groundwater quality and soil toxicity. Emissions from solid waste could pace the city's air quality in long-term, therefore, if ineffective solid waste management keeps practiced for a long time.

2.2 GHG Emission Reduction Ambitions and Mitigation Technologies

Laos has a very low GHG emission in the global context, and its historical contribution to climate change has been minimal. It emitted around 0.05% in 2014 compared to global emissions (MONRE, 2020). The Government of Laos, despite its status as a least developed country (LDC), has developed a series of climate change policies and intends to implement mitigation policies to support the UNFCCC in achieving the long-term goal of limiting global GHG emissions, particularly the objective of Paris Agreement to keep an increase of global average temperature to "well below 2 degree Celsius above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5 degree Celsius above pre-industrial levels" (MONRE, 2015).

Initiative mitigation activities have been started since Laos ratified the Kyoto protocol in 2003 and then initiated promoting clean development projects through a clean development mechanism (CDM). Under CDM, various low-emission activities have been facilitated and implemented, including water waste treatment at Lao Brewery Company. Through the bilateral cooperation called Joint Crediting Mechanism (JCM), Laos collaborates with Japan to promote and support low carbon projects in Laos, where most activities focus on renewable energy and energy efficiency. However, at the last annual meeting in Mach 2022, low-carbon activities in the transport sector were presented and discussed, particularly promoting EVs, an extension of EV charge stations.

Apart from the above mechanisms, Nationally Appropriate Mitigation Action (NAMA) is one of the channels to initiate low emissions in the transport sector has been studied. JICA conducted a feasibility study on an emission reduction estimation from road transport. The study showed the result comparing NAMA project emission reduction in 2020 between without and with EV penetration, with EV promotion could achieve a reduction of approximately 0.3 million tones (JICA, 2012).

Responding to climate change issues is linked with concerning agencies. Therefore, ensuring wide stakeholder involvement and mainstreaming this into sectoral, the Decree on climate change was adopted in 2019 to define principles, regulations, and measures for management and monitoring climate matters (Lao PDR, 2019). Simultaneously, the Decree also states that climate change must be mainstreamed into the national socio-economic development plans (NSEDP), sectoral, and sub-national strategies and plans. Consequently, climate change subjects have been fully integrated into the latest 9th NSEDP (2021-2025), including sectoral and sub-national long-term plans (Lao PDR, 2021).

The first NDC was adopted in 2015 and has identified several actions to reduce the country's future GHG emissions. The actions have been drawn from various sectoral strategies, and the preliminary projections of potential emission reduction were estimated. Improving a road network is one of the countermeasures listed in INDC. Developing a road network will provide better road networks so that smoothly and shortened vehicle kilometers travelled can contribute to reducing emissions from road transport activities (Lao PDR, 2015).

In order to enhance the ambitions, 2021 NDC updated mitigation actions through introduction of three emission scenarios, namely BAU, unconditional/conditional scenario to 2030 and 2050 net zero scenario. In the updated NDC 2021, both transport sector, 30% EV 2-wheelers and passenger's cars penetration in national vehicle mix, and waste management are included under conditional scenario (Lao PDR, 2021). The EV penetration 30% target covers 2-wheelers and passenger's cars in national vehicle mix, includes 10% of biofuels to replace transport fossil fuels are targeted to have an average reduction between 2020 and 2030 about 59 $ktCO_{2eq}$ per year comparing to BAU scenario.

For the waste sector, emissions of methane associated with the open burning of waste and disposal of organic waste in a solid waste disposal site without a landfill gas capture system are expected to keep growing steadily together with economic development. The transition towards a circular economy is one of the priority areas to be applied for waste management, including material and product recirculation, circular business models, product resource efficiency, and prioritizing the use of regenerative material resources. Regarding sustainable municipal solid waste management, for example, 500 tones per day waste treatment is projected to achieve an average reduction of around 280 $ktCO_{2eq}$ per year between 2020-2030.

Currently, carbon market development in Laos, in order to promote and facilitate more mitigation project, is being discussed. Carbon market mechanism is believed to be a key role to mobilizing the fund from both national and international to invest in low carbon projects which can contribute to NDC target for net zero emission in 2050. In last decade, most of mitigation projects were developed based on CDM mechanism. However, since the Kyoto protocol had ended in 2020 and based on Paris Agreement, new scheme is needed to be developed. Therefore, carbon market development is a challenge mechanism to boost low carbon activities in Laos. In addition, supporting information from scientific studies is also necessary for establishing this scheme.

The emission reduction ambitious is set under NDC, three main goals were defined to achieve the emission reduction targets, namely, the reduction goal under unconditional and conditional mitigation targets in 2030, and net zero emission in 2050 targets. Under the unconditional mitigation target, the contribution of the country to the Paris Agreement is set to achieve 60% GHG emission reduction in 2030 comparing to baseline scenario. Under the 2030 conditional mitigation target, more mitigation measures were added, in which 30% EV penetration for 2-wheelers and passengers' cars in national vehicles mix and implementation of 500 tons per day sustainable municipal solid waste management project are included. In the longer-term the 2050 net zero emission pathway is determined (MONRE, 2021).

Laos has made efforts to transfer and promote mitigation technologies, the countermeasures for mitigating climate change are identified, especially in the last 10 years. Key mitigation actions were identified and implemented under the first National Strategy on Climate Change (MONRE, 2010), Climate Change Action Plan (MONRE, 2012), the first Intended Nationally Determined Contributions (INDC) (MONRE, 2015), Climate Change Technology Action Plan (MONRE, 2017). In addition, the Decree on Climate Change, which has been in place since September 2019, is also a reference for promote low emission in Laos. Moreover, climate change mitigation actions were integrated in the national and sectoral policies and plans, such as the current 9th National Socioeconomic Development Plan (NSEDP) 2021-2025 (MPI, 2021a) and the revised Strategy on Renewable Energy (MEM, 2022), latest updated NDC and includes National Green Growth Strategy (MPI, 2018). At the sub-national level, urban low-emission development strategy is developed, and list of low emission projects are identified.

2.2.1 Mitigation Technologies for Energy and Transport Sectors

Structure of the energy sector in Laos, hydropower is the main source of energy generation accounting for more than 90%, In order to mitigate emissions and contribute to achieving the Paris Agreement (PA) target to limit a rise of GHG emission not more than 2 degrees Celsius, Laos as a party member of the PA, has developed policies and defined the targets to promote GHG mitigation activities in the country.

2.2.1.1 Electric Vehicle (EV) Promotion

Transport sector is a significant emitter in energy sector, the total emission from energy sector in 2014 were 3,730 ktCO_2eq, accounting for about 15% of the national total emissions of which about 99.9% were emissions from fuel combustion, particularly fuel combustion from transport sector (MONRE, 2021). Transport sector seized about 62% of total emission from energy sector, accounting for 2,330 ktCO_2eq. Currently, the most vehicles in Laos are conventional vehicles. These vehicles completely consume imported fossil fuels. Therefore, the action to reduce consuming fossil fuels of transport sector will not only mitigate emission from this sector but also will indirectly mitigate trade deficit as well.

To promote use of sustainable internal energy, particularly hydro energy, electric vehicle (EV) is considered as a key mitigation for road transport in Laos. Since EV is considered as an advance technology for more efficient energy combustion which has multiple advantages when compares to the conventional vehicles (Shukla, 2009) such as a largest capacity on reducing energy consumption and producing less life-cycle GHG emissions. In addition, it operates with less noise and produces zero-tail emissions. Due to the multi-advantages on energy conversion efficiency and environmental-oriented, and consequently EVs have been extensively deployed and utilized in many regions. In the case of Lao, most of the electricity is produced from hydropower, and that means the EV can exert its ability on environment.

Government of Laos has defined the targets to promote electric vehicle (EV) use in Laos by set the target to achieve EV penetration in road transport, specifically passenger vehicles, 14% by 2050, 30% by 2030 and 50% by 2050 (MEM, 2020). However, due to Covid-19 outbreak and global economic recession, the government has revised the target to achieve EV penetration. As the results of economic recession and inflation, includes oil crisis due to Russia-Ukraine war and sanction of western world on oil export of Russia, the drivers in Laos are considering and turning to use more EVs, consequent the imported EVs is increasing at the present.

2.2.1.2 Renewable Energy

Renewable energy (RE), including solar, wind, hydro, biofuels and others, are at the centre of the transition to less carbon-intensive and more sustainable energy systems.

Laos has an enormous hydropower potential for energy generation, and this is the main source of energy generation, by 2025 the electricity production is expected to reach totaling 12,000 MW, and the target installed hydropower capacity by 2030 is set at 20,000 MW, of which more than 5,000 MW is for export (MPI, 2021). Since Laos is an abundant country with natural water resources for the development of hydropower, so the government is promoting and facilitating the utilization of clean electricity for road transport, EV specifically. The EV is considered an effective mitigation technology and consequently contributes to reducing emissions from road transportation which is identified in national policy towards climate change issues and aligns with sustainable social-economic development direction (MEM, 2020).

Promoting EV use will not only utilize local energy resources, but the cost of fuel is undoubtedly low compared to conventional vehicles as fossil fuel costs are In the EV strategy document is estimated the comparing cost, in average the conventional vehicles spend USD 6 per 100 Km drive. In comparison, EVs spend an average of 100 Km drive about USD 2 for a fast charge (MEM, 2020). In addition, EV promotion is strongly believed to lessen Laos's trade deficit and diminish fossil fuel imports.

Apart from hydropower, Lao government is also boosting growth of renewable energies. RE generation can supply to national grids and use directly. Nowadays, private companies in Laos are investing on solar PV for supply directly to EV fast charging stations.

Solar energy is the conversion of sunlight into usable energy forms. Solar PV combines two advantages: module manufacturing can be done in large plants, which allows for economies of scale, and it is also a very modular technology and can be developed in small quantities at a time. At the present, electricity is produced from solar VP is only 0.9%, however, Laos government set the target to have a share of production around 2.6% in 2025 (MEM, 2021).

Onshore wind is a proven, mature technology with an extensive global supply chain. This technology has evolved over the last five years to maximize electricity produced per megawatt capacity installed to unlock more sites with lower wind speech. Wind turbines have become bigger with taller hub heights, and larger rotor diameters (MEM, 2022). Currently, seven wind power projects are under feasibility studies and one plant is being constructed. The wind power plants are estimated to have capacity for electricity generation around 2,700 MW by 2030.

Bioenergy is an option biofuel for Lao transport sector. Laos has a potential for producing bioenergy, particularly available land for cultivating bioenergy crops. The government set the target to supply biodiesel for transport sector about 5% by 2030. Biodiesel will not only contribute to diminish the emission and fossil fuel use, but it will also boost small business and create jobs for rural people (MEM, 2022).

2.2.2 Mitigation Technologies for Waste Sector

Municipal solid waste (MSW) is one of the most urgent issues in developing countries which related to economic growth and urbanization. Untreated waste can be harmful the soil due to toxic substances spreading out (Ali et al., 2014). However, when treated unproperly, they can generate significant amount of GHG emissions that directly contributing to global warming (IPCC, 2007; Clarke et al., 2019). Unmanaged well landfill is a significant source of methane (CH4) emission (Scheutz et al., 2014) which developing countries are now facing. Generally, the CH4 emission contribute about 40-60% of total GHG from landfill (Xydis et al., 2013).

Result of the economic activities in Laos are expanding rapidly along with urbanization and waste. But mostly MSWM in Lao PDR is very simple and does not fully take care of the environment and most of the waste disposal is open burned or illegally dumped. Based on government policy on green and clean growth, sustainable waste management initiative is being focused on, particularly “waster-to-resource” initiatives.

Currently, solid waste management practices in Laos are primarily based on a "collect and dispose" approach that disregards the tremendous potential for converting waste into resources. The initiative is identified based on the assumption that initiatives to be prioritized are aligned with the principles of 3R, and that they are at the top of the waste management hierarchy pyramid (Hoornweng and Bhaha-Tata, 2021) and (UNEP, 2013).

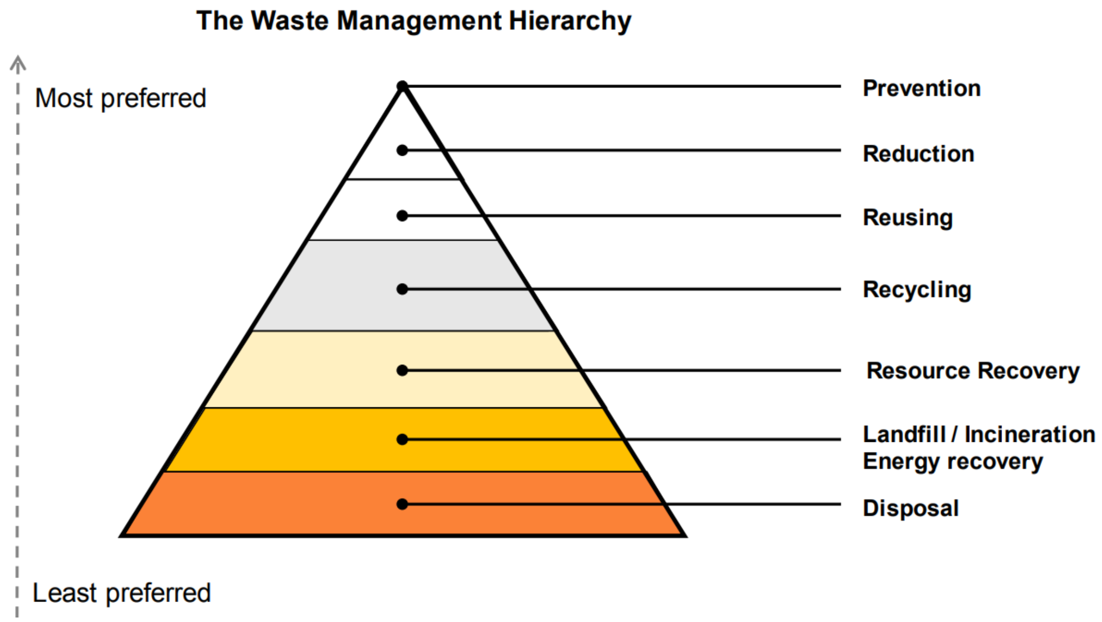


Fig. 2.7. Waste management hierarchy

Source: Modified based on Hoornweng and Bhaha-Tata (2021) and UNEP (2013).

The adoption of waste-to-resource approaches have the potential of contributing to national development priorities and several of the United Nations Sustainable Development Goals (SDGs). For instance, a cleaner environment resulting from improved solid waste management practices could support healthier lives and well-being of populations (SDG 3). Other SDGs could be indirectly promoted through sound waste management practices, such as SDG 7 (on affordable and clean energy, in case solid waste is harnessed in the form of energy), and SDG 13 on climate action, as the adoption of waste-to-resource approaches has the potential of reducing emissions of methane, a greenhouse gas, from disposal sites (Ying-Chu Chen, 2018).

In order to manage municipal solid waste in Laos, GGGI conducted a situation assessment and opportunities for waste-to-sources. A series of "waste-to-resources" was analyzed and discussed such as recovery and recycling of recyclable materials; conversion of waste to compost; recovery of waste as animal feed; waste-to-energy conversion through anaerobic digestion; and resource recovery options for mixed waste.

2.2.2.1 Opportunities for Enhancing Recovery and Recycling of Recyclable Materials

Recyclable materials taking part in solid waste streams in Laos, such as plastics, paper or glass, are routinely collected and transacted through informal and formal services. Informal actors include waste pickers or junk collectors, while the formal networks are city office workers for management and services who collect and sell recyclables. Formal participants integrating these networks consist of recycling buying centres, recycling workshops or processing companies, which are formally licensed to operate and conduct profit-driven activities with recyclables.

2.2.2.2 Opportunities for Converting Organic Waste into Compost

Organic waste composting is a process of biodegradation of turning organic waste into fertilizer through the activity of microorganisms that operate in the presence of oxygen. Composting is a natural decay process in which the volume of organic waste can be degrade up to 85%, occurring under conditional operation (FAO, 2011). The composting methods range from small to large-scale applications. For the smallest plants that families or individuals usually adopt, the baskets are applied for composting, while the largest ones, industrial plants, need machinery for composting large quantities of solid waste.

Based on the Laos context that major economic sector and most employment are in agriculture, composting can be a good option for treating organic solid waste. Since the final product from applying this approach is the fertilizer that can be utilized for agriculture purposed and partly substitute the consumption of chemical fertilizer. However, final products from composting, in case the compost produced is low in quality, does not focused on agricultural purposes only, but it can be material for landfill soil cover as well.

2.2.2.3 Opportunities for Recovering Organic Waste as Animal Feeding

Feeding animals with organic food waste is common in South-East Asian countries, particularly in households. Daily food waste is always feeding as additional food for their animals. Some working papers have been mentioned initiatively about the existing animal feeding practices in Laos. This opportunity to recover organic waste as animal feed could improve municipal solid waste management and promote urban organic waste utilization in Laos (IGES, 2012; AIT/UNEP, 2010). However, even though there is the existing feeding of animals in Laos, limited data exist on the extent, dimension, and formal recognition of these practices.

2.2.2.4 Waste-to-Energy Opportunities through Anaerobic Digestion

One of the opportunities for converting solid waste into energy is the anaerobic digestion (AD). The AD is a biological treatment approach by which the biogas is produced from decomposing of organic fraction of waste due to the activities of anaerobic bacteria. The AD, in principle, is the most applicable to Laos, particularly when considering the raw material inputs, for example, waste from animal manure.

The biogas products can be utilized as a direct heating fuel or converted into electricity. The application of the AD methods, therefore, could extend the network of clean and renewable energy sources. Especially, could facilitate the access of the people in rural areas to indigenous and cleaner energy. However, the AD approach is also significant for the country's urban population, specifically utilizing as fuel for cooking because more 65% still relies on traditional biomass (MEM, 2020).

2.3 Goal of this Dissertation

Based on long-term development of the government, economic growth target is an axis, however, decarbonizing growth is also remarkably considered. Following the increasing emissions, for example, in transport and waste sector, series of policy documents were developed. Even though relevant policies and strategies were formulated but scientific information are needed to guiding the ground implementation. The goal of this study, therefore, is to illustrate the analysis pathways to achieve the decarbonization goal, particularly decarbonization in road transport and solid waste management.

4. Methodology

This study uses a Computable General Equilibrium (CGE) for the assessment on the effect of decarbonization policies in Laos with the focus on the transportation sector (Electric Vehicle (EV)) and waste sector.
The CGE model is a computer-based simulation to describe the whole economy and its sectoral interaction by using a system of equation. CGE model is often applied for policy analysis that tried to join all sectors in the economy. The model also can be developed based on the real-world data of a single country or multi parties. The simulation usually begun with the business-as-usual followed by the introduction of some policy constraints (e.g., countermeasure policies) and the model will create a new general equilibrium after the shock (Babatunde et al., 2017). This model is a recursive dynamic model and only the equilibrium condition within a year is considered. The technology introduction is determined by the change of the capital stock, capital formation, and the capital depreciation that determined by the previous year.
This study is consisting of two simulations, the assessment on the 1.) transport sector and 2.) waste Sector. The assessments are done to achieve two main purposes: 1). For analyzing the impacts of promoting EV technology, and 2). Examine the mitigation policy on sustainable solid waste management.
In general, the simulation is done by comparing the Business-as-Usual Scenario (BaU) and the countermeasures (CM) scenarios. In the assessment for the transport sector, the CM scenarios consist of three scenarios 1.) introduction of EV technology, 2.) Introduction of Carbon Tax, and 3.) the introduction of subsidy. While there is only one CM scenario for the simulation in the waste sector, that is the extension of the scale of waste recycle services (figure 3.1).

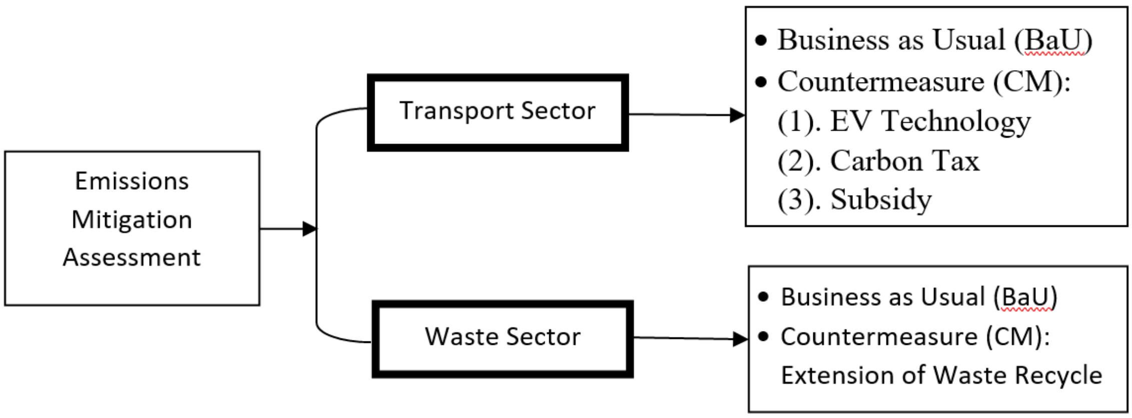


Fig. 3.1. Outline of the study

3.1 General CGE Framework

The CGE model is applied, for this study, to carry out an assessment on GDP and GHG emission impacts through introducing greenhouse gas mitigation options in the transport and waste sectors. The concept of general equilibrium theory was originally set down by the French economist Leon Walras. This theoretical concept was then extended by Kenneth Arrow and Gerard Debreu to examine of the existence and equilibrium of the model (Albert Jolink and Jan Van Daal, 1993) and the CGE framework was designed and developed for evaluation and analysis of the policies by Johansen (Dixon and Rimmer, 2016).

A simplified CGE model framework which the data from input-output table (IO table) is the important input for the model. The structure briefly presented the production sector which the virtual firm produces one or more commodities based on the fixed yield coefficients and under available production technology the virtual firm possesses is assumed to maximize the profit (Figure 3.2).

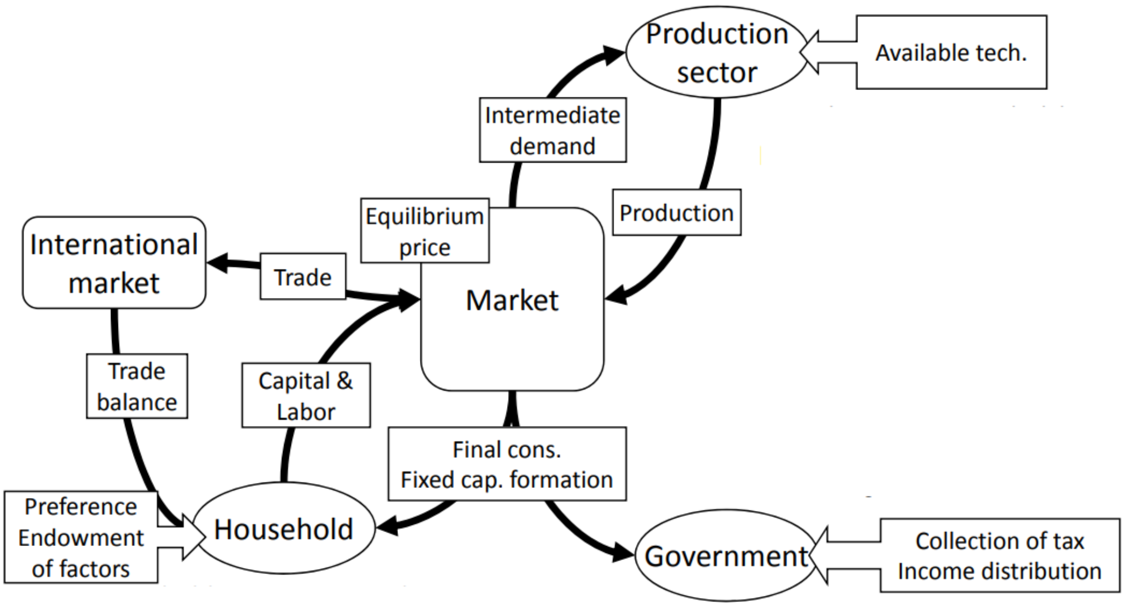


Fig. 3.2. Simplified CGE model framework

Many production functions applied in the production sectors in the several economic models, however, the functions that common apply in the production sectors under the standard CGE model is a constant elasticity of substitution (CES) function, Leontief function and Cobb-Douglas function. There are many production sectors of the CGE model whereas production sector will get the input as intermediate demand from the market and be able to form the several production nesting levels. The design of the nesting production structure of each study is different according to the availability of data, assumptions, the development of the CGE model and the research objective (Löfgren et al., 2002). In this study, production structure shows in Figure 3.3 included the intermediate production inputs, of which they included non-energy sectors input, energy and value-added composite sector input and GHG emissions from production activities input. Inside the value added and energy composite input, capital and labor are also aggregated as composite goods, refer to as value added input in this study. And individual energies are aggregated to be energy composite input under the value-added and energy nest. It is worth noting that burning the fuel generates the GHG emission, each one of energy input is a nesting of energy and GHG.

As for the household sector, the economic behavior of household is that household will sell its endowed factors to earn income. Earning the income, household will spend the income to consume commodities and services from the corresponding commodity market to maximize household's utility (welfare) under the budget constraint of the household. The remaining income which has not been used as expenditure will be kept as saving. In this study, net export is equivalent to saving minus investment. In the government sector, it is assumed that government will collect tax from household endowed factor income, indirect tax from production goods and import tax. At the same time, it is assumed that government will expense their income to purchase goods from the market and proceed the income distribution. It should be noted that there is no single perfect way of modelling government activities from the viewpoint of micro economic foundation, while this study modelled the behavior of a firm and household based on the micro economic foundation (Hosoe and Hashimoto, 2015). This study assumed government role to satisfy the modeling approach and research goal. Furthermore, to reflect more real economic situation, the framework in the figure 3.2, shows an open economy in which a national economy will be connected to the rest of the world through the trade in the model. As Lao economy is very small compared to the world economy, this can be implied that Laos trading price could not have an impact or alter the commodity price of the international market. The foundation of the small economy is that export and import prices quoted in foreign currency term are exogenous variable into the model. In the market, the role of it is to equilibrate demand and supply by adjusting prices. Goods with excess supply price will fall and goods with excess demand price will rise. The price mechanism is a powerful device capable of solving the equilibrium of these supply and demand of every commodity and services.

3.2 Model Structure

This CGE[Lao] model consist of 41 sectors that developed based in the original Lao's Input Output (IO) table. The original Lao's IO table has 35 sectors, however due to the disaggregation process, especially for the electricity sector, the final sector classification becomes 41 sectors.

3.2.1 Overall Model Structure

The model captures the equilibrium of supply and demand in the economy. In the economy, those sectors link between each other, and in this model, the connection of each sector is described in Figure 3.3. The model consists of three main blocks: production block, domestic final demand block, and international transaction block.

In the production block, each production sector inputs capital, labor, materials, energy, and outputs the related product. GHG emissions from fuel combustions and activities such as IPPU, waste and agriculture are taken into account in the model. Each sector has two types of production processes using the existing capital and the new capital. The new capital comes from new investment in the previous year, and it can be distributed to any sector. After the capital is installed into a sector, this capital becomes existing capital in that sector from the next period. The efficiency in each sector will be improved in proportion to the new capital. In each production process using the existing capital and the new capital, different types of technology; conventional technology and advanced technologies are distinguished as shown in Fig. 3.4. Conventional technology is defined as the averaged technology in the base year, and the advanced technologies are regarded as the GHG mitigation technologies.

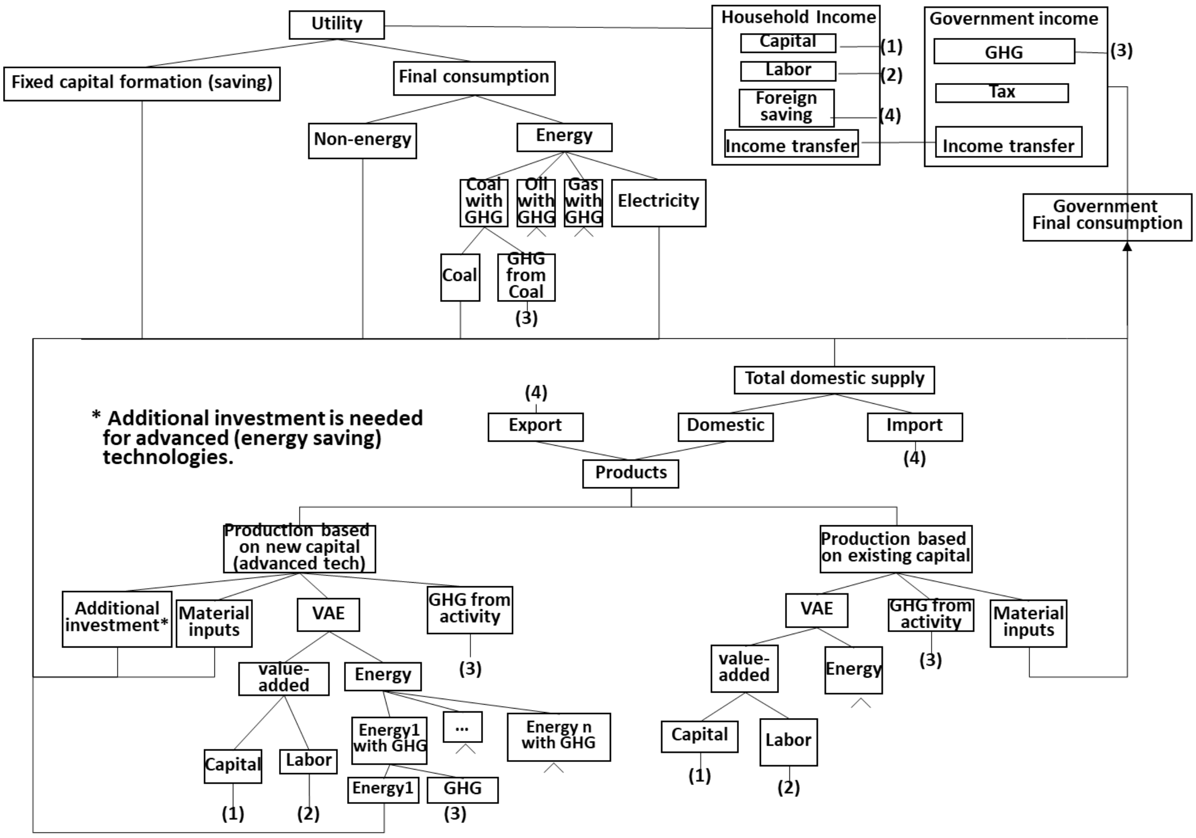
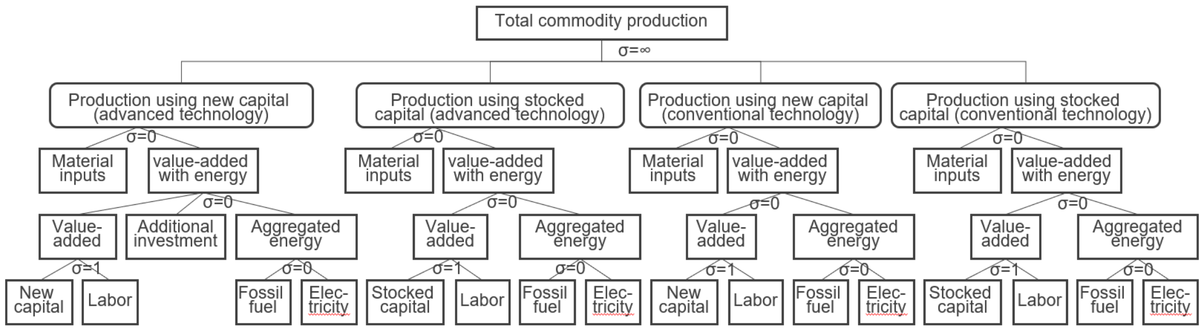


Fig. 3.3 General CGE model structure



Note: σ means elasticity of substitution among the inputs.
Stocked capital cannot be moved to other sectors, but new capital is decided internally to maximize the profit.
"Additional investment" must be paid when the advanced technology is introduced new. After installed, the additional cost is not needed.
Input-output coefficient is calculated year by year according to the deployment of new capital.

Fig. 3.4 CGE structure for production sector

In the domestic final demand, household and government are defined as the components. The original role of government is income redistribution using tax revenue. That is to say, government incomes is used for final consumption or government saving (investment). While the role of household is to earn their income through providing labor to production sector, and utilize the income for consuming produced goods from portion sector.

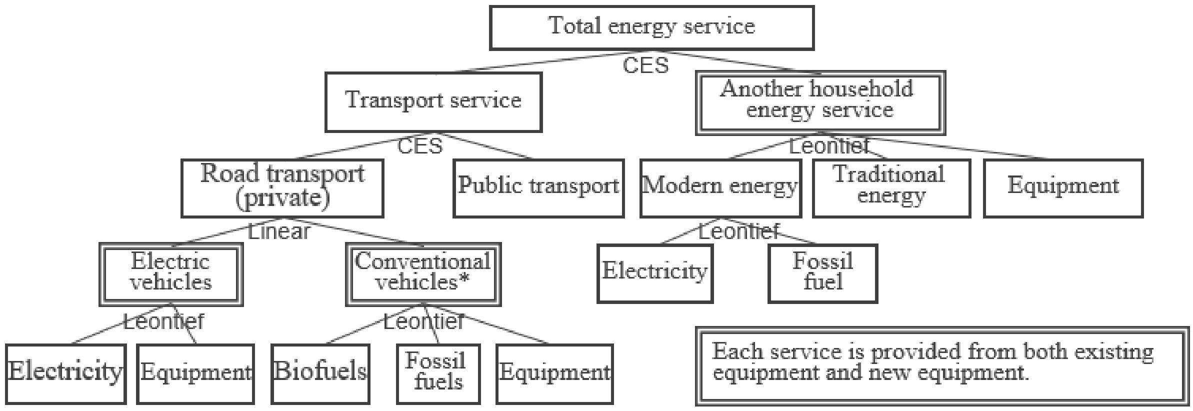
In the international transaction block, basically, exported goods are produced in the country, and imported goods are demanded in the country. To meet the demand in the country, produced goods are exported to domestic markets, or the country will import goods to meet domestic market demand.

3.2.2 Updated of CGE Model Structure in this Study

Some extensions are added to the model to meet this study's objective, which needs to capture waste management services and electric vehicles (EV) provision.

Hydro electricity and biofuels are treated as clean energy options. The electricity in Laos is produced from two main sources; renewable energy, mostly generated by hydropower plants and electricity generated by coal power plants. The future capacity of each power plant is set as a scenario, but the electricity production is calculated endogenously. Biofuel is a substitute for fossil fuels in the transport sector. Agricultural products such as palm and jatropha fruits are necessary for producing biofuels. The production process still generates CO_2 emissions since fossil fuel is needed for palm mill processing and blending palm oil with fossil fuels.

In transport service, conventional technology comprises vehicle which needs fuels, and currently, the share of conventional vehicles in Laos is 100 %. The advanced technology vehicle has multiple advanced options; for example, a vehicle with more efficient energy combustion with less CO_2 emission when compared to the conventional vehicle (Shukla and Dolcera, 2009). In this analysis, EVs are regarded as advanced vehicles. It needs only electricity, and its dissemination will be able to contribute to reducing CO_2 emissions since it consumes cleaner energy, particularly electricity generated from hydropower plants. New 36 hydropower projects are being constructed with the capacity to produce energy of 20,890 Gwh/y (MEM, 2018). The introduction of EVs is regarded as a mitigation option for transportation. Based on the government target, the share of biofuel is assumed to meet 5% of transport fuels in 2030 and 10% in 2050. Fig. 3.5 shows the household sector's CGE model structure of energy demand.



- Share of EV will be14%, 30% and 50% in 2025, 2030, 2040 and 2050, respectively
- Fossil fuel is assumed to mix with biofuels by 50% in 2030 and 80% in 2050

Fig 3.5: CGE structure of energy consumption in household sector

Regarding the waste sector, this model estimates GHG emissions by introducing the "waste-to-sources" approach for municipal solid waste management in Laos, such as increasing the waste collection rate and recycling rate. The model includes the MSW and is categorized into five waste types; organic waste, plastic, paper, glass and steel. It is assumed that all MSW per capita generates from the household sector in proportion to the per capita income, and the share of each waste will be the same until 2050. The generated MSW is collected and treated in the recycling sector or uncollected and self-disposal. In the recycling sector, the collected MSW is treated, some parts of treated waste can be recycled, and the rest of the treatment is dumped at the final disposal site. Recycled plastic, paper, glass and steel wastes are supplied to the related material markets. The organic waste can be recycled for fertilizer (chemical products in the model) or electricity. The total dumped waste consists of uncollected self-disposal and residue after the treatment. Fig. 3.6 shows the waste flow in this model.

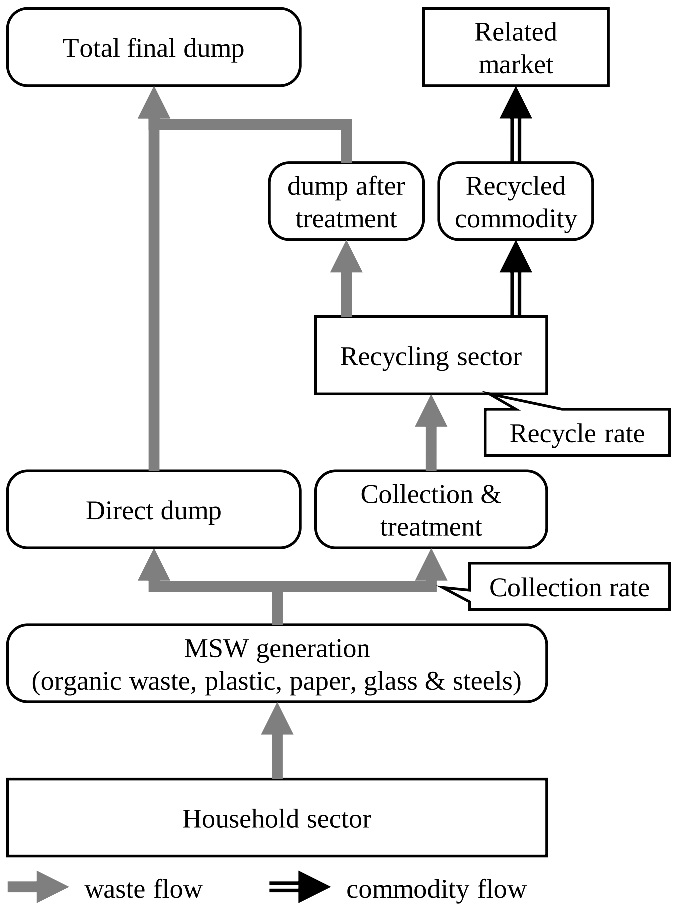


Fig. 3.6. Flow of MSW in this model

3.2.3 Formulation of CGE Model Structure

In this section, the mathematical formulations in each sector are explained. The program of this CGE model is described using MPSGE (Mathematical Programming System for General Equilibrium analysis) of GAMS (General Algebraic Modeling System). As a solver, PATH is used.

3.2.3.1 Production Sector

The production sector composes of a set of production factors including capital and labor that aggregated as value-added., so it is also included in the *Production Block* in the model. The production in each sector is disaggregated into subsectors, using the existing capital stock and the new capital stock. Each subsector has a nested production function (figure 3.7).

3.2.3.1.1 Activity based on existing capital

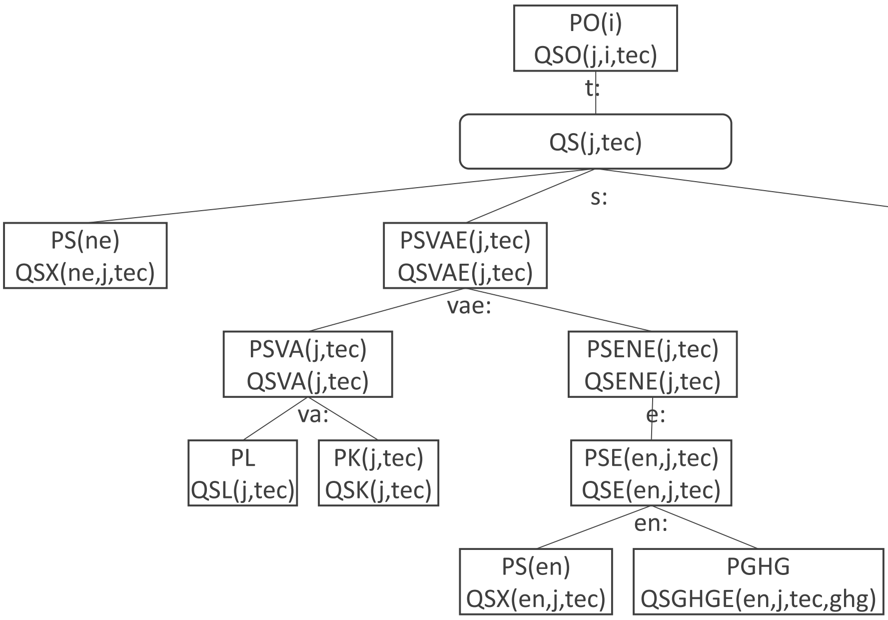


Fig 3.7 Production sector using existing capital

The top of the nested production function is assumed to use the Leontief production function. The emission from the activities (GHGJA) is associated with the production activity in the economy. The equation in the production block can be written as:

$$out(j,tec)\cdot QS(j,tec) = \min\left(\frac{QSX(ne,j,tec)}{asx(ne,j,tec)}, \frac{QSVAE(j,tec)}{asvae(j,tec)}, \frac{QSGHGA(ghg,j,tec)}{efsa(ghg,j,tec)}\right)$$

$$QSX(ne,j,tec) = asx(ne,j,tec)\cdot out(j,tec)\cdot QS(j,tec)$$

$$QSVAE(j,tec) = asvae(j,tec)\cdot out(j,tec)\cdot QS(j,tec)$$

$$QSGHGA(ghg,j,tec) = fsa(ghg,j,tec)\cdot out(j,tec)\cdot QS(j,tec)$$

$$PQS(j,tec)\cdot out(j,tec)\cdot QS(j,tec) = \sum_{ne} PS(ne)\cdot QSX(ne,j,tec) + PSVAE(j,tec)\cdot QSVAE(j,tec) + \sum_{ghg} PGHG\cdot QSGHGA(ghg,j,tec)$$

Where:

QS(j,tec) : Activity level of sector j & technology tec using existing capital
QSVAE(j,tec) : Value added with energy input in sector j & technology tec
QSGHGA(ghg,j,tec) : GHG emissions from activity in sector j & technology tec
QSX(ne,j,tec) : Intermediate demand of non-energy goods ne in sector j & technology tec
PS(j,tec) : Price of activity of sector j & technology tec
PSVAE(j,tec) : Price of value added with energy in sector j & technology tec
PGHG : Price of GHG
PS(ne) : Price of non-energy goods ne
asvae(j,tec) : coefficient of value added with primary energy in sector j & technology tec

asx(ne,j,tec) : coefficient of intermediate non-energy good ne in sector j & technology tec
efsa(ghg,j,tec) : GHG emission factor to unit activity in sector j & technology tec

$$QSVAE(j,tec) = \min\left[\frac{QSENE(j,tec)}{ssene(j,tec)}, \frac{QSVA(j,tec)}{ssva(j,tec)}\right]$$
$$QSENE(j,tec) = ssene(j,tec)\cdot QSVAE(j,tec)$$
$$QSVA(j,tec) = ssva(j,tec)\cdot QSVAE(j,tec)$$
$$PSVAE(j,tec)\cdot QSVAE(j,tec) = PSVA(j,tec)\cdot QSVA(j,tec) + PSENE(j,tec)\cdot QSENE(j,tec)$$

where:

QSVAE(j,tec) : Value added with aggregated energy in sector j & technology tec

QSENE(j,tec) : Aggregated energy in sector j & technology tec

QSVA(j,tec) : Value added in sector j & technology tec

PSVAE(j,tec) : Price of value added with energy input in sector j & technology tec

PSENE(j,tec) : Price of aggregated energy in sector j & technology tec

PSVA(j,tec) : Price of value added in sector j & technology tec

ssene(j,tec) : Share parameter of aggregated energy in value added with energy in sector j & technology tec

ssva(j,tec) : Share parameter of value added in value added with energy in sector j & technology tec.

Regarding to the value-added part, it will include capital and labor, which uses the Cobb-Douglass function.

$$QSVA(j,tec) = asva(j,tec)\cdot QSL(j,tec)^{ssl(j,tec)}\cdot QSK(j,tec)^{ssk(j,tec)}$$
$$QSL(j,tec) = \frac{ssl(j,tec)\cdot PSVA(j,tec)\cdot QSVA(j,tec)}{PL\cdot(1+tx\_l(j))}$$
$$QSK(j,tec) = \frac{ssk(j,tec)\cdot PSVA(j,tec)\cdot QSVA(j,tec)}{PSK(j,tec)\cdot(1+tx\_k(j))}$$

Where:
QSVA(j,tec) : Value added in sector j & technology tec
QSK(j,tec) : Capital demand in sector j & technology tec
QSL(j,tec) : Labor demand in sector j & technology tec
PSVA(j,tec) : Price of value added in sector j & technology tec
PSK(j,tec) : Price of capital of sector j & technology tec

PSL : Price of labor
ssk(j,tec), ssl(j,tec): Share parameters of QSK and QSL to value added in sector j & technology tec
asva(j,tec) : Adjustment parameter for value added in sector j & technology tec
tx_l(j) : Tax rate on labor in sector j
tx_k(j) : Tax rate on capital in sector j

The energy itself also consists of the energy goods and its emission that connected by Leontief function. The energy input (ENE) comprises of intermediate energy input and CO_2 emission. The elasticity of substitution between energy and CO_2 is assumed to be 0 (Leontief function) is assumed. In the case that the total CO_2 emission potential exceeds the CO_2 constraint, the GHG price, PGHG, becomes the positive value.

$$QSENE(j,tec) = \min\left(\frac{QSE(en,j,tec)}{sse(en,j,tec)}\right)$$

$$QSE(en,j,tec) = sse(en,j,tec) \cdot QSENE(j,tec)$$

$$PSENE(j,tec) \cdot QSENE(j,tec) = \sum\nolimits_{en} PSE(en,j,tec) \cdot QSE(en,j,tec)$$

Where:
QSENE(j,tec) : Aggregated energy of sector j & technology tec
QSE(en,j,tec) : Demand of energy en in sector j & technology tec
PSENE(j,tec) : Price of aggregated energy in sector j & technology tec
PSE(en,j,tec) : Price of energy en in sector s & technology tec
sse(en,j,tec) : Share parameters of energy en to total energy in sector j & technology tec

In addition, energy with GHG composite input is needed for production is a composited energy goods and GHG emission. Leontief production function is assumed in this nesting part which followed the same concept as previous study (Rajbhandari et al., 2019). In this model, it also sets that if total GHG emissions exceed the GHG limit set by the scenario, GHG price will become effective.

$$QSE(en,j,tec) = \min\left(QSX(en,j,tec), \frac{QSGHGE(ghg,en,j,tec)}{efe(ghg,en)}\right)$$

$$QSX(en,j,tec) = QSE(en,j,tec)$$

$$QSGHGE(ghg,en,j,tec) = efe(ghg,en) \cdot QSE(en,j,tec)$$

$$PSE(en,j,tec) \cdot QSE(en,j,tec) = PS(en) \cdot QSX(en,j,tec) + \sum\nolimits_{ghg} PGHG \cdot QSGHGE(ghg,en,j,tec)$$

Where:
QSE(en,j,tec) : Energy with GHG composite variable in sector j & technology tec
QSX(en,j,tec) : Energy demand variable in sector j & technology tec
QSGHGE(ghg,en,j,tec) : GHG emissions from energy goods variable in sector j &

technology tec

PSE(en,j,tec) : Price of energy with GHG composite variable in sector j & technology tec
PS(en) : Price of each energy commodity variable
PGHG : Price of GHG variable
efe(ghg,en) : GHG emission factor by each energy & technology tec

At the last production block, production output in sector j will be used as commodity i by using make matrix. In this study, the elasticity among the outputs is set to be 0.

$$QSO(j,i,tec) = vs(j,i,tec) \cdot QS(j,tec)$$
$$\sum_i PO(i) \cdot QSO(j,i,tec) = PQS(j,tec) \cdot QS(j,tec)$$

Where:

QS(j,tec) : Production activity level variable in sector j & technology tec
QSO(j,i,tec) : Produced goods i in sector j & technology tec
PQS(j) : Production price variable of sector j & technology tec
PO(i) : Sales price of goods i
vs(j,i,tec) : Production of commodity i to production level in sector j & technology tec

3.2.3.1.2 Activity for Sector Based on New Capital

The structure of the production in activities using new capital is also similar to the activities using existing capital. New capital is distributed into any sectors to get the maximum profits. Moreover, it is set that the efficiency and other parameters from activities using new capital are improved more compared with those under the existing capital. The production of new capital with advance technology is required additional investment as shown in Fig. 3.8. When the new capital is installed, it cannot be moved or relocated to other sectors. The model structure of activities using new capital which is different from activities using existing capital can be explained as below equation.

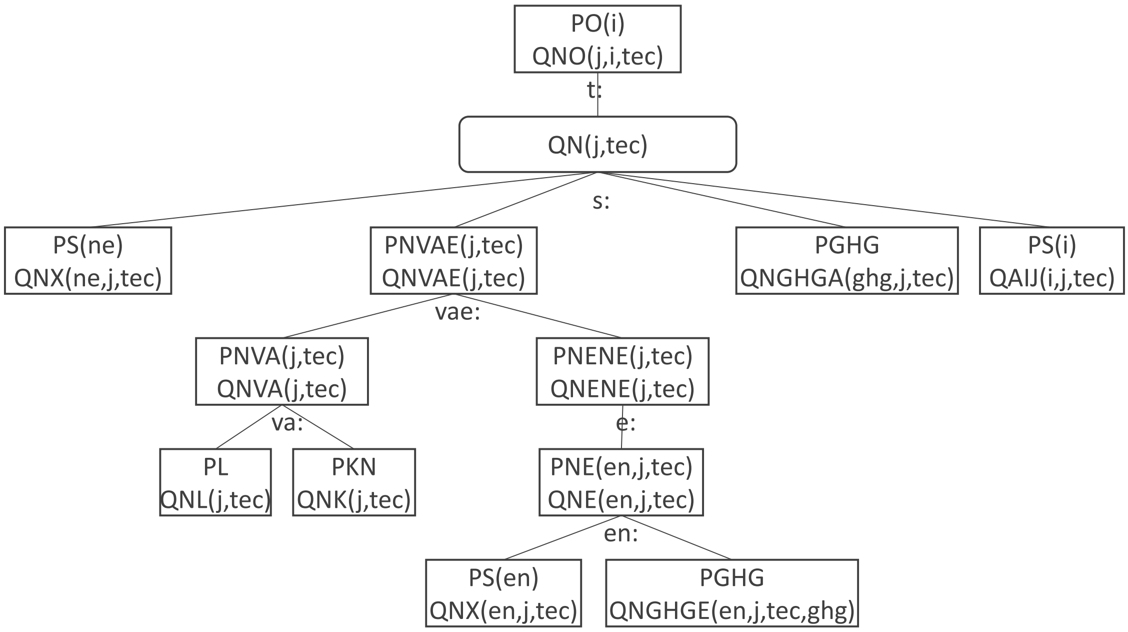


Fig. 3.8 Structure of production using new capital

The nested production function at the first top level in this nest is the Leontief production function., Total sales, under the perfect market competition, are equal to total production cost. Compared to the existing capital, advanced technologies need the additional investment, QAIJ(i,j,tec). By introducing the advanced technology, the energy saving technology will be available. After the advanced technologies are installed, there is no additional cost to that existing capital.

$$out(j,tec)\cdot QN(j,tec)=\min\left(\frac{QNX(ne,j,tec)}{anx(ne,j,tec)},\frac{QNVAE(j,tec)}{anvae(j,tec)},\frac{QNGHGA(ghg,j,tec)}{efna(ghg,j,tec)},\frac{QAIJ(i,j,tec)}{aaij(i,j,tec)}\right)$$

$$QNX(ne,j,tec)=anx(ne,j,tec)\cdot out(j,tec)\cdot QN(j,tec)$$

$$QNVAE(j,tec)=anvae(j,tec)\cdot out(j,tec)\cdot QN(j,tec)$$

$$QNGHGA(ghg,j,tec)=fna(ghg,j,tec)\cdot out(j,tec)\cdot QN(j,tec)$$

$$QAIJ(i,j,tec)=aaij(i,j,tec)\cdot out(j,tec)\cdot QN(j,tec)$$

$$\begin{aligned}PQN(j,tec)\cdot out(j,tec)\cdot QN(j,tec)&=\textstyle\sum_{ne}PS(ne)\cdot QNX(ne,j,tec)\\&+PNVAE(j,tec)\cdot QNVAE(j,tec)+\textstyle\sum_{ghg}PGHG\cdot QNGHGA(ghg,j,tec)+\sum_{i}PS(i)\cdot QAIJ(i,j,tec)\end{aligned}$$

Where:
QN(j) : Activity level of sector j & technology tec using new capital
QNVAE(j,tec) : Value added with energy input in sector j & technology tec
QNGHGA(ghg,j,tec) : GHG emissions from activity in sector j & technology tec
QNX(ne,j,tec) : Intermediate demand of non-energy goods ne in sector j & technology tec
AIJ (i,j,tec) : Additional investment for the advanced technology
PQN(j,tec) : Price of activity of sector j & technology tec
PNVAE(j,tec) : Price of value added with energy in sector j & technology tec

PGHG : Price of GHG
PS(ne) : Price of non-energy goods ne
anvae(j,tec) : coefficient of value added with primary energy in sector j & technology tec
anx(ne,j,tec) : coefficient of intermediate non-energy good ne in sector j & technology tec
efna(ghg,j,tec) : GHG emission factor to unit activity in sector j & technology tec
aaij(i,j,tec) : Input coefficient of additional investment in sector j & technology tec

$$QNVAE(j,tec) = \min\left[\frac{QNENE(j,tec)}{snene(j,tec)}, \frac{QNVA(j,tec)}{snva(j,tec)}\right]$$

$$QNENE(j,tec) = snene(j,tec) \cdot QNVAE(j,tec)$$

$$QNVA(j,tec) = snva(j,tec) \cdot QNVAE(j,tec)$$

$$PNVAE(j,tec) \cdot QNVAE(j,tec) = PNVA(j,tec) \cdot QNVA(j,tec) + PNENE(j,tec) \cdot QNENE(j,tec)$$

where:
QNVAE(j,tec) : Value added with aggregated energy in sector j & technology tec
QNENE(j,tec) : Aggregated energy in sector j & technology tec
QNVA(j,tec) : Value added in sector j & technology tec
PNVAE(j,tec) : Price of value added with energy input in sector j & technology tec
PNENE(j,tec) : Price of aggregated energy in sector j & technology tec
PNVA(j,tec) : Price of value added in sector j & technology tec
snene(j,tec) : Share parameter of aggregated energy in value added with energy in sector j & technology tec
snva(j,tec) : Share parameter of value added in value added with energy in sector j & technology tec

The value added which in the third nesting part composes of capital and labor. New capital in sector j (QKN(j)) is aggregated to the labor in sector j to become value added nest. Cobb-Douglass function is assumed. It should be noted that new capital can be installed in any sectors, not PK(j,tec) but PKN is used to estimate the cost.

$$QNVA(j,tec) = anva(j,tec) \cdot QNL(j,tec)^{ssl(j,tec)} \cdot QNK(j,tec)^{ssk(j,tec)}$$

$$QNL(j,tec) = \frac{snl(j,tec) \cdot PNVA(j,tec) \cdot QNVA(j,tec)}{PL \cdot (1 + tx\_l(j))}$$

$$QNK(j,tec) = \frac{snk(j,tec) \cdot PNVA(j,tec) \cdot QNVA(j,tec)}{PKN \cdot (1 + tx\_k(j))}$$

Where:
QNVA(j,tec) : Value added in sector j & technology tec
QNK(j,tec) : Capital demand in sector j & technology tec
QNL(j,tec) : Labor demand in sector j & technology tec
PNVA(j,tec) : Price of value added in sector j & technology tec
PKN : Price of new capital
PL : Price of labor
snk(j,tec), snl(j,tec): Share parameters of QNK and QNL to value added in sector j & technology tec

anva(j,tec) : Adjustment parameter for value added in sector j & technology tec
tx_l(j) : Tax rate on labor in sector j
tx_k(j) : Tax rate on capital in sector j

The energy itself also consists of the energy goods and its emission that connected by Leontief function. The energy input (ENE) comprises of intermediate energy inputs. The elasticity of substitution between energies is assumed to be 0 (Leontief function).

$$QNENE\left(j,tec\right)=\min\left(\frac{QNE\left(en,j,tec\right)}{sne\left(en,j,tec\right)}\right)$$

$$QNE\left(en,j,tec\right)=sne\left(en,j,tec\right)\cdot QNENE\left(j,tec\right)$$

$$PNENE\left(j,tec\right)\cdot QNENE\left(j,tec\right)=\sum\nolimits_{en}PNE\left(en,j,tec\right)\cdot QNE\left(en,j,tec\right)$$

Where:
QNENE(j,tec) : Aggregated energy of sector j & technology tec
QNE(en,j,tec) : Demand of energy en in sector j & technology tec
PNENE(j,tec) : Price of aggregated energy in sector j & technology tec
PNE(en,j,tec) : Price of energy en in sector s & technology tec
sne(en,j,tec) : Share parameters of energy en to total energy in sector j & technology tec

In addition, energy needed for production is a composited energy goods and GHG emission. Leontief production function is assumed in this nesting part which followed the same concept as previous study (Rajbhandari et al., 2019). In this model, it also sets that if total GHG emissions exceed the GHG limit set by the scenario, GHG price will become effective.

$$QNE\left(en,j,tec\right)=\min\left(QNX\left(en,j,tec\right),\frac{QNGHGE\left(ghg,en,j,tec\right)}{efe\left(ghg,en\right)}\right)$$

$$QNX\left(en,j,tec\right)=QNE\left(en,j,tec\right)$$

$$QNGHGE\left(ghg,en,j,tec\right)=efe\left(ghg,en\right)\cdot QNE\left(en,j,tec\right)$$

$$\begin{aligned}PNE\left(en,j,tec\right)\cdot QNE\left(en,j,tec\right)=&\ PS\left(en\right)\cdot QNX\left(en,j,tec\right)\\&+\sum\nolimits_{ghg}PGHG\cdot QNGHGE\left(ghg,en,j,tec\right)\end{aligned}$$

Where:
QNE(en,j,tec) : Energy with GHG composite variable in sector j & technology tec
QNX(en,j,tec) : Energy demand variable in sector j & technology tec
QNGHGE(ghg,en,j,tec) : GHG emissions from energy goods variable in sector j & technology tec
PNE(en,j,tec) : Price of energy with GHG composite in sector j & technology tec
PS(en) : Price of each energy commodity
PGHG : Price of GHG
efe(ghg,en) : GHG emission factor by each energy & technology tec

At the last production block, production output in sector j will be used as commodity i by using make matrix. In this study, the elasticity among the outputs is set to be 0.

$$QNO\left(j,i,tec\right)=vn\left(j,i,tec\right)\cdot QN\left(j,tec\right)$$
$$\sum_i PO\left(i\right)\cdot QNO\left(j,i,tec\right)=PQN\left(j,tec\right)\cdot QN\left(j,tec\right)$$

Where:
QN(j,tec) : Production activity level using new capital in sector j & technology tec
QNO(j,i,tec) : Produced goods i in sector j & technology tec
PQN(j) : Price of production level in sector j & technology tec
PO(i) : Sales price of goods i
vs(j,i,tec) : Production of commodity i to production level in sector j & technology tec

3.1.2 Household sector

In the model, the household sectors earn income through providing service its endowed factors to the production sectors, such as capital, labor.

3.1.2.1 Household Income

Household income consists of income from endowments and valuable waste generation. Existing equipment for energy service demand in household is also regarded as an endowment. Total costs for energy service demand are also evaluated in the household income.

$$\begin{aligned} MH = {} & PL\cdot end\_l+\sum_j\sum_{tec}PKS\left(j,tec\right)\cdot end\_ks\left(j,tec\right)+PKN\cdot end\_kn \\ & +\sum_i PO\left(i\right)\cdot cw\left(i\right)-\sum_i PS\left(i\right)\cdot stc\left(i\right)+g\_h-hs \\ & -\sum_{hse}PHES\left(hes\right)\cdot QHES\left(hes\right)+\sum_{hs}PZ\left(hes,tec\right)\cdot QSH\left(hes,tec\right) \end{aligned}$$

Where:
MH : Households income
QHES(hes) : Household energy service demand hes
QSH(hes,tec) : Existing stock equipment for energy service hes and technology tec in household
PL : Price of labor
PKS(j,tec) : Price of existing capital for sector j & technology tec
PKN : Price of new capital
PO(i) : Price of produced goods i
PS(i) : Price of domestic market goods i
PHES(hes) : Price of household energy service hes
PZ(hes,tec) : Price of stock equipment for energy service hes & technology tec in household
end_l : Labor endowment
end_ks(j,tec) : Capital endowment of existing capital for sector j & technology tec
end_kn : Capital endowment of new capital
cw(i) : valuable waste generation of commodity i form household sector
stc(i) : Stock change of goods i
g_h : Transfer income between household and government

hs : household saving

3.1.2.2 Composition of Non-Energy Goods

All non-energy goods excluding energy services are aggregated using Cobb-Douglas function as follows;

$$QCH = aqc \cdot \sum_{nex} QC(nex)^{sqc(ne)x}$$

$$QC(nex) = \frac{PCH \cdot QCH \cdot sqc(nex)}{PS(nex)}$$

Where:
QCH : Total households final consumption
QC(nex) : Households final consumption goods nex (excluding commodities related to energy service)
PCH : Price of total households final consumption
PS(nex) : Price of goods nex
aqc : Adjustment parameter
sqc(nex) : Share parameter of nex

3.1.2.3 Energy Service Demand

Household energy service demand consist of two parts; directly using energy and equipment, and purchase of public services. Total energy service demands are linked to the population, income and price of energy service demand.

$$QHES(hes) = \frac{qesh0(hes)}{pop0} \cdot pop \cdot \left(\frac{MH}{mh0}\right)^{elinc(hes)} \cdot \left(\frac{PESH(hes)}{pesh0(hes)}\right)^{elpr(hes)}$$

$$= aes(hes) \cdot \left(shch(hes) \cdot QECF(hes)^{-\rho hes(hes)} + shsrv(hes) \cdot \left(QSRV(hes)\right)^{-\rho hes(hes)}\right)^{-\frac{1}{\rho hes(hes)}}$$

$$QECF(hes) = QHES(hes) \cdot \left(\frac{aes(hes)^{-\rho hes(hes)} \cdot shch(hes) \cdot PHES(hes)}{PECF(hes)}\right)^{\frac{1}{1+\rho hes(hes)}}$$

$$QSRV(hes) = QHES(hes) \cdot \left(\frac{aes(hes)^{-\rho hes(hes)} \cdot shsrv(hes) \cdot PHES(hes)}{PSRV(hes)}\right)^{\frac{1}{1+\rho hes(hes)}}$$

Where:
QESH(hes) : Energy service demand hes in household
MH : Household income
QECF(hes) : Energy service demand hes in household

QSRV(hes) : Energy service demand hes from public service
PESH(hes) : Price of total energy service hes in household
PECF(hes) : Price of private energy service hes in household
PSRV(hes) : Price of public energy service hes in household
qesh0(hes) : Energy service demand hes in household in the base year
pop : Population
pop0 : Population in the base year
mh0 : Income of household in the base year
pesh0(hes) : Price of energy service demand hes in household in the base year
elinc(hes) : Income elasticity of energy service demand hes
elpr(hes) : Price elasticity of energy service demand hes
aes(hes) : Adjustment parameter of energy service demand hes
shch(hes) : Share parameter of private energy service demand hes in household
shsrv(hes) : Share parameter of public energy service demand hes in household
ρ hes(hes) : Elasticity of substitution between private and public energy service demand in household

3.3.2.4 Energy Service Using New Equipment

(1) Energy service demand

Household energy service demand can be provided from new equipment using energy and actual energy demand in household sector. When new technologies are introduced, the related additional investment is needed.

$$QNC(hes,tec) = \min\left(\frac{QNHE(en,hes,tec)}{snce(en,hes,tec)}, \frac{QNH(ne,hes,tec)}{snc(ne,hes,tec)}, \frac{QAIH(i,hes,tec)}{aaih(i,hes,tec)}\right)$$

$$QNHE(en,hes,tec) = snce(en,hes,tec) \cdot QNC(hes,tec)$$

$$QNH(ne,hes,tec) = snc(ne,hes,tec) \cdot QNC(hes,tec)$$

$$QAIH(i,hes,tec) = aaih(i,hes,tec) \cdot QNC(hes,tec)$$

$$\begin{aligned} PECF(hes,tec) \cdot QNC(hes,tec) &= \sum\nolimits_{en} PSEH(en,hes,tec) \cdot QNHE(en,hes,tec) \\ &+ \sum\nolimits_{ne} PS(ne) \cdot QNH(ne,hes,tec) + \sum\nolimits_{ne} PS(i) \cdot QAIH(i,hes,tec) \end{aligned}$$

where:
QNC(hes,tec) : Energy service demand hes in household using new device technology tec
QNHE(en,hes,tec) : Energy demand en for energy service hes & technology tec
QNH(ne,hes,tec) : Demand of devices for energy service hes & technology tec in household
QAIH(i,hes,tec) : Additional investment i for energy service hes & technology tec
PECF(hes, tec) : Price of energy service hes & technology tec in household
PNEH(en,hes,tec) : Price of energy en for energy service hes & technology tec
PS(i) : Price of goods i
snce(en,hes,tec) : Share parameter of energy en for energy service hes & technology tec in household
snc(ne,hes,tec) : Share parameter of new device ne for energy service hes & technology

tec in household

aaih(i,hes,tec) : coefficient on additional investment for energy service hes & technology tec in household

(2). Energy demand and GHG emissions using new equipment

Energy demands using new equipment are represented as follows. GHG emissions are also calculated here.

$$QNHE(en,hes,tec) = \min\left(QNC(en,hes,tec), \frac{QNGHGH(ghg,en,hes,tec)}{efe(ghg,en)} \right)$$

$$QNC(en,hes,tec) = QNHE(en,hes,tec)$$

$$QNGHGH(ghg,en,hes,tec) = efe(ghg,en) \cdot QNHE(en,hes,tec)$$

$$\begin{aligned} PNHE(en,hes,tec) \cdot QNHE(en,hes,tec) = {} & PS(en) \cdot QNC(en,hes,tec) \\ & + \sum_{ghg} PGHG \cdot QNGHGH(ghg,en,hes,tec) \end{aligned}$$

where:

QNHE(en,hes,tec) : Energy demand en for energy service hes & technology tec in household

QNC(en,hes,tec) : Energy service demand hes & technology tec in household using new device

QNGHGH(ghg,en,hes,tec) : GHG emissions from energy en for energy service hes & technology tec

PNHE(en,hes,tec) : Price of energy in energy service hes & technology tec

PS(en) : Price of energy goods en

PGHG : Price of GHG

efe(ghg,en) : GHG emission factor of energy en

3.1.2.5 Energy Service Using Existing Equipment

(1) Energy service demand

Household sector can produce the energy service demand using the existing equipment as follows;

$$QSC(hes,tec) = \min\left(\frac{QSHE(en,hes,tec)}{ssce(en,hes,tec)}, \frac{QSH(hes,tec)}{ssc(hes,tec)} \right)$$

$$QSHE(en,hes,tec) = ssce(en,hes,tec) \cdot QSC(hes,tec)$$

$$QSH(hes,tec) = ssc(hes,tec) \cdot QSC(hes,tec)$$

$$\begin{aligned} PECF(hes,tec) \cdot QSC(hes,tec) = {} & \sum_{en} PSHE(en,hes,tec) \cdot QSHE(en,hes,tec) \\ & + PZ(hes,tec) \cdot QSH(hes,tec) \end{aligned}$$

where:

QSC(hes,tec) : Energy service demand hes & technology tec in household using new device

QSHE(en,hes,tec) : Energy demand en for energy service hes & technology tec in household

QSH(hes,tec) : Devices for energy service hes & technology tec in household
PECF(hes,tec) : Price of energy service hes & technology tec in household
PSHE(en,hes,tec) : Price of energy demand en for energy service hes & technology tec
PZ(hes,tec) : Price of existing equipment for hes & technology tec
ssce(en,hes,tec) : Share parameter of energy en for energy service hes & technology tec in household
ssc(hes,tec) : Share parameter of existing device for energy service hes & technology tec in household

(2) Energy demand and GHG emissions using equipment

Energy demand and GHG emissions are calculated from the following equations;

$$QSHE(en,hes,tec) = \min\left(QSC(en,hes,tec), \frac{QSGHGH(ghg,en,hes,tec)}{efe(ghg,en)} \right)$$

$$QSC(en,hes,tec) = QSHE(en,hes,tec)$$

$$QSGHGH(ghg,en,hes,tec) = efe(ghg,en) \cdot QSHE(en,hes,tec)$$

$$PSHE(en,hes,tec) \cdot QSHE(en,hes,tec) = PS(en) \cdot QSC(en,hes,tec) + \sum_{ghg} PGHG \cdot QSGHGH(ghg,en,hes,tec)$$

where:
QSHE(en,hes,tec) : Energy demand en for energy service hes & technology tec in household
QSC(en,hes,tec) : Energy service demand hes & technology tec in household using new device
QSGHGH(ghg,en,hes,tec) : GHG emissions from energy en for energy service hes & technology tec
PSHE(en,hes,tec) : Price of energy in energy service hes & technology tec
PS(en) : Price of energy goods en
PGHG : Price of GHG
efe(ghg,en) : GHG emission factor of energy en

3.1.3 Government Sector

Government, in this study, will obtain income by collecting taxes which includes direct tax on household endowed factor income and indirect tax on production output, other taxes are import tax and carbon tax. However, the government are responsible for well-being of its citizen by providing its revenue on public services for improving the general living standard.

$$\begin{aligned} GH = & \sum_i \left(PIM(i) \cdot tr\_m(i) \cdot QIM(i) + PD(i) \cdot tr\_d(i) \cdot QD(i) \right) \\ & + \sum_j \sum_{tec} \left(PL \cdot tr\_l(j) \cdot \left(QSL(j,tec) + QNL(j,tec) \right) \right. \\ & \qquad \left. + PSK(j,tec) \cdot tr\_k(j) \cdot QSK(j,tec) + PNK \cdot tr\_k(j) \cdot QNK(j,tec) \right) \\ & + PGHG \cdot end\_ghg - g\_h - gs \end{aligned}$$

Where:
GH : Government income
PIM(i) : Price of imported goods i

PD(i) :Price of domestic goods i
PL : Price of labor
PSK(j,tec) : Price of existing capital in sector j & technology tec
PNK : Price of new capital
PGHG : Price of GHG
QIM(i) : Quantity of imported goods i
QD(i) : Quantity of domestic product goods i
QSL(j,tec) : Labor input in sector j & technology tec using existing capital
QNL(j,tec) : Labor input in sector j & technology tec using new capital
QSK(j,tec) : Existing capital input in sector j & technology tec
QNK(j,tec) : New capital input in sector j & technology tec
tr_m(i) : Tax rate on imported goods i
tr_d(i) : Tax rate on domestic goods i
tr_l(j) : Tax rate on capital in sector j
tr_k(j) : Tax rate on labor in sector j
end_ghg : Greenhouse gas endowment
g_h : Income transfer from government to household
gs : Public saving

$$QCG = acg \cdot \prod_{ne} QGC(ne)^{sgc(ne)}$$

$$QGC(ne) = \frac{sgc(ne) \cdot PCG \cdot QCG}{PS(ne)}$$

Where:
QCG : Total government final demand
QGC(ne) : Government final demand of commodity i
OCG : Price of total government final demand
PGC(ne) : Price of government final demand of commodity i
sgc(ne) : Share of government final consumption of commodity i

3.1.4 Fix Capital Formation

Total saving is used as investment. Capital formation goods are linked using Leontief function as follows;

$$INV = \min\left(\frac{QINV(i)}{sinv(i)}\right)$$

$$QINV(i) = sinv(i) \cdot INV$$

$$PINV \cdot INV = \sum_i PS(i) \cdot QINV(i) = hs + gs + EXR \cdot fs$$

Where:

INV : Total investment
QINV(i) : Individual fixed capital formation goods i
PINV : Price of total investment
PS(i) : Price of commodity i

EXR : Exchange rate for international trade
sinv(i) : Share of individual fixed capital formation goods i to total investment
hs : Private saving
gs : Government saving
fs : Foreign saving

3.1.5 Relationship between Output, Export, Import, and Domestic Market

The domestic produced goods are allocated for domestic use and to be exported. While the domestic supplied goods are from the imported goods that allocated for the domestic use (fig. 3.9).

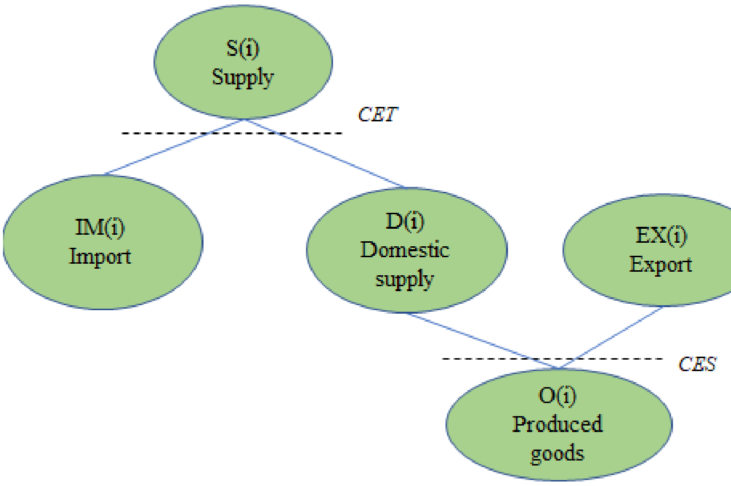


Fig. 3.9. Relationship between Output, Export, Import, and Domestic Markets

In this model, the elasticity assumption for international trade uses assumption for the import and domestic supplied goods, that there is imperfect substitution between import and the supplied goods. The elasticity of the transformation of produced goods between export and domestic is assumed to be constant under the CET function. This function calculates the values of export and domestic goods from the total produced goods and their prices.

$$QO(i) = aex(i) \cdot \left(sex(i) \cdot QEX(i)^{\theta ex(i)} + sxd(i) \cdot QD(i)^{\theta ex(i)} \right)^{\frac{1}{\theta ex(i)}}$$

$$QEX(i) = QO(i) \cdot \left(\frac{aex(i)^{\theta ex(i)} \cdot sex(i) \cdot PO(i)}{PEX(i)} \right)^{\frac{1}{1-\theta ex(i)}}$$

$$QD(i) = QO(i) \cdot \left(\frac{aex(i)^{\theta ex(i)} \cdot sxd(i) \cdot PO(i)}{PD(i)} \right)^{\frac{1}{1-\theta ex(i)}}$$

Where:
QO(i) : Produced goods i

QEX(i) : Export of goods i
QD(i) : Domestic produced goods i
PO(i) : Price of produced goods i
PEX(i) : Price of exported goods i
aex(i) : Adjustment parameter for export
sex(i) : Share parameter of export
sxd(i) : Share parameter of domestic goods
θ ex(i) : Transformation parameter to export and domestic goods

The elasticity of substitution between imported goods and domestic goods is also constant but using the CES function and can be written as:

$$QS(i) = aim(i) \cdot \left(sim(i) \cdot QIM(i)^{-\rho im(i)} + smd(i) \cdot QD(i)^{-\rho im(i)} \right)^{\frac{1}{-\rho im(i)}}$$

$$QIM(i) = QS(i) \cdot \left(\frac{aim(i)^{\rho im(i)} \cdot sim(i) \cdot PS(i)}{PIM(i) \cdot (1 + tr\_m(i))} \right)^{\frac{1}{1-\rho im(i)}}$$

$$QD(i) = QS(i) \cdot \left(\frac{aim(i)^{\rho im(i)} \cdot smd(i) \cdot PS(i)}{PD(i) \cdot (1 + tr\_o(i))} \right)^{\frac{1}{1-\rho im(i)}}$$

Where,
QS(i) : Total supply of goods i
QD(i) : Domestic produced goods i
QIM(i) : Imported goods i
PS(i) : Price of supplied goods i
PD(i) : Price of domestically produced goods i
PIM(i) : Price of imported goods i
sim(i) : Share of import
smd(i) : Share of domestic use
aim(i) : Adjustment of import and domestic goods
ρ im(i): Substitution parameter between import and domestic goods
tr_m(i) : Tax rate for imported goods i
tr_o(i) : Tax rate for domestic products i
The international commodity prices (pintx(i) and pintm(i)) and trade surplus (fs) are assumed to be exogenous parameters. The exchange rate (EXR) is described as:

$$PEX(i) = EXR \cdot pintx(i)$$

$$PIM(i) = EXR \cdot pintm(i)$$

$$\sum_i pintx(i) \cdot QEX(i) + fs = \sum_i pintm(i) \cdot QIM(i)$$

Where:
EXR : Exchange rate
PEX(i) : Price of exported goods i
PIM(i) : Price of imported goods i

QEX(i) : Exported goods i
QIM(i) : Imported goods i
pintx(i) : International commodity price for export goods
pintm(i) : International commodity price for import goods

3.1.6 Market equilibrium

In order to develop the CGE model, following five equilibrium conditions are required, such as market goods, the market of capital, the market of labor, and market of GHG. Based on market theory, when the demand exceeds the supply, the corresponding price become positive value.

3.1.6.1 Production Market

Based on activities using existing capital and activities using new capital, total produced goods will be equal to the total production.

$$O(i)=\sum_{j}\sum_{tec}QSO(j,i,tec)+QNO(j,i,tec)+cw(i)$$

Where,
O(i) : Total produced goods i
QSO(j,i,tec) : Produced goods i by activities using existing capital in sector j & technology tec
QNO(j,i,tec) : Produced goods i by activities using new capital in sector j& technology tec
cw(i) : Valuable waste generation of commodity i from household

3.1.6.2 Market of Domestic Supply Goods

Under condition of the market of domestic supply goods, the supply of goods and demand of goods are balanced. PS(i) is decided in this market.

$$\begin{aligned}S(i)=&\sum_{j}\sum_{tec}\left(QSX(i,j,tec)+QNX(i,j,tec)+QAIJ(i,j,tec)\right)\\&+QC(nex)+\sum_{hes}\sum_{tec}\left(QSC(en,hes,tec)+QNC(en,hes,tec)+QNH(ne,hes,tec)+QAIH(i,hes,tec)\right)\\&+QGC(i)+QINV(i)+stc(i)\end{aligned}$$

Where,
S(i) : Supply of goods i
QSX(i,j,tec) : Intermediate demand i in sector j , of which production using existing capital
QNX(i,j,tec) : Intermediate demand i in sector j , of which production using new capital
QAIJ(i,j,tec) : Additional investment for sector j & technology tec
QC(nex) : Final household consumption goods nex (non-energy and non-equipment)
QSC(en,hes,tec) : Household energy demand in energy service hes & technology tec for existing equipment
QNC(en,hes,tec) : Household energy demand in energy service hes & technology tec for new

equipment
QNH(ne,hes,tec) : Household equipment demand for energy service hes & technology tec
QAIH(i,hes,tec) : Additional investment for energy service hes & technology tec
QGC(i) : Government consumption goods i
QINV(i) : Investment using goods i
stc(i) : Stock change of goods i

3.1.6.3 Market of labor

Total labor demand is equal with the labor endowment, and from this market, the labor price PL is calculated.

$$end\_l = \sum_j \sum_{tec} \left(QSL(j,tec) + QNL(j,tec) \right)$$

Where,
end_l : Endowment of labor
QSL(j,tec) : Labor input in sector j and technology tec of existing capital
QNL(j,tec) : Labor input in sector j and technology tec of new capital

3.1.6.4 Market of Capital

The capital supplied in the market will be equal to the capital endowment. There are two types of capital in this study, the existing capital and the new capital. In order to maximize the profit in each sector, new capital can be installed in any sector. But when it is installed, it becomes existing capital and cannot move to any sectors. In each market, capital price, PSK(j,tec) and PKN are calculated.

$$end\_ks(j,tec) = QSK(j,tec)$$

$$end\_kn = \sum_j \sum_{tec} QNK(j,tec)$$

Where,
QKS(j,tec) : Existing capital in sector j & technology tec
QKN(j,tec) : New capital in sector j & technology tec
end_ks(j,tec) : Endowment of existing capital in sector j & technology tec
end_kn : Endowment of new capital

3.1.6.5 Market of GHG

The total GHG emission which emitting from both the activities and energy sectors are summed and equal with the GHG endowment and can be written as:

$$end\_ghg = \sum_{j}\sum_{tec}\Big(QSGHGA(j,tec) + QNGHGA(j,tec)$$
$$+\sum_{en}\big(QSGHGE(en,j,tec) + QNGHGE(en,j,tec)\big)\Big)$$
$$+\sum_{hes}\sum_{tec}\sum_{en}\big(QSGHGH(en,hes,tec) + QNGHGH(en,hes,tec)\big)$$

Where,

end_ghg	: Total GHG emission
GHGSA(j,tec)	: GHG emission from activity in sector j of existing capital
GHGNA(j,tec)	: GHG emission from activity in sector j of new capital
GHGSE(en,j,tec)	: GHG emission from fuel combustion en in sector j of existing capital
GHGNE(en,j,tec)	: GHG emission from fuel combustion en in sector j of new capital
GHGSH(en,hes,tec)	: GHG emission from household energy service hes using existing equipment
GHGNH(en,hes,tec)	: GHG emission from household energy service hes using new equipment

3.1.6.6 Household energy service

Household energy service consists of that from new equipment and existing equipment.

$$QECF(hes) = \sum_{tec} QNC(hes,tec) + QSC(hes,tec)$$

Where,

QECF(hes)	: Energy service in household energy service hes
QNC(hes,tec)	: Energy service using new capital
QSC(hes,tec)	: Energy service using existing capital

3.2 Recursive Dynamic Process

The recursive dynamic model formed from the benchmark year to the target year, in this study, has been presented. The relation of the recursive dynamic model is to unravel the solution of the period of time. The defined parameters, namely, capital endowment, labor endowment, energy efficiency, upper limit of GHG emissions and intermediate input-output coefficients are updated based on the modeling result of previous period and the future scenario. In addition, the market equilibrium conditions of production market, market of supply goods, capital market, labor market and GHG market for CGE model under the previous section still take into account in each period of this recursive dynamic procedure iterations.

3.2.1 Labor Supply

The growth rate of labor is determined by an exogenous parameter, which is defined based on direct relation to the population growth and Lao demographic structure that were projected by the national statistical bureau, under Ministry of Planning and Investment.

$$end\_l_t = end\_l_{t+1} \cdot (1 + lab\_gr_t)$$

Where:

end_l_t : Total labor in year t

lab_gr_t : Exogenous parameter of labor growth rate in year t

3.2.2 Capital Stock Accumulation and Investment

The trend of economic growth, under this study, is set in advance and defined as an exogenous parameter. Firstly, in order to examine, this study determined the growing pathway of Lao economy by defining the economic growth rate as an exogenous parameter. The total existing capital stock is then estimated to reach the growing pathway of exogenous growth parameter. investment and parameter such as depreciation and economic growth is calculated from the existing capital in a benchmark year. The economic growth is projected by examining the total investment based on the acceleration principle of capital. New capital can be installed in any sectors, but after it is installed in a sector, it cannot be moved in the future. Depreciation at 5% per year is assumed in this study. Equations below define the relationship among them.

The investment and capital stock relationship in base year is firstly assumed on the optimal economic growth direction. Such a case, the base year investment is compatible with the capital stock in the next year. Secondly, instead of use capital stock directly, the capital income is identified as a capital input, thus the assumption of linear relationship between capital stock and capital income is defined. In addition, capital stock converted to capital income (cap_cnv) is used as a rate of return to capital stock (Hosoe et al., 2016). And thirdly, values of rate of return of capital in all sectors are assumed the same, since the capital distribution among the sectors in the base year is also regarded as an optimal result. Based on this, the ratio of the capital stock is the same as the ratio of its capital input in each sector.

Below equations are related to investment and capital stock process, which suffix “t” (year) is identified.

Based on 1st assumption, the relationship between total capital stock and fixed capital is illustrated;

$$\text{CAPSTKT}(t0) = \frac{INV(t0)}{g(t0)+\delta}$$

Where:

CAPSTKT(t0) : Total capital stock in base year (t0)

INV(t0) : Total fixed capital formation in base year (t0) = Σi invh(i,t0)

g(t0) : Economic growth rate in base year (t0)

δ : Depreciation rate

Based on the parameter between capital stock and capital income, the rate of return on capital is calculated from the total capital income and total capital stock in the base year as follow.

$$\sum_j end\_KS(j,t0) \; = \; cap\_cnv.CAPSTKT(t0)$$

Where:

end_KS(j,t0) : Capital income in existing stock in sector j in base year (t0)

CAPSTKT(t0) : Total capital stock in base year (t0)

cap_cnv : Rate of return on capital

The assumption of rate of return on capital, in this model, is constant among the sectors and in the future.

The total capital stock, expected economic growth rate and depreciation rate are decided for total fixed capital formation. The total capital stock is calculated from that in the previous year and the total fixed capital formation in the previous year. The share of each capital formation goods to the total is assumed to be constant. Corresponding to total fixed capital formation and the net foreign saving, the household saving is decided.

$$CAPSTKT(t)=CAPSTKT(t-1).(1-\delta)+INV(t-1)$$

$$INV(t+1)=CAPSTKT(t).(g(t)+\delta)$$

Where:

CAPSTKT(t)	: Total capital stock in year t
INV(t)	: Total fixed capital formation in year t
g(t)	: Economic growth rate in year t
δ	: Depreciation rate

The new capital endowment is calculated from the total fixed capital formation in the previous year and the rate of return on capital.

$$End\_KN(t+1) = \frac{INV(t)}{cap\_cnv}$$

Where:

end_KN(t)	: Endowment of new capital in year t
INV(t)	: Total fixed capital formation in year t
cap_cnv	: Rate of return on capital

The existing capital endowment of sector j is calculated from that in the previous year and the demand of new capital in the previous year. The new capital demand in each sector is decided endogenously.

$$End\_KS(j,t+1) = (end\_KS(j,t)+KN(j,i).(1-\delta)$$

Where:

end_KS(j,t)	: Endowment of existing capital in sector j in year t
KN(j,t)	: New capital demand in sector j in year t
δ	: Depreciation rate

3.2.3 Update of Parameter

In the recursive dynamic process, the model exogenous parameter is updated year by year. The labor efficiency value, capital efficiency, energy efficiency and material input efficiency in the model in each year are updated through new parameter, in which is defined by the scenario setting in advance. In addition, in this CGE model sets that the model output values from existing period is calculated from the results in the previous year.

The updated parameter will be used to update the model output value in proportion to the value in the previous year. The value of parameter for existing capital is calculated in proportion to the values of existing stock and new stock. The parameters in new capital activity is updated exogenously, as presented in equations below.

The efficiency of existing stock such as labor productivity and energy efficiency, in proportion to the stock of new capital, will be improved, and efficiency of new capital is set exogenously.

$$\text{paras(j,t+1)} = \frac{\text{paras(j,t).end\_KS(j,t)+paran(j,t).KN(j,t)}}{\text{end\_KS(j,t)+KN(j,t)}}$$

paran(j,t+1) = paran(j,t).eff_imp(j,t)

Where:

paras(j,t)	: Efficiency of existing stock in sector j in year t
paran(j,t)	: Efficiency of new capital in sector j in year t
eff_imp(j,t)	: Efficiency improvement in sector j in year t
end_KS(j,t)	: Endowment of existing capital stock in sector j in year t
KN(j,t)	: Demand of new capital in sector j in year t

3.3 Waste generation

In order to assess amount of waste generation in this simulation, income per capita and number of population are defined as the factors influencing volume of waste generation. Income elasticity is defined, this means if income increases the amount of waste will increase.

$$\text{wg(wst)} = w_0 \cdot \left(\frac{income_t}{income_0}\right)^{\sigma} \cdot \frac{Pop_t}{Pop_0}$$

where:

wg(wst)	: waste generation
w_0	: initial waste generation
$income_0$	: initial income per capita
$income_t$	: income per capita in time t
Pop_0	: initial number of population
Pop_t	: number of population in time t
σ	: income elasticity

Waste collection is calculated from waste generation and waste collection rate. The waste collection rate is defined to extend in each period.

wc(wst) = wg(wst) . w_cr(wst)

Where:

wc(wst)	: solid waste collection
wg(wst)	: solid waste generation
w_cr(wst)	: solid waste collection rate

Waste direct dump is calculated from waste generation and share of waste collection rate, waste direct dump consists of direct dump by household and residual dump after recycle.

wdd(wst) = wg(wst) . (1 - w_cr(wst))

Where:

wdd(wst) : solid waste direct dump
wg(wst) : solid waste generation
w_cr(wst) : solid waste collection rate

Waste recycle is calculated from waste recycle and recycle rate in waste management. Volume of waste recycle will increase based on increase of waste collection.

$$wr(wst,tec) = wc(wst) \cdot w\_rr(wst,tec)$$

Where:
wr(wst,tec) : solid waste recycle with technology
wc(wst) : solid waste collection
w_rr(wst, tec) : recycle rate in waste management with technology

Waste dump after recycle is calculated from waste collection and share of waste recycle rate, waste dump after recycle is the residual from recycle process.

$$wrd(wst,tec) = wc(wst) \cdot (1 - w\_rr(wst,tec))$$

where:
wrd(wst,tec) : solid waste dump after recycle with technology
wc(wst) : solid waste collection
w_rr(wst,tec) : recycle rate in waste management with technology

The endowment of waste dump consists of solid waste dump after recycle and waste direct dump.

$$end\_dump = \sum_{wst}((wrd(wst, tco) + wdd(wst))$$

where:
end_dump : endowment of waste direct dump
wrd(wst,tec) : solid waste dump after recycle with technology
wdd(wst) : solid waste direct dump

3.4 Data

The main data to develop the AIM/CGE [Laos] model is based on the Laos input-output (IO) table in 2014, which was developed and published by ADB in 2018 (ADB, 2018), with the original table consisting of 35 commodities. In order to meet the study objectives, because some commodities are aggregated with other groups, nevertheless, the data is disaggregated into the base year data and future assumption. The 35 commodities were disaggregated into 41 commodities, included biofuel, as a new one commodity was added (table 3.1).

The decision to choose this dataset as the main data is due to the most recent national GHG inventory availability. In this study, based on their energy sources, some sectors are divided into more detailed sectors such as hydro power plants and coal thermal power plants, refined petroleum. The agriculture sector was also disaggregated into cropping, livestock, forest and fishing. Additional input socio-economic data based on the National Yearbook, in order to set a future scenario, are potential gross domestic product (GDP), the trade balance, capacity of power generation, and population growth. Moreover, the biofuel production sector is added.

Table 3.1. Modified Input-Output Table Commodity Classification

Aggregated Commodity	Disaggregated Commodity
1. Agriculture, hunting, forestry, and fishing	1. Agriculture, hunting, forestry, and fishing 1.1 Cropping 1.2 Livestock 1.3 Forest 1.4 Fishing
2. Mining and quarrying	2. Mining and quarrying
3. Food, beverages, and tobacco	3. Food, beverages, and tobacco
4. Textiles and textile products	4. Textiles and textile products
5. Leather, leather products, and footwear	5. Leather, leather products, and footwear
6. Wood and products of wood and cork	6. Wood and products of wood and cork
7. Pulp, paper, paper products, printing, and publishing	7. Pulp, paper, paper products, printing, and publishing
8. Coke, refined petroleum, and nuclear fuel	8. Coke, refined petroleum, and nuclear fuel 8.1 Coke and nuclear fuel 8.2 Refined petroleum
9. Chemicals and chemical products	9. Chemicals and chemical products
10. Rubber and plastics	10. Rubber and plastics
11. Other non-metallic minerals	11. Other non-metallic minerals
12. Basic metals and fabricated metal	12. Basic metals and fabricated metal
13. Machinery, nec	13. Machinery, nec
14. Electrical and optical equipment	14. Electrical and optical equipment
15. Transport equipment	15. Transport equipment
16. Manufacturing, nec; recycling	16. Manufacturing, nec; recycling
17. Electricity, gas, and water supply	17. Electricity, gas, and water supply 17.1 Electricity [Hydropower and Coal thermal power] 17.2 Water supply
18. Construction	18. Construction
19. Sale, maintenance, and repair of motor vehicles and motorcycles; retail sale of fuel	19. Sale, maintenance, and repair of motor vehicles and motorcycles; retail sale of fuel
20. Wholesale trade and commission trade, except of motor vehicles and motorcycles	20. Wholesale trade and commission trade, except of motor vehicles and motorcycles
21. Retail trade, except of motor vehicles and motorcycles; repair of household goods	21. Retail trade, except of motor vehicles and motorcycles; repair of household goods
22. Hotels and restaurants	22. Hotels and restaurants
23. Inland transport	23. Inland transport
24. Water transport	24. Water transport
25. Air transport	25. Air transport
26. Other supporting and auxiliary transport activities; activities of travel agencies	26. Other supporting and auxiliary transport activities; activities of travel agencies
27. Post and telecommunications	27. Post and telecommunications
28. Financial intermediation	28. Financial intermediation
29. Real estate activities	29. Real estate activities
30. Renting of M&Eq and other business activities	30. Renting of M&Eq and other business activities
31. Public administration and defense; compulsory social security	31. Public administration and defense; compulsory social security

32. Education	32. Education
33. Health and social work	33. Health and social work
34. Other community, social, and personal services	34. Other community, social, and personal services
35. Private households with employed persons	35. Private households with employed persons
	36. Biofuel

The IO Table also provides an insight into supply and demand. Generally, the total demand and supply in the national economy on the IO table 2014 are 38,819 million kip (USD 2.6 million). On the demand side, the final consumption expenditure by household is 8,663 million kip (USD 0.5 million) and the final consumption expenditure by government is 1,655 million kip (ADB, 2020).

The information related to the bioenergy production is obtained from renewable energy development strategy of Lao government (MEM, 2022). Besides the data mentioned above, other socio-economic data like GDP, trade balance, power generation capacity, and population growth are needed for the simulation. Since EV technology consumes cleaner energy, particularly electricity that is generated from hydropower plants. New 36 hydro power projects are being constructed with capacity to produce energy of 20,890 GWh/y (MEM, 2018).

The information related to the waste generation, in this study, gained from national statistic yearbook (MPI, 2018). Based on the JICA initial survey (JICA, 2021), the amount of solid waste generated in Laos in 2015 was 1.3 million tone, and it is assumed that the solid waste generation per capita will increase linearly. In addition, it is assumed that the share of each solid waste to the total waste is the same by 2050. The collection rate to generate of each waste in 2014 is set 34%, and recycle rate to collected waste in 2014 is set 10%. In this analysis, due to the lack of data, it is assumed that extension of the waste collection and recycling in waste management sector can be implemented without any additional costs.

GDP growth rate is needed to project the impacts on the GDP value from the import. The GDP growth rate data has obtained from annual national statistics reports during 2014-2019. An average growth rate during 2014-2019 was 7% (table 3.2). While from 2020 to 2050, the average growth is assumed to be 5.7% per year.

Table 3.2. GDP Growth Rate

No.	Year	Growth rate (%)
1	2014	8
2	2015	7
3	2016	7
4	2017	7
5	2018	6
6	2019	6

Source: Annual Statistic Yearbook (2014-2019)

Population data is required for projection of the increase of vehicles and waste volume in the model. Lao population steadily increased during last 15 years, based on the result of the 2015 Population and Housing Census indicated that since the last census conducted in 2005, the total population of Laos increased by about 870 thousand persons implying that the population increased, on average, by 1.5% annually (MPI, 2015), (table 3.3). The population growth is projected to lowly decrease in 2030, at the growth rate by 1.1% and will continue lowly grow at 0.7% in 2040 (UNDP, 2022).

Table 3.3 Number of Population

Year	Population (million persons)	Age 0-14	Age 15-46	Age >46
2005	5.6	2.2	3.2	0.2
2010	6.2	2.4	3.6	0.2
2015	6.6	2.3	4.2	0.1

Source: Lao population and household census report, MPI (2015)

3.5 Scenarios Development

3.5.1 Business as Usual (BaU)

BaU scenario is a reference case with no mitigating countermeasures policy. In this scenario, the future patterns of activity which assumes that there will be no significant change in people's attitudes and priorities, or no major changes of continuing current trends in population, technology, economy and human behavior, or policies, so that normal circumstances can be expected to continue unchanged. Under this scenario, the annual GDP growth rate from 2020 to 2050 is assumed to be 5.7%/y. Population growth rate from 2020 to 2050 is assumed to be 1.2%/y.

In case of baseline scenario of road transportation, the number of conventional vehicles will increase gradually following the extension of population and urbanization. The expected number of conventional vehicles will expand from 2.2 million vehicles in 2019 to be 6.6 million vehicles in 2050. The increasing automobile will undoubtedly demand more imported fossil fuels that government spent more than USD 500 million for fuels import during 2010-2016. The transport fuel combustion is a key driver of CO_2 emissions from transport sector and causing severe city air pollution in main cities.

Population and economic growth are the main factor influencing people migrate to settle and work in the main cities, resulting in rapid urbanization and households afford to consume more that driving the increase of waste generation, particularly municipal solid waste (MSW). When the MSW is treated unproperly, it can generate GHG emissions. In Laos, due to budget constraints, low skill workers, and lack of technologies, therefore the common challenges are low rate of solid waste collection, and openly dumping and burning are common practices. Due to waste collection rates remain low, vacant lots are without proper treatment and landfill is ordinarily practiced for waste disposal, thus environmentally sound landfills are not possible, and problems such as GHG emission is still apparent.

3.5.2 Countermeasure Scenarios

Since global warming has a direct connection with concentration of GHG emissions in the atmosphere. There is a series of solutions combat the climate change problem, specifically in decreasing the amount of emissions released into the atmosphere and in reducing the current concentration of carbon dioxide. The climate change mitigation action will play a vital role in limiting such the increase of GHG emissions to be aligned with the Paris Agreement target. In general, climate change mitigation means avoiding and reducing emissions of heat-trapping greenhouse gases into the atmosphere to prevent the planet from warming to more extreme temperatures (UNFCCC, 2016). Such mitigation actions including but not limited to the formulation and implementation of the programs containing measures to mitigate global warming by targeting the economic activities with an aim to incentivize actions that are cleaner or disincentive those that result in large amounts of GHG emissions. Mitigation actions include policies, incentives schemes and investment programs on the advanced technologies to the main GHG intensive sectors, ranging from energy and electricity generation sectors to transport, industry, agriculture, and waste management sectors. Mitigation action measures are translated in, for example, an increased use of renewable energy, the application of new technologies such as electric vehicles, carbon capture and storage and energy efficiency improvement. It would be much comfortable to manage the increase of the average global surface temperature (WWF, 2021), if the global communities start to reduce more GHG emissions by now. In Laos, a series of mitigation technologies were identified in NDC to achieve the net zero pathway. In this study, however, assessed deeper decarbonization technologies, namely, EV penetration scenario, extension of waste recycle scenario, and other low carbon technologies scenario.

Countermeasure (CM) scenario is a case with mitigating countermeasures policy, under this CM scenario, the socioeconomic assumptions are the same except for adopting the mitigation technologies.

3.5.2.1 Introduction of EV Technology

Electric vehicle technology is a mitigating countermeasure which Lao government considered as a mitigation technology for CO_2 emissions reduction in transport sector. The EV technology with certain market penetration levels, which had a 1% penetration in 2020, Lao government set target to replace conventional vehicles in households by 14% in 2025, 30% in 2030, and 50% in 2050 (MEM, 2020). To assess the impacts from EV introduction, additional countermeasures are considered, namely, carbon tax (USD 10/tCO_2) and subsidy. Due to the drivers of conventional vehicle have to responsible for carbon tax, so the carbon tax will be supplementarily introduced aiming to be a persuading mechanism to influence households to shift from conventional vehicles to the EV. While the subsidy is for mitigating the cost of EV technology. In this analysis, it is assumed that carbon tax and subsidy will be introduced exogenously as a mitigation measure to determine the EV promotion. In this countermeasure scenario, in order to reduce fossil fuel import and mitigate emission from fuel combustion in road transport, the biofuel is assumed to be mixed with petrol by 50% in 2030 and 80% in 2050. In this scenario, the subsidy will exogenously reduce the EV cost (table 3.4). It is assumed that Lao government will introduce the carbon tax and subsidy for supporting EV technology penetration. In order to introduce the EV, each sector will need to pay more as an "additional cost". In this analysis, the cost of EV is considered as 50% more as compared to the conventional vehicle, which is the cost of electric equipment including battery. To diminish the cost, the government should consider subsidy. However, the conventional vehicles user will need to pay for carbon tax. Through the comparison of energy consumption, GDP and CO_2 emissions in these scenarios, the impacts of introducing EV with additional carbon tax and subsidy mechanisms for road transportation in Laos is assessed in this analysis.

Table 3.4. Scenario in this analysis

Scenario	Carbon tax	Subsidy	EV
BaU	-	-	-
EV tech	-	-	endogenous
Tax	USD 10/tCO_2	-	exogenous
Subsidy	-	subsidy	exogenous

Note: Fossil fuel is assumed to mix with biofuels by 50% in 2030 and 80% in 2050.

3.5.2.2 Extension of Waste Recycle

The target for waste recycle has not yet define, the national waste management strategy is being prepared. However, assumption under this study is based on MSW management target for sub-nationals, particularly MSW management strategy for Vientiane Capital. Thus targets for waste collection and recycle were modified for this study.

In the CM scenario, the socioeconomic assumptions are the same except for adopting the "waste-to-resource" approach for MSW management. In this analysis, the following two targets on MSW collection and treatment are assumed in the CM scenario respectively; (1) the collection rate of MSW will increase from 34% in 2014 to 100% in 2050, and (2) the MSW recycling rate will increase from 10% in 2014 to 40% in 2040 and 80% in 2050 (table 3.5). In the CM scenario, the contribution of these targets to GHG emission reduction in the Lao is assessed.

The socio-economic data is assumed as BaU scenario, an average GDP growth rate from 2020 to 2050 is set to be 5.7% per year, while a population growth rate from the same period is assumed to be 1.2% per year.

Table 3.5 Ratio of waste collection and recycles

Scenario	Base year		2040		2050	
	wc	wr	wc	wr	wc	wr
BaU	34%	10%	34%	10%	34%	10%
Extenstion of waste recycle	34%	10%	70%	40%	100%	80%

Note: wc: waste collection rate; wr: waste recycle rate

4. Results

In this chapter, the BaU case summary is described first, including the GDP and GHG emissions of BaU calibrated result from the developed CGE model. The final energy consumption by road transport and BaU case of households' direct waste disposal are also summarized. The second section describes the model simulation results, including the impacts from introducing EV technology and additional actions, and extension of waste recycling on GDP, emission reduction, energy consumption of transport sector and direct waste disposal of households.

4.1 BaU Scenario

During the last decade, the GDP of Laos grew average at 8%, however, from last two years it was negatively affected from Covid-19 pandemic resulting in decrease GDP growth rate. However, in long-term, government set the target to achieve the growth of average at least 4% per year up to 2030. As Lao economic activities have progressed as usual and there are many mega projects for attracting foreign investment, this will boost Lao economy's growth, as align with the economic growth will conduce GHG emission-related activities. Comparing the GDP value, from the AIM/CGE [Laos] model simulation, will increase by 7.5 times from about USD 12,600 million in base year 2014 to be USD 93,000 million in 2050 (figure 4.1).

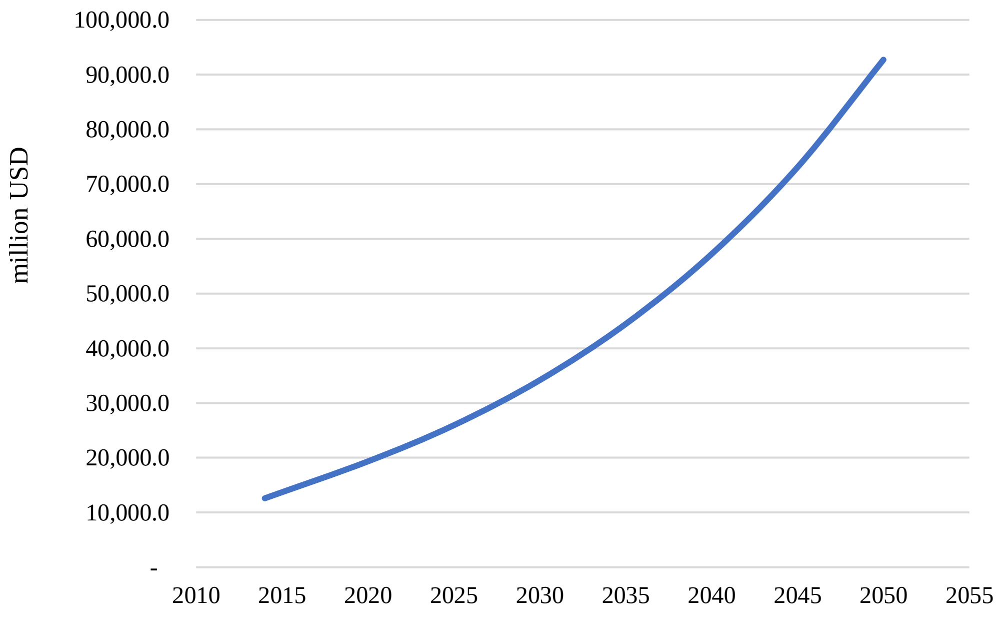


Fig. 4.1 GDP

Aligning with the economic growth, this will drive the GHG emission-related activities. The GHG emission in BaU case will increase from 600 $ktCO_2$ in 2014 to 800 $ktCO_2$ in 2030 with a total growth rate of 65%, then sharply enlarge to 1,400 $ktCO_2$ in 2050, with a remarkable total growth rate of 184% (figure 4.2).

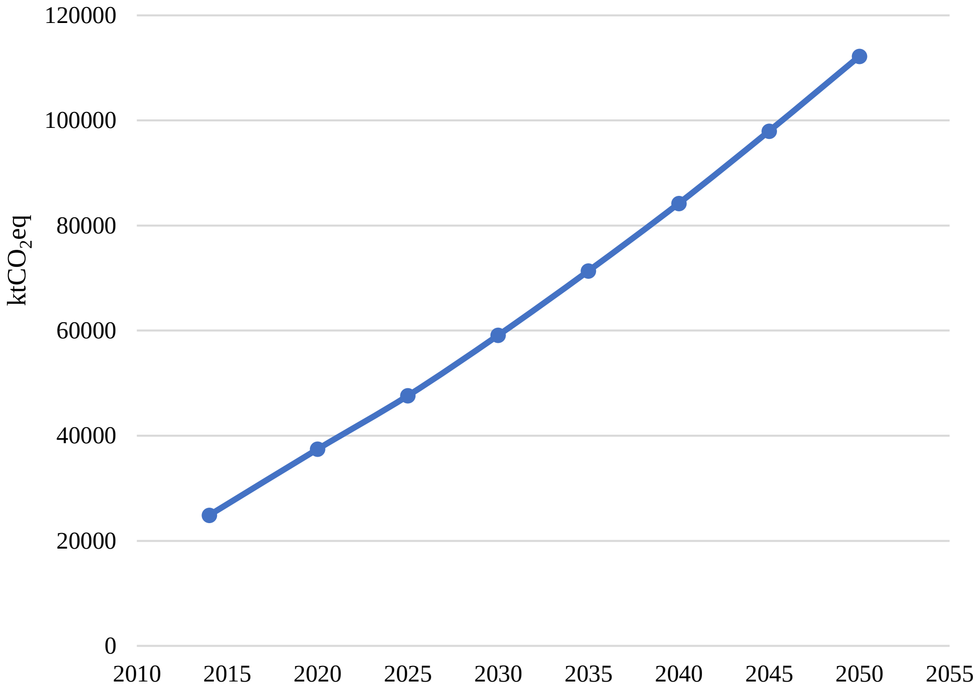


Fig. 4.2 GHG emissions

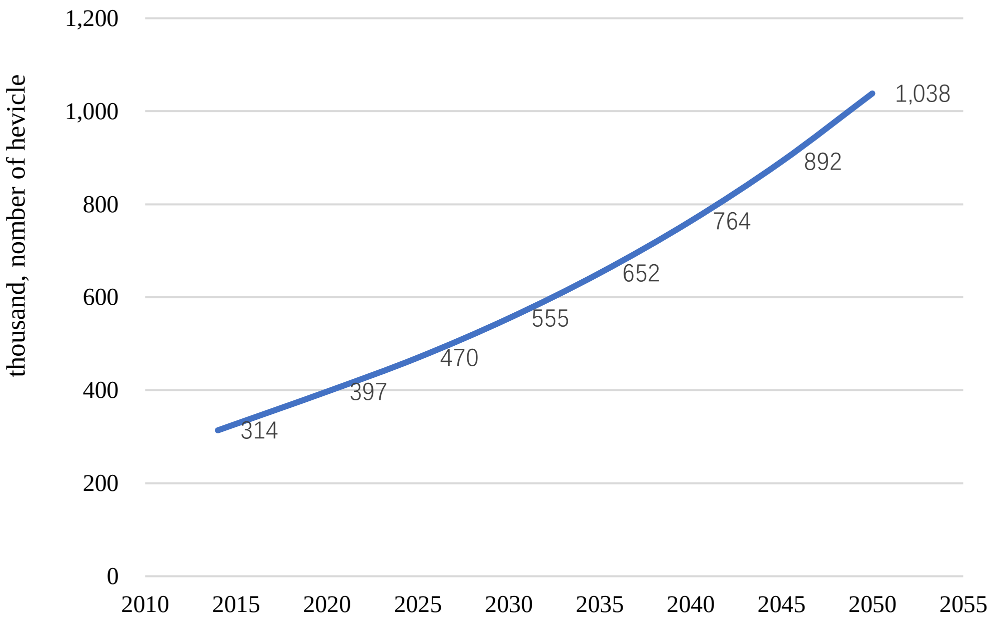


Fig. 4.3 Number of private vehicle

Number of private conventional vehicle without EV policy intervention will grow more than two times from about 300,000 vehicles in 2014 to be around one million vehicles in 2050 (figure 3.4).

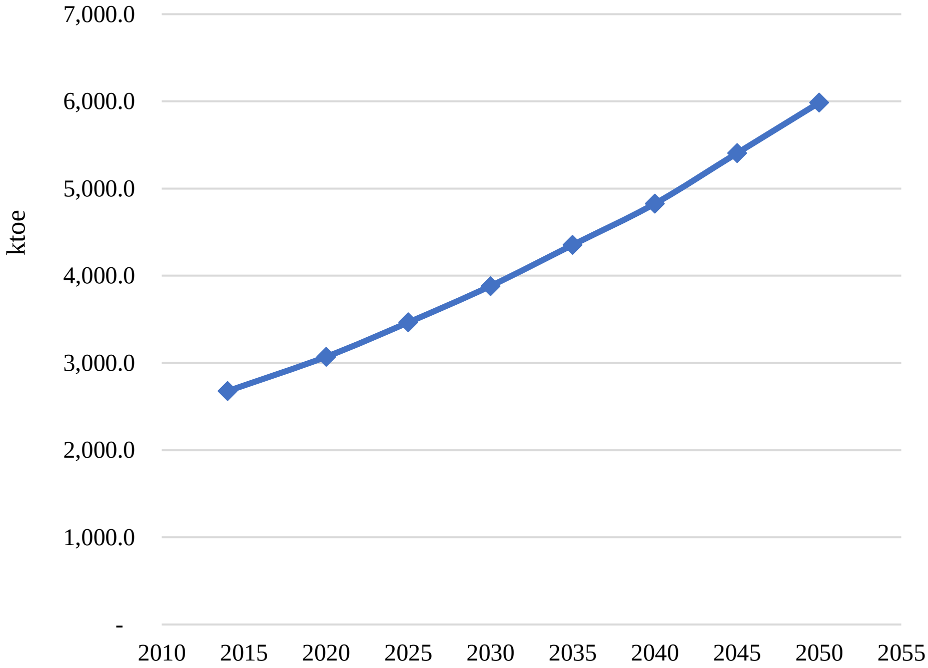


Fig. 4.4 Final energy consumption

The growth of economic activities will demand higher final consumption. The final energy consumption, in BaU scenario, will increase from 2,600 ktoe in 2014 to 3,800 ktoe, 4,800 ktoe and 5,900 ktoe, with the growth rates of 45%, 80%, 123%, respectively, in 2030, 2040 and 2050 (figure 4.4).

The economic growth will also generate income for households which will facilitate households to consume more commodities and generate more solid waste. The MSW generation by household the BaU case will keep growing to 8 times in 2050 comparing to that in 2014 (figure 4.5).

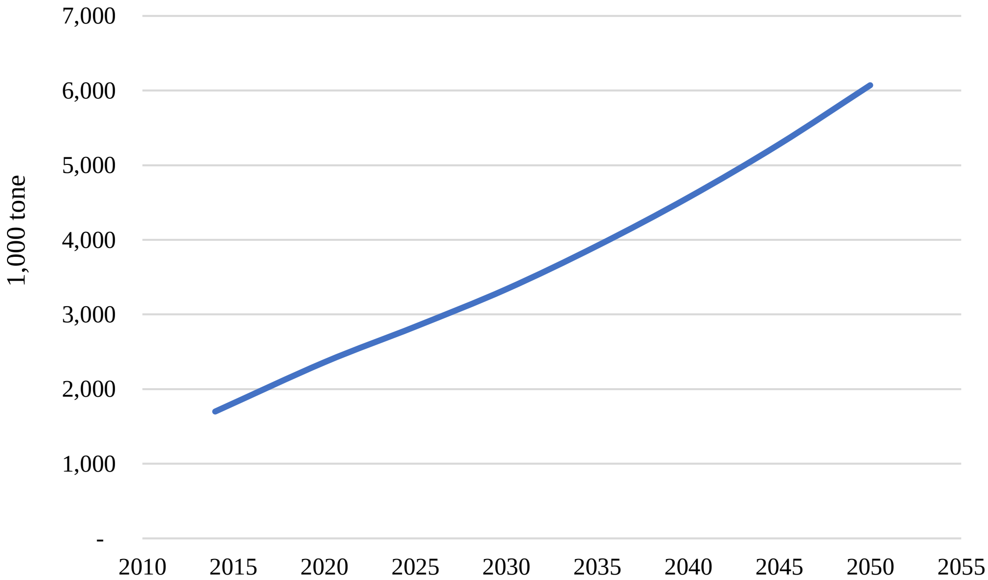


Fig. 4.5 Solid waste generation

4.2 Assessing the Impacts of Introducing of Carbon Tax and Technologies for Road Transportation in Laos

This section presents the results of the scenario analysis for road transport sector in Laos through introduction of EV technology, carbon tax for conventional transportation, subsidy for EV cost, and promoting biofuel to reduce fossil use. The results for BaU and countermeasure scenarios are presented along the lines of energy consumption, CO_2 emissions, and impact on GDP growth.

4.2.1 Comparison of GDP

GDP growth in BaU and that in the scenarios with introduction of the EV, carbon tax and subsidy with biofuel are compared. Since the cost of the electric vehicles is higher than the cost of the conventional ones, promoting EVs may have some negative economic impact. Carbon tax and subsidy policies may also create some impacts on annual GDP growth rate. Figure 4.6. shows that the carbon tax at USD 10/tCO_2 scenario will have no negative impact on GDP growth. This carbon pricing will not impact the consumption behavior of households. This might be because this carbon price is quite low and the people will have not much options for fuels selection and there will be limited public transport services, and consequently travel by their own private vehicles will still be the most convenient way. But the GDP value will gradually decrease during 2030-2050 in the countermeasure scenario of introducing the EV and biofuels. The GDP loss will be about USD 353 million, accounting for 1%, in 2030; USD 900 million, accounting for 1.6%, in 2040; and USD 1,780 million, accounting for 1.9%, in 2050. The GDP loss may be due to the introduction of subsidy policy by the government. Specifically, the government will lose the tax income from mitigating import tax for import of EV technology and will spend more foreign currency for importing EV since the cost of EV is higher than conventional vehicles.

The subsidy scenario will have smaller disadvantage than introducing EV scenario. For examples, the GDP loss will be about USD 25 million, accounting for 0.1%, in 2030; USD 249 million, accounting for 0.4%, in 2040; and USD 750 million, accounting for 0.8%, in 2050.

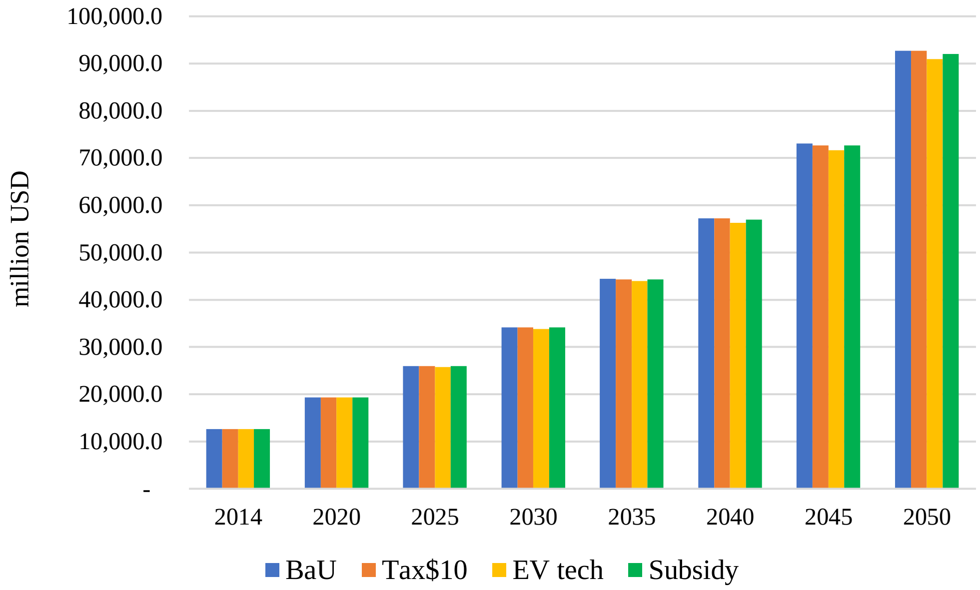


Fig. 4.6. Comparison of GDP value in the BaU and countermeasure scenario

4.2.2 Comparison of Carbon Dioxide Emission in Transport Sector

Figure 4.7. displays the CO_2 emission in Laos's road transport sector in BaU and countermeasure scenarios. As seen in the energy consumption results (figure 4.8), CO_2 emission in transport sector also illustrates the same trend due to increasing energy demand and high fossil fuel consumption, resulting CO_2 emission in BaU scenario will increase from 600 ktCO_2 in 2014 to 800 ktCO_2 in 2030 with a total growth rate of 65%, then sharply enlarge to 1,400 ktCO_2 in 2050, with a remarkable total growth rate of 184%. The increasing trend of CO_2 emission is aligned with the projected growth of number of vehicles, in which number of vehicles has been increased sharply during the last decade because households can earn more income and average GDP growth rate was 8% per year. In the future, their afford to acquire own vehicle is expected increase due to government set a policy to promote economic growth by defined economic special zones, and fundamental infrastructure was updated and developed, high speech train between Laos-China, for example.

By adopting the countermeasures, on the other hand, it will result in noticeable decreasing of CO_2 emission, especially the introducing EV and subsidy. However, the carbon tax policy will just insignificantly mitigate CO_2 emission. The reasons it might be that at the current and in the short-term, the public transport will not improve well, thus most of citizens will still travel by their own vehicles.

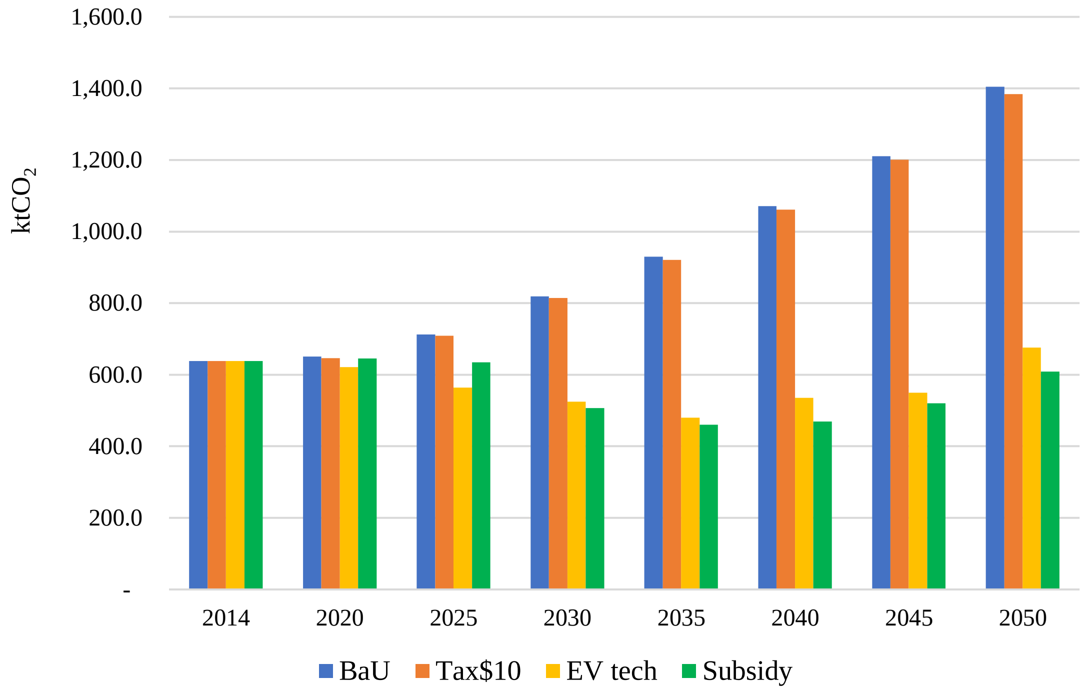


Fig. 4.7. Comparison of CO_2 emission in transport sector

The CO_2 mitigation countermeasure of EV technology will result in declining of CO_2 emission from 800 ktCO_2 in BaU scenario to around 500 ktCO_2 in 2030, reduction accounting for 36%; and in 2050, the emission will noteworthily drop from 1,400, in BaU scenario to about 680 ktCO_2, the reduction amount is 720 ktCO_2, accounting for 52%. While countermeasure of subsidy policy will have the most significant fall of CO_2 emission among all mitigation countermeasures, particularly during 2030 to 2050. Comparing the emission in BaU and subsidy scenarios will go down from 800 Gg CO_2 to 500 ktCO_2, accounting for 38% in 2030; in 2040, this will still continue to emit smaller from 1,000 ktCO_2 to 470 ktCO_2, with reduction amount of 530 ktCO_2, accounting for 56%; and in 2050, the emission will diminish from 1,400 ktCO_2 to 600 ktCO_2, accounting for 57% and with an amount of reduction around 800 ktCO_2. Based on this result, when comparing to introduce only EV technology itself (Fig. 4.7), additional countermeasures, carbon tax and subsidy, will uphold more CO_2 emission reduction in road transport sector. Particularly subsidy mechanism since EV cost is still high.

4.2.3 Number of Private Vehicle

With EV policy intervention, ratio comparison between conventional vehicle population or Non-EV and EV, the ratio of EV population will have an increasing trend. The share of the EV will be 4.4% of Non-EV in 2025 and then number of EV will keep growing to have a share at 48% and 76% of Non-EV in 2040 and 2050, respectively (figure 4.8).

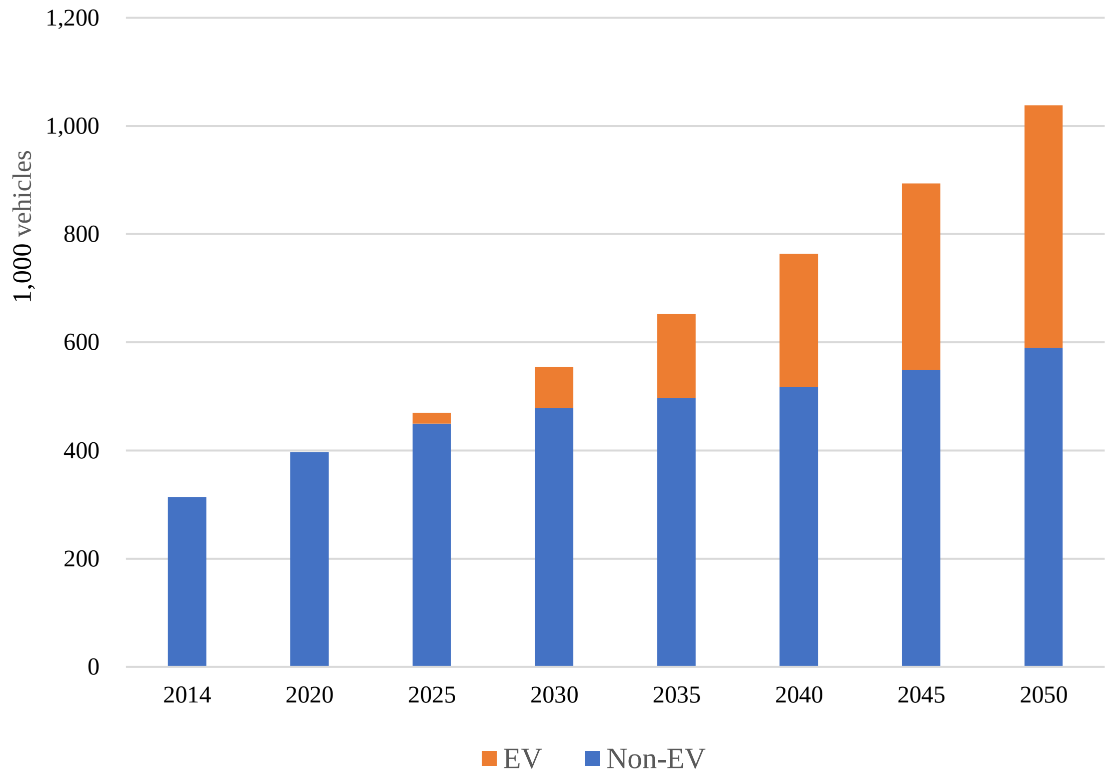


Fig. 4.8 Number of vehicles in EV scenario

4.2.3 Comparison of Final Energy Consumption

Figure 4.9 presents the total final energy consumption in the BaU and countermeasure scenarios between 2014 and 2050. It can be seen that, in BaU scenario, the final energy consumption will increase from 2,600 ktoe in 2014 to 3,800 ktoe, 4,800 ktoe and 5,900 ktoe, representing total growth rates of 46% in 2030, 84% in 2040, and 127%, in 2050. However, the scenario of introduction of carbon tax at USD 10/tCO_2 will have no significant impact on energy consumption. This is because USD 10/tCO_2 may not be enough to replace the conventional vehicle by EV. The other reason there is no more alternative option, for example biofuel may not cover main parts of the country. Thus the proposed carbon tax rate may not influence energy consumption behavior of households.

AIM/CGE is recursive dynamic model in which energy efficiency improvement and energy switch are derived from the introduction of new equipment. However, the additional cost of EV is very high and therefore it is hard to select EV endogenously. By introducing EV and biofuels endogenously with carbon tax or subsidy, it is observed that, compared with BaU scenario, the final energy consumption will gradually reduce in 2040 and 2050. The total final energy consumption in 2040 will fall from 4,800 ktoe in BaU to 4,600 ktoe in that countermeasure scenario, accounting for 3% reduction. In 2050, final energy consumption will decrease from 5,900 ktoe in BaU to 5,700 ktoe in the countermeasure scenario, accounting for 4% reduction.

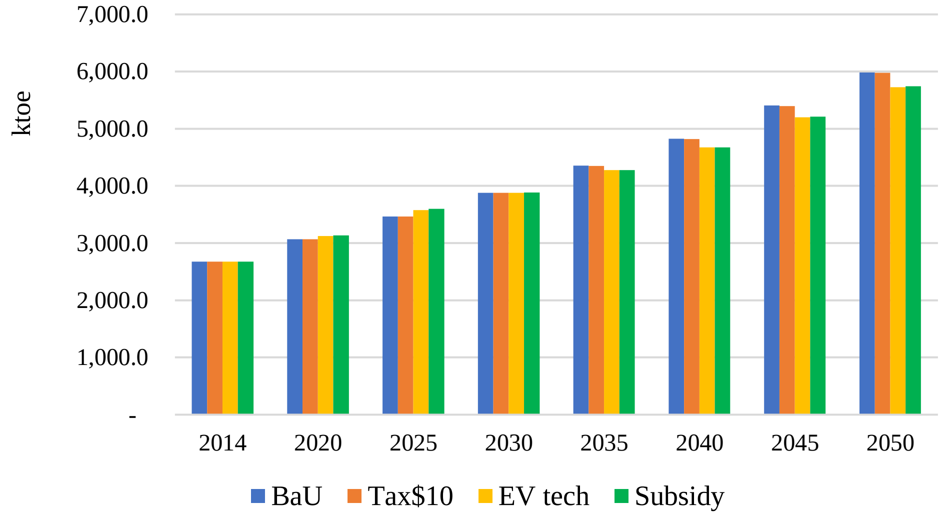


Fig. 4.9 Total final energy consumption

4.2.4 Conclusion on simulation of Introducing of Carbon Tax and Technologies for Road Transportation

This study considered the alternative countermeasure options to support EV promotion. Even though the last papers analyzed similar EV technology, however, the impacts on GDP growth from EV penetration was not considered and the assumptions were not consistent to current government targets. This paper, therefore, analyses the CO_2 mitigation potential in the transport sector for Laos by the effectiveness of policy packets/countermeasures (CMs) which include the carbon tax and subsidy policies, mitigation actions such as introduction of EV and biofuel countermeasures. The model results of CMs scenario shows that EV policy intervention, Non-EV under EV scenario will reduce by 43% compared to BaU case in 2050. While EV population will have the share of Non-EV at 76% of Non-EV in 2050, in which will result in reduction of energy consumption, CO_2 emissions and impact on GDP growth. The total energy consumption will increase from 2,600 ktoe in 2014 to 5,900 ktoe in 2050 with a total growth rate of 123%. However, the CMs will have a gradually effect on reduction of energy consumption in 2050 comparing with BaU scenario. GDP will gradually decrease during 2030-2050 when the countermeasures scenario, EV and subsidy policy, will be applied. For instances, the GDP will be about USD 1,780 million accounting for 1.9% loss in 2050 compared with the BaU result. Regarding the impacts on CO_2 emission in BaU scenario will increase from 600 $ktCO_2$ in 2014 to 1,400 $ktCO_2$ in 2050, with a remarkable total growth rate of 184%. While EV case will result in declining of CO_2 emission to around 720 $ktCO_2$ in 2050, and the subsidy policy will have the greatest fall of CO_2 emission. In sum up, introduction of only carbon tax in transport sector will not influence on household behavior for energy consumption in both short-term and long-term, resulting in no impact on CO_2 emission. Nevertheless, the mitigation actions (EV and biofuel) and subsidy countermeasures can have significant consequences on their final energy consumption and CO_2 emission. But in the long-term, the introduction of mitigation countermeasures, except introducing carbon tax only, the GDP growth will gradually decline.

4.3. Simulation Result on the Extension of Waste Recycle

4.3.1 Gross Domestic Product

In the CM scenario, extension of the material recycle is assumed. When comparing the GDP value between the BaU and CM scenarios, it can be seen that CM scenario will have some negative impact on GDP which the GDP value will reduce about 0.3% in 2040 and 0.7% in 2050 comparing with the BaU scenario as shown in Fig.4.10. Since the cost for waste disposal is needed. However, the cost for waste recycles is not considered in this analysis. In case, the recycling price takes into account the impact on GDP may be larger.

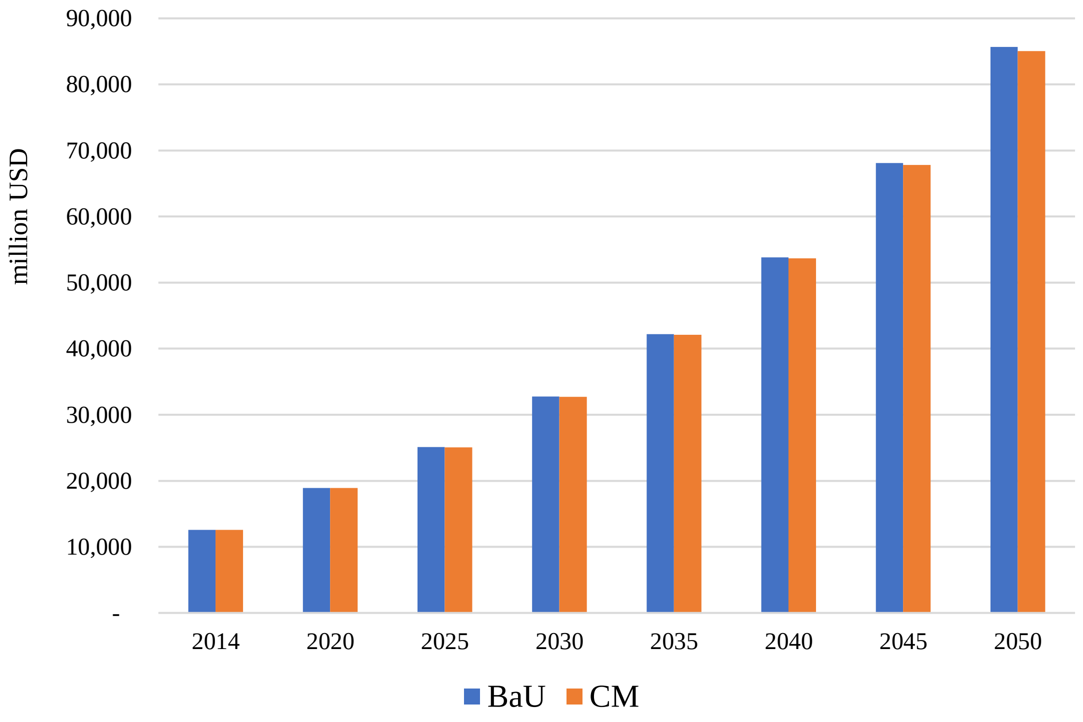


Fig. 4.10 Simulation result of the GDP

4.3.2 GHG Emissions from MSW

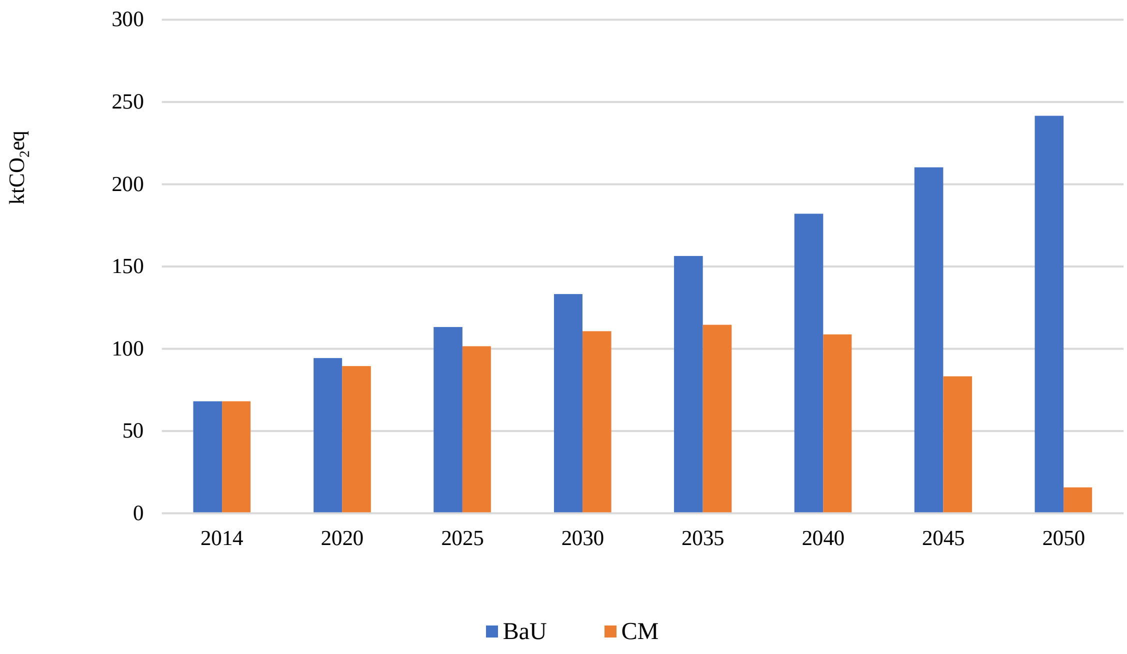


Fig. 4.11 GHG emissions from MSW management

Under BaU scenario, the GHG emissions from MSW management will increase almost seven times from base year 2014 that emitted 68 $ktCO_2eq$ to 240 $ktCO_2eq$ in 2050. However, by introducing of MSW recycling under CM scenario, the GHG emissions from the emissions through the process of direct disposal of organic waste can be reduced, and as a result, the GHG emissions from MSW management can reduce to 16% in 2030 and 93% in 2050 compared to those of BaU scenario (figure. 4.11).

The total GHG emissions, except AFOLU sector, in BaU scenario will increase more than three times from 2014 to 2050. In the case of CM scenario, the total GHG emissions in 2050 will reduce by 250 $ktCO_2eq$ compared with those of BaU scenario as shown in figure 4.12. In the CM scenario, the GHG emissions in the sectors in which the recycled material is provided will unremarkably decrease even though the assumption of increase of recycle, the energy related CO_2 in this sector in 2050 will decrease only by 9 $ktCO_2eq$ compared to the BaU scenario. However, GHG mitigation actions in the recycling sector will be important. In addition, due to the economic growth, the rebound effects of GHG emissions can be observed. In this analysis, other mitigation actions except SWM recycling are not considered, but in order to avoid the rebound effects, countermeasures in various sectors should be taken into account.

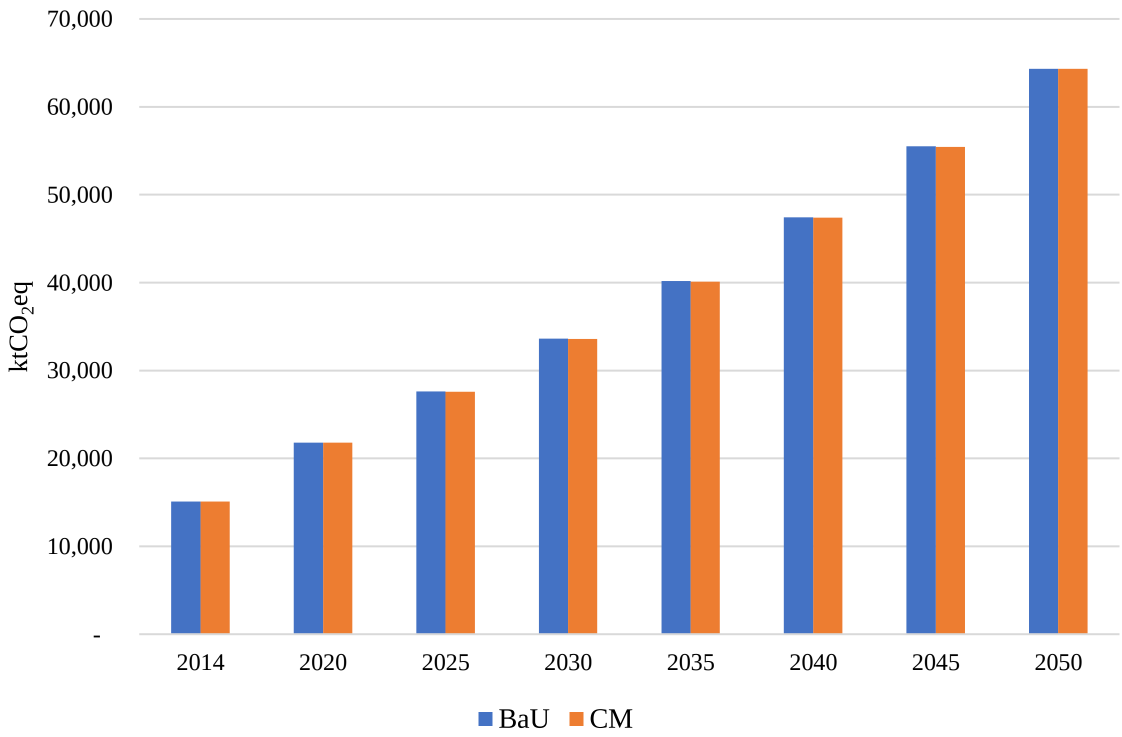


Fig. 4.12 Total GHG

4.3.3 Final Waste Disposal

In proportion to increase of income level, waste generation will increase. As a results, final waste disposal in BaU will also increase as shown in figure 4.13. The total final disposal waste, which consists of both uncollected self-disposal by households and residue after treatment, keeps growing to 6.6 times in 2050 comparing to that in 2014.

In the case of CM scenario, because of increase of the collection rate of MSW to 100% by 2050, the direct waste dumping by household will gradually decrease compared to BaU scenario, and in 2050 direct waste dumping will be 0. At the same time, the treated MSW will increase, but because of increase of recycle rate, residue of treatment in 2050 will increase compared to based year but this increase is still lower than BaU scenario. As a result, total final waste disposal in 2050 of CM scenario will be 16% of that of BaU scenario.

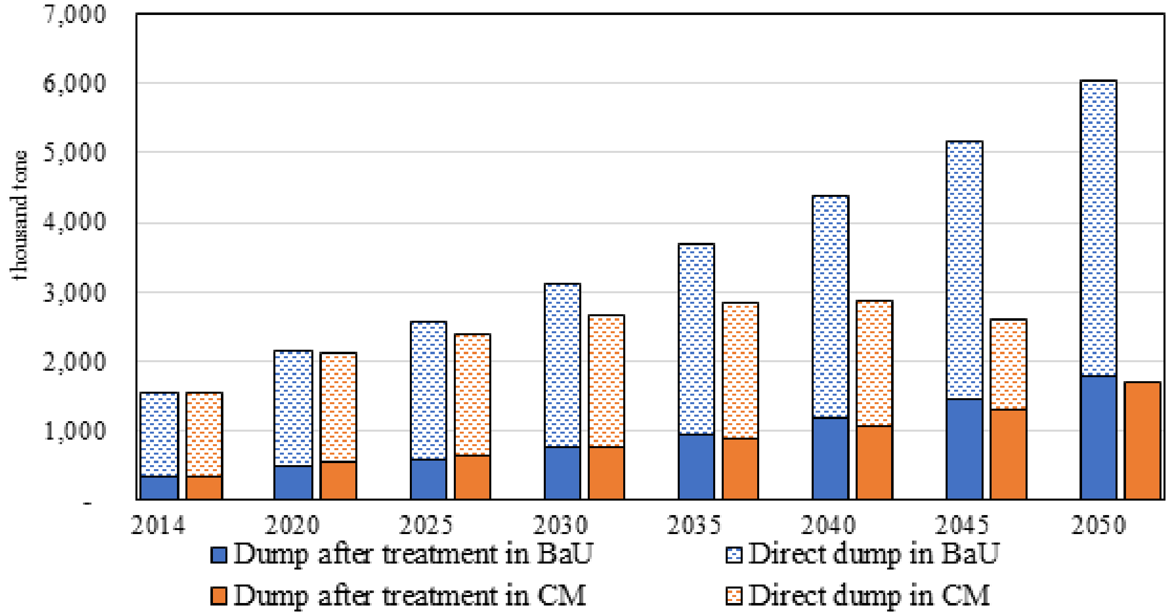


Fig. 4.13 Final waste disposal

4.3.4 Conclusion on the Simulation for the Solid Waste Management

This paper assessed the contribution of MSW management to decarbonization in Laos by analyzed the adoption of "waste-to-resource" approach as a countermeasure policy for sustainable MSW treatment. By adoption of this action will have significant impacts on final waste disposal, direct waste dumping by household will slightly decline particularly. Due to the increase of recycle rate, however, the residue of treatment will gradually enlarge. By introducing of MSW recycling, the emissions through the process of direct disposal of organic waste can be decreased. In addition, because of increase of recycle rate, the GHG emissions in the sectors in which the recycled material is supplied will be declined. But because the treated MSW will increase in recycling sector will result in an increase of energy related CO_2. Since the recycled material and energy can be provided to the related market, thus the extension of waste recycling will contribute the GDP growth, which in previous studies did not consider economic aspects.

In Laos, furthermore, like other developing countries, common practices to handle with the solid waste are dumping and open burning. Based on MONRE report (2022) on pollution situation in Laos mentioned that the unproper waste disposal, apart from the emission from road transport which is a main source of city air pollution, is also threating city air quality in main cities. Sustainable MSW management, particularly adoption of "waste-to-resource" approach will have the potential of contributing to national development priorities, sustainable and green growth, for instance. In addition, sustainable MSW management will contribute to achieve several of the United Nations Sustainable Development Goals (SDGs). For example, a cleaner environment resulting from improved solid waste management practices that could support healthier lives and well-being of populations (SDG 3). Other SDGs could be indirectly promoted through sound waste management practices, such as SDG 7 (on affordable and clean energy, in case solid waste is harnessed in the form of energy).

4.4 Sensitivity Analysis

Sensitivity analysis is caried out with different assumptions from those defined in the primary analysis (Chin and Lee, 2008). Sensitivity analysis addresses the questions on how the results of the study will change if we use other assumptions. Sensitivity analysis is typically performed to check the robustness of the results.

Sensitivity analysis is a crucial part of every assessment, quantitative and qualitative (Gorris and Yoe, 2014). The gaps in our knowledge are bridged by assumptions, probability distributions, expert opinion, best guesses, and a variety of other techniques. Sensitivity analysis is a systematic investigation of the means by which assessors bridge these uncertainty gaps

The term "sensitivity" essentially refers to the way in which the results change when we change our model's assumptions. If sensitivity is high, then the results vary greatly when we change certain assumptions; these assumptions must be very robustly established for our model to have any validity.

4.4.1 Sensitivity Analysis for Elasticity of Substitution

This study assumed two types of transport service in Laos, private and public transports. There are two vehicle cars, electric vehicle (EV cars) and conventional cars (non-EV), which are driving by households. The EV cars demand only energy from electricity, while non-EV consumes fossil fuels and fossil fuel mixing with biofuels. However, non-EV can be modified with additional equipment to transform to consume electricity.

Modern energy demand for road transport is both electricity and fossil fuels. The aggregated energy demand for road transport is treated by Leontief function and elastic parameter of energy demand is assumed to be zero. However, this sensitivity analysis considered elastic parameter options to examine the aggregated energy demand through EV introduction. The elastic parameters; 0, 0.1, 0.5, and 1; are examined.

Figure 4.14 shows the elastic impact result of energy demand through EV introduction on GDP. The testing of the elastic parameter range 0 to 1, there is no significant on GDP value. This implies that demand on energy sources for EV and non-EV does not respond to the flexibility of available energy consumption. Therefore, this can conclude that electricity is necessary energy for EV, in other word, fossil fuel cannot be substitute energy for EV. When the elasticity for energy demand is limited, resulting in not significant contribution to CO_2 emission reduction (figure 4.15).

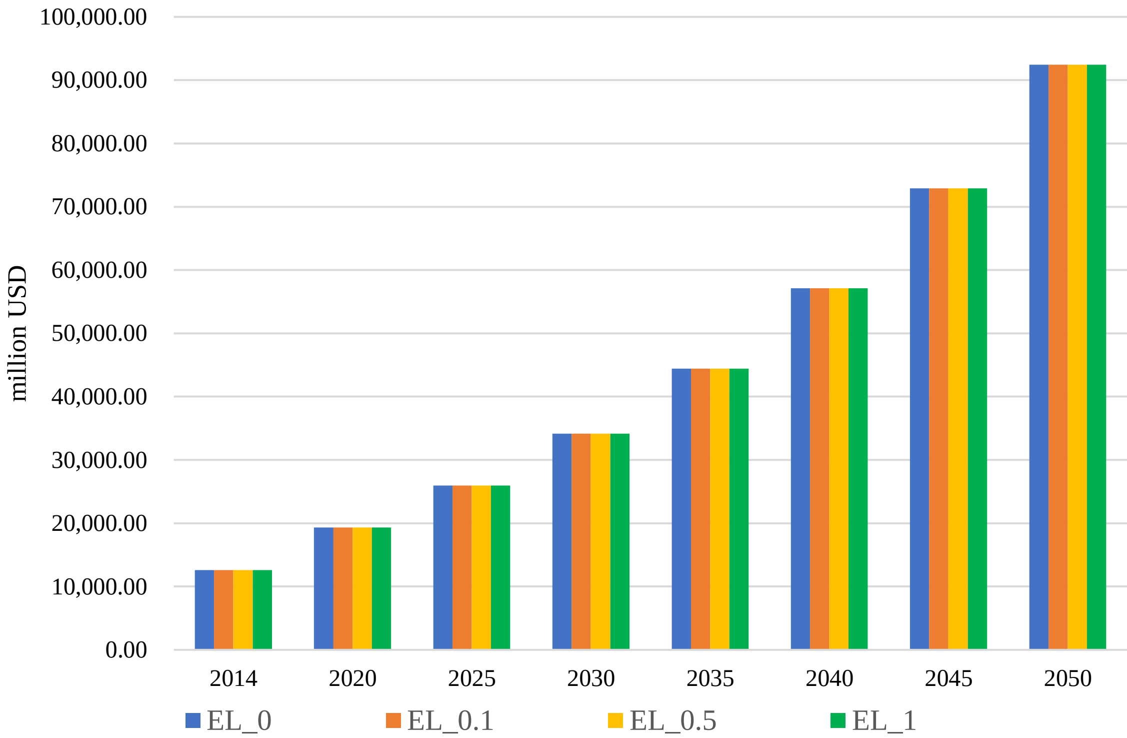


Fig. 4.14 Comparison of energy demand elasticity on GDP

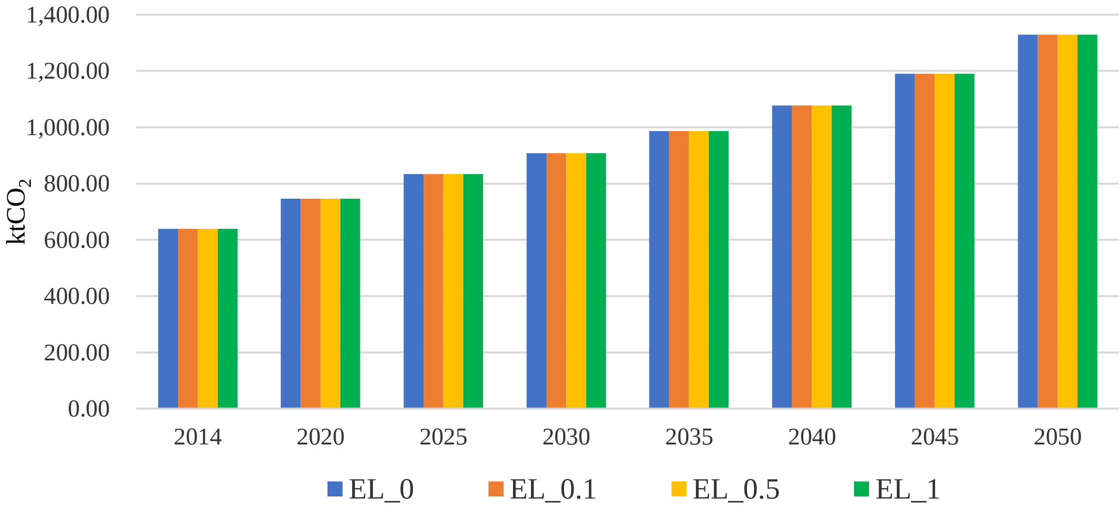


Fig. 4.15 Comparison of energy demand elasticity on CO_2 emission

4.4.2 Sensitivity Analysis for Income Elasticity

Income elasticity related to waste generation is the sensitivity of the quantity generated for a certain waste volume to change in the real income of households who generate waste. Income elasticity is directly related to waste generation, higher income assumption will result in increasing waste amount due to households can afford and consume more goods.

In case the assumption of income elasticity to be 1, this implies that when households earn more income, the generated waste by from the household will be in double. However, this study assumed option senility analysis is to test the most suitable income elasticity for estimating the waste generation scenario. The result shows that the assumption of income elasticity at 0.5 and 1, the different amount of waste generation will start to have larger gaps during 2020 to 2050. In 2040 and 2050, the waste generation scenario will have about half different level (figure 4.16). The waste generation scenario at 0.5 of income elastic assumption is closely to an assessment government report. Therefore, the simulation results on the extension of waste recycle are re-simulated based on income elasticity at 0.5.

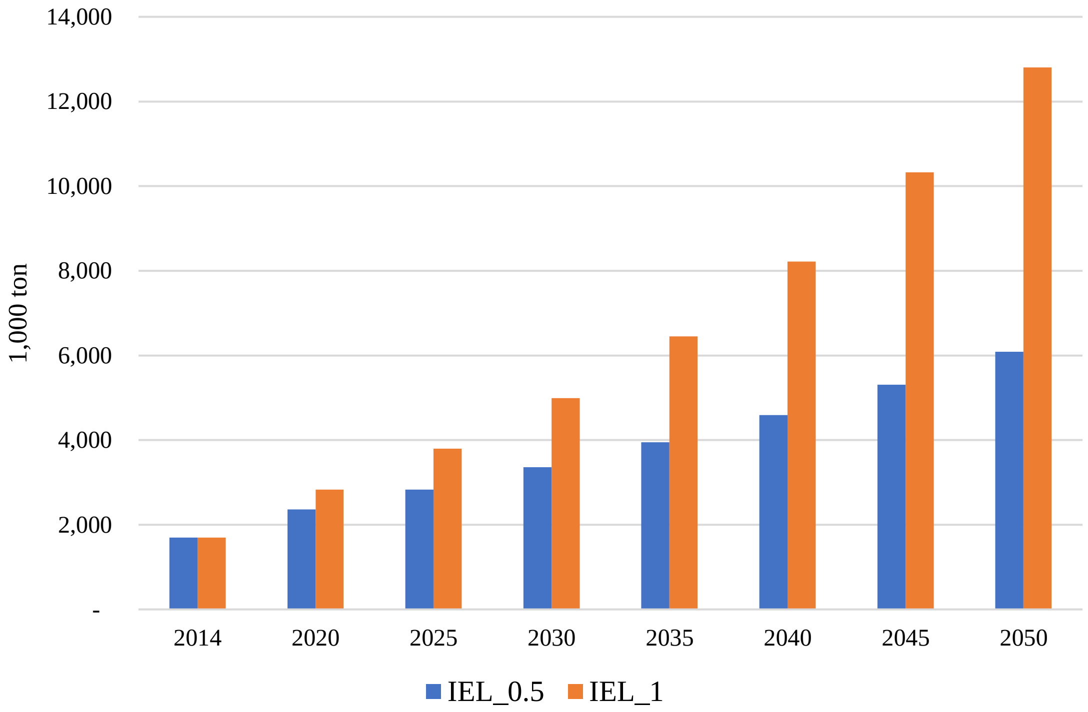


Fig. 4.16 Waste generation

Following the waste generation scenario in figure 4.6, there is some different impact on GDP value between assumption of income elasticity at 0.5 and 1. The figure 4.17 shows that the difference impact on GDP will be 0.9% in 2040 and 1.9% in 2050.

Comparison of the assumption of income elasticity at 0.5 and 1 on GHG emission from solid waste treatment scenario, the figure 4.18 shows the GHG emission from soldi waste management will have similar trend with the waste generation scenario in figure 4.16.

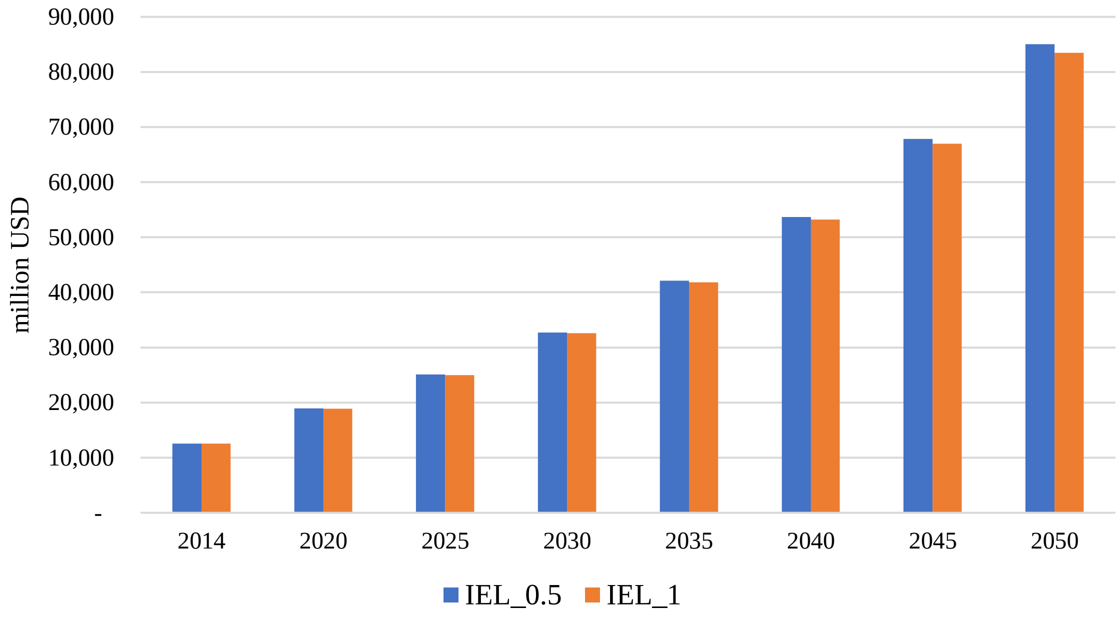


Fig. 4.17 GDP

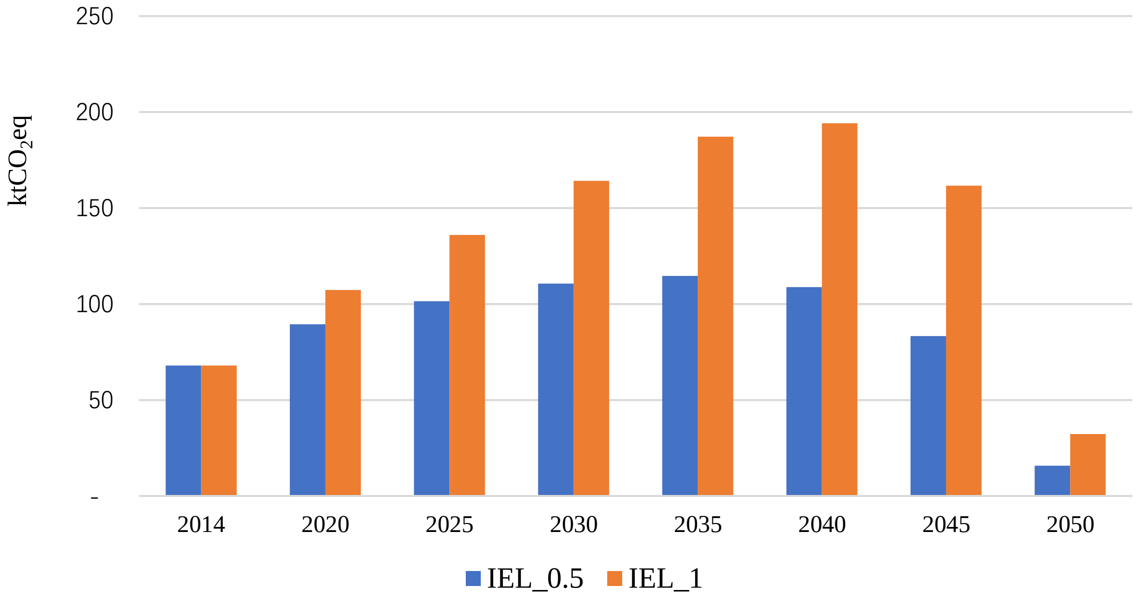


Fig. 4.18 GHG emission

5. Conclusion and Future Works

This chapter is a conclusion of findings from applying the AIM/CGE [Laos] model to assess impacts of introduction emission mitigation actions in Laos. The study is divided into three main parts: First part is CGE for introducing of EV technology for mitigating emission for road transport sector; the second part is an analysis of introducing the additional countermeasures to complement the EV use, for road transport sector, also; and last part is an adopting of recycling policy for MSW management.

5.1 Remarkable Findings

This dissertation carried out an assessment of decarbonization in transport and waste sectors in Laos in 2050 by introducing GHG mitigation technologies, The simulation results illustrate noticeable impacts on the GDP and CO2 emissions, therefore, following are the key findings summarized in this study.

1) Non-EV under EV scenario will reduce by 43% compared to BaU case in 2050. While the share of the EV will be 16% of Non-EV in 2030 and will keep growing to have a share at 76% of Non-EV in 2050.
2) Due to the cost of the electric vehicles generally higher than the cost of the conventional ones, by promoting EV cars only, the GDP value will be gradually damaged during 2025-2050, the GDP value will lose about USD 112.1 million, accounts for 0.3% in 2030, however this loss is still lower than the average expenditure during 2010-2016 that Laos spent for fossil fuel import at USD 522 million. In the long-term by 2050, the GDP value will reduce up to one percent with a lost amount of USD 891 million.
3) Overall, the EV technology would noteworthily contribute the remarkable CO_2 emission mitigation in the transport sector. Average potential CO_2 emission in the EV scenario would be lesser than the BaU case 23% during 2020-2050. The middle-term 2030, the amount of BaU emission will be 1,190 $ktCO_2$, as the EV one will emit smaller by 959 $ktCO_2$, accounting for 19% lower. However, the difference of emission between the BaU and EV scenarios in 2050 will be 36%. The cumulative CO_2 emission from 2020 to 2050 in BaU case will be 12,000 $ktCO_2$ and those in the EV mitigation case will be 9,300 $ktCO_2$ which accounting for likely 23% cumulative CO_2 emission reduction in road transport sector by introducing the EV technology.
   The mitigation countermeasure of extenuation technology plus carbon tax will result in declining to around 500 $ktCO_2$ in 2030, reduction accounting for 36%; and in 2050. While countermeasure of subsidy policy will have the most significant fall of CO_2 emission among all mitigation countermeasures, in 2050, the emission can be reduced by 57% and with an amount of reduction around 800 $ktCO_2$.
4) When considering the complementary countermeasures to support EV promotion such carbon tax, biofuels and subsidy for EV cost. The final energy consumption, in BaU scenario, will increase from 2,600 ktoe in 2014 to 5,900 ktoe with a total growth rate of 123% in 2050. However, the scenario of introduction of only carbon tax countermeasures at 10$/$tCO_2$ will have no significant impacts on energy consumption,

because USD 10/tCO_2 of carbon tax may not enough to replace the conventional vehicle by EV. However, by introducing EV and biofuels exogenously with carbon tax or subsidy, The total final energy consumption will fall down from 5,900 ktoe to 5,700 ktoe in 2050, accounting 4% of total potential energy demand mitigation.

5) The carbon tax at USD 10/tCO_2 scenario will have no any negative impact on GDP growth. However, the GDP value will gradually decrease during 2030-2050 when the countermeasures scenario, EV and biofuels plus carbon tax, will be applied. For instances, the GDP value will lose about USD 1,787 million, accounting for 1.9% in 2050. However, the subsidy scenario will have smaller disadvantage than mitigations plus carbon tax scenario. For examples, the GDP value will lose about 750 million US$, accounting for 0.8% in 2050.
6) Through the assumption of extension of the material recycle, the GDP will give an increase of 0.6% in 2050 comparing with the BaU scenario. This result shows that the sustainable MSW management through waste recycling will contribute the GDP growth, because the recycled material and energy can be provided to the related market.
7) The waste generation, in the BaU scenario, will keep an increase follows the increase of income level, this will result in waste volume increase by 6.6 times in 2050 comparing to the volume in base year 2014. However, due to an increasing assumption of the collection rate of MSW to 100% by 2050, the direct waste dumping will be 0 in 2050. In meanwhile, because of increase of recycle rate, residue of treatment in 2050 will also increase, but only 16% compared to that of BaU scenario.
8) Based on BaU scenario of the GHG emissions in waste sector, the emissions from MSW management will increase more than seven times from based year 2014 that emitted 68 ktCO_2eq to 500 ktCO_2eq in 2050. However, by introducing of MSW recycling the direct disposal of organic waste can be reduced, and this policy will have a result in reducing of the GHG emissions from MSW management about 93% in 2050 compared to those of BaU scenario.
9) The finding also observed that without introducing of waste recycle, the emissions from waste sector will make an increase of the total GHG emissions about 4.2 times from 2014 to 2050. In the case of waste recycling scenario, the total GHG emissions in 2050 will reduce by 250 ktCO_2eq compared with those of BaU scenario. In this scenario also observes that the GHG emissions in the sectors in which the recycled material is provided will decrease because of increase of recycle. On the other hand, the energy related CO_2 in this sector in 2050 will increase by 430 ktCO_2 compared to the BaU scenario due to the treated MSW will increase in recycling sector in the CM scenario. From these results, GHG mitigation actions in the recycling sector will be important. In addition, due to the economic growth, the rebound effects of GHG emissions can be observed. In this analysis, other mitigation actions except waste recycling are not considered, but in order to avoid the rebound effects, countermeasures in various sectors should be taken into account.

5.2 Conclusion

Promoting both EV technology and waste recycle will significantly conduce to decarbonization and contribute remarkably to the decarbonization pathway in Laos. More CO_2 emission can be reduced in road transport sector, in case additional complementary countermeasures are introduced such as carbon tax and subsidy, particularly subsidy policy for EV cost. Nevertheless, these mitigation countermeasures can cause a negative effect on GDP growth, introducing the EV technology for example. Due to in general, the cost of EV is higher than conventional vehicles, thus the EV technology penetration in road transportation may cause of loss of GDP.

Adopting waste recycle can furthermore significantly reduce direct waste disposal by households which it is a source of emissions from unproperly solid waste treatment. Therefore, extension of waste recycle will be a key countermeasure to deal with emissions from solid management.

Since the waste-to-resources concept is aligned with the principles of 3R, and that they are at the top of the waste management hierarchy pyramid. The adoption of waste-to-resource approach has the potential of contributing to national development priorities, green growth direction, for example, and that will undoubtedly result in limiting emission from MSW treatment. By the way, a cleaner environment resulting from improved solid waste management practices could support healthier lives and well-being of populations.

5.3 Policy Implications

Since Laos government aims to boost up using internal energy, electricity produced from hydropower plants, specifically. Reduce trade deficit from importing goods as well. EV technology is a good option to promote using local electricity and ensuring energy security. During Covid-19 pandemic and fuel crisis, Laos had suffered seriously from fossil fuels shortage. Moreover, the price of fossil fuels has been increasing since Russia and Ukraine war commenced. Despite the EV cost is still higher than conventional vehicles but considering in long-term, EV technology can save more due to the expenditure for electric charging and price of fossil fuels are big gap, in addition, EV technology require less maintaining. However, in order to accomplish the targets, additional countermeasures need to be introduced, subsidy for EV cost and carbon tax, for example. Recent decades, more vehicles increasing in main cities that results in more pollution affecting town people. Therefore, more EV use will not only mitigate fossil fuels import but will improve city air quality as well. Furthermore, government launched policy on energy efficiency and save, EV can be a countermeasure to contribute to the policy implementation. Particularly replacing EV cars for government’s conventional ones. In long-term, policy to support fundamental infrastructure is required. To facilitate establishing EV development in the country can overcome some cost of EV technologies.

Regarding MSW management, urbanization citizens are generating more waste due to they can afford more for daily life, but the current rate of waste collection service is relative low. Extension of waste recycling can reduce direct damage of households. However, raising public awareness is necessary to drive adopting this approach. Extension of waste recycling can also create jobs in waste sector, since more labor will be recruited. In addition, proper MSW treatment will not only reduce direct disposal that is a resource of emitting methane but will directly improve city sceneries that can attract and facilitate tourism.

5.4 Future Works

In the future, the model can be improved by taking into account introducing more options, for example, various alternative carbon tax rates and additional mechanism. Followings are the points should be considered for further studies.

1) In order to promote penetrating EV cars, however, there is other aspect should be considered, for examples, fundamental infrastructure for EV technology development, in case the EV car manufactory can be facilitated installation in Laos the cost of EV cars trends be declined than the current cost and more households may afford for this technology. This impact should be assessed to show more options for promoting.
2) Introducing subsidy for EV cost is a key driver to accelerate the EV penetration. This implies that lower cost of imported EV cars from interfering of subsidy policy can encourage households' consumption more on EV technology. Thus, considering the subsidy policy for local EV manufactures can save more for EV cost that will facilitate more households can afford for EV technology, then will result in remarkable declining of fossil consumption and CO_2 emission reduction, as well as on the increase of GDP value from saving foreign currency for importing. The suitable aspects of subsidy policy and mechanism are needed for further discussion.
3) In longer-term, facilitation of EV manufactures in Laos would be more sustainable EV promotion. In meantime, this would not only mitigate CO_2 emission in road transport sector but would also create jobs and contribute to economic growth.
4) In order to make sure that the promotion of EV penetration will accomplish the defined targets. Additional policies are needed to be determined and implemented. Since now the global economic recession due to Covid pandemic and invasion of Russia on Ukraine, and high inflation are the key factors affecting household consumption. Moreover, the trust of households on EV technology is still low because the high cost and necessary charging stations not yet covers main cities, therefore conventional vehicles are still better option for travel. In addition, EV category is still limited and the import are mostly from China.
5) More detail information on recycling cost is needed, other mitigation options will have to be considered, actions avoiding the rebound effects should be considered, and so on will be introduced. In this analysis, since it is assumed that the extension of material recycling can be realized without any additional costs, these actions lead an positive impacts on GDP. In the real world, it may need some additional costs. Those impacts will have to be assessed to show the comprehensive analysis.
6) Since the additional cost for waste recycling is needed, the options for sustainable MSW management and avoiding the cost, specifically, limitation of waste generation at beginning stage that this is aligned with slogan "use less waste less" should be assessed.
7) Future similar study, this study considered 41 disaggregated commodities, considering more commodity disaggregation may affect some changes on the results, if detail data for more disaggregation are available.

Acknowledgement

Firstly, I would like to express my sincere thanks and appreciates the Project for Human Resource Development Scholarship by Japanese Grant Aid (JDS), through Japan International Cooperation Center (JICE) for offering the scholarship for my PhD course. Secondly, I would kindly like to thank and highly appreciate Professor Toshihiko Masui for being my academic supervisor. His tireless guidance and kind support during my PhD course at Tokyotech. He always encouraged me to deeply recognize academic analysis. Without his support, it may not be possible to achieve my big goal. I have learnt that Professor Masui always works hard, he also devotes for decarbonization works not only in Japan but in the regionals as well. I also have learned more how researchers and policy makers can support and reach each side. During study in Japan, I have networked with local and international researchers that I would hopefully have further collaboration in the future. I would also like to thank Dr. Marissa Malahayati for her technical support on my research works, particularly guiding me on GAMS program and research-related discussions. I would also like to thank all professors and my lap mates at Tokyotech. My sincere thank also goes to all researchers and assistant staffs for their kind support on my life at NIES. Kindly thanks Prof. Takehiko YAMATO, Prof. Kota Ogasawara, Prof. Takeo HORI, Prof. Tomomi MATSUI, and Prof. Koji TOKIMATSU for their constructive suggestions and kind advice on my dissertation and presentations.

Lastly, I would like to express my big thanks to my family, who are always standby me and encourage me with love to achieve this challenge goal.

Thank you very much.

Appendix A:

Relationship between this study sector classification and original IO sectors

This IO table was prepared and published by ADB under collaboration with Ministry of Energy and Mines of Laos. This input-output table provides a detailed picture of an economy through which mutual interrelationships among the producers and consumers in the economy can be systematically quantified. The IO table was constructed to show the relation between each sector interaction (supply and demand) in Laos.

Since this study disaggregated 35 sectors from original IO table into 41 sectors and added one more sector (biofuel) for the research, this appendix shows the relationship between this study sector classification and the original IO sectors. The detail of disaggregate IO table of 35 sectors is also shown in this appendix.

However, the original 35 commodities can consider to be disaggregated into more than this and/or aggregated lesser than 35 commodities which depends on the purposes of the study. In case of this study, we defined sector classification into 41 sectors due to research objective emphasizes on energy sector, so the original aggregated related-energy commodities are disaggregated. In addition, some sectors may disaggregate more but limitation of additional data, for example, electricity generation from solar PV and wind power is the key constrain.

Table 1-A Original IO table (35 sectors)

Industry \ Industry		Agriculture, hunting, forestry, and fishing	Mining and quarrying	Food, beverages, and tobacco	Textiles and textile products	Leather, leather products, and footwear	Wood and products of wood and cork	Pulp, paper, paper products, printing, and publishing	Coke, refined petroleum, and nuclear fuel	Chemicals and chemical products	Rubber and plastics	Other nonmetallic minerals	Basic metals and fabricated metal	Machinery, nec	Electrical and optical equipment	Transport equipment	Manufacturing, nec; recycling	Electricity, gas, and water supply	Construction	Sale, maintenance, and repair of motor vehicles and motorcycles; retail sale of fuel	Wholesale trade and commission trade, except of motor vehicles and motorcycles	Retail trade, except of motor vehicles and motorcycles; repair of household goods	Hotels and restaurants	Inland transport	Water transport	Air transport	Other supporting and auxiliary transport activities; activities of travel agencies	Post and telecommunication	Financial intermediation	Real estate activities	Renting of M&Eq and other business activities	Public administration and defense; compulsory social security	Education	Health and social work	Other community, social, and personal services	Private households with employed persons	Final consumption expenditure by households	Final consumption expenditure by non-profit organisations serving households	Final consumption expenditure by government	Gross fixed capital formation	Changes in inventories and valuables	Exports	TOTAL
		c1	c2	c3	c4	c5	c6	c7	c8	c9	c10	c11	c12	c13	c14	c15	c16	c17	c18	c19	c20	c21	c22	c23	c24	c25	c26	c27	c28	c29	c30	c31	c32	c33	c34	c35	F1	F2	F3	F4	F5	F6	
Agriculture, hunting, forestry, and fishing	c1	109	1	460	2	0	81	3	1	0	0	0	0	0	0	0	15	0	4	0	0	1	53	-	-	-	-	0	-	-	0	-	3	-	0	-	1,348	-	-	-	0	439	2,521
Mining and quarrying	c2	0	566	12	2	0	1	0	8	3	2	49	1	0	0	0	1	77	360	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	17	-	143	-	-	-	1	1,866	3,112
Food, beverages, and tobacco	c3	24	1	91	-	-	0	0	0	0	0	0	-	-	-	-	0	-	-	0	0	0	134	0	-	0	0	-	-	-	0	-	1	0	0	-	785	-	-	-	0	256	1,293
Textiles and textile products	c4	1	0	0	26	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	-	0	0	0	-	-	0	1	0	0	1	-	40	-	-	-	0	173	252
Leather, leather products, and footwear	c5	0	0	0	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	-	-	0	0	0	0	0	-	9	-	-	-	0	32	49
Wood and products of wood and cork	c6	1	0	4	1	0	17	1	1	0	0	0	0	0	0	0	5	0	10	1	1	4	3	0	-	0	0	6	2	-	1	15	2	0	2	-	17	-	-	-	0	179	271
Pulp, paper, paper products, printing, and publishing	c7	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	-	0	1	0	0	0	-	1	-	-	-	0	6	10
Coke, refined petroleum, and nuclear fuel	c8	7	12	2	1	0	1	0	1	0	0	0	0	0	0	0	0	1	13	2	1	5	4	6	-	0	0	0	1	0	0	9	1	3	1	-	20	-	-	-	(0)	7	102
Chemicals and chemical products	c9	4	7	1	1	0	1	0	1	0	0	0	0	0	0	0	0	1	7	1	1	3	2	4	-	0	0	0	1	0	0	5	1	2	1	-	11	-	-	-	0	7	59
Rubber and plastics	c10	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	1	1	-	0	0	0	0	0	0	2	0	1	0	-	4	-	-	-	0	3	24
Other nonmetallic minerals	c11	0	2	1	-	-	-	-	0	0	0	4	0	0	0	0	1	0	115	0	0	12	20	0	-	0	0	2	-	5	1	2	-	-	2	-	26	-	-	-	0	4	197
Basic metals and fabricated metal	c12	1	5	3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	18	1	1	5	0	1	-	0	0	1	0	0	0	3	0	0	0	-	9	-	-	37	(0)	5	95
Machinery, nec	c13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	-	0	-	-	0	(0)	0	1
Electrical and optical equipment	c14	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	-	0	0	0	0	0	0	0	0	0	0	-	1	-	-	5	(0)	4	15
Transport equipment	c15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	-	0	-	-	2	(0)	1	5
Manufacturing, nec; recycling	c16	1	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	4	2	1	1	3	2	2	-	0	0	0	2	1	1	6	1	2	1	-	19	-	-	50	(0)	17	121
Electricity, gas, and water supply	c17	2	32	5	1	0	1	0	0	0	0	1	0	0	0	0	0	8	2	3	3	12	13	0	-	0	0	1	2	2	0	19	2	1	3	-	43	-	-	-	0	714	871
Construction	c18	1	9	0	0	0	0	0	-	-	-	-	0	0	0	0	0	2	140	5	4	16	6	0	-	0	0	1	0	57	1	77	8	2	2	-	19	-	-	2,262	(0)	176	2,787
Sale, maintenance, and repair of motor vehicles and motorcycles; retail sale of fuel	c19	7	10	23	5	1	3	0	0	0	0	0	0	0	0	0	1	1	27	2	2	8	17	4	-	0	0	1	1	0	1	16	1	1	1	-	75	-	-	52	(0)	55	319
Wholesale trade and commission trade, except of motor vehicles and motorcycles	c20	10	14	32	7	1	4	0	1	0	0	0	0	0	0	0	2	2	38	3	3	11	24	6	-	0	0	2	1	1	1	22	1	2	1	-	104	-	-	71	0	76	441
Retail trade, except of motor vehicles and motorcycles; repair of household goods	c21	33	46	104	24	5	12	0	2	1	1	2	1	0	0	0	3	7	124	10	9	35	79	19	-	0	0	6	3	2	3	71	5	6	5	-	342	-	-	234	(0)	234	1,429
Hotels and restaurants	c22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	5	3	0	-	0	0	0	3	0	10	31	3	0	1	-	831	-	-	-	0	27	921
Inland transport	c23	2	6	7	1	0	1	0	1	0	0	0	0	0	0	0	1	1	34	10	8	34	8	4	-	0	0	2	7	2	10	46	4	1	2	-	31	-	-	-	0	79	302
Water transport	c24	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	3	2	9	2	1	-	0	0	0	2	0	3	12	1	0	0	-	7	-	-	-	(0)	8	64
Air transport	c25	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	1	5	1	1	-	0	0	0	1	0	1	6	1	0	0	-	4	-	-	-	(0)	5	35
Other supporting and auxiliary	c26	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	1	4	1	0	-	0	0	0	1	0	1	5	0	0	0	-	3	-	-	-	(0)	8	32
Post and telecommunications	c27	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	2	10	3	0	-	0	0	19	4	-	2	34	3	0	3	-	105	-	-	-	0	71	261
Financial intermediation	c28	2	8	1	2	0	2	0	1	0	0	0	0	0	0	0	0	1	13	13	11	46	25	3	-	0	0	1	135	3	4	39	3	0	2	-	160	-	2	-	0	17	494
Real estate activities	c29	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	18	15	62	18	1	-	0	0	1	22	18	3	23	20	0	5	-	905	-	-	-	0	1	1,117
Renting of M&Eq and other	c30	1	2	6	1	0	0	0	1	1	0	0	0	0	0	0	0	0	15	8	7	29	9	3	-	0	0	3	12	6	12	48	6	0	2	-	75	-	-	-	0	2	250
Public administration and defense;	c31	-	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	80	2	-	0	-	358	-	1,480	-	0	70	1,991
Education	c32	0	0	0	-	-	-	-	0	0	0	-	0	0	0	0	0	-	-	0	0	1	0	0	-	0	0	0	0	-	0	6	3	-	0	-	234	-	144	-	0	22	410
Health and social work	c33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	83	-	29	-	(0)	19	131
Other community, social, and personal services	c34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	1	2	0	-	0	0	0	0	-	0	8	0	-	1	-	282	-	-	-	(0)	15	310
Private households with employed	c35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	(1)	12	12
Imports	M	111	302	133	37	7	27	1	33	14	9	38	49	0	8	3	23	78	838	41	33	125	75	64	56	30	24	25	22	16	12	113	27	18	35	-	2,027	-	0	689	0	-	5,142
Intermediate input total	r60	322	1,033	896	120	23	153	5	52	22	15	95	52	0	8	3	56	185	1,788	131	108	446	509	122	56	31	24	74	220	113	69	701	98	41	88	-	8,120	-	1,655	3,402	(0)	4,612	25,445
Taxes less subsidies on products	r99	19	57	19	7	2	10	1	2	4	2	7	5	0	2	1	5	16	107	5	7	25	51	25	1	1	1	7	3	2	3	25	2	3	5	-	542	-	-	184	0	-	1,157
CIF / FOB adjustments on exports	r61	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Direct purchases abroad by	r62	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Purchases on the domestic territory by non-residents	r63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Value added at basic prices	r64	2,180	2,023	378	125	25	109	4	48	33	7	95	38	0	5	1	61	670	892	183	325	957	362	156	7	3	7	180	271	1,002	177	1,266	310	88	217	12	-	-	-	-	-	-	12,216
International Transport Margins	trs	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gross Value Added		2,199	2,080	397	132	26	118	4	50	38	9	102	43	0	8	2	65	686	998	188	333	983	413	180	9	4	8	187	274	1,004	180	1,291	313	91	222	12	542	-	-	184	0	-	13,373
TOTAL	r69	2,521	3,112	1,293	252	49	271	10	102	59	24	197	95	1	15	5	121	871	2,787	319	441	1,429	921	302	64	35	32	261	494	1,117	250	1,991	410	131	310	12	8,663	-	1,655	3,587	(0)	4,612	**38,819**

Table 2-A Disaggregated IO table of 40 sectors for this study

Industry		Agriculture, Hunting, Forestry, and Fishing	cropping '01	livestock '02	forestry '03	fishing '04	Mining and Quarrying '05	Food, Beverages, and Tobacco '06	Textiles and Textile Products '07	Leather, Leather Products, and Footwear '08	Wood and Products of Wood and Cork '09	Pulp, Paper, Paper Products, Printing, and Publishing '10	Coke, Refined Petroleum, and Nuclear Fuel	'11	'12	Chemicals and Chemical Products '13	Rubber and Plastics '14	Other Nonmetallic Minerals '15	Basic Metals and Fabricated Metal '16	Machinery, nec '17	Electrical and Optical Equipment '18	Transport Equipment '19	Manufacturing, nec; Recycling '20	Electricity, Gas, and Water Supply	Elec 21h	Water '22	Construction '23	Sale, Maintenance, and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel '24	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles '25	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods '26	Hotels and Restaurants '27	Inland Transport '28	Water Transport '29	Air Transport '30	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies '31	Post and Telecommunications '32	Financial Intermediation '33	Real Estate Activities 34	Renting of M&Eq and Other Business Activities 35	Public Administration and Defense; Compulsory Social Security 36	Education 37	Health and Social Work 38	Other Community, Social, and Personal Services 39	Private Households with Employed Persons 40	Final Consumption Expenditure h	Final Consumption Expenditure by Government g	Gross Fixed Capital Formation hi	Changes in Inventories and Valuables s	Exports ex	Imports im	Total Output tot
Agriculture, hunting, forestry, and fishing		111	72	20	4	16	1	479	2	0	81	3	1			0	0	0	0	0	0	0	15	0	0	0	4	0	0	1	54	0	0	0	0	0	0	0	0	0	3	0	0	0	1412	0	0	0	439	-88	2521
cropping	'01		48	13	3	10	0	320	1	0	0	0	1	1	0	0	0	0	0	0	0	0	10		0	0	3	0	0	1	36	0	0	0	0	0	0	0	0	0	2	0	0	0	941	0	0	0	293	-58	1624
livestock	'02		13	4	1	3	0	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3		0	0	1	0	0	0	10	0	0	0	0	0	0	0	0	0	1	0	0	0	257	0	0	0	80	-16	444
forestry	'03		0	0	0	0	0	3	0	0	81	3	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	3	-1	98
fishing	'04		10	3	1	2	0	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2		0	0	1	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	206	0	0	0	64	-13	355
Mining and quarrying	'05	0	0	0	0	0	568	12	2	0	1	0	8	8	0	3	2	49	1	0	0	0	1	78	71	7	361	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	17	0	144	0	0	0	1867	-4	3112
Food, beverages, and tobacco	'06	32	21	6	1	4	1	121	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	158	0	0	0	0	0	0	0	0	0	1	0	0	0	1034	0	0	0	256	-313	1293
Textiles and textile products	'07	3	2	0	0	0	0	0	46	9	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	4	0	0	0	0	0	0	0	1	1	0	0	1	0	97	0	0	0	173	-87	252
Leather, leather products, and footwear	'08	0	0	0	0	0	0	0	9	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	32	-13	49
Wood and products of wood and cork	'09	1	1	0	0	0	0	6	2	0	26	1	1	1	0	1	0	1	0	0	0	0	9	0	0	0	19	2	1	6	5	0	0	0	0	8	2	0	1	19	2	0	3	0	26	0	0	0	179	-49	271
Pulp, paper, paper products, printing, and	'10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	6	-2	10
Coke, Refined Petroleum, and Nuclear Fuel		85	55	15	3	12	193	28	11	2	11	0	30			11	7	14	6	0	0	0	6	33	30	3	203	17	9	55	49	32	46	25	20	3	6	2	4	63	13	18	16	0	573	0	0	0	7	-1497	102
Coke and nuclear fuel	'11		0	0	0	0	0	19	7	1	7	0	30	30	0	7	5	9	4	0	0	0	4		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	102
Refined petroleum	'12		55	15	3	12	193	9	4	1	4	0	0	0	0	4	3	5	2	0	0	0	2		30	3	203	17	9	55	49	32	46	25	20	3	6	2	4	63	13	18	16	0	573	0	0	0	0	-1497	0
Chemicals and chemical products	'13	5	3	1	0	1	7	1	1	0	1	0	1	1	0	1	0	0	0	0	0	0	0	1	1	0	8	1	1	3	3	4	0	0	0	0	1	0	0	5	1	2	1	0	11	0	0	0	7	-4	59
Rubber and plastics	'14	2	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	1	1	0	0	0	0	0	0	0	2	0	1	0	0	4	0	0	0	3	0	24
Other nonmetallic minerals	'15	0	0	0	0	0	3	2	0	0	0	0	1	1	0	0	0	15	1	0	0	0	1	0	0	0	350	0	0	0	1	0	0	0	0	3	0	8	1	3	0	0	4	0	30	0	0	0	4	-230	197
Basic metals and fabricated metal	'16	10	6	2	0	1	93	43	2	0	4	0	1	1	0	1	0	5	36	0	3	2	11	31	29	3	345	17	9	55	5	25	1	1	1	9	2	5	4	24	4	1	5	0	816	0	38	0	5	-1515	95
Machinery, nec	'17	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	16	0	0	-25	1
Electrical and optical equipment	18	1	1	0	0	0	9	4	0	0	0	0	0	0	0	0	0	1	3	0	1	0	1	3	3	0	36	2	1	6	0	3	0	0	0	1	0	0	1	3	0	0	1	0	82	0	360	0	0	-511	11
Transport equipment	19	1	0	0	0	0	5	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	2	1	0	20	1	1	4	0	1	0	0	0	1	0	0	0	2	0	0	0	0	49	0	221	0	0	-309	5
Manufacturing, nec; recycling	20	1	1	0	0	0	4	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	5	0	3	1	1	4	2	2	0	0	0	0	2	1	1	6	1	3	1	0	44	0	124	0	21	-106	125
Electricity, gas, and water supply		2	1	0	0	0	41	6	1	0	1	0	0			0	0	1	0	0	0	0	0	11	10	1	3	4	3	13	15	0	0	0	0	1	2	2	0	20	2	1	3	0	41	0	0	0	723	-27	871
Elec	21		1	0	0	0	23	3	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0		6	1	1	2	2	7	9	0	0	0	0	1	1	1	0	11	1	1	2	0	23	0	0	0	723	-27	796
Water	22		1	0	0	0	17	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0		4	0	1	2	1	5	6	0	0	0	0	0	1	1	0	9	1	1	1	0	18	0	0	0	0	0	75
Construction	23	2	1	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	141	5	4	16	6	0	0	0	0	1	0	58	1	77	8	2	2	0	20	0	2284	0	176	-26	2787
Sale, maintenance, and repair of motor vehicles and motorcycles; retail sale of fuel	24	7	5	1	0	1	10	23	5	1	3	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	27	2	2	8	17	4	0	0	0	1	1	0	1	16	1	1	1	0	75	0	52	0	55	0	319
Wholesale trade and commission trade, except of motor vehicles and motorcycles	25	11	7	2	0	2	14	35	8	1	4	0	1	1	0	0	0	0	0	0	0	0	2	2	2	0	39	6	13	15	25	9	1	2	0	4	1	3	1	31	2	2	2	0	132	0	72	0	76	-75	441
Retail trade, except of motor vehicles and motorcycles; repair of household goods	26	33	21	6	1	5	46	105	24	5	12	0	2	2	0	1	1	2	1	0	0	0	5	6	5	0	124	10	9	36	79	19	0	0	0	6	3	2	3	71	5	6	5	0	347	0	234	0	234	-8	1429
Hotels and restaurants	27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	5	3	0	0	0	0	0	3	0	10	31	3	0	1	0	831	0	0	0	27	0	921
Inland transport	28	2	1	0	0	0	7	8	1	0	1	0	1	1	0	1	0	0	0	0	0	0	1	1	1	0	40	11	9	38	9	5	0	0	0	2	7	2	11	50	6	1	2	0	33	0	0	0	79	-27	302
Water transport	29	1	1	0	0	0	2	3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	11	3	3	10	2	2	6	0	1	2	2	1	3	16	2	0	0	0	8	0	0	0	8	-28	64
Air transport	30	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	1	5	2	1	0	1	0	1	1	0	1	8	1	0	0	0	8	0	0	0	5	-12	35
Other supporting and auxiliary transport activities; activities of travel agencies	31	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	1	4	1	1	0	0	1	1	1	0	1	6	1	0	0	0	3	0	0	0	8	-4	32
Post and telecommunications	32	2	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	3	3	3	13	4	2	0	0	1	22	4	0	3	36	5	0	3	0	117	0	0	0	71	-35	261
Financial intermediation	33	4	3	1	0	1	12	3	2	0	3	0	1	1	0	1	1	5	0	0	0	0	1	3	3	0	18	16	13	55	33	5	0	0	0	3	148	4	4	43	7	0	11	0	187	2	1	0	17	-113	494
Real estate activities	34	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	18	15	62	18	1	0	0	0	1	22	18	3	23	20	0	5	0	905	0	0	0	1	-1	1117
Renting of M&Eq and other business activities	35	1	1	0	0	0	2	6	1	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	15	8	7	29	9	3	0	0	0	3	12	6	13	48	6	1	2	0	75	0	0	0	2	-3	250
Public administration and defense; compulsory social security	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	2	0	0	0	358	1480	0	0	70	-1	1991
Education	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6	3	0	0	0	234	144	0	0	22	0	410
Health and social work	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	92	29	0	0	11	0	131
Other community, social, and personal services	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	8	0	0	1	0	309	0	0	0	15	-28	310
Private households with employed persons	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	10	0	12

Appendix B:

Mitigation targets under updated nationally determine contribution (NDC 2020).

The updated nationally determine contribution (NDC 2020) had defined mitigation targets under unconditional and conditional targets.

Table 1-B Unconditional mitigation targets

Sectors	**Unconditional mitigation targets**
Forestry	• Reduced emissions from deforestation and forest degradation, foster conservation, sustainable management of forests, buffer zones of national parks and other preserves, and enhancement of forest carbon stocks.
Hydropower	• 13GW total hydropower capacity (domestic and export use) in the country
Energy Efficiency	• Introduction of 50,000 energy efficient cook stoves
Transport	• New Bus Rapid Transit system in Vientiane Capital and associated Non-Motorized Transport (NMT) component • Lao-China Railway

Table 2-B Conditional mitigation targets

Sectors	**Conditional Mitigation targets**
Forestry	• Increased forest cover to 70% of land area (i.e. to 16.58 million hectares) through reduced emissions from deforestation and forest degradation, foster conservation, sustainable management of forests, buffer zones of national parks and other preserves, and enhancement of forest carbon stocks, preserves, and enhancement of forest carbon stocks.
Other renewables	• SOLAR and WIND: 1 GW total installed capacity in the country • BIOMASS: 300 MW total installed capacity in the country
Transport	• 30% Electric Vehicles penetration for 2-wheelers and passengers' cars in national vehicles mix • Biofuels to meet 10% of transport fuels
Energy Efficiency	• 10% reduction of final energy consumption compared to business-as-usual scenario
Agriculture	• 50,000 hectares adjusted water management practices in lowland rice cultivation
Waste	• Implementation of 500 tons/day sustainable municipal solid waste management project

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