A Study on Low Carbon Development with a Computable General Equilibrium Model
- Application to Vietnam -

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List of Abbreviations

ADB	Asian Development Bank
AIDADS	An Implicitly Directly Additive Demand System
ASEAN	Association of South East Asian Nations
AIM/CGE	Asian Integrated Modeling/Computable General Equilibrium
BaU	Business-as-Usual case
C&C	Contraction and Convergence
CDM	Clean Development Mechanism
CGE	Computable General Equilibrium
C.I.F	Cost Insurance and Freight
CM	Counter-Measure case
EEDD	Energy Economic Driver Database
EIOT	Energy Input-Output Table
ESMAP	Energy Sector Management Assistance Program
F.O.B	Free On Board
GAMS	General Algebraic Modeling System
GDP	Gross Domestic Product
GDX	GAMS Data Exchange
GHG	Greenhouse Gases
GMID	Global Market Information Database
GTAP	Global Trade Analysis Project
$GtCO_2eq$	Giga-ton Carbon dioxide equivalent
ICP	International Comparison Program
IDA	International Development Association
IEA	International Energy Agency
IEEJ	Institute of Energy Economics Japan
IPCC	Intergovernmental Panel on Climate Change
LCD	Low Carbon Development
LCS	Low Carbon Society
LES	Linear Expenditure System

MDGs	Millennium Development Goals
NAMA	Nationally Appropriate Mitigation Action
ODA	Official Development Assistance
OECD	Organization for Economic Cooperation and Development
RS	Reconciliation System
SAM	Social Accounting Matrix
SNA	System of National Accounts
TOE	Ton of Oil Equivalent
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organization

EXECUTIVE SUMMARY

Currently, there is no doubt that climate change has adverse impacts to the environment, society and economic activities of all countries all over the world. However, putting more efforts on the low GHG emissions development might implicate the social and economic targets of a nation, particularly for those developing countries that have very low GHG emissions but still put targets on energy security and minimizing the emission. As a result, the socio-economic and energy scenarios development may provide benchmarks for long-term policy making as one of the main tools for dealing with the complexity and uncertainty of future challenges.

AIM/CGE[basic] model has been applied to analyze the change of energy consumption and the CO_2 emissions structure in Vietnam from 1986 to 2005. This work would provide the reliable historical information on economic development, energy consumption, and CO_2 emissions in supporting studies on the future potential for CO_2 emissions reduction in Vietnam. Lately, the AIM/CGE[basic] model has been developed to be a quasi-recursive dynamic model with an extension of production function and the well-disaggregated energy sectors, especially in power generation. The objective is to analyze the feasibility of implementing climate change mitigation measures and their socio-economic implications in Vietnam towards 2050.

However, in current AIM/CGE[basic] model, the household demand function follows Linear Expenditure System (LES) function, in which income increase does not affect the household expenditure behavior (consumption share), leading to possible over-predicting growth in private demand, import, and output growth requirement for food products and under-predicts that for non-food products in developing countries, especially energy commodities. Therefore, in order to analyze the future household consumption behavior towards Low Carbon Society, the LES function in AIM/CGE[basic] model is replaced by An Implicitly Directly Additive Demand System (AIDADS) function that follows Engel's law in describing the household expenditure change when income increases.

Two societies for the future of Vietnam are drawn based on main indicators such as socio-economic and political factors; dependency on imported energy; energy diversity; advanced technology progress; household consumption behavior towards environmental-friendly products; and lastly is the CO_2 emissions reduction target. The level of these scenario indicators, except same emission reduction target, varies from low to high for SSTAG (A-scenario-of-rather-stagnant-society) and SLCS (A-scenario-for-Low-Carbon-Society), respectively. These two societies are targeted towards GHG emissions reduction in order to analyze the socio-economic implications and energy-environmental issues of Low Caron Development (LCD) (through comparing the Business-as-Usual (BaU) and

Counter-Measure (CM) scenarios of each society). In which, SSTAG_BaU and SLCS_BaU do not consider the emission reduction target while SSTAG_CM and SLCS_CM have to take into account some mitigation measures in order to achieve the reduction target with the minimum compromising to their societies. In both societies, the underlying hypothesis of carbon tax (or emission price) is that by internationalizing externalities, high-emission fuels become less attractive.

The SSTAG represents a continuation of the current trends in socio-economic and energy development of Vietnam without any major changes. In which, the main bottleneck of economic development and energy provision is the lack of resources and capital investment. Meanwhile, The SLCS represents a higher trend in socio-economic and energy development of Vietnam compared to SSTAG. There is higher potential of resources and capital investment that encourage the development of a cleaner and more efficient energy system.

Results show that there would be an economy loss for both SSTAG and SLCS in order to reach the GHG emissions reduction target (emission in 2050 is same as that of 2005, which is around 0.37GtCO_2eq). However, with higher GDP growth rate, energy efficiency, good governance, and skilled labor; SLCS shows more promising society for Vietnam in developing towards low carbon society.

The demand of transportation is changed according to income and GDP increases, which is very high in SLCS compared to SSTAG, especially in the increase of truck transport demand. In SLCS, electric truck is used at small rate while this mode is not available in SSTAG. In general, the usage of electric vehicles for industry and household transportation is depended on the technology change and also the price of electricity.

Secondary sector is still the main contributor to the GDP, even the share of tertiary sector has been increased in both SSTAG and SLCS. It is projected that the total import of goods and services in 2050 of BaU_SLCS is 2.4 times that of BaU_SSTAG and this ratio is around 2.0 times for [CM_SLCS/CM_SSTAG]. On the other hand, the value of this ratio for export is 2.6 times for [BaU_SLCS/BaU_SSTAG] and 2.1 times for [CM_SLCS/CM_SSTAG]. Generally, in SLCS the price of all commodities is higher than those in SSTAG, which is around 1.5-2 times of SSTAG in 2050, except for petroleum product whose price in SLCS is cheaper than in SSTAG.

In overall, the total GDP of SLCS is around 2.3 times that of SSTAG. The total GDP of SSTAG in 2050 is around 7.4 times compared to 2005 while this ratio in SLCS is around 17 times. In SSTAG, the GDP loss is around 1.2% of its total GDP in 2050. Meanwhile, in 2050 SLCS has higher GDP loss which is around 10% of its total GDP. It means that the total direct cost of implementing climate change mitigation measures in

SLCS is higher than in SSTAG, under the context of dramatic economic development compared to SSTAG.

In SSTAG, the total GHG emissions in 2050 is around 1.9 times compared to 2005 while total GDP is nearly 7.4 times together with 1.6 times increase in total primary energy supply; 1.5 times increase in total final energy consumption; and 6.4 times increase in total electricity generation. In order to achieve the GHG emissions reduction target in 2050 (around 0.37 $GtCO_2eq$), SSTAG has to reduce 12.4% of its total emission.

In SLCS, the total GHG emissions in 2050 is nearly 3.6 times compared to 2005, which is also much higher compared to the emission in 2050. Meanwhile, the increase of total GDP in 2050 is more than 17 times compared to 2005; together with 3.7 times increase in total primary energy supply, 2.5 times increase in total final energy consumption, and nearly 10 times increase in total electricity generation. With the target of total GHG emissions in 2050 around 0.37 $GtCO_2eq$, SLCS has to reduce nearly 53% of its total emission in SLCS.

In term of social implication; in SSTAG, the household income loss starts since 2030 with 0.2% and reaches around 10% of its total income in 2050. Meanwhile, SLCS starts to suffer the income loss since 2025 with very small lost and dramatic increase and reach more than 15% of its total income. In SLCS, the total household expenditure increases substantially to around 16.3 times in 2050 compared to 2005, much higher than the increase in SSTAG. In SLCS, spending on foods is still highest share, which is around 29% of total household expenditure in 2050, followed by spending on services, electricity, machinery and other manufacturing, transportation, and petroleum products at the share of 18.5%, 14.5%, 10.4%, 7.7%, 7.7%, respectively.

With similar assumption of GDP growth rate as Vietnamese Government, the results of total primary energy supply, total final consumption, and power generation are compared and show similar with some projections of international organization such as International Energy Agency (IEA) and Institute of Energy Economics Japan (IEEJ).

Under more stringent emission reduction (C&C target), SSTAG has to rely more on renewable energy due to the unavailability of CCS technology. Meanwhile, SLCS increases the contribution of CCS technology, making this technology becomes the most important countermeasure in order to reduce the GHG emissions in SLCS. The contribution of CCS technology in SLCS increases to more than 0.25 $GtCO_2eq$ in 2050, higher than under CM target. Both SSTAG and SLCS have to face more expensive emission price. In which, in 2050; the emission price of SSTAG is very high, around 400 US$/$tCO_2eq$, while the maximum emission price in SLCS is around 306 US$/$tCO_2eq$ (in 2038) before falling down to around 150 US$/$tCO_2eq$ (in 2050). The emission price of

SSTAG is higher than that of SLCS since 2043 and become more than twice of SLCS in 2050 due to the unavailable CCS technology in SSTAG.

Even CGE model is one of the powerful tools to describe the whole economy of a nation, as well as the integration of one nation with the rest of the world; so far it cannot perform the real flexibility of the country in term of improvement in energy system and technology system, especially in developing country like Vietnam. On the other hand, in order to propose more appropriate climate change mitigation options and the well-designed scenarios for future low carbon development, the methodology in this research should extend the study to more detail household disaggregation (such as urban and rural, and by income levels). Moreover, the simulation of household energy consumption should be in more detail by through coupling with bottom-up household energy modeling.

Chapter 1 INTRODUCTION

Chapter 1 provides the international and Vietnam national rationales leading to the necessity of this research.

Section 1.1 not only provides the international framework towards global GHG emissions reduction (subsection 1.1.1) in which the Kyoto Protocol is the background but also the Vietnamese legal frameworks (subsection 1.1.2) in terms of socio-economic development, energy development, environmental protection and climate change mitigation. The subsection 1.1.3 summarizes concrete actions of Vietnamese Government towards Low Carbon Development (LCD) Plan.

Section 1.2 summarizes the objectives of this research and related activities.

Section 1.3 provides the research originalities in both methodology and analytical finding that is explained deeply in Chapter 3.

Section 1.4 describes the structure of this dissertation.

1.1 Rationale

1.1.1 International framework towards global GHG emissions reduction

Currently, there is no doubt that climate change has adverse impacts to the environment, societal and economic activities of all countries in all over the world. Since 1997, 187 countries have signed and ratified the Kyoto Protocol with main objective is to set up the Greenhouse Gases (GHG) emissions limitation especially for developed (Annex I) countries. As a result, it helps to develop strategies for developing (non-Annex I) countries in achieving the sustainable socioeconomic development through Clean Development Mechanism (CDM) which is implemented in sectors such as energy, industry, transportation, agriculture, forestry, and waste management.

The G8 nations at recent summits have endorsed the goal of reducing global emissions by at least 50% by 2050 (which should be relative to 1990). Such cuts are broadly in line with a path could hold GHG level below 500ppm CO_2eq and then start to reduce them. According to World Bank (2009), this could reduce the probability of a 5ºC increase in global temperature from around 50% to 3% or less. The target 50% reduction means halving global emissions from 40 $GtCO_2$eq a year to 20 $GtCO_2$eq, or little more than 2 ton per capita with around 9 bil. people in 2050; it also means little scope for deviation of actual emissions from the mean for any major country, developed or developing (note that similar per capita actual emissions does not mean similar per capita quotas). Therefore, C&C (Contraction and Convergence) scheme (Meyer, 2000) is a simple and compelling idea of achieving the global emission reduction by equally allocating the reduction burden to everyone in the world.

Many of the poorest people in the world will be the most exposed and vulnerable to the impacts of climate change that will occur over the next few decades. These are also the people who are least able to afford the costs of adaptation, and who have contributed much less than those in the rich world to the current levels of GHG in the atmosphere. There is a fundamental inequity here and a strong imperative for the rich countries to provide more funds to developing countries, in addition to current development commitments, to fund the extra costs created by climate change (World Bank, 2009).

Beside some adaptation measures that developing countries are taking to minimize the impact of changing climate, these countries including Vietnam should also follow developed countries in considering mitigation measures especially in energy consumption; reduce GHG emissions; and integrating these problems into policy and decision making. Signed in Kyoto Protocol in 1998, Vietnam has been gaining benefits as other developing countries in getting financial supports and technology transfer from developed countries through CDM projects; therefore will improve the quality of economic development and people's living standards.

However, putting more efforts on the low GHG emissions development might implicate the social and economic targets of a nation, particularly for those developing countries that have very low GHG emissions but still put targets on energy security and minimizing emissions.

As a result, the socio-economic and energy scenarios development may provide benchmarks for long-term policy making therefore support policy makers better develop a flexible strategy, or at least to assess risk associated with an unpredictable future. Scenarios were and continue to be one of the main tools for dealing with the complexity and uncertainty of future challenges.

1.1.2 Legal frameworks towards Climate Change mitigation in Vietnam

Vietnam is undergoing a very rapid economic development and the energy consumption is increasing even faster, due to lack of incentives for and knowledge of energy efficiency measures. The energy intensity of Vietnamese enterprises is high and there is room for significant improvements. Moreover, Vietnam is one of the countries in the world foreseen to be impacted most by climate change due to the country's significant economic development zones in the flood prone major river deltas of Mekong and Red River. In addition the country's 3,200 km long coast line is already now impacted by typhoons, which are expected to increase in number and intensity.

1.1.2.1 Socio-economic development framework

According to Ministry of Planning and Investment (Vietnamese MOPI, 2011), Vietnamese Government focuses on transforming the economic structure, upgrading the level of technology and management, both at macro and micro levels, in order to achieve 7% per year growth rate, until 2030. The country also put target on reducing the population growth rate through the "two-child policy", to maintain the 1% per year during the next one decade. In order to achieve the socio-economic targets, Vietnamese Government approved many plans for infrastructure development, particularly transportation (Vietnamese Government, 2009) and housing (Vietnamese Government, 2008a). As a result, the energy demand therefore also increases that leads the Vietnamese government to develop more detail energy development plan.

1.1.2.2 Energy development framework

With the improvement from the "Power Master Plan VI" (Vietnamese Government, 2007a), the Prime Minister of Vietnam approved the national power development plan for the 2011-2020 period with the vision to 2030 (the "Power Master Plan VII") on 21st July 2011 under the Decision No. 1208/2011/QD-TTg (Vietnamese Government, 2011a). The Power Master Plan VII puts strong emphasis on energy security, energy efficiency, renewable energy development and power market liberalization. It also aims to address various problems encountered during the implementation of the previous Power Master Plan VI.

In order to ensure the energy security, Vietnamese Government puts effort on developing renewable energy such as biofuel (Vietnamese Government, 2007b) and wind (Vietnamese Government, 2011b). Moreover, Vietnamese Government still approves the "Master plan to implement the Nuclear Power development strategy for peaceful purposes by 2020" (Vietnamese Government, 2007c) which is revised in 2010 (Vietnamese Government, 2010a) for the extension to the year 2030. Together with the decision of nuclear power development is the Vietnamese law on nuclear power (Vietnamese Government, 2008b) with its detail instruction (Vietnamese Government, 2010b). After the Fukushima nuclear accidents due to the big double disasters (earthquake leading to tsunami) in Japan on 11th March 2011, many countries have modified and even canceled the nuclear power development in order to avoid the disaster risks. Despite that, Vietnamese Government still maintains the nuclear power plant (NPP) development in which Russia and Japan have been chosen as partners of the Ninh Thuan 1 and Ninh Thuan 2 NPPs Projects, respectively. The desired target is to increase the contribution of renewable energy (RE) and nuclear power in the commercial energy structure mix, up to 11% and 15-20% by 2025 and 2050, respectively.

Many energy efficiency programs are launched after the Vietnamese Government approved the decree on thrifty and efficient use of energy (Vietnamese Government, 2003a) and the national target program on energy efficiency and effectiveness (Vietnamese Government, 2006a), together with the decision on electricity saving program (Vietnamese Government, 2006b). The energy efficiency issue was later put into law in 2010 (Vietnamese Government, 2010c), however, with very general rules for industrial and lighting, transportation, agricultural, residential and commercial sectors.

1.1.2.3 Environmental protection and climate change mitigation framework

After the Vietnam Environmental Law (Vietnamese Government, 2003b), the Vietnamese Government issued the "Strategic Orientation for Sustainable Development in Vietnam (Vietnam Agenda 21)" (Vietnamese Government, 2004) in order to sustainably develop the country on the basis of close, reasonable and harmonious coordination of economic and social development and environmental protection (Vietnamese Government, 2003c).

Lately, Vietnamese Government issued the Instruction of suitable mechanism to adjust the operations related to Convention of Climate and Kyoto Protocol up to 2012 (Vietnamese Government, 2005), with detail revision issued in 2007 (Vietnamese Government, 2007d). In that year 2007, Vietnamese Government decided the "National target program on Climate change" (Vietnamese Government, 2007e) and assigned related organizations to develop climate change mitigation measures to support the "Vietnam Energy Efficiency Program" (Vietnamese MOIT, 2008) and detail "National Target Program to respond to Climate Change" (Vietnamese MONRE, 2008).

1.1.3 Concrete actions of Vietnamese Government towards LCD Plan

Being one of non-Annex I Parties, Vietnam is not responsible for reduce the quantitative GHG emissions as defined in the Kyoto Protocol but responsible for implementing some general tasks as other developing countries such as:

- develop National Communication on climate change to United Nations Framework Convention on Climate Change (UNFCCC);
- implement GHG inventory;
- assess the impacts of climate change on socio-economic sectors and identify the areas and sectors that are most affected by climate change, especially sea level rise;
- develop and implement adaptation measures;
- develop and implement mitigation options with financial and technical supports from developed countries and international organizations;

- research and observe climate change;
- update and disseminate related information in order for public awareness raising and capacity building for policy makers on climate change and CDM.

Implement the responsibility of one non-Annex I Party to UNFCCC, The Ministry of Natural Resources and Environment (MONRE) in cooperation with related agencies developed the Second National Communication (Vietnamese MONRE, 2010) which was submitted to the UNFCCC Secretariat in 2010. The Second National has main contents: results of national GHG inventory for the year 2000 and estimation of the GHG emissions for the period 2010-2020-2030; vulnerable assessment, developing climate change mitigation options and adaptation measures based on scenarios in Vietnam in the period 2020-2100; technology transfer; education, training and public awareness raising; integration climate change into sustainable development program and systematic observation and climate change monitoring information, etc.

MONRE was assigned by Vietnamese Government as a National Focal Agency for taking part in and implementing the UNFCCC and Kyoto Protocol. Department of Meteorology Hydrology and Climate Change under MONRE is the Designated National Authority for CDM in Vietnam. Up to May 2008, five CDM projects of Vietnam were registered by CDM Executive Board as CDM projects.

Strategic objectives of the National Target Program (NTP) (Vietnamese MONRE, 2008) are to assess climate change impacts on sectors and regions in specific periods and to develop feasible action plans to effectively respond to climate change in the short-term and long-term to ensure sustainable development of Vietnam, to take opportunities to develop towards a low-carbon economy, and to join the international community's efforts in mitigating climate change and protecting the climatic system. The NTP will be implemented for the whole country in three phases: first phase (2009-2010) is starting up, second phase (2011-2015) is implementation and third phase (after 2015) is development.

1.2 Research objectives and activities

The main objectives of this research are to:

- Propose a methodological framework and its application to support the low carbon policies analysis;
- Analyze the socio-economic implications of LCD in Vietnam by the year 2050.

Figure 1.1 illustrates the relationship between main research objectives and specific methods/tools as well as research activities which are describes in each chapter of this dissertation. Main tools supporting the first objective are: scenario development system, [Asian Integrated Modeling]/ [Computable General Equilibrium_Basic]

(AIM/CGE[basic]) model, and the An Implicitly Directly Additive Demand System (AIDADS) estimation system. Meanwhile, second objective is achieved by analyzing the results from AIM/CGE[basic] model. Literature reviews in Act. 1 and Act. 2 indirectly support the methodology development (Obj. 1 – Act. 3) through providing the rationales and the methodological background for this research, respectively. Furthermore, the review of Vietnamese governmental outlook (Act. 4) provides the background for Obj. 2 including the assumption and description of future societies in Vietnam (Act. 5) and the analysis of results from AIM/CGE[basic] model (Act. 6).

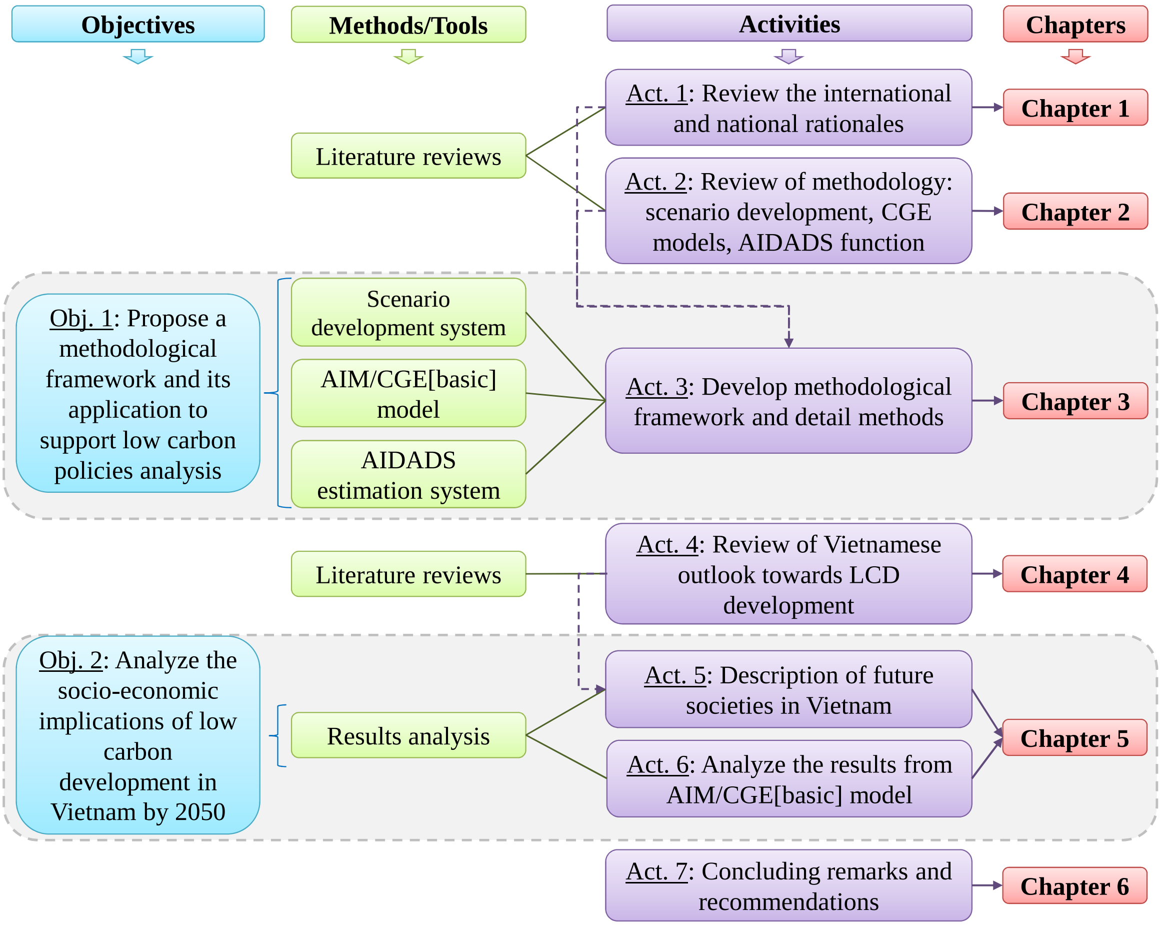

Figure 1.1: Overview of research framework

1.3 Research originalities

The methodology proposed in this dissertation is outstanding from a viewpoint of future scenario development framework towards Low Carbon Development (LCD):

- A standard methodology for the national-based scenario development of Vietnam, and lately can be applicable for other Asian countries.
- An AIM/CGE[basic] model with improved production function (well-disaggregated energy sectors), extended transport and land-use parts, and improved consumption

function (AIDADS). Moreover, Logit function is utilized, in which the share parameters (of energy input technology, energy sources for transport service, energy commodities production and allocation, and energy fuel consumed by household passenger transport) can be modified based on the price elasticity parameters to be assumed for long term simulation that has not yet been available in other CGE models.

In term of research finding, the analysis of historical energy consumption and CO_2 emissions structure provides the background for reliable disaggregated information on relative changes of economic structure, energy structure, and CO_2 emissions. Meanwhile, the national-based scenarios (based on national development targets) are developed to be the main input assumptions for future projections. Therefore, this research analyzes the socio-economic implications of LCD and GHG emissions constraints towards Low Carbon Society (LCS) in Vietnam.

The results of analyzing socio-economic implications of LCD in Vietnam have high contribution in supporting local governments to develop comprehensive low-carbon action plans that promote the adoption and implementation of sustainable energy policies without or with minimum compromising the society and economy.

The future projection which is integrated with national development targets will help to development more reliable and concrete scenarios of future society. This research emphasizes that the resulting scenarios do not represent what is *likely to happen*, rather, *what is feasible* if Vietnamese government is sufficiently motivated and provided with the necessary resources towards LCD.

1.3.1 National-based scenario development for Vietnam

In order to provide the benchmark for the estimation of energy consumption and GHG emissions in Vietnam, the Vietnam national-based scenarios are developed, in term of socio-economic, transportation and infrastructure development. This scenario development process is mainly based on Vietnamese national targets and development plans. However, most of the national targets and plans only provide specific target for pre-2030 years; therefore, other projections from national organizations and research institutes are also taken into account in order to develop scenarios up to 2050.

Output of this national-based scenario development process is the national macroeconomic targets that are used as main input assumptions in AIM/CGE[basic] model for the reference scenario without any climate change mitigation action. When mitigation actions and emission reduction target are considered, the countermeasure scenario is conducted and compared with the reference scenario in order to highlight the socio-economic implications of LCD. Detail of national-based scenario development is described in Section 3.2.1 of Chapter 3.

1.3.2 New application theme of CGE model for Vietnam

According to Devarajan and Robinson (2002), the range of issues on which CGE models have has an influence is quite wide, and includes structural adjustment policies, international trade, public finance, agriculture, income distribution, and energy and environmental policy. These CGE models also capture particular features of the economy, such as some structural rigidities and institutional constraints; as well as provide a consistent framework to assess the linkages and tradeoffs among different policy packages.

However, as reviewed previously, the CGE models are applied for Vietnam mainly in the field of analyzing the effects of trade liberalization and tariff policy on income distribution, welfare and poverty (as summarized in Table 1.1). Instead of climate change and environmental analysis, those studies focus only on the most crucial economic policy of Vietnamese government since the Doi Moi policy in 1986.

Table 1.1: Summary of CGE model applications for Vietnam

Application of CGE models		Static CGE models	Dynamic CGE models
Trade liberalization and tariff policy	on welfare	Chan *et al.* (1998)	Harris *et al.* (2007)
	on labor market	Chan *et al.* (2005)	Doanh and Heo (2009) (improved from Chan *et al.* (2005))
	on income distribution	Dung (2002), Chan and Dung (2002), Huong (2003), Chan and Dung (2006)	Thanh and Toan (2007)
	on poverty	Roland-Holst (2004), Dung and Ezaki (2005), Fujii and Roland-Holst (2007)	Dung (2009) (improved from Dung and Ezaki (2005))
	directly on economic growth and structural change		Nhi and Giesecke (2008)
Overseas remittances	on Vietnamese economy	Thanh (2006)	
Educational investment policy	on wage gape and income distribution	Cloutier *et al.* (2008)	

Even though many types of CGE models have been used to analyze the various policy implications of climate policies on socio-economic of other countries (such as Japan, USA, China, India and so on), none of those have been done for Vietnam and most of developing countries. In Vietnam, the Central Institute for Economic Management (CIEM), under the support of the Department for International Development (DFID) and World Bank, also starts conducting the study into economics of low carbon, however, so far only at scoping phase as reviewed previously.

Therefore, this research contributes to the expansion of CGE model applications, to Vietnam where climate change mitigation policies also have impacts on the society and economy. The AIM/CGE[basic] model is the main tool in this research in order to analyze the socio-economic implications of LCD in Vietnam. Detail of AIM/CGE[basic] model is described in Section 3.2.2 of Chapter 3.

1.3.3 Estimation of AIDADS function and its integration in AIM/CGE[basic] model

Previous studies on the estimation of AIDADS function mainly base on the cross-national data household expenditure namely International Comparison Program (ICP) in the year 1985 with the focus is only on food's commodities. In this research, Global Market Information Database (GMID) (Euromonitor, 2010) is used since it provides detail commodity household expenditure for most of the countries during 1990-2010, with some projections until 2020. Moreover, in estimating the Vietnamese AIDADS's parameters, the Household Living Standard Surveys (HLSSs) (Vietnamese GSO, 2011) are also used in order to closely perform the consumption characteristic of Vietnamese households.

In addition, this research not only focuses on food commodity but also on other industrial and commercial services for the people, in which, energy sector is well-disaggregated for the climate change analysis purpose. As a result, estimated AIDADS parameters based on well-disaggregated commodities form a new consumption function for AIM/CGE[basic] model. Detail of AIDADS consumption function estimation is described in Section 3.2.3 of Chapter 3.

1.4 Structure of this dissertation

This dissertation is structured as follow:

- **Chapter 1** provides the international and Vietnam national rationales leading to the necessity of this research. Section 1.1 not only provides the international framework towards global GHG emissions reduction (subsection 1.1.1) in which the Kyoto Protocol is the background but also the Vietnamese legal frameworks (subsection 1.1.2) in terms of socio-economic development, energy development, environmental protection and climate change mitigation. The subsection 1.1.3 summarizes concrete actions of Vietnamese Government towards LCD Plan. Section 1.2 summarizes the objectives of this research and related activities. Section 1.3 provides the research originalities in both methodology and analytical finding that is explained deeply in Chapter 3. Section 1.4 describes the structure of this dissertation.
- **Chapter 2** summarizes the methodological literature review in which this research stands on. Section 2.1 summarizes previous studies on the national-based scenario development towards LCD in the world. As main tool which is used in this research, it's important to review the previous applications of CGE models for LCD analysis, especially the application of CGE models in Vietnam (Section 2.2). Recently, many economic analysis models are extended for analyzing the LCD; such as model's structure change, disaggregation of energy commodities, and the improvement of consumption function; which are reviewed in Section 2.3.

- **Chapter 3** provides the overview of methodological framework of this research and its detail methods. Section 3.1 provides the overview of methodological framework, in which Scenario Development System is the overarching process controlling the AIM/CGE[basic] model for analysis. Moreover, detail methodology is written in Section 3.2 for: AIM/CGE[basic] country model (subsection 3.2.2), National-based scenarios development process (subsection 3.2.1), and the Estimation of AIDADS consumption function (subsection 3.2.2).
- **Chapter 4** reviews the governmental outlook of Vietnam based on the national development targets and plans. This review is the background for the national-based scenario development conducted in Chapter 5 of this dissertation. In this chapter, "review" does not only mean gathering information of current governmental socio-economic outlook (Section 4.2) but also include back-casting the historical development of Vietnam from the LCD viewpoint (Section 4.1). Moreover, the energy development outlook including the energy pricing system and detail content of latest Vietnam Power Development Plan (PDP7) is reviewed in Section 4.3.
- **Chapter 5** discusses the research results. Section 5.1 describes the vision of future society in Vietnam with a Scenario-for-Low-Carbon-Society (SLCS) and a Scenario-of-rather-STAGnant-Society (SSTAG). Section 5.2 analyzes the economic implications and Vietnamese climate change mitigation measures by 2050. Detail analysis of social implications is described in Section 5.3 while the energy and environmental issues of low carbon development in Vietnam is discussed in Section 5.4.
- **Chapter 6** summarizes main findings of this research through the concluding remarks in Section 6.1 for the characteristic of future society in Vietnam; the implications of low carbon development on social and economic; as well as the energy and environmental issues of low carbon society in Vietnam. Section 6.2 discusses the reliability of the results analyzed in this study and the limitation of the applied methodology, therefore provides suggestion for future direction.

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Chapter 2 METHODOLOGICAL LITERATURE REVIEWS

Chapter 2 summarizes the methodological literature review in which this research stands on.

Section 2.1 summarizes previous studies on the national-based scenario development towards LCD in the world.

As main tool which is used in this research, it's important to review the previous applications of CGE models for LCD analysis, especially the application of CGE models in Vietnam (Section 2.2).

Recently, many economic analysis models are extended for analyzing the LCD; such as model's structure change, disaggregation of energy commodities, and the improvement of consumption function; which are reviewed in Section 2.3.

2.1 National-based LCD studies in the world

2.1.1 World Bank's LCD studies for six emerging economies

In 2008, the World Bank operates a team providing support to countries in Europe and Central Asia on energy, climate mitigation and adaptation (the Energy Sector Management Assistance Program (ESMAP)) for six emerging economies - Brazil, China, India, Indonesia, Mexico and South Africa - that are proactively seeking to identify opportunities and related financial, technical and policy requirements to move towards a low carbon growth path.

The program has been underway for two years and individual country studies have been managed by World Bank operational teams. The governments of these countries have initiated country-specific studies to assess their goals and development priorities, in conjunction with GHG mitigation opportunities, and examine the additional costs and benefits of lower carbon growth. This requires analysis of various development pathways - policy and investment options that contribute to growth and development objectives while moderating increases in GHG emissions.

ESMAP's donors have a strong interest in supporting knowledge exchange and transfer in general and partnering now with the World Bank on how best to develop and support a knowledge program around the Low Carbon Growth Country Study Program. The knowledge generated is broad due to the varied scope and focus of each study that responds to national priorities and spans multiple sectors and issues: land use change and forestry, renewable energy, energy efficiency, transport, policy implementation, financing, macro-economic modeling and capacity building.

Studies confirm opportunities for growth on lower carbon pathways in all six countries and significant GHG emissions reduction potential in: energy efficiency, demand side management, renewable power production, sustainable transport, forestry and cogeneration, among others. Steps are being taken to implement mitigation strategies, but practical problems, capacity limitations, and market and institutional barriers are endemic. Stakeholders spanning multiple sectors of the economy - including the public and private sector, academics and civil society - are central to the study and time spent on engaging key constituents has supported sustainability and a national dialogue on lower carbon development.

Table 2.1 summarizes the main purposes and outputs of ESMAP conducted by the World Bank towards the LCD studies in six emerging economies, including Brazil, India, Indonesia, Mexico, Poland, and South Africa.

Table 2.1: Summary of ESMAP's activities and outputs towards LCD studies

Country	Purpose	Outputs/Reports
Brazil	Assess the potential to lower the carbon content of development; develop a model for land use and land use change; simulate transport sector expansion, project and liquid waste disposal, energy demand and supply; and estimate consistently mitigation potential and associated costs in these four sectors.	1. Brazil Low-carbon Country Case Study - Full Report 2. Brazil Low-carbon Country Case Study - Executive Summary 3. Brazil Low Carbon Country Case Study - Technical Synthesis Report - Waste 4. Brazil Low Carbon Country Case Study - Technical Synthesis Report - Energy
India	Develop analytical to i) help identify low-carbon growth opportunities, up to 2032, in major sectors of the economy; and ii) facilitate informed decision making.	1. Energy Intensive Sectors of the Indian Economy: Path to Low Carbon Development - Briefing Note 006/11. 2. India: Options for Low Carbon Development - Synopsis of a Study by the World Bank for the Government of India 3. Energy Intensive Sectors of the Indian Economy - Path to Low Carbon Development. Full Report. South Asia Region.
Indonesia	Address macro-economic questions of costs and effects of low carbon development on economic growth; offer strategic low carbon options for development.	1. Climate Change & Fiscal Policy Issues: 2009 Initiatives 2. Emissions Reduction Opportunities and Policies - Transport Sector 3. Domestic Fiscal Policy Framework for Climate Finance in Indonesia 4. Low Carbon Development for Indonesia - Status Report and
Mexico	Support a comprehensive mitigation program through the identification and analysis of low-carbon options, policies and strategies	Low Carbon Development for Mexico
Poland	Provide an integrated strategy for GHG mitigation by building on previous work in developing a methodology that integrates detailed "bottom-up" sectoralwork with "top-down" macro-economic modeling.	1. Transition to a Low-Carbon Economy in Poland - Presentation 2. Transition to a Low-Carbon Economy in Poland - ESMAP Briefing Note 009/11
South Africa	Review South Africa's Long-Term Mitigation Scenarios and develop implementation strategies in energy efficiency and other key sectors.	1. Implementing Energy Efficiency and Demand Side Management: South Africa's Standard Offer Mode - ESMAP Briefing Note 007/11 2. Best Practices for Market-Based Power Rationing: Implications for South Africa. ESMAP Briefing Note 008/11

Source: http://www.esmap.org

2.1.2 DIIS's conference on the LCD and poverty reduction in low income countries

The world's low income countries are facing an enormous task in the years to come. Not only are they continuing their uphill battle for economic growth and poverty reduction; they also have to wrestle the global climate changes that are threatening exactly these countries the most. Authorities and organizations in many of the most vulnerable developing countries are increasingly concerned about how to adapt to climate change, protect populations from storms and floods, prevent drastic declines in agricultural output due to drought and water stress, ensure water supplies, tackle health problems, etc. These concerns often push aside any considerations and debate on how the developing countries can contribute to a more carbon neutral world and on how low carbon technologies can contribute to development in these countries.

Recently, however, there has been an increasing interest in “LCD strategies” among developing countries. These interests primarily focus at exploring the opportunities for funding and technology transfer within the global climate change mitigation mechanisms or other similar schemes, but also look at reducing future dependencies on fossil fuels, benefitting from sustainable management of forests and land use, and ensuring “cleaner development” in general. Such efforts would lead to more robust and resilient development and would contribute to global climate change mitigation by avoiding or reducing future GHG emissions from these growing economies.

For low income countries, the challenge is how to address economic development and poverty alleviation while at the same time engaging in climate change adaptation and LCD efforts. In the context of development assistance to low income countries, much emphasis has been placed on adaptation efforts, while the calls for LCD are more recent and less well explored. Moreover, in some regions practical experiences with LCD within the established carbon finance mechanisms are limited and require inspiration and innovation from outside the established frameworks. In particular, the options for combining LCD with direct poverty alleviation need to be better understood in the context of development assistance.

By bringing together a broad range of stakeholders from the private sector, NGOs, researchers and policy makers, the conference provided an opportunity to discuss and exchange experiences on some of the key issues (practical as well as policy related) in addressing LCD in the low income countries. The outputs of the conference feed into a Danida-commissioned study on options and constraints for donor support to LCD in the least developed countries carried out by the Danish Institute for International Studies (DIIS).

2.1.3 ECN’s project on LCD strategies

Energy research Centre of the Netherlands (ECN) conducted a project namely “Paving the way for LCD strategies” (Tilburg *et. al*, 2011). LCD strategies have attracted interest in the climate negotiations as a soft alternative to voluntary or obligatory GHG emissions reduction targets in developing countries. Several developing countries have taken the initiative to embark on the process of drafting an LCD strategy. LCD strategies are usually thought of as happening on the country level, but depending on the size or the situation of the country, provincial or sector-specific LCD strategies are also possible.

Although there is no internationally agreed definition of LCD strategies, in this study ECN focuses on integrated climate and (low-carbon) development government strategies that cover the intersection of development and GHG mitigation. Adaptation issues are included only if they are related to mitigation actions.

The ultimate aim of a LCD strategy is to catalyze concrete actions that support development, but with less emissions than without intervention. To establish this, an LCD strategy can serve different audiences and have different purposes depending on the stakeholder. For governments an LCD strategy can be used to present a long term vision on climate and development and a strategic LCD pathway. It can also be used to establish a policy framework in which policies across different sectors are put in place and aligned. Moreover, governments can use an LCD strategy to increase awareness on climate change with stakeholders and present to them what LCD could mean for each of the stakeholders.

To the private sector, an LCD strategy can identify what is needed to establish a favorable investment climate for LCD actions, and signal to potential investors what the long-term ambitions and priority sectors are, and what interventions, such as regulatory frameworks or policies, the government will undertake to help achieve these ambitions. In addition, an LCD strategy may also have a purpose internationally. It can help identify needs and priorities, and be used to coordinate donor support. In relation to other international climate instruments, an LCD strategy can provide a coherent framework for Nationally Appropriate Mitigation Action (NAMA) priorities and for Measurement, Reporting and Verification (MRV) needs. Lastly, an LCD strategy can function as a reporting platform to international climate change community. Signaling national emissions and expected impacts of climate change can provide insight in global trends on results of existing mitigation actions and prospect of future policies.

Evidence shows that countries differ significantly in terms of development context, possibilities and priorities. As a result of this variation it is ineffective to approach developing an LCD strategy with a generalized template. Therefore, an LCD strategy development process can have different “building blocks”. Although it would not be justified to say that some of the building blocks are optional, the specific (country) context may determine which of the building blocks below are included, and how much they are emphasized.

2.1.4 International research network towards LCS studies in Asian countries

International Research Network for Low Carbon Societies (LCS-RNet) is a global research network aiming for building LCSs in the world. The LCS-RNet involves researchers from various institutions in the world (as listed in Table 2.2). Realizing LCS is an urgent global challenge, the LCS-RNet puts effort on promoting the information exchange and research cooperation that cover various issues relating to LCS, contributing to international policy-making processes on climate change including G8 by providing research outcomes and recommendations.

The basic nature of LCS-RNet is a platform to support and encourage information sharing and voluntary cooperation among research institutions specifically in the field of LCS research. LCS-RNet also facilitates the interaction between researchers and various stakeholders, and delivers their findings to policy-makers to assist science-based policy making in transitioning to low-carbon societies.

Table 2.2: List of research institutes in LCS-RNet

Country	Name of research institutes in LCS-RNet
France	International Research Center on Environmental and Development (CIRED) Academy of Technologies French Environment and Energy Management Agency (ADEME) Institute for Sustainable Development and International Relations (IDDRI)
Germany	Wuppertal Institute for Climate, Environment and Energy
Italy	Euro Mediterranean Centre for Climate Change (CMCC) The Fondazione Eni Enrico Mattei (FEEM) Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
Japan	National Institute for Environmental Studies (NIES) Institute for Global Environmental Strategies (IGES)
Korea	National Institute of Environmental Research (NIER)
United Kingdom	UK Energy Research Centre (UKERC)
India	Indian Institute of Management (IIMA) Indian Council of Agricultural Research (ICAR) Indian Institute of Technology Delhi Indian Institute of Technology Bombay Indian Institute of Tropical Meteorology

Source: http://lcs-rnet.org

2.2 Previous applications of CGE models

2.2.1 Extension and application of CGE models for LCD analysis

CGE models are computer-based simulations of future effects of a specified set of policy changes. In the trade field, CGE models are, as an example, used to gauge the trade, income, and poverty effects of different liberalization scenarios. The CGE models take into account that any policy targeted at one sector or group has indirect economic effects on the rest of the economy. That is, the supply and demand sides of a shock and the mediating effects of markets are analyzed simultaneously. The models capture the effects of linkages through factor and product markets, to household decisions, further on to trading partners, and back again through the factor and product markets.

One main benefit of CGE models is that they offer a consistent economy-wide framework for analyzing trade policy questions. Piermartini and Teh (2005) emphasize that the results of the models vary depending on what goes into the models by way of structure and data. Choices among scenarios and model specifications can imply different results. During the last few decades, the CGE model has been applied to various countries and to the whole world for not only economic analysis but also energy consumption and GHG emissions analysis towards low carbon studies.

2.2.1.1 IMAGE

The Integrated Model to Assess the Global Environment (IMAGE) is a complex modeling framework, consisting of several connected stand-alone software like the TIMER model, the FAIR model, the IMAGE land-atmosphere model. Additional to that, IMAGE also uses results from agro-economic models (Bouwman *et al.*, 2006).

IMAGE is an ecological-environmental framework that simulates the environmental consequences of human activities worldwide. It represents interactions between society, the biosphere and the climate system to assess sustainability issues like climate change, biodiversity and human well-being. The core application of IMAGE is the development and analysis of scenarios of global environmental change. Recently, IMAGE results have played a key role in several global studies, including the IPCC Special Report on Emissions Scenarios (SRES), the United Nations Environmental Program (UNEP) 3rd Global Environment Outlook (GEO-3), the Millennium Ecosystem Assessment (MA), the Second Global Biodiversity Outlook, and the Global Nutrients from Watersheds project of the UNESCO Intergovernmental Oceanographic Committee. At the European level, IMAGE has been involved in the Eururalis study on future prospects for agriculture and the rural areas of the EU-25 countries, and the GHG Reduction Policy (GRP).

The objective of the IMAGE version 2.4 is to explore the long-term dynamics of global change as the result of interacting demographic, technological, economic, social, cultural and political factors. The IMAGE 2.4 shares many of the basic structural components of its predecessors. Assuming change, population and the macro-economy as key drivers, the model establishes physical indicators for both the energy/industry system and the agriculture/land-use system for assessment of changes in land cover, climate, and the carbon and nitrogen cycles.

IMAGE results are also used for the evaluation of climate policies in conjunction with the policy decision-support model FAIR (Framework to Assess International Regimes). FAIR is widely used to assess the environmental and abatement cost implications of international regimes for the differentiation of future emission reductions of GHG. The model links long-term climate targets and global reduction objectives with regional emission allowances and abatement costs, accounting for the Kyoto Mechanisms.

Valuable steps are being taken in the development of IMAGE 2.4 to secure the position of IMAGE as one of the leading frameworks for integrated assessment of global sustainability issues. The further developments initiated within the network of collaborating institutes offer excellent prospects for the future, in which the IMAGE model framework will make an important contribution to the analysis of crucial interactions between human well-being and ecological goods and services.

2.2.1.2 IGEM

The Inter-temporal General Equilibrium Model (IGEM) is a dynamic model of the United Nation (U.S.) economy which describes growth due to capital accumulation, technical change and population change. It is a multi-sector model that tracks changes in the composition of industry output, as well as changes in input mix used by each industry, including energy use (Goettle *et al.*, 2007). It also depicts changes in consumption patterns due to demographic changes, price and income effects. The main driver of economic growth in this model is capital accumulation and technological change. Capital accumulation arises from savings of a household that is modeled as an economic actor with "perfect foresight". Aggregate household consumption and savings are chosen to maximize a utility function that is a discounted sum of the stream of future consumption. Within each period, the consumption- or demand- side of the model is driven by a detailed model of household demand that includes demographic characteristics.

The production- or supply- side of the model characterizes the industrial structure in detail. 35 industries are identified, of which 21 are manufacturing and 5 are energy-related. Each industry produces output using capital, labor, energy and non-energy intermediate inputs using constant returns to scale technology. The production technology used changes over time due to both exogenously specified changes and endogenous changes from price effects. Coal, refined oil and gas are separately identified energy inputs. The output from domestic industries is supplemented by imports from the rest of the world to form the total supply of each commodity.

This model is implemented econometrically, by which is meant that the parameters governing the behavior of producers and consumers are statistically estimated over a time series dataset that is constructed specifically for this purpose. This is in contrast to many other multi-sector models that are calibrated to the economy of one particular year. These data are based on a system of national accounts that integrates the capital accounts with the National Income Accounts. These capital accounts include an equation linking the price of investment goods to the stream of future rental flows, a link that is essential to modeling the dynamics of growth.

To capture differences among households, the household sector is subdivided into demographic groups including region of residence. Each household is treated as a consuming unit, i.e. it is the unit maximizing some utility function over all commodities in IGEM, including leisure. As currently specified, demographic differences in IGEM are limited to the allocation of commodity consumption. These differences do not enter the allocation of time between work and leisure nor do they enter the allocation of income between consumption and saving. IGEM's household model thus has three stages. At the first stage, lifetime income is allocated to consumption and saving in each period. This consumption consists of commodities and leisure and is referred to as "full consumption". In the second stage, full consumption is allocated to total goods and services and leisure. In the third stage, total goods and services are allocated to IGEM's various energy and non-energy commodities. This third stage is actually a series of stages and is where the detailed demographic information appears.

2.2.1.3 ADAGE

Applied Dynamic Analysis of the Global Economy (ADAGE) is a dynamic CGE model capable of examining many types of economic, energy, environmental, climate change mitigation, and trade policies at the international, national, U.S. regional, and U.S. state levels (Ross, 2008). To investigate proposed policy effects, the CGE model combines a consistent theoretical structure with economic data covering all interactions among businesses and households.

The ADAGE model can be used to investigate climate-change mitigation policy issues affecting six types of GHG at a range of geographic scales. To investigate implications of policies, the ADAGE model combines a consistent theoretical structure with observed economic data covering all interactions among businesses and households. These economic linkages include firms purchasing material inputs from other businesses and factors of production (labor, capital, and natural resources) from households to produce goods, households receiving income from factor sales and buying goods from firms, and trade flows among regions. Nested Constant Elasticity of Substitution (CES) equations are used to characterize firm and household behaviors (which are intended to maximize profits and welfare, respectively), as well as options for technological improvements.

ADAGE uses a classical Arrow-Debreu general equilibrium framework to describe these features of the economy. Households are assumed to have perfect foresight and maximize their welfare (received from consumption of goods and leisure time) subject to budget constraints across all years in the model horizon, while firms maximize profits subject to technology constraints.

To investigate policy effects, the CGE model combines a consistent theoretical structure with economic data covering all interactions among businesses and households. A classical Arrow-Debreu general equilibrium framework is used to describe economic behaviors of these agents. Households are assumed to have perfect foresight and maximize their welfare (received from consumption of goods and leisure time) subject to budget constraints across all years in the model horizon, while firms maximize profits subject to technology constraints. Economic data in ADAGE come from the Global Trade Analysis Project 2 (GTAP2) and IMpact analysis for PLANing 3 (IMPLAN3) databases, and energy data and various growth forecasts come from the International Energy Agency (IEA) and Energy Information Administration (EIA) of the U.S. Department of Energy.

ADAGE incorporates four sources of economic growth: (1) growth in the available effective labor supply from population growth and changes in labor productivity, (2) capital accumulation through savings and investment, (3) increases in stocks of natural resources, and (4) technological change from improvements in manufacturing and energy efficiency. By means of these factors, a baseline growth forecast is established for ADAGE using IEA and EIA forecasts for economic growth, industrial output, energy consumption and prices, and GHG emissions. Starting from the year 2010, ADAGE normally solves in 5-year time intervals along these forecast paths, which are extended into the future as necessary for each policy investigation.

2.2.1.4 ENVISAGE

The ENVironmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) model (Mensbrugghe, 2008) is designed to analyze a variety of issues related to the economics of climate change, such as: Baseline emissions of CO_2 and other GHG; Impacts of climate change on the economy; Adaptation by economic agents to climate change; GHG mitigation policies - taxes, caps and trade; The role of land use in future emissions and mitigation; and The distributional consequences of climate change impacts, adaptation and mitigation - at both the national and household level.

ENVISAGE is intended to be flexible in terms of its dimensions. The core database - that includes energy volumes and CO_2 emissions - is the GTAP database, currently version 7.0 with a 2004 as base-year. The latter divides the world into 113 countries and regions, of which 95 are countries and the other region-based aggregations. The database divides global production into 57 sectors - with extensive details for agriculture and food and energy (coal mining, crude oil production, natural gas production, refined oil, electricity, and distributed natural gas). This current version of ENVISAGE model includes the following:

- Capital vintage production technology that permits analysis of the flexibility of economies;
- A detailed specification of energy demand in each economy, with additions yet to come (see below);
- The ability to introduce future alternative energy (or backstop) technologies;
- CO_2 emissions that are fuel and demand specific;
- A flexible system for incorporating any combination of carbon taxes, emission caps and tradable permits;
- A simplified climate module that links GHG emissions to atmospheric concentrations combined with a carbon cycle that leads to radiative forcing and temperature changes.

The structure of ENVISAGE model includes: production block (Constant Elasticity of Substitution - CES function), income block (through tax mechanism), demand block (expenditure and final demand for goods and services); fuels block (of electricity, coal, gas, and oil); trade block (Armington nests, export supply, homogeneous traded goods, domestic supply, international trade and transport services). Moreover, there are equilibriums of production market, factor market, and macro closure. As extended for the study of climate mitigation, ENVISAGE model has a climate module which includes the emissions; concentration, forcing and temperature; emission taxes, caps and trade.

Besides, the model dynamics is driven by three factors - similar to most neo-classical growth models. Population and labor force growth rates are exogenous and given essentially by the UN Population Division scenario. The labor force growth rate is equated to the growth rate of the working age population (15-64 years old). The second factor is capital accumulation and the third factor is productivity.

The model contains four different possible demand systems for determining household demand for goods and services:

- Constant Differences in Elasticities (CDE) - largely derived from the GTAP model
- Extended Linear Expenditure System (ELES)
- Linear Expenditure System (LES)
- An Implicitly Directly Additive Demand System (AIDADS) - an extension of the LES that allows for more plausible Engel behavior.

2.2.1.5 GCAM

The Global Change Assessment Model (GCAM) is a partial equilibrium model of the world with 14 regions. GCAM operates in five-year time steps from 1990 to 2095 and is designed to examine long-term changes in the coupled energy, agriculture/land use, and climate system. GCAM includes a 151-region agriculture land-use module and a reduced form carbon cycle and climate module in addition to its incorporation of demographics, resources, energy production and consumption. The model has been used extensively in a number of assessment and modeling activities such as the Energy Modeling Forum (EMF), the U.S. Climate Change Technology Program, and the U.S. Climate Change Science Program and Intergovernmental Panel on Climate Change (IPCC) assessment reports (Kim, 2010).

The GCAM is a global integrated assessment model with particular emphasis on the representation of human earth systems including interactions between the global economic, energy, agricultural, land use and technology systems. Previously known as MiniCAM, this model traces its origins to the Edmonds and Reilly model. Over time the model has developed and evolved through a series of advances documented in a variety of papers. The GCAM physical atmosphere and climate are represented by the Model for the Assessment of GHG Induced Climate Change (MAGICC).

The GCAM is global in scope and disaggregated into 14 geopolitical regions, explicitly linked through international trade in energy commodities, agricultural and forest products, and other goods such as emissions permits. It is a dynamic-recursive market equilibrium model. The scale of human activities is determined by the interaction between labor force, determined by work-aged population, labor participation and unemployment rate assumptions and the price of energy services. An important feature of the GCAM architecture is that the GCAM terrestrial carbon cycle model is embedded within the agriculture-land-use system model.

The energy system model produces and transforms energy for use in three end-use sectors: buildings, industry and transport. Production is limited by resource availability, which varies by region. Fossil fuel and uranium resources are finite and depletable. Wind, solar, hydro, and geothermal resources are renewable. Bioenergy is also renewable, but is treated as an explicit product of the agriculture-land-use portion of the model. Resources are disaggregated by region and by grade of the resource. Extraction costs rise as the resource is depleted, fall with technological change for extraction technologies, and can rise or fall depending on other environmental costs.

Primary energy can be transformed into other energy forms. These transformations are performed in energy transformation sectors and together provide a suite of final energy forms for consumption by end-use sectors: buildings, industry and transport. These sectors in turn have multiple technology options with which to transform final energy forms into energy services. For example residential buildings demand heating, cooling, lighting, hot water, appliance and other services. These services can be provided by technologies that employ various end-use fuels: coal, liquids, natural gas, electricity, bioenergy, or hydrogen.

GCAM also tracks waste streams and treats the storage of nuclear waste and captured CO_2 explicitly. CO_2 storage reservoirs are disaggregated by region, type and grade. Similarly nuclear waste storage represents a potential limit on cumulative deployment and reactor choice.

2.2.1.6 IMACLIM

The computation of long term economic pathways and the assessment of sustainable development policies require models able to embark information and expectations from economists, engineers, earth scientists and stakeholders. International Research Center on Environmental and Development (CIRED) has drawn the architecture of modeling IMpact Assessment of CLIMate policies (IMACLIM) in order to cope with this scientific challenge at the interface of environment and development issues, in particular to assess climatic and energy policies. It relies on a hybrid model which combines a macroeconomic approach with sectional-engineers views, in which IMACLIM-R is a recursive version (Cassen *et al.*, 2010).

As a policy-oriented model, IMACLIM-R aims at facilitating the dialog between economists, engineers and decision-makers. As a scientific tool, it tries to reinforce the consistency of long-term scenarios, by including the main feedbacks between technology deployment, macroeconomic conditions, and the behavior of agents with bounded rationality. In its current state of development, the model now deserves a comparison with other simulation tools to assess how its alternative features modify the evaluation of development, climate and energy policies.

IMACLIM-R projects the economy as series of annual static equilibrium whose evolution is guided by demographic trends. 12 detailed sectional modules (electricity, transport, fossil fuels, residential, etc.) applied in 12 regions are connected to the input-output model of the static version. IMACLIM-R is used to make long term evolution of energetic systems scenarios and assess GHG emissions reduction.

IMACLIM-R is a multi-sector multi-region dynamic recursive growth model (12 sectors and 12 regions). It provides a macroeconomic framework which analyses the relations between the economy and energy sectors. It represents interactions between sectors and regions through the equilibrium of goods market and simulates the economic impact of changes which occur in the energy sector both in the macroeconomic level (change in welfare, gains or losses of competitiveness) and the microeconomic level (weight of energy in the structure of production costs or in households expenditures).

IMACLIM-R is able to produce long-term scenarios of the world economy evolution. But these scenarios are highly uncertain as they depend on unknown exogenous trends (e.g., future population) and poorly understood mechanisms (e.g., penetration of new technology through investment). To get a better understanding of this uncertainty, IMACLIM-R computes a large number of scenarios from the combination of hypotheses on selected exogenous parameters. These hypotheses are derived from expert's judgment and represent possible values for the parameters.

Decisions for large scale technological projects like the EV (Electric Vehicle), the nuclear power or the bioenergy have to be made in a context of radical uncertainty. The approach selected in this study tries and avoids both the traps of the "best guess" or "most likely" scenarios, which come to an illusory reduction of uncertainty and the symmetric trap of defining somewhat arbitrary "storylines" amongst the many possible ones.

2.2.1.7 LINKAGE

The Organization for Economic Cooperation and Development (OECD) ENV-Linkages General Equilibrium (GE) model is the successor to the OECD GREEN model for environmental studies, which was initially developed by the OECD Economics Department and is now hosted at the OECD Environment Directorate. It was developed into the LINKAGE model. A version of LINKAGE model is also currently in use at the World Bank (Mensbrugghe, 2011) for research in global economic development issues.

The LINKAGE Model is a global dynamic CGE model with a 2004 as base-year. In its standard version, it is a neo-classical model with both factor and goods market clearing. It features three production archetypes - crops, livestock, and other, a full range of tax instruments, price markups, multiple labor skills, vintage capital, and energy as an input combined with capital. Trade is modeled using nested Armington and production transformation structures to determine bilateral trade flows. Tariffs are fully bilateral and the model captures international trade and transportation costs - both direct and indirect (using iceberg trade costs). The current version of the model also implements Tariff Rate Quotas (TRQs). A recursive framework is used to drive dynamics, with savings-led investment and productivity. The model incorporates adjustment costs in capital markets and trade-responsive endogenous productivity.

In production block, all sectors are assumed to operate under cost optimization. By default all production takes place under constant returns to scale but the model allows for increasing returns to scale using fixed production costs. The latter are represented by some fixed combination of capital and labor. Marginal costs are modeled by a series of nested CES production functions, which are intended to represent the different substitution and complementarity relations across the various inputs in each sector.

In consumption block and the closure rule, all income generated by economic activity is assumed to be distributed to consumers. A single representative consumer allocates optimally his/her disposable income among the consumer goods and saving. Government collects income taxes, indirect taxes on intermediate and final consumption, production taxes, tariffs, and export taxes/subsidies. Aggregate government expenditures are linked to changes in real GDP. The real government deficit is exogenous. Closure therefore implies that some fiscal instrument is endogenous in order to achieve a given government deficit.

The world trade block is based on a set of regional bilateral flows. The basic assumption in LINKAGE model is that imports originating in different regions are imperfect substitutes. Therefore in each region, total import demand for each good is allocated across trading partners according to the relationship between their export prices. The LINKAGE model is fully homogeneous in prices, i.e. only relative prices are solved for. The price of a single good, or of a basket of goods, is arbitrarily chosen as the anchor to the price system.

The LINKAGE model has a simple recursive dynamic structure as agents are assumed to be myopic and to base their decisions on static expectations about prices and quantities. Dynamics in LINKAGE originate from three sources: (i) accumulation of productive capital; (ii) the putty/semi-putty specification of technology; and (iii) productivity changes.

Similar to ENVISAGE model, LINKAGE model also utilizes four different possible demand systems for determining household demand for goods and services, which are CDE, ELES, LES, and AIDADS.

2.2.2 Application of CGE models in Vietnam

2.2.2.1 Static CGE models

One of the first applications of CGE model for Vietnam is the evaluation of tax reform (Chan *et al.*, 1998). Co-authors and he focus on aggregate welfare impacts as well as welfare of household groups ranked by income, with the base data is in year 1995. Later on, Chan and other researchers develop more assessment of trade liberalization, focusing on the implications of different labor market adjustment formulations (Chan *et al.*, 2005). The data set of year 1997 was used for 5 different adjustment cost treatments that provide similar results as in Chan *et al.* (1998).

Dung (2002) uses neoclassical CGE model with base-year data 1996 to assess the impacts of unilateral trade liberalization at both macro and sectoral levels and examine the role of complementary policies. In later work of Chan and Dung (2002), they develop a CGE model named VNT01, using base-year 1996, to evaluate the efficiency and distributional effects of trade liberalization and tariff policy in Vietnam. The VNT01 remains a standard small-open-price-taking economic model with more disaggregated model structure than author's previous researches.

In order to analyze more about the impact of trade liberalization, particularly on household welfare, Chan and Dung (2006) develop additional simulations to make clearer the transmission mechanisms linking tariff policy to income distribution and household welfare. Beside, Huong (2003) uses CGE model with 1996 base-year data to quantify the income distribution impacts of a tariff reduction of up to 5% follows the common WTO commitments. This is also a static model in which macroeconomic closure is taken into account and trade accounts as well as household savings rate are fixed exogenously. The author examined the impact of tariff reduction in association with government policy alternatives that are indirect taxation and external borrowing.

Recently, more and more researches using CGE models to analyze the effects of economic policies on poverty. One of them is a new approach to micro-macro CGE modeling developed by Roland-Holst (2004), using 2000 base-year data, that better captures rural sector production/consumption and its linkages to regional, national and international markets. Lately, an integrated micro-simulation-CGE model with the small area estimation is used to evaluate the spatial incidence of Vietnam's accession to the World Trade Organization (WTO) (Fujii and Roland-Holst, 2007). Besides the Social Accounting Matrix (SAM) of 2000 used previously, the authors also combine the microeconomic data, population and housing census, and a compilation of geographic variables.

The other application of CGE model in analyzing poverty is to examine the impacts of the ongoing regional economic integration on Vietnam's economy, focusing on growth, poverty reductions and income distribution (Dung and Ezaki, 2005). Another first attempt is the application of CGE model to investigate the effects of the overseas remittances on the Vietnamese economy as a whole (Thanh, 2006).

A very newly application of CGE model is for investigating the interactions between educational investment policy with wage gap and income distribution (Cloutier *et al.*, 2008). This is static CGE model using data year 2000 to fully integrate household's education decisions and labor skill acquisition.

2.2.2.2 Dynamic CGE models

As reviewed above, most of mentioned CGE models are static that do not provide growth and accumulation effects. Therefore, Harris *et al.* (2007) employ a multi-sector, multi-region dynamic CGE model obtaining mostly international data such as GTAP, Asian Development Bank (ADB), United Nation (UN) to simulate 2 scenarios: (1) bilateral liberalization between Association of South East Asian Nations (ASEAN) and Vietnam and (2) unilateral liberalization in Vietnam.

Previous studies show contradict results between Huong (2003) and Chan and Dung (2002 and 2006), respectively, about the narrowing or increase of poverty gap due to trade liberalization. As a result, another multi-sector and multi-household small-open-price-taking economic dynamic CGE model is developed by Thanh and Toan (2007), using base-year 2000, to evaluate the effect of trade liberalization on income distribution among household groups. The results of this study support the later research group when showing that trade liberalization will enhance the economic growth and national welfare while widening the income gap between rural and urban areas, and among each group themselves.

One of few research focuses directly on investigating the economic growth and structural change by using CGE model is Nhi and Giesecke (2008). The authors impose neoclassical structure on these features of Vietnam by undertaking a detailed historical and decomposition simulation with a multi-sectoral dynamic CGE model. Since Vietnam is more and more integrated in the regional economy, it is crucial to assess the impacts of regional economic integration on its economy. Dung (2009) conducts a dynamic simulation analysis based on a global CGE model developed by Dung and Ezaki (2005).

A CGE model for Vietnam (Chan *et al.*, 2005) is updated into a single-country model that follows standard assumptions, including perfect competition, constant returns to scale, small-price taking country assumption about the import price, and national product differentiation in traded goods (Doanh and Heo, 2009). The aim of this study is to analyze the impacts of Vietnam's WTO commitments in reducing tariffs, as well as changes in Vietnam's domestic taxes on the its economy. Similar to previous studies (Fujii and Roland-Holst, 2007), this study shows that Vietnam would benefit from the tariff reductions illustrated by increase in GDP, export and import, in accompany with a distributional effect due to the change in factor prices, domestic demand and the consumption pattern. As a consequence, it leads to the increase in inequality in Vietnam.

Lately in March 2011, Vietnam's CIEM conducted a "Study into the Economics of Low Carbon, Climate-Resilient Development in Vietnam" (CEIM, 2011). The study was prepared with support from the United Kingdom DFID and the World Bank. Even determining that CGE model is the main tool for this study together with some bottom-up models, this study has just started the scoping phase. Main objectives of the scoping phase are: i) to collate and evaluate available data as well as required data for the study; ii) to review the proposed methodology and tools/models and their relevance; iii) to assess the existing capacity of Vietnam researchers for further training if needed; iv) and to identify and consult with key stakeholder groups on the work scope, its phasing and key steps for engagement. The scoping phase is supposed to be implemented within one year before the input studies phase and main study phases are implemented.

2.3 Improvement of consumption function in CGE model for LCD analysis

Most of CGE models use the LES function (in which the marginal budget shares are constant) for final demand which satisfies the regularity conditions but not the Engel-flexibility which performs change of expenditure share once income changes. The simulation results from Yu *et al.* (2000 and 2002) show that for regions with rapid income growth, the LES over-predicts growth in private demand, import, and output growth requirement for food products and under-predicts that for non-food products.

In order to best describe the demand behavior in real world, the demand system function must satisfy both regularity conditions (adding-up, symmetry, homogeneity, and negativity) and the Engel-flexibility (declining budget shares for food as income rises). In order to track historical behavior and predict future changes of food consumption patterns, Engel properties and regularity of these demand systems are the two important considerations, with the latter ensuring that the extrapolating of these systems with large income shocks would not lead to negative budget shares.

Meyer *et al.* (2011) compared several popular demand systems in estimating elasticities, including LES *(Linear Expenditure System)*, BTL *(Basic Translog)*, AIDS *(Almost Ideal Demand System)*, QES *(Quadratic Expenditure System)*, QUAIDS *(Quadratic Almost Ideal Demand System)*, and AIDADS *(An implicitly, directly additive demand System)*. In overall, AIDADS model (invented by Rimmer and Powell (1996) and simplified for empirical applications by Cranfield *et al.* (2000)) has shown the best performance, especially in simulating income elasticity. AIDADS generalizes the LES by assuming marginal budget shares vary with utility and hence with expenditure.

The AIDADS expenditure function is non-negative, continuous, homogenous of degree one in prices, non-decreasing in prices, and concave in prices. And the expenditure function is non-decreasing inutility under certain condition. The Engel elasticities will in general vary non-linearly with respect to income changes. Although as real income grows indefinitely all Engel elasticities will converge to unity, it should be noted that these asymptotes are not approached monotonically. This is a very important point that distinguishes AIDADS from the widely used LES.

Yu *et al.* (2000) examine how the newly developed AIDADS demand system is estimated, calibrated and how the AIDADS system and its econometrically estimated income elasticities are incorporated into the standard GTAP model. A demand side experiment with the modified GTAP model is conducted using different demand specification (LES, CD and AIDADS) to illustrate where the AIDADS functional form makes a substantial difference, and where it does not. The simulation results show that for regions with rapid income growth, the LES over-predicted growth in private demand, import and output growth requirement for food products and under-predicts that for non-food products. On the other hand, for high-income regions with smaller income growth, model results based on calibrated LES produces similar results to the model with AIDADS.

Recently, some CGE models, such as ENVISAGE and LINKAGE, started to utilize the AIDADS function as default consumption function. However, most of the AIDADS estimation uses data from the International Comparison Project (ICP) for cross-country dataset in 1985.

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Chapter 3 RESEARCH METHODOLOGY

Detail of the methodology including the scenario development process, CGE model and extension of its consumption function is described in Chapter 3.

Section 3.1 provides the overview of methodological framework, in which Scenario Development System is the overarching process controlling the AIM/CGE[basic] model for analysis.

Moreover, detail methodology is written in Section 3.2 for: AIM/CGE[basic] country model (subsection 3.2.2), National-based scenarios development process (subsection 3.2.1), and the Estimation of AIDADS consumption function (subsection 3.2.2).

3.1 Outline of methodological framework

Figure 3.1 shows the overview of methodological framework in assessing the socio-economic implications of national LCD policies.

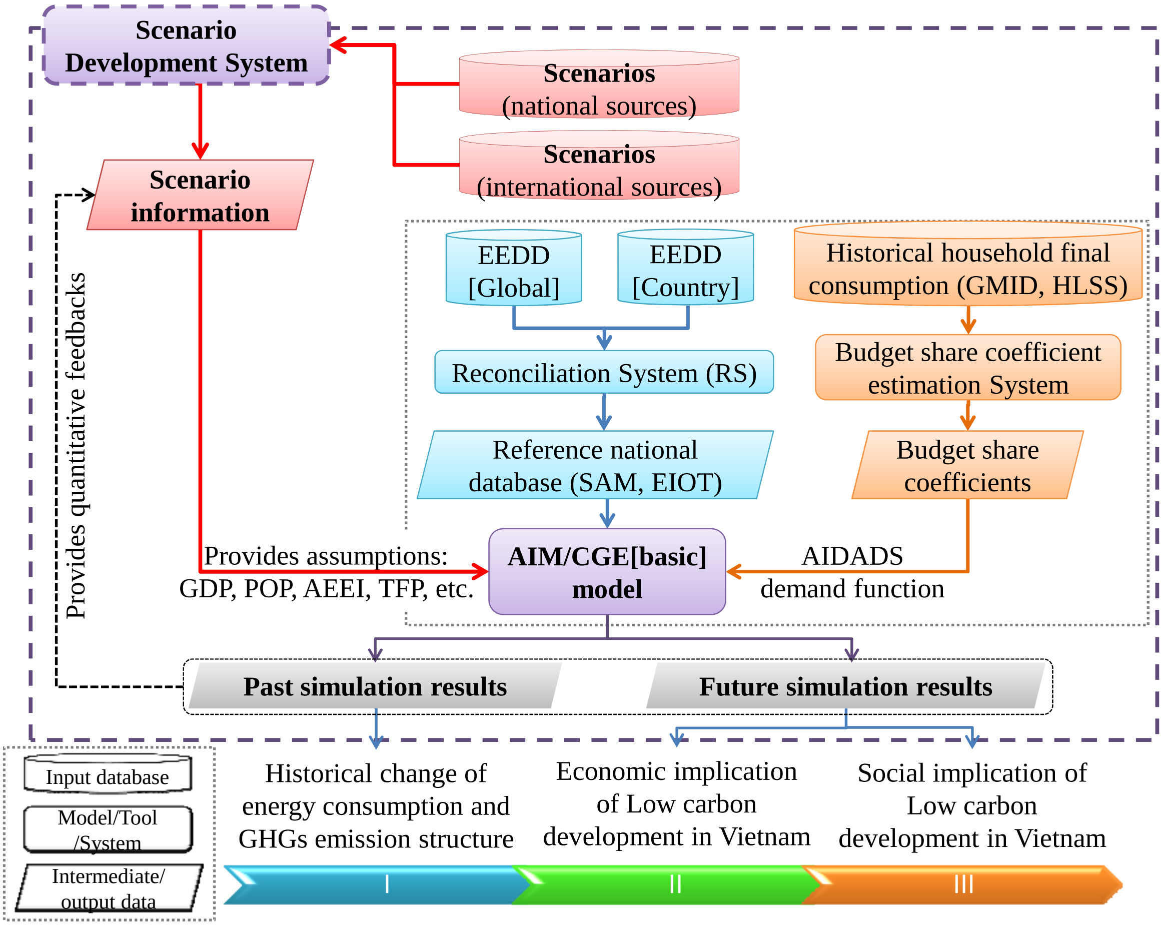


Figure 3.1: Overview of methodological framework

According to Figure 3.1, the Scenario Development is an overarching process, in which CGE model is the main tool supporting the analysis:

- Firstly, the scenario information from international and national sources is collected for various years up to 2050. These scenarios are used as input in the Scenario Database Development (Tran *et al.*, 2010) in order to provide complemented national-based scenario information. This scenario information provides assumption for the AIM/CGE[basic] model (such as GDP and population growth, Autonomous Energy Efficiency Improvement (AEEI), Total Factor Productivity (TFP), etc.). These assumptions are used in AIM/CGE[basic] model in order to simulate future socio-economic indicators, energy consumption and GHG emissions. Quantitative outputs from AIM/CGE[basic] model are sent back to the scenario information conducted previously to support the detail description of future LCD society and evaluate the socio-economic implications of national climate change mitigation policies. The method of conducting the scenario database is described in Section 3.2.1 of Chapter 3 while the detail future scenario description is written in Section 5.1 of Chapter 5.
- Secondly, within the AIM/CGE[basic] model framework, the global and country Energy Economic Driver Database (EEDD) are collected as input for the Reconciliation System (RS) (Fujimori *et al.*, 2010a) in order to produce the reference national database such as Social Accounting Matrix (SAM) and Energy Input-Output Table (EIOT). The purpose of the RS is to harmonize inconsistent statistical information of a nation, especially developing countries whose SAM and EIOT are not published officially or lacking. These SAM and EIOT are used as input into AIM/CGE[basic] model (Fujimori *et al.*, 2010b) in order to produce the past simulation results. The purpose of this activity is to assess the feasibility of the model when comparing the results with national statistics information. After the AIM/CGE[basic] model has been assessed as feasible, the results of year 2005 are chosen as base-year to support the future simulation. Detail description of AIM/CGE[basic] model is written in Section 3.2.2 of Chapter 3. The results of past simulation activity are written in Section 4.1 as part of the review of Vietnamese outlook towards LCD (Chapter 4).
- Since AIDADS has been set as default consumption function in many CGE models (such as LINKAGE, ENVISAGE, etc.), it is important for AIM/CGE[basic] model to have similar improvement. Therefore, in second step, the household consumption function in AIM/CGE[basic] model is changed from LES to AIDADS. The AIDADS's parameters are calibrated using historical household consumption survey (Global Market Information Database - GMID and Household Living Standards Surveys - HLSSs) in order to estimate the budget share coefficient for

AIM/CGE[basic] model. This modification supports the analytical purpose in which household consumption behavior will be changed once their income is increased, especially in the context of climate change mitigation. The method of estimating AIDADS function is described in Section 3.2.3 of Chapter 3. Detail analyses of implications due to climate change mitigation policies on socio-economic, energy and environmental issues are written in Sections 5.2, 5.3, 5.4, respectively.

3.2 Detail methodology

This section describes the scenario development system firstly because it is the overarching process that controls the analysis using AIM/CGE[basic] model. The AIM/CGE[basic] model is described lately since it is the main tool for this research. The supplements of the model including its database and function improvement are described in latter subsections.

The GAMS (General Algebraic Modeling System) is a high-level modeling system for mathematical programming and optimization. It consists of a language compiler and a stable of integrated high-performance solvers. GAMS language is tailored for complex and large scale modeling applications. GAMS programming is used for the calculation and simulation throughout this research.

3.2.1 National-based scenario database development

3.2.1.1 Overview

In supporting research on the socio-economic implication of energy and climate change mitigation policies, future scenarios are needed. Currently, most of the developing countries, especially in Southeast Asia, do not have specific targets for energy development and reducing the GHG emissions rather than putting their main focus on economic growth. However, under natural constraints, especially energy resources, these countries should develop their own pathways in order to achieve socio-economic targets without compromising the environment and scarce natural resources. This activity provides the methodology to develop the platform of socio-economic and energy scenarios that includes two main steps. Firstly, the controversial parameters such as GDP and population (POP) are developed to be scale indices. Lately, the scale-based linear complement uses these scale indices to estimate the full-trend scenario for other parameters.

This study provides the social, economic, and energy platform for researchers and policy-makers in analyzing the implication of socio-economic development, energy consumption as well as the possible CO_2 emissions, towards achieving LCD. Similarly to Vietnam, other developing countries may also face the lack of an energy database problem. Therefore, this study can be improved and expanded to those countries, especially in the Asian Pacific region.

This process (as described in Figure 3.2) briefly draws the image of future society in Vietnam.

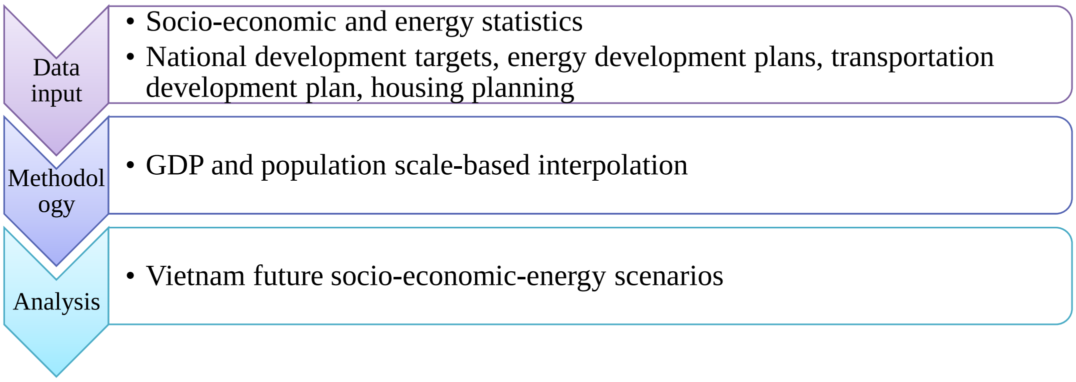


Figure 3.2: Overview of National-based Scenario Development

3.2.1.2 Description

The purpose of this process is to develop the national reference scenario information as background for the assumption of future societies to be analyzed by AIM/CGE[basic] model (as explained previously in Figure 3.1). Moreover, the simulation results from AIM/CGE[basic] model support the quantitative feedbacks to the scenario information for the future society (as descripted later in Chapter 5).

Figure 3.3 shows the structure of this process. The general process of reference development for future socio-economic and energy simulation of Asian countries is mainly based on the data from national government. The process of developing the national reference scenario information includes two main steps: database compilation and scenario complement.

Currently, a simple scenario complement method named scale-based interpolation is applied. In current scenario complement method, the scale-based interpolation is used in which determining the scale (driver) for each parameter is quite difficult. For each specific country, the potential drivers of each detailed parameter might be different from other countries, depends on the socio-economic and energy development targets or an economy they want to achieve.

Database is compiled from: (1) collected national statistics for historical data and from (2) reports of various organizations, both national and international to gain national future socioeconomic and energy/power development targets. These scatter scenarios are complemented for 50 years annually until 2050 by using scale-based interpolation.

Table 3.1 shows the list of macro parameters along with their potential drivers. In this table, we assume that the POP (scenarios developed by UN) puts influence on related indicators of population, employment, transport demand, and housing/building demand. Therefore, POP is used as scale index to estimate these parameters. Meanwhile, GDP is assumed as driver of gross domestic product, import, and export. Each country might have different national targets of GDP growth rate achievement. Thus, this GDP (from GDP growth rate) is be used as scale index to estimate these parameters. In case of energy and energy consumption demand, these parameters are affected by both GDP and POP. Therefore, the GDP-per-capita (GDPCAP) is used as scale for estimating these parameters.

The most difficult part of choosing driving force is for energy potential and electricity generation. These parameters are not affected by either POP or GDP rather than rely mainly on the natural resource ability of a nation. As a result, we assume that these parameters are estimated based on the energy and power development plans of that country. Therefore, the quantitative results from AIM/CGE[basic] model can support the projection of future energy consumption and GHG emissions according to socio-economic development and other technological conditions.

Table 3.1: List of macro parameters and potential drivers

General parameter	Driver	Source
Population	POP	United Nations
Labor	POP	United Nations
GDP	GDP	National GDP growthrate targets or CIESIN
Import	GDP	National GDP growthrate targets or CIESIN
Export	GDP	National GDP growthrate targets or CIESIN
Transport demand	POP	United Nations
Housing demand	POP	United Nations
Energy consumption	GDPCAP	However, it may also depends on the technology efficiency
Energy reservation		National Energy development plan
Electricity		National Energy development plan

Note: These assumptions are acceptable as long as we can find a reliable rationale in order to be able to explain for the results. (CIESIN = Center for International Earth Science Information Network)

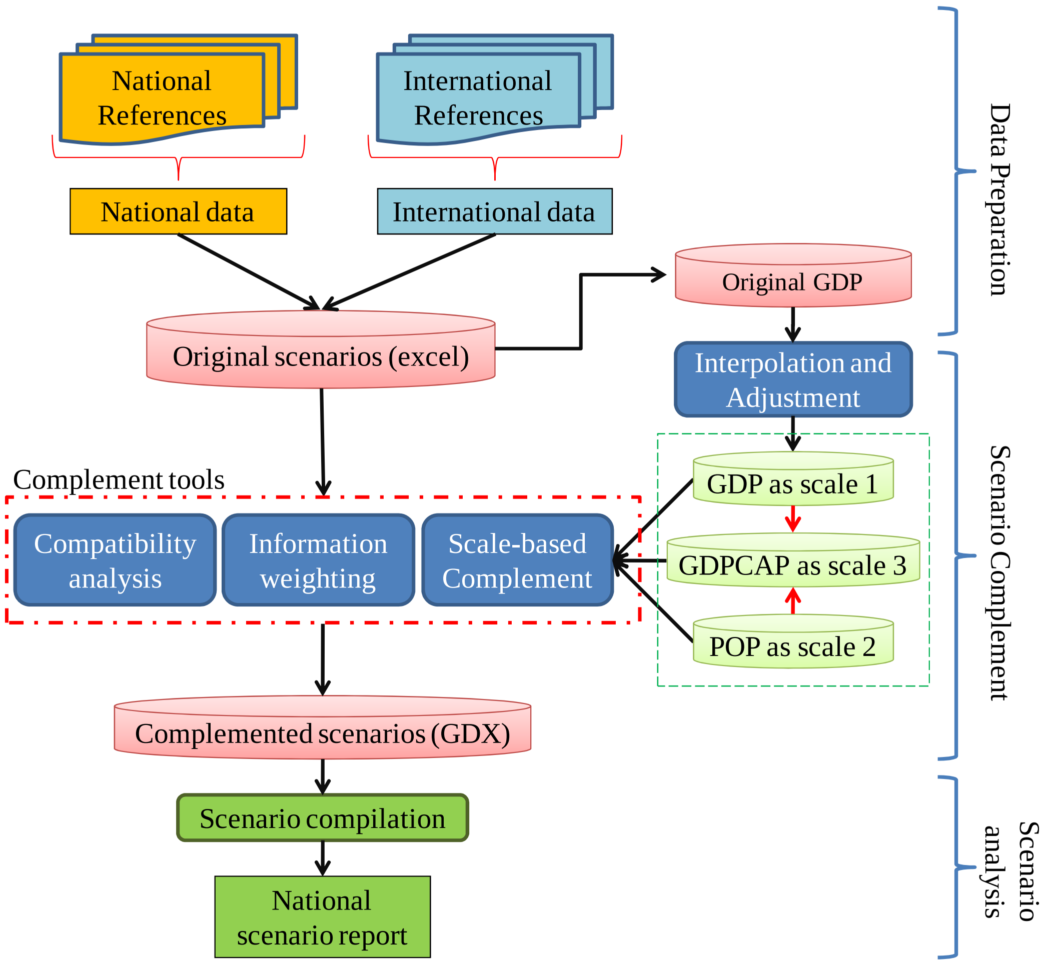


Figure 3.3: Structure of National-based Scenario Development

This process has two main steps: (1) database preparation and (2) scenario complement and compilation. Database is compiled from *(1) collected national statistics for historical data* (for years t_s = 2000 to 2009) and from *(2) reports of various organizations, both national and international* (for years after 2009); to gain national future socioeconomic and energy/power development targets. These scatter scenarios are complemented for 50 years annually until 2050.

The collected scenario information is classified into 2 main fields that are Driver and Energy (as listed in Table 3.2 and Table 3.3, respectively). In Driver field (Table 3.2) indicators such as employment, household size, urbanization, housing demand, transportation demand, and resource reservation are mainly driven by POP; even GDP is also a strong driving force. Meanwhile, economic indicators such as economic value added, export and import are only controlled by GDP.

Table 3.2: List of collected indicators in Driver field

Definition	Parameter	Sub-parameter	Category	Parameter code	Category code	Unit	Scale
Total population	SOC	POP	TPOP	SOC_POP	CA_SOC_TPOP	1000P	POP
Urban rate	SOC	URB	UBR	SOC_URB	CA_SOC_UBR	R	POP
Urban household size	SOC	HOU	SHSU	SOC_HOU	CA_SOC_SHSU	N	POP
Rural household size	SOC	HOU	SHSR	SOC_HOU	CA_SOC_SHSR	N	POP
Total number of household	SOC	HOU	NHS	SOC_HOU	CA_SOC_NHS	1000H	POP
Total employment	SOC	EMP	TOT	SOC_EMP	CA_SOC_TOT	1000P	POP
Urban employment	SOC	EMP	UBN	SOC_EMP	CA_SOC_UBN	1000P	POP
Rural employment	SOC	EMP	RRL	SOC_EMP	CA_SOC_RRL	1000P	POP
Employment in Agriculture and Fishery and Forestry sector	SOC	EMP	AGR	SOC_EMP	CA_SOC_AGR	1000P	POP
Employment Industry sector	SOC	EMP	IND	SOC_EMP	CA_SOC_IND	1000P	POP
Employment Service sector	SOC	EMP	SER	SOC_EMP	CA_SOC_SER	1000P	POP
Total GDP	ECO	MEI	GDP	ECO_MEI	CA_ECO_GDP	US2005D	GDP
Agriculture and Fishery and Forestry value added	ECO	MEI	AGR	ECO_MEI	CA_ECO_AGR	US2005D	GDP
Industry value added	ECO	MEI	IND	ECO_MEI	CA_ECO_IND	US2005D	GDP
Service value added	ECO	MEI	SER	ECO_MEI	CA_ECO_SER	US2005D	GDP
Import	ECO	IMP	IMP	ECO_IMP	CA_ECO_IMP	US2005D	GDP
Export	ECO	EXP	EXP	ECO_EXP	CA_ECO_EXP	US2005D	GDP
Road _Passenger transportation volume (passsenger)	TRS	PS	RD	TRS_PS	CA_TRS_RD	1000PS	POP
Road_Passenger transportation volume (passenger-km)	TRS	PK	RD	TRS_PK	CA_TRS_RD	MPK	POP
Road_Freight transportaion volume (tonne)	TRS	TN	RD	TRS_TN	CA_TRS_RD	1000T	POP
Road_Freight transportaion volume (tonne-km)	TRS	TK	RD	TRS_TK	CA_TRS_RD	MTK	POP
Passenger car , Vehicle in use	TRS	ST	PC	TRS_ST	CA_TRS_PC	1000N	POP
Bike , Vehicle in use	TRS	ST	BK	TRS_ST	CA_TRS_BK	1000N	POP
Rail_Passenger transportation volume (passsenger)	TRS	PS	RL	TRS_PS	CA_TRS_RL	1000PS	POP
Rail_Passenger transportation volume (passenger-km)	TRS	PK	RL	TRS_PK	CA_TRS_RL	MPK	POP
Rail_Fright transportaion volume (tonne)	TRS	TN	RL	TRS_TN	CA_TRS_RL	1000T	POP
Rail_Freight transportaion volume (tonne-km)	TRS	TK	RL	TRS_TK	CA_TRS_RL	MTK	POP
Aviation_Passenger transportation volume (passsenger)	TRS	PS	AR	TRS_PS	CA_TRS_AR	1000PS	POP
Aviation_Passenger transportation volume (passenger-km)	TRS	PK	AR	TRS_PK	CA_TRS_AR	MPK	POP
Aviation_Freight transportaion volume (tonne)	TRS	TN	AR	TRS_TN	CA_TRS_AR	1000T	POP
Aviation_Freight transportaion volume (tonne-km)	TRS	TK	AR	TRS_TK	CA_TRS_AR	MTK	POP
Aviation (the number of passenger) , transportation capacity	TRS	CAP	ARPS	TRS_CAP	CA_TRS_ARPS	1000PS	POP
Aviation (the volume of freight) , transportation capacity	TRS	CAP	ARTN	TRS_CAP	CA_TRS_ARTN	1000T	POP
Ship_Passenger transportation volume (passsenger)	TRS	PS	NV	TRS_PS	CA_TRS_NV	1000PS	POP
Ship_Passenger transportation volume (passenger-km)	TRS	PK	NV	TRS_PK	CA_TRS_NV	MPK	POP
Ship_Fright transportaion volume (tonne)	TRS	TN	NV	TRS_TN	CA_TRS_NV	1000T	POP
Ship_Freight transportaion volume (tonne-km)	TRS	TK	NV	TRS_TK	CA_TRS_NV	MTK	POP
Urban area (the size of urban part) , urban rate	SOC	URB	ARU	SOC_URB	CA_SOC_ARU	HA	POP
Total Dwellings , Floor per person	SOC	FLP	DWE	SOC_FLP	CA_SOC_DWE	m2	POP
Coal_Reservation	IND	RSV	COL	IND_RSV	CA_IND_COL	1000T	POP
Rude oil_Reservation	IND	RSV	CRU	IND_RSV	CA_IND_CRU	1000T	POP
Natural gas_Reservation	IND	RSV	NGS	IND_RSV	CA_IND_NGS	M3	POP
Biomass_Reservation	IND	RSV	BIO	IND_RSV	CA_IND_BIO	1000T	POP
Hydro energy_Reservation	IND	RSV	HYD	IND_RSV	CA_IND_HYD	KW	POP
Wind energy_Reservation	IND	RSV	WIN	IND_RSV	CA_IND_WIN	KW	POP
Geothermal energy_Reservation	IND	RSV	GEO	IND_RSV	CA_IND_GEO	KW	POP
Photocoltaic energy_Reservation	IND	RSV	SPV	IND_RSV	CA_IND_SPV	KW	POP
Total_Reservation	IND	RSV	TOT	IND_RSV	CA_IND_TOT	KTOE	POP
Total except biomass_Reservation	IND	RSV	TAC	IND_RSV	CA_IND_TAC	KTOE	POP

As mentioned earlier, GDPCAP is the driving force of energy consumption (by energy type and by sector) as well as the power generation and its import (if any) (as shown in Table 3.3).

Table 3.3: List of collected indicators in Energy field

Definition	Energy flow	Energy product	Final code	Scale	Unit
Total Final Consumption	TFC	TOT	TFC_TOT	GDPCAP	KTOE
Total Final Consumption (without biomass)	TFC	TAC	TFC_TAC	GDPCAP	KTOE
Total energy consumption of Agriculture, Forestry and Fisheries sector	TAG	TOT	TAG_TOT	GDPCAP	KTOE
Total energy consumption of total Industry	TIN	TOT	TIN_TOT	GDPCAP	KTOE
Total energy consumption of Transportation sector	TTR	TOT	TTR_TOT	GDPCAP	KTOE
Total energy consumption of Commercial and Public Services	SER	TOT	SER_TOT	GDPCAP	KTOE
Total energy consumption of Residential	RSD	TOT	RSD_TOT	GDPCAP	KTOE
Total Final Consumption of Coal	TFC	COL	TFC_COL	GDPCAP	KTOE
Total Final Consumption of Oil Product	TFC	OIL	TFC_OIL	GDPCAP	KTOE
Total Final Consumption of Natural Gas	TFC	NGS	TFC_NGS	GDPCAP	KTOE
Total Final Consumption of Electricity	TFC	ELY	TFC_ELY	GDPCAP	KTOE
Total Final Consumption of Biomass	TFC	TBI	TFC_TBI	GDPCAP	KTOE
Total output of electricity from All Energy Sources	TOE	TOT	TOE_TOT	GDPCAP	KTOE
Total output of electricity from Hydro	TOE	HYD	TOE_HYD	GDPCAP	KTOE
Total output of electricity from Coal	TOE	COL	TOE_COL	GDPCAP	KTOE
Total output of electricity from Renewable energy	TOE	RNE	TOE_RNE	GDPCAP	KTOE
Total output of electricity from Gas Diesel Oil	TOE	OLD	TOE_OLD	GDPCAP	KTOE
Total output of electricity from Nuclear	TOE	NUC	TOE_NUC	GDPCAP	KTOE
Import of Electricity	IMP	ELY	IMP_ELY	GDPCAP	KTOE

3.2.1.3 Data input

The data input for national-based scenario database development are the socio-economic and energy statistics (up to 2009) and the national development targets for the future. As a country develops based on the economic condition, GDP and POP are chosen as scale for the interpolation of other indicators.

There are not so many references from national government providing data for future socioeconomic and energy scenarios, so we don’t have much choice to consider, rather than combining data from available sources (from Office of Prime Minister, Ministry of Industry and Trade, Ministry of Planning and Investment, Institute of Energy, Hanoi University of Technology, etc.).

3.2.1.4 Main mathematical equations

Equations SC_1, SC_2, SC_6, and SC_7 are for the scale-based interpolation while the other equations are for the adjustment of target parameters based on the interpolated results. For the historical years (pre-2010), the value is adjusted into statistical data. All the codes of parameters for scenarios development are exactly the same with EEDD, therefore they can be fully referred in the EEDD manual.

(a) Scale index preparation (POP, GDP, GDPCAP)

- *Interpolation of scale index:*

Scale ratio:

$$Xo_t = \frac{GDP\_org_t}{POP_t} \qquad \text{(SC\_1)}$$

Where:

t	: a year which does not have value in the reference
Xo	: ratio of target scenario and scale index
GDP_org	: original GDP scenario (described in the reference)
POP	: population scenario (from UN prospects)

Interpolated scale ratio:

$$Xo\_itp_t = Xo_{tmax}^{\frac{t-tmin}{tmax-tmin}} \cdot Xo_{tmin}^{\frac{tmax-t}{tmax-tmin}} \qquad , tmin < t < tmax \qquad \text{(SC\_2)}$$

Where:

$tmax$	: a year which has value in the reference, bigger than the year t, and the closest to the year t
$tmin$	: a year which has value in the reference, smaller than the year t, and the closest to the year t
Xo_itp	: interpolated Xo

- *Adjustment of scale index:*

Reference scale ratio:

$$Xref_{tref} = \frac{GDP\_ref_{tref}}{POP_{tref}} \qquad \text{(SC\_3)}$$

Where:

$tref$	: observed year
$Xref$	: ratio of observed GDP and population
GDP_ref	: observed GDP data

Adjusted scale ratio and completed GDP:

$$X_t = Xref_{tref} \cdot \frac{Xo\_itp_t \cdot POP_t}{Xo\_itp_{tref} \cdot POP_{tref}} \cdot \frac{Xref_{tref} \cdot POP_{tref}}{Xref_{tref} \cdot POP_t} \qquad \text{(SC\_4)}$$

$$GDP\_comp_t = X_t \cdot POP_t \qquad \text{(SC\_5)}$$

Where:

X	: adjusted Xo
GDP_comp	: complemented GDP scenario

(b) Scenario complement

- *Interpolation of targeted scenario:*

$$Xo_t = \frac{TGT\_org_t}{SCL_t} \qquad \text{(SC\_6)}$$

Where:

TGT_org : original target scenario

SCL : scale index (GDP, POP, GDPCAP)

$$Xo\_itp_t = Xo_{tmax}{}^{\frac{t-tmin}{tmax-tmin}} \cdot Xo_{tmin}{}^{\frac{tmax-t}{tmax-tmin}} \quad , tmin < t < tmax \qquad \text{(SC\_2)}$$

- *Adjustment of targeted scenario:*

$$Xref_{tref} = \frac{TGT\_ref_{tref}}{SCL_{tref}} \qquad \text{(SC\_7)}$$

Where: TGT_ref : observed target parameter data

$$X_t = Xref_{tref} \cdot \frac{Xo\_itp_t \cdot SCL_t}{Xo\_itp_{tref} \cdot SCL_{tref}} \cdot \frac{Xref_{tref} \cdot SCL_{tref}}{Xref_{tref} \cdot SCL_t} \qquad \text{(SC\_8)}$$

Convert into target parameter (TGT)

$$TGT\_comp_t = X_t \cdot SCL_t \qquad \text{(SC\_9)}$$

Where: TGT_comp : complemented target scenario

3.2.2 AIM/CGE[basic] model

3.2.2.1 Overview

The data input for AIM/CGE[basic] model are SAM and EIOT of the base-year 2005 resulted from Reconciliation System (detail is described in Appendix E). This AIM/CGE[basic] model is the extension from standard CGE model (Lofgren *et al.*, 2002), into dynamic model in terms of capital stock, energy capacity, as well as GHG emissions constraint. Moreover, the production function and consumption function are also improved. The transport and land-use sectors are also integrated in this model. Therefore, this model is used to analyze the future socio-economic implications of climate change mitigation measures and the energy as well as environmental issues in Vietnam by 2050 (as shown in Figure 3.4).

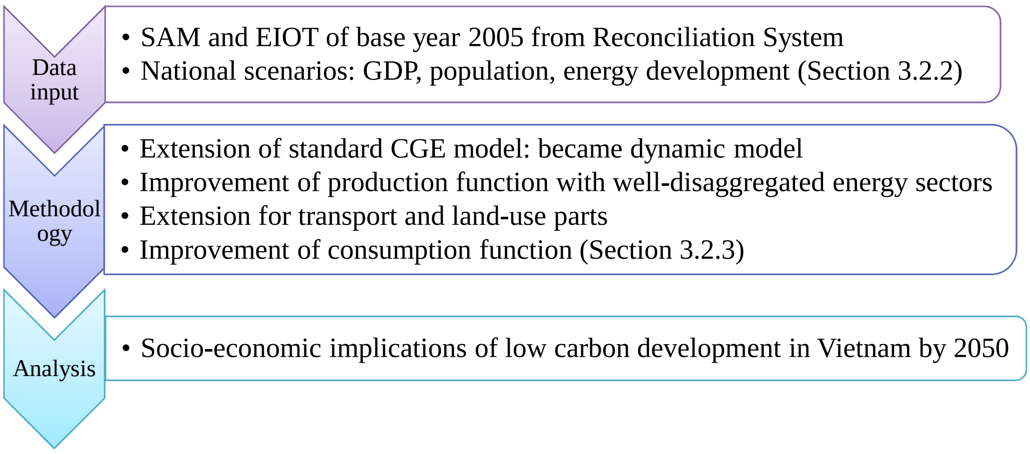


Figure 3.4: Overview of AIM/CGE[basic] model

3.2.2.2 Description

The CGE model is used for the analysis of global and country CO_2 emissions, mitigation costs or carbon taxes. This AIM/CGE[basic] model is rebuilt from the standard CGE model (Lofgren *et al.*, 2002). The model explains all of the payments recorded in the SAM and energy flows in that economy. It therefore covers: (1) activity production and factor markets, (2) institutions (households, enterprises, government, and the rest of the world), (3) commodity market (domestic outputs and imports), (4) macroeconomic balances (government balance, external balance, and savings-investment balance), (5) energy commodities, and (6) air pollutants and GHG emissions.

The model is written as a set of simultaneous equations, many of them are nonlinear. There is no objective function. The equations define the behavior of the different actors. In part, this behavior follows simple rules captured by fixed coefficients (for example, ad valorem tax rates). There are four blocks (as shown in Figure 3.5): production, income distribution, final consumption, and market. The first block, production, represents the structure of the production functions. We apply a nested CES function for production activities with multiple nested CES functions. Secondly, incomes are distributed to three institutional sectors: enterprises, government, and households. The government takes in income by collecting taxes. Thirdly, institutions consume goods as final consumption. Government expenditure and capital formation are defined as a constant coefficient function. The LES or AIDADS function is used for household consumption. Lastly, the CES function is applied to the import of goods and the CET (Constant Elasticity of Transformation) function is applied to the export of goods. A goods-consumption-and-supply equilibrium is achieved for each market.

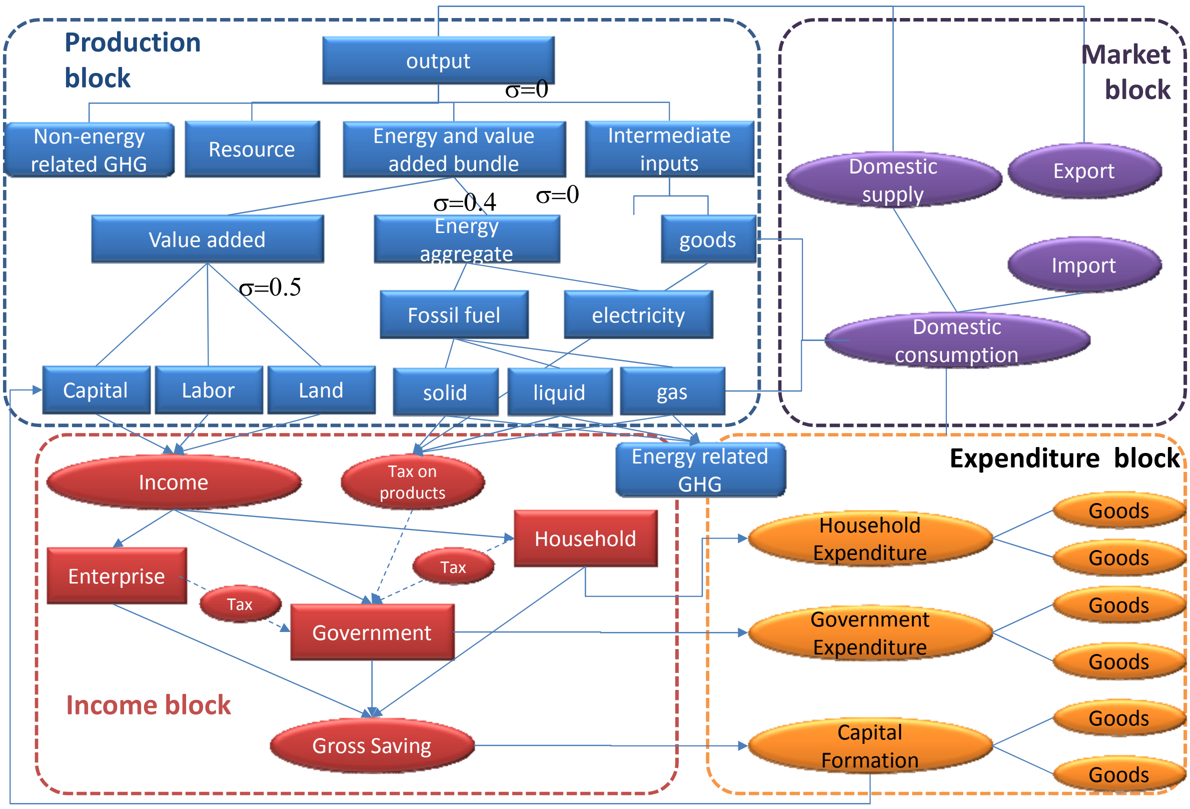


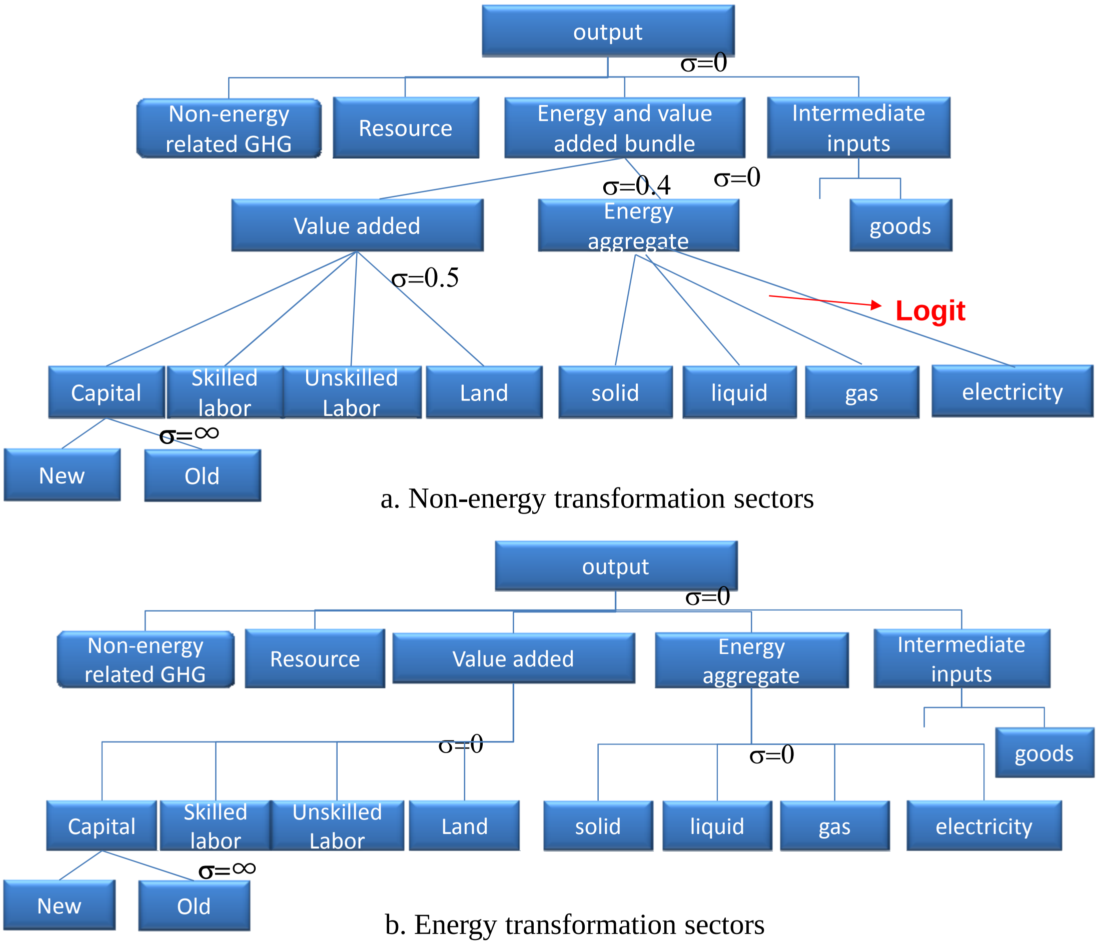
Figure 3.5: Overall structure of AIM/CGE[basic] model

For production and consumption decisions, behavior is captured by nonlinear, first-order optimality conditions - that is, production and consumption decisions are driven by the maximization of profits and utility, respectively. The equations also include a set of constraints that have to be satisfied by the system as a whole but are not necessarily considered by any individual actor. These constraints cover markets (for factors and commodities) and macroeconomic aggregates (balances for Savings - Investment, the government, and the current account of the rest of the world).

➢ Activity production

Each producer (represented by an activity) is assumed to maximize profits, defined as the difference between revenue earned and the cost of factors and intermediate inputs. Profits are maximized subject to a production technology of which the structure is shown in Figure 3.6.

At the top level, there are non-energy related GHG emissions and conventional inputs. This GHG emissions treatment is described in detailed by Hyman (Hyman *et. al*, 2003). Conventional inputs technology is specified by a Leontief function of the quantities of energy and value-added bundle, aggregate non-energy intermediate input and resource input. Energy and value added bundle is nested by valued added and energy inputs. Value added is itself a CES function of primary factors. The aggregated energy inputs is specified by a Logit function of electricity and aggregated fossil fuel inputs. The aggregate intermediate input is a Leontief function of disaggregated intermediate inputs.



a. Non-energy transformation sectors

b. Energy transformation sectors

Figure 3.6: Production structure in AIM/CGE[basic] model

The energy transformation sectors such as power and petroleum refinery sectors are assumed to be different production functions from the other sectors. The structure is drawn as below. Value added aggregation and energy inputs are specified by Leontief. Moreover, the consumption function in AIM/CGE[basic] model can be switched between LES and AIDADS function as some CGE models (ENVISAGE, LINKAGE) already applied.

In AIM/CGE[basic] model, the share of imported and domestic consumption is determined by the ratio of the current price to previous year's price. The share of exported and domestic consumption, and the share of the same commodity production are determined as well as the import composition. The share is controlled by the ratio of previous year's and calculation year price with an elasticity parameter. For example, if import price is increased over that of domestic products, the share of import commodity would be decreased.

Another extension of the AIM/CGE[basic] model is the inclusion of air pollutants and GHG emissions module. The emission gases treated in this model are CO, NH_3, NMVOC, NO_x, SO_2, BC, OC, CO_2, CH_4 and N_2O; with main focus on CO_2, CH_4 and N_2O. The emission sources are classified into two groups. (1) One is related to fuel combustion and this kind of emissions is proportional to the energy consumption. (2) The other is related to the activity level, e.g. CO_2 emissions from cement production, and this kind of emissions is proportional to the activity level. In addition, biomass consumption is also introduced in this model to estimate the air pollutants.

The originality of AIM/CGE[basic] model compared to other current CGE models is the utilization of Logit function, in which the share parameters (of energy input technology, energy sources for transport service, energy commodities production and allocation, and energy fuel consumed by household passenger transport) can be modified, based on the price elasticity parameters to be assumed for long term simulation. Moreover, the transport module with detail energy mix is also another improved point of AIM/CGE[basic] model

3.2.2.3 Data input

The SAM and EIOT of base-year 2005 are obtained from the reconciled SAM developed by Fujimori and Matsuoka (2008, 2009a, and 2009b). This SAM contains all production and consumption of commodities and services, income, savings and investment for a region with the energy and GHG emissions are in physical volume.

In AIM/CGE[basic] model, CCS technology is considered as one of the effective mitigation options. However, since CCS is still in the experiment stage for most countries including Vietnam, we do not have specific information about the future cost of CCS in Vietnam. Therefore, in this study, the price of CCS technology is borrowed from IEA (2008) (as shown in Table 3.4). This CCS technology cost is kept to be constant in all simulated period.

Table 3.4: CCS technology cost

Sectors		Price (US2005$/tCO$_2$)
Manufacturing	Petroleum refinery and coal transformation	100
	Non-metal and mineral	200
	Paper and pulp	150
	Chemical	150
Power	Coal fired (EC_COL)	50
	Oil fired (EC_OIL)	70
	Gas fired (EC_GAS)	70
	Biomass fired (EC_BIO)	70

Souce: IEA (2008)

The main input assumptions for future simulation are listed in Table 3.5. The actual value of these indicators is assumed depending on the imagination of future society in Vietnam, which is descripted in Section 5.1 of Chapter 5.

Table 3.5: Indicators of input assumption for AIM/CGE[basic] model

Group	Indicator
Socio-economic and technology change	GDP growth rate Population growth rate Input coefficient change (mainly for material) Price elasticity for power source selection Input coefficient for freight transport demand Income elasticity for passenger transport demand Price elasticity for transport energy demand Price elasticity for transport fuel selection Price elasticity for industry fuel selection Income and price elasticities for household energy demand Price elasticity for household fuel selection
Energy and environment	Energy efficient change CCS technology availability Availability of emission trading permit and amount of permission Power generation by energy mix

Table 3.6 shows the list of GHG emissions reduction measures that are analyzed in this research. The unit reduction potential of each measure is based on bottom-up model (Akashi *et al*., 2011).

Table 3.6: Description of GHG emissions reduction measures

Series	Definition
Non-energy GHG	Non-energy related emission reduction
Landuse	Reduction of land-use change related emission
Enduse_activity_level	Enduse sector's activity level change factor (normally GDP loss)
Enduse_structure	Enduse sector's structure change factor (industrial shift)
Enduse_efficiecy	Enduse sector's energy intensity improvement factor
Enduse_fuel_switch	Enduse sector's fuel switch factor
Electricity_demand	Electricity generation change factor
Electricity_efficiency	Electricity conversion effiiency mainly due to fired power plants transformation efficiency improvement
Renewable	Renewable energy share change factor
Nuclear	Nuclear energy share change factor
CCS	Carbon Capture and Storage technology deployment
Import	Emission trading (amount of import)
Export	Emission trading (amount of export)
Emission	Actual amount of emission

3.2.2.4 Main mathematical equations

Currently, the AIM/CGE[basic] model used in this research is exactly the same with what has been developed in AIM/CGE[basic] manual (Fujimori *et al.*, 2010). Therefore, all the equations and mathematical summary statements are referred from the AIM/CGE[basic] manual (Appendix C).

Basically, the equations are grouped into standard model equations and dynamic part. The first group includes (1) Price block, (2) Production block, (3) Institution block, (4) International trade block, (5) System constraint block, (6) Activity constraint block, (7) Traditional biomass consumption as fuel combustion; and (8) Air pollutants and GHG emissions. Most of the equations are modified based on Lofgren *et al.* (2002), except the equations in blocks (7) and (8) are brand new parts in this model.

The second group is for the extension of the standard model into dynamic one. Therefore, it includes equations for (1) Capital, Labor, (2) TFP (Total Factor Productivity), and (3) AEEI (Autonomous Energy Efficiency Improvement).

The section below only described main equations of (a) basic features, (b) transport module, (c) household energy consumption, (d) the utilization of Logit function, (e) GHG emissions and reduction measures, and (f) dynamic features as they are originally developed in this AIM/CGE[basic] model.

(a) Basic features

The basic features of AIM/CGE[basic] model is represented by main equations of each model's block, including pricing, production, institution, system constraint, and activity constraint.

- *Commodity market monetary balance* (equation CGE_1): The balance of domestic market is described in term of intermediate consumption, household consumption, government consumption, and investment and savings.

$$PQ_{r,c} \cdot QQ_{r,c} = PQD_{r,c} \cdot \begin{pmatrix} \sum_{a \in A} pfdq_{r,c,a} \cdot QINT_{r,c,a} + \sum_{h \in H} pfdq_{r,c,h} \cdot QH_{r,c,h} \\ + pfdq_{r,c,"gov"} \cdot QG_{r,c} + pfdq_{r,c,"S-I"} \cdot QINV_{r,c} \end{pmatrix} \quad , \forall r \in R, c \in CX \qquad \text{(CGE\_1)}$$

Where:

$a \in A$	: a set of activities
$c \in C$	: a set of commodities
$PQ_{r,c}$	: composite (supply) commodity price excluding sales tax
$QQ_{r,c}$	: quantity of goods supplied to domestic market (composite supply)
$PQD_{r,c}$	: composite (demand) commodity price excluding sales tax

$pfdq_{r,c,ac}$: price differences of commodity price among inputs sectors

$QINT_{r,c,a}$: quantity of commodity *c* as intermediate input to activity *a*

$QH_{r,c,h}$: quantity of consumption of marketed commodity *c* for household *h*

$QG_{r,c}$: government consumption demand for commodity

$QINV_{r,c}$: quantity of fixed investment demand for commodity

- *Activity revenue and costs (non-energy transformation sector)* (equations CGE_2 and CGE_3): Activity cost is different between the energy transformation sector and non-energy transformation sector. The difference is energy and value added treatment. For each activity, total revenue net of taxes is fully exhausted by payments for value-added and intermediate inputs. If we had GHG emissions constraints, each activity is levied on to its GHG emissions. The GHG emissions cost related to biomass burning is represented as $GHGCA\_NENE_{r,a}$. The GHG emissions cost related to energy consumption is included in energy cost. Moreover, sometimes activity level is constrained by political decisions; for example, nuclear power plant construction is not determined only by economic rationality. In such cases, a rent is absorbed by the activity as *VRENCAP*. The emission reduction counter measures for CCS technology cost is *QRED*.

$$PA_{r,a} \cdot \left(1 - ta_{r,a}\right) \cdot QA_{r,a} = PVAE_{r,a} \cdot QVAE_{r,a} + PINTA_{r,a} \cdot QINTA_{r,a} + PRES_{r,a} \cdot QRES_{r,a} + GHGCA\_NENE_{r,a} + VRENCAP_{r,a} \cdot QA_{r,a} + \sum_{emcm \in EMCM} QRED_{r,emcm,a} \quad , \forall r \in R, a \in ACES \qquad \text{(CGE\_2)}$$

Where:

$a \in ACES \left(\subset A\right)$: a set for non-energy transformation

$emcm \in EMCM$: a set of emission reduction counter measures (CCS)

$PA_{r,a}$: activity price (gross revenue per activity unit)

$QA_{r,a}$: quantity (level) of activity

$ta_{r,a}$: tax rate for activity

$PVAE_{r,a}$: price of (aggregate) energy and value-added bundle (non-energy transformation sector)

$QVAE_{r,a}$: quantity of (aggregate) energy and value-added bundle (non-energy transformation sector)

$PINTA_{r,a}$: aggregate intermediate input price for activity *a*

$QINTA_{r,a}$: quantity of aggregate intermediate input

$PRES_{r,a}$: price of resource input

$QRES_{r,a}$: quantity of resource input

$GHGCA\_NENE_{r,a}$: GHG emissions cost related to biomass burning and CCS negative emissions of activity *a* in region *r*

$VRENCAP_{r,a}$: rent of electricity capacity activity *a* in region *r*

$QRED_{r,emcm,a}$: input of emission reduction counter measures of activity *a* and measure *emcm*

- *Activity revenue and costs (energy transformation sector)* (equation CGE_3):

$$PA_{r,a} \cdot \left(1 - ta_{r,a}\right) \cdot QA_{r,a} = PVA_{r,a} \cdot QVA_{r,a} + PINTA_{r,a} \cdot QINTA_{r,a} + PENE_{r,a} \cdot QENE_{r,a} \quad \text{(CGE\_3)}$$
$$+ PRES_{r,a} \cdot QRES_{r,a} + GHGCA\_NENE_{r,a} + VRENCAP_{r,a} \cdot QA_{r,a} \sum_{emcm \in EMCM} QRED_{r,emcm,a}$$
$$, \forall r \in R, a \in ALEO$$

Where:

$a \in ALEO\left(\subset A\right)$: a set for energy transformation

$PVA_{r,a}$: price of (aggregate) value-added

$QVA_{r,a}$: quantity of (aggregate) value-added

$PENE_{r,a}$: price of (aggregate) energy input

$QENE_{r,a}$: quantity of (aggregate) energy input

- *Capital aggregation and operation ratio* (equations CGE_4 and CGE_5): Capital vintage is taken into account and the old and new capitals are aggregated. Equation CGE_4 represents quantity of operated capital *"ccap"* is sum of new and old capital quantity. The old capital has operation rate $COPR_{r,a}$. The $COPR_{r,a}$ works only if the rate of return of a sector is less than country average rate of return. In other word the sector does not require any new capital (equation CGE_5).

$$QF_{r,"ccap",a} = QF_{r,"ncap",a} + QF_{r,"cap",a} \cdot COPR_{r,a} \quad \text{(CGE\_4)}$$
$$= QF_{r,"ncap",a} + QF_{r,"cap",a} \cdot \left(\frac{WF_{r,"cap"} \cdot WFDIST_{r,"cap",a}}{WF_{r,"ncap"} \cdot WFDIST_{r,"ncap",a}} \right)^{\varsigma_{r,a}} \quad , \forall r \in R, a \in A$$

$$WF_{r,"ncap"} \cdot WFDIST_{r,"ncap",a} \geq WF_{r,"cap"} \cdot WFDIST_{r,"cap",a} \perp QF_{r,"ncap",a} \geq 0 \quad , \forall r \in R, a \in A \quad \text{(CGE\_5)}$$

Where:

$f \in FCAP\left(= F\right)$: a set of capital (new and old; *"ncap"* and *"cap"*)

$QF_{r,f,a}$: quantity demand of factor *f* from activity *a*

$COPR_{r,a}$: operation ratio

$WF_{r,f}$: average price of factor *f*

$WFDIST_{r,f,a}$: factor price distortion factor for factor *f* in activity *a*

$\varsigma_{r,a}$: a parameter for operation ratio

- *Income of non-government domestic institutions* (equation CGE_6): Domestic nongovernment institutions form a subset of the set of domestic institutions. The total income of any domestic nongovernment institution is the sum of factor incomes, transfers from other domestic nongovernment institutions, balance of payment of GHG emissions trading, CCS installation cost, rent generated by the quota of the activity level and electricity generation capacity rent.

$$\begin{aligned} YI_{r,i} = & \sum_{f \in F} YIF_{r,i,f} + TRII\_Resource_{r,i} + shincome_{r,i} \cdot GHGTCOST_r + VRENCAPTOT_{r,i} \\ & - \left(PGHG\_G + PGHG\_IMP\_QUO_r - PGHG\_EXP\_QUO_r \right) \cdot GHG\_IMP_r \cdot \overline{EXR_r} \cdot shincome_{r,i} \\ & + shres_{r,i} \cdot \sum_{a \in A} PRES_{r,a} \cdot QRES_{r,a} + shincome_{r,i} \cdot \sum_{a \in A} QENE_{r,a} \cdot PENE_{r,a} \cdot \left(\frac{1}{1 - ADEEI_{r,a}} - 1 \right) \\ & + shincome_{r,i} \cdot \sum_{a \in A} \sum_{emcm \in EMCM} QRED_{r,emcm,a} + shincome_{r,i} \cdot \sum_{a \in A} RQUOQA_{r,a} \cdot QA_{r,a} \cdot PA_{r,a} \\ & + shincome_{r,i} \cdot \sum_{e \in E} \sum_{a \in A} QBIOF_{r,e,a} \cdot PBIOF_{r,e,a} \cdot (1 + RPBIOF_{r,e,a}) \quad , \forall r \in R, i \in INSDNG \end{aligned} \qquad \text{(CGE\_6)}$$

Where:

$i \in INSDNG (\subset INSD)$: a set of domestic nongovernment institutions

$YI_{r,i}$: income of institution *i* (in the set INSDNG)

$YIF_{r,i,f}$: income to domestic institution *i* from factor *f*

$TRII\_Resource_{r,i}$: transfers to institution *i*

$shincome_{r,i}$: total income share of GHG emissions cost for institution *i*

$GHGTCOST_r$: GHG emissions cost

$VRENCAPTOT_r$: rent related to electricity capacity

$PGHG\_G_r$: global GHG emissions price

$PGHG\_IMP\_QUO_r$: GHG emissions price generated by import quota

$PGHG\_EXP\_QUO_r$: GHG emissions price generated by export quota

GHG_IMP_r : GHG emissions credit import (net)

$\overline{EXR_r}$: currency exchange rate

$shres_{r,i}$: resource income share of institution *i*

$ADEEI_{r,a}$: additional energy efficiency improvement coefficient

$RQUOQA_{r,a}$: shadow subsidies of the fixed activity level

$QBIOF_{r,e,a}$: biomass consumption of activity *a*

$PBIOF_{r,e,a}$: price of biomass for activity *a*

$RPBIOF_{r,e,a}$: reduction rate of the price of biomass for activity *a*

- *Government revenue* (equation CGE_7): Total government revenue is the sum of revenues from taxes, factors, and transfers from the rest of the world. Emission trade cost is paid by government.

$$\begin{aligned} YG_r = & \sum_{i \in INSDNG} TINS_{r,i} \cdot YI_{r,i} + \sum_{f \in F} tf_{r,f} \cdot YF_{r,f} + \sum_{a \in A} ta_{r,a} \cdot PA_{r,a} \cdot QA_{r,a} + \sum_{a \in A} tva_{r,a} \cdot PVA_{r,a} \cdot QVA_{r,a} \\ & + \sum_{c \in CM} tm_{r,c} \cdot PWM_c \cdot dis\_imp_{r,c} \cdot QM_{r,c} \cdot \overline{EXR_r} + \sum_{c \in CE} te_{r,c} \cdot PWE_c \cdot dis\_exp_{r,c} \cdot QE_{r,c} \cdot \overline{EXR_r} \quad \text{(CGE\_7)} \\ & + \sum_{c \in C} \sum_{a \in A} tqd_{r,c,a} \cdot dfpq_{r,c,a} \cdot PQD_{r,c} \cdot QINT_{r,c,a} + \sum_{c \in C} \sum_{h \in H} tqd_{r,c,h} \cdot dfpq_{r,c,h} \cdot PQD_{r,c} \cdot QH_{r,c,h} \\ & + \sum_{c \in C} tqd_{r,c,"gov"} \cdot dfpq_{r,c,"gov"} \cdot PQD_{r,c} \cdot QG_{r,c} + \sum_{c \in C} tqd_{r,c,"S-I"} \cdot dfpq_{r,c,"S-I"} \cdot PQD_{r,c} \cdot QINV_{r,c} \\ & + \sum_{f \in F} YIF_{r,"gov",f} + TRII\_Resource_{r,"gov"} - TRII\_Use_{r,"gov"} + GHGTCOST_r \cdot shincome_{r,"gov"} \\ & + GHG\_IMP_r \cdot \overline{EXR_r} \cdot \left(PGHG\_IMP\_QUO_r - PGHG\_EXP\_QUO_r \right) \\ & + shres_{r,"gov"} \cdot \sum_{a \in A} PRES_{r,a} \cdot QRES_{r,a} \qquad , \forall r \in R \end{aligned}$$

Where:

YG_r : government revenue

$TINS_{r,i}$: direct tax rate for institution *i*

$tf_{r,f}$: direct tax rate for factor *f*

$tva_{r,a}$: rate of value-added tax for activity *a*

$tm_{r,c}$ and $te_{r,c}$: import tariff and export tax rates

PWM_c and PWE_c : world import price *(c.i.f)* and *(f.o.b.)* export price of commodity *c*

$dis\_imp_{r,c}$ and $dis\_exp_{r,c}$: price difference of the import and export commodity *c*

$QM_{r,c}$ and $QE_{r,c}$: import and export quantities of commodity

$tqd_{r,c,ac}$: rate of sales tax (as share of composite price inclusive of sales tax). Suffix *ac* includes activity *a* and institution *i*

- *Composite commodity markets* (equation CGE_8): This imposes the equality between quantities supplied and demanded of the composite commodity. The demand side includes endogenous terms and a new exogenous term for stock change. Among the endogenous terms, $QG_{r,c}$ and $QINV_{r,c}$ are fixed in the basic model version.

$$QQ_{r,c} - \left(QX2_{r,c} + QM_{r,c}\right) \cdot loss_{r,c} + stch2_{r,c}$$
$$= \sum_{a \in A} QINT_{r,c,a} + \sum_{h \in H} QH_{r,c,h} + QG_{r,c} + QINV_{r,c} \qquad , \forall r \in R, c \in C \qquad \text{(CGE\_8)}$$

Where:

$QX2_{r,c}$: aggregated marketed quantity of domestic output of commodity including stock change

$loss_{r,c}$: distribution loss rate

$stch2_{r,c}$: stock change of commodity c (negative)

- *Activity constraints* (equations CGE_9, CGE_10, CGE_11): Climate policy analysis requires us to simulate power sectors activities in detail; however, their activity levels are decided not only by economic rationality but also political decision. Therefore, the power share or activity level should be constrained exogenously.

$$(renew\_up_{r,a} - QA_{r,a}) \cdot \theta_{r,a,\text{"COM\_ELY"}} \geq 0, \quad VRENCAP_{r,a} \geq 0 \quad , \forall r \in R, a \in A = \{renew\_up_{r,a} > 0\} \quad \text{(CGE\_9)}$$

$$sh\_ely\_up_{r,a} - \frac{QXAC_{r,a,\text{"ely"}}}{QX_{r,\text{"ely"}}} \geq 0, \quad VRENCAP_{r,a} \geq 0 \qquad , \forall r \in R, a \in A = \{sh\_ely\_up_{r,a} > 0\} \quad \text{(CGE\_10)}$$

$$quotaqa_{ragg,aagg} = \sum_{r \in Map\_Ragg(r,ragg)} \sum_{a \in Map\_aagg(a,aagg)} \sum_{c \in C} QA_{r,a} \cdot \theta_{r,a,c} \geq 0 \perp RQUOQA\_agg_{ragg,aagg} \geq 0 \quad \text{(CGE\_11)}$$
$$, \forall ragg \in Ragg, aagg \in Aagg$$

Where:

$aagg \in Aagg$: a set of aggregated activity

$ragg \in Ragg$: a set of aggregated regions

$renew\_up_{r,a}$: capacity of the activity level a (for power sector energy)

$\theta_{r,a,c}$: yield of output c per unit of activity a

$VRENCAP_{r,a}$: rent of electricity capacity activity a in region r

$sh\_ely\_up_{r,a}$: power generation share of activity a

$QX_{r,c}$: aggregated marketed quantity of domestic output of commodity

$QXAC_{r,a,c}$: marketed output quantity of commodity c from activity a

$quotaqa_{ragg,aagg}$: quota of aggregated region $ragg$ and aggregated activity $aagg$

$RQUOQA_{r,a}$: shadow subsidies of the fixed activity level

(b)Transport module

Transport sector has different production structure. Transport sector provides two types of transport services, which are passenger and freight. The transport service is provided by 11 modes.

- *Total freight transport demand* (equation CGE_12): The freight transport mode demand is caused by industrial activity and household consumption.

$$QDTRST_{r,tr} = \sum_{ac \in AC} QDTRS_{r,tr,ac} = QDTRS_{r,tr,a} + QDTRS_{r,tr,h}$$

$$= QINT_{r,"COM\_TRS",a} \cdot trscvf_{r,tr,a} + QH_{r,"COM\_TRS",h} \cdot trscvf_{r,tr,h} \quad \text{(CGE\_12)}$$

$$, \forall r \in R, a \in A, h \in H, tr \in TR\_FRT$$

Where:

$QDTRST_{r,tr}$: total transport service demand by modes

$QDTRS_{r,tr,ac}$: freight transport service demand by sector *ac* and modes

$trscvf_{r,tr,ac}$: transport service demand by modes (*ac* includes *a* and *h*)

$tr \in TR\_FRT$: a set of transport mode for freight

- *Passenger transport demand (excluding household passenger transport)* (equation CGE_13): The passenger transport mode demand is caused by industrial activity only. Household passenger transport is calculated in different equation. The demand of passenger transport depends on the change of GDP (or income).

$$QDTRST_{r,tr} = trspss\_base_{r,tr} \cdot \left(\frac{GDP_r}{GDP\_base_r} \right)^{el^{pssincome}_{r,tr}} \quad , \forall r \in R, tr \in TR\_PSS \quad \text{(CGE\_13)}$$

Where:

$trspss\_base_{r,tr}$: passenger transport demand in base-year

$el^{pssincome}_{r,tr}$: passenger transport income elasticity

- *Total energy demand for transportation (excluding household passenger transport)* (equation CGE_14): Energy consumption of transport sector is derived from the transport volume and energy price.

$$TRS\_ENE_{r,tr} = QDTRST_{r,tr} \cdot trseneeffi_{r,tr} \cdot \left(\frac{PENE\_TR_{r,tr}}{pene\_tr\_base_{r,tr}} \right)^{el^{trspr}_{r,tr}} \quad \text{(CGE\_14)}$$

$$, \forall r \in R, a \in A, tr \in TR$$

Where:

$TRS\_ENE_{r,tr}$: transport energy demand by modes

$el^{trspr}_{r,tr}$: transport energy demand price elasticity

$trseneeffi_{r,tr}$: transport energy efficiency

$PENE\_TR_{r,tr}$: energy price of transport mode *tr*

$pene\_tr\_base_{r,tr}$: energy price of transport mode *tr* in base-year

(c) Household energy consumption

Household expenditure is divided into two sources, one is energy and the other is non-energy commodities. Non-energy commodity expenditure is determined by LES or alternatively by AIDADS (described in subsection 3.2.3). The energy expenditure has two classifications: one is household passenger transport and the other is non-transport energy-use functions such as lighting, space heating, space cooling, cooking, etc. The passenger transport made by household is formulated by the income level and its elasticity.

- *Household passenger transport demand* (equation CGE_15): The demand for household passenger transport depends on the relatively change in income and commodity price.

$$QCARU_{r,h} = pcaru_{r,h} \cdot \left(\frac{EH_{r,h} / CPI_r}{EH\_base_{r,h} / CPI\_base_r} \right)^{pasch_{r,h}} \quad ,\forall r \in R, h \in H \qquad \text{(CGE\_15)}$$

Where:

$QCARU_{r,h}$: household passenger transport service demand

$pcaru_{r,h}$: household passenger transport service demand in base-year

$pasch_{r,h}$: income elasticity of passenger transport service demand

$EH_{r,h}$ and $EH\_base_{r,h}$: total household expenditure of year *y* and base-year

CPI_r and CPI_base_r : CPI of year *y* and base-year

- *Energy demand for household passenger transport* (equation CGE_16): The total energy demand for household passenger transport is a function of transport demand and its energy coefficient.

$$QCARUENET_{r,h} = QCARU_{r,h} \cdot careneeff_{r,h} \quad ,\forall r \in R, h \in H \qquad \text{(CGE\_16)}$$

Where:

$QCARUENET_{r,h}$: household passenger transport energy use

$careneeff_{r,h}$: household passenger transport energy coefficient

- *Non-transport energy-use functions* (equation CGE_17): The quantity of energy demand for household non-transport functions is calculated based on base-year's demand and the change in total income, commodity price and especially energy price.

$$QHENE_{r,h} = HEHE\_base_{r,h} \cdot \left(\frac{EH_{r,h} / CPI_r}{EH\_base_{r,h} / CPI\_base_r} \right)^{el_{r,h}^{eneincome}} \cdot \left(\frac{PENE\_H_{r,h}}{PENE\_H\_base_{r,h}} \right)^{el_{r,h}^{eneagpr}} \quad \text{(CGE\_17)}$$

$$, \forall r \in R, h \in H$$

Where:

$QHENE_{r,h}$ and $HEHE\_base_{r,h}$: energy demand in household non-transport functions in year *y* and base-year

$PENE\_H_{r,h}$ and $PENE\_H\_base_{r,h}$: energy price for household in year *y* and base-year

$el_{r,h}^{eneincome}$: income elasticity for energy demand in household

$el_{r,h}^{eneagpr}$: price elasticity for energy demand in household

- *Energy price for household* (equation CGE_18): The price of energy for household is calculated based on the commodity price and consumption quantity.

$$PENE\_H_{r,h} = \frac{\sum_{c \in ENE} \left(PQD_{r,c} \cdot dfpq_{r,c,h} \cdot \left(1 + tqd_{r,c,h}\right) + \sum_{g \in G} PGHG_r \cdot gwp_g \cdot efffc_{r,c,h,g} \right) \cdot QH_{r,c,h}}{\sum_{c \in ENE} QH_{r,c,h}} \quad \text{(CGE\_18)}$$

$$, \forall r \in R, \ \forall h \in H$$

Where:

$g \in G$: a set of emission gases

$PQD_{r,c}$: composite commodity price excluding sales tax

$PGHG_r$: GHG emissions price in region *r* (US2005$/t$CO_2$)

$efffc_{r,c,ac,g}$: emission factors for emissions related fossil fuel combustion by sector *ac* consuming of goods *c*

gwp_g : global warming potential of gas *g*

(d)Logit function in AIM/CGE[basic] model

As mentioned earlier, the Logit function, which is originality of AIM/CGE[basic] model compared to other CGE models, is utilized in below equations for: Energy input technology share, Energy sources for transport service, Share of energy commodities production and allocation, and Energy fuel consumed by household passenger transport:

- *Energy input technology share* (equation CGE_19): This equation has two parameters; one determines base share and the other represents price elasticity. Price includes tax and carbon emission tax which is formulated as multiplying energy use ratio, emission coefficient and GWP (Global Warming Potential) associated with carbon tax rate.

$$QINT_{r,c,a} = QENE_{r,a} \cdot \frac{\beta^{inden}_{r,c,a} \cdot \left\{ PQD_{r,c} \cdot \left(1+tqd_{r,c,a}\right) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g} \right\}^{el^{inden}_{r,c,a}}}{\sum_{cp \in ENE} \beta^{inden}_{r,cp,a} \cdot \left\{ PQD_{r,cp} \cdot \left(1+tqd_{r,cp,a}\right) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,cp,a} \cdot efffc_{r,cp,a,g} \right\}^{el^{inden}_{r,cp,a}}} \quad \text{(CGE\_19)}$$

$$, \forall r \in R, c \in ENE, a \in A$$

Where:

$a \in ACES\_ENE\,(\subset A)$: a set of activities with a CES function at energy nest (Suffix *ac* includes activity *a* and institution *i*)

$QENE_{r,a}$: quantity of (aggregate) energy input

$enur_{r,c,ac}$: energy-used ratio (1-non-energy-use ratio)

$\beta^{inden}_{r,c,a}$: share parameter of Logit function for industrial activity energy selection

$el^{inden}_{r,c,a}$: price elasticity parameter of Logit function for industrial activity energy source selection

- *Energy sources for transport service* (equation CGE_20): Source of energy supplied for transport sector is determined based on the price of energy and its elasticity.

$$TRS\_ENE\_FL_{r,c,tr} = TRS\_ENE_{r,tr} \quad \text{(CGE\_20)}$$

$$\cdot \frac{\beta^{trsen}_{r,c,tr} \cdot \left\{ PQD_{r,c} \cdot \left(1+tqd_{r,c,\text{"TRS"}}\right) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,c,\text{"trs"}} \cdot efffc_{r,c,\text{"trs"},g} \right\}^{el^{trsen}_{r,c,tr}}}{\sum_{cp \in ENE} \beta^{trsen}_{r,cp,tr} \cdot \left\{ PQD_{r,cp} \cdot \left(1+tqd_{r,cp,\text{"TRS"}}\right) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,cp,\text{"trs"}} \cdot efffc_{r,cp,\text{"trs"},g} \right\}^{el^{trsen}_{r,cp,tr}}}$$

$$, \forall r \in R, c \in ENE, tr \in TR$$

Where:

$TRS\_ENE\_FL_{r,c,tr}$: transport energy demand by modes and energy sources

$\beta^{trsen}_{r,c,tr}$: share parameter of Logit function for transport mode energy source

$el^{trsen}_{r,c,a}$: price elasticity parameter of Logit function for transport mode energy source selection

- *Share of energy commodities production and allocation* (equation CGE_21): Aggregate marketed production of the energy commodity is defined as a share function. The share is determined by Logit function. The volume is calculated by multiplying the share and the total produced commodity volume.

$$SHAC_{r,a,c} = \frac{\psi^{ac}_{r,a,c} PXAC_{r,a,c}^{\eta^{ac}_{r,a,c}}}{\sum_{ap \in A} \psi^{ac}_{r,ap,c} PXAC_{r,ap,c}^{\eta^{ac}_{r,ap,c}}} \quad , \forall r \in R, c \in (CX \cap ENE) \qquad \text{(CGE\_21)}$$

Where:

$SHAC_{r,a,c}$: share of the commodity *c* produced by activity *a*

$PXAC_{r,a,c}$: producer price of commodity *c* for activity *a*

$\psi^{ac}_{r,a,c}$: share parameter of the commodity *c* produced by activity *a*

$\eta^{ac}_{r,a,c}$: elasticity of domestic commodity aggregation

- *Energy fuel consumed by household passenger transport* (equation CGE_22): The Logit function is applied for the energy fuel consumption caused by household passenger transport.

$$QCARUENE_{r,h,c} = QCARUENET_{r,h} \cdot \frac{\beta^{carh}_{r,c,h} \cdot \left\{ PQD_{r,c} \cdot \left(1 + tqd_{r,c,h}\right) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,c,h} \cdot efffc_{r,c,h,g} \right\}^{el^{carh}_{r,c,h}}}{\sum_{cp} \beta^{carh}_{r,cp,h} \cdot \left\{ PQD_{r,cp} \cdot \left(1 + tqd_{r,cp,h}\right) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,cp,h} \cdot efffc_{r,cp,h,g} \right\}^{el^{carh}_{r,cp,h}}} \quad , \forall r \in R, h \in H, c \in ENE \qquad \text{(CGE\_22)}$$

Where:

$QCARUENE_{r,h,c}$: energy use for household passenger transport (by energy sources)

$\beta^{carh}_{r,c,h}$: share parameter of Logit function for transport mode energy source

$el^{carh}_{r,c,h}$: price elasticity parameter of Logit function for transport mode energy source selection

(e) GHG emissions and reduction measures

The emission sources are classified into two groups, which are formulated separately. One is related to fuel combustion and this kind of emissions is proportional to the energy consumption. The other is related to the activity level, e.g. CO_2 emissions from cement production, and this kind of emissions is proportional to the activity level.

- *Emissions related to activity level (industrial activities)* (equation CGE_23): The emissions related to activity level such as CO_2 emissions from cement production is calculated by multiplying the activity level by the emission factor $efacl_{r,a,g}$. However, non-energy related GHG emissions related to activity levels such as CH_4 emissions from rice fields and CO_2 emissions from the cement industry is defined at the top nest of the production function. If an industrial sector can install CCS technology, it reduces the emission. In addition, there is additional emission reduction in mitigation case as *NERED*.

$$EMALI_{r,a,g} = QA_{r,a} \cdot efacl_{r,a,g} \cdot \left(1 - NERED_{r,a,g}\right) \cdot \left(1 + \chi_{r,a,g}\right) - \sum_{emcm \in EMCM} \left(QRED_{r,emcm,a} \middle/ \eta_{emcm,a} \right) \quad , \forall r \in R, a \in A, g \in G \qquad \text{(CGE\_23)}$$

Where:

$EMALI_{r,a,g}$: emissions related to industrial activity *a*

$efacl_{r,a,g}$: emission factors for emissions related to activity level by sector *ac*

$NERED_{r,a,g}$: emission reduction caused by the GHG emissions price

$\chi_{r,a,g}$: reference case emission reduction coefficient

- *Emissions related to activity level (household activities)* (equation CGE_24):

$$EMALH_{r,h,g} = \frac{EH_{r,h}}{CPI_r} \cdot efacl_{r,h,g} \quad , \forall r \in R, h \in H, g \in G \qquad \text{(CGE\_24)}$$

Where: $EMALH_{r,h,g}$: emissions related to activity level by household *h*

- *Emissions related to fossil fuel combustion (industrial activities)* (equation CGE_25):

$$EMFFI_{r,c,a,g} = QINT_{r,c,a} \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g} \quad , \forall r \in R, c \in ENE, a \in A, g \in G \qquad \text{(CGE\_25)}$$

Where:

$EMFFI_{r,c,a,g}$: emissions related to fossil fuel combustion emitted by industrial activity *a* consuming of goods *c*

- *Emissions related to fossil fuel combustion (household activities)* (equation CGE_26):

$$EMFFH_{r,c,h,g} = QH_{r,c,h} \cdot efffc_{r,c,h,g} \quad , \forall r \in R, c \in ENE, h \in H, g \in G \qquad \text{(CGE\_26)}$$

Where:

$EMFFH_{r,c,h,g}$: emissions related to fossil fuel combustion emitted by household *h* consumption of goods *c*

- *Emissions related to biomass combustion (industrial activities)* (equation CGE_27):

$$EMBII_{r,a,g} = TBI_{r,a} \cdot efbio_{r,a,g} \quad , \forall r \in R, a \in A, g \in G \qquad \text{(CGE\_27)}$$

Where:

$EMBII_{r,a,g}$: emissions related to biomass combustion by industrial activity

$TBI_{r,a}$: total biomass consumption by activity *a*

$efbio_{r,a,g}$: emission factors for emissions related to biomass combustion by sector *ac*

- *Emissions related to biomass fuel combustion (household activities)* (equation CGE_28):

$$EMBIH_{r,h,g} = TBH_{r,h} \cdot efbio_{r,h,g} \qquad , \forall r \in R, h \in H \ , g \in G \qquad \text{(CGE\_28)}$$

Where:

$EMBIH_{r,h,g}$: emissions related to biomass combustion emitted by household *h*.

$TBH_{r,h}$: total biomass consumption by household *h*

- *Emissions trading* (equations CGE_28, CGE_29, CGE_30, CGE_31): GHG emission permits can be imported from foreign countries. In reality, the amount of emission trading is constrained to a certain level which can be treated as an import or export quota. In addition, these import and export quota make the emission price higher or lower considering global and domestic emission prices. If emission trade is equal to the limit, the domestic GHG emissions price ($PGHG_r$) will be different from global price ($PGHG\_G$).

$$\overline{ghgt\_imp\_cap_r} - GHGT\_IMP_r \geq 0 \ \perp PGHG\_IMP\_QUO_r \geq 0 \qquad ,\forall r \in R \qquad \text{(CGE\_28)}$$

$$GHGT\_IMP_r - \overline{ghgt\_exp\_cap_r} \geq 0 \ \perp PGHG\_EXP\_QUO_r \geq 0 \qquad ,\forall r \in R \qquad \text{(CGE\_29)}$$

$$PGHG_r = EXR_r \cdot \left(PGHG\_G + PGHG\_IMP\_QUO_r - PGHG\_EXP\_QUO_r \right) \qquad ,\forall r \in R \qquad \text{(CGE\_30)}$$

$$\overline{ghgc_r} - GHGT\_CT_r \geq 0 \ \perp PGHG_r \geq 0 \qquad ,\forall r \in R \qquad \text{(CGE\_31)}$$

Where:

$\overline{ghgt\_imp\_cap_r}$: GHG emissions trading (import) limit

$\overline{ghgt\_exp\_cap_r}$: GHG emissions trading (export) limit

$\overline{ghgc_r}$: GHG emissions constraint

$GHGT\_CT_r$: GHG emissions from region *r* includes imported emission permit

- *Reduction measures (non-energy related, energy related, biomass power plant)* (equations CGE_32, CGE_33, CGE_34): Emission reduction counter measures are installable when the emission is constrained. The emission reduction inputs is $QRED_{r,emcm,a}$ and their cost (\$/tonCO_2eq) is η. The installation percentage has upper boundary as ξ. The constraint equation of the boundary is shown as in the equation. The complementary variable is $SURGHG_{r,emcm,a}$.

$$QRED_{r,emcm,a} = \xi_{emcm,a}^{\max} \cdot \eta_{emcm,a} \cdot \sum_{g \in G} gwp_g \cdot EMALI_{r,a,g} \cdot \left(\frac{PGHG_r}{\eta_{emcm,a} \cdot \left(1 + SURGHG_{r,emcm,a}\right)} \right)^2 \quad \text{(CGE\_32)}$$

$$, \forall r \in R, a \in A, emcm \in EMCM0$$

$$QRED_{r,emcm,a} = \xi_{emcm,a}^{\max} \cdot \eta_{emcm,a} \cdot \sum_{c \in ENE} \sum_{g \in G} gwp_g \cdot EMFFI_{r,a,c,g} \cdot \left(\frac{PGHG_r}{\eta_{emcm,a} \cdot \left(1 + SURGHG_{r,emcm,a}\right)} \right)^2 \quad \text{(CGE\_33)}$$

$$, \forall r \in R, a \in A, emcm \in EMCM1$$

$$QRED_{r,emcm,a} = \xi_{emcm,a}^{\max} \cdot \eta_{emcm,a} \cdot \sum_{g \in G} gwp_g \cdot EMBII_{r,a,g} \cdot \left(\frac{PGHG_r}{\eta_{emcm,a} \cdot \left(1 + SURGHG_{r,emcm,a}\right)} \right)^2 \quad \text{(CGE\_34)}$$

$$, \forall r \in R, a \in A, emcm \in EMCM2$$

Where:

$emcm \in EMCM0(\subset EMCM)$: a subset of emission reduction counter measures which are for non-energy related emissions

$emcm \in EMCM1(\subset EMCM)$: a subset of emission reduction counter measures which are for energy related emissions

$emcm \in EMCM2(\subset EMCM)$: a subset of emission reduction counter measures which are for biomass power plant absorption

$SURGHG_{r,emcm,a}$: complementary variable for the upper boundary of the counter measure installation

(f) Dynamic features

- *Capital* (equation CGE_35): The capital stock is determined by the previous year's capital stock, capital formation and capital depreciation. As is mentioned in the previous chapter the old capital is fixed to each sector exogenously. The current year's new capital is determined as previous year's capital formation. In this framework, the capital stock is calculated except for the base-year.

$$QF_{r,"cap",a}^{t} = QF_{r,"cap",a}^{t-1} \cdot \left(1 - dep_r^{t-1}\right) \qquad , \forall r \in R,\ t \in T \qquad \text{(CGE\_35)}$$

Where:

$t \in T$: a set of time series

dep_r^t : capital depreciation rate in time *t* and region *r*

- *Labor* (equation CGE_36): The population and labor is dynamically determined.

$$labor\_stock_r^t = labor\_stock_r^{t-1} \cdot lab\_gr_r^t \qquad , \forall r \in R,\ t \in T \qquad \text{(CGE\_36)}$$

Where:

$labor\_stock_r^t$: labor stock in time *t* and region *r*

$lab\_gr_r^t$: labor stock (annual) growth rate in time *t* and region *r*

- *Total Factor Productivity (TFP)* (equation CGE_37): The TFP is calculated based on GDP and factor growths.

$$\alpha_{r,a}^{va*} = \frac{QVA_{r,a}^{t-1} \cdot \left(1 + gdp\_gr_r^{t*}\right)}{\left(\sum_{f \in F} \delta_{r,a}^{va} \cdot \left(QF_{r,f,a}^{t-1} \cdot \left(1 + fac\_gr_{r,f}^{t}\right)\right)^{-\rho_{r,a}^{va}}\right)^{-\frac{1}{\rho_{r,a}^{va}}}} \quad , \forall r \in R, a \in A \qquad \text{(CGE\_37)}$$

Where:

$\alpha_{r,a}^{va*}$: adjusted efficiency parameter in the CES value-added function

$gdp\_gr_r^{t*}$: expected GDP growth target (annual growth rate)

$fac\_gr_{r,f}^{t}$: expected factor input growth rate

- *Autonomous Energy Efficiency Improvement (AEEI)* (equations CGE_38, CGE_39, CGE_40): The energy demand is controlled by calibration of the AEEI. We set the annually AEEI improvement rate and revise the intermediate input coefficients and household energy commodity consumption rate. CES parameters determining energy consumption is also dynamically calibrated.

$$iene_{r,c,a}^{t} = iene_{r,c,a}^{"base\_year"} \cdot aeei_{r,c,a}^{t} \quad , \forall r \in R, c \in ENE, a \in A \qquad \text{(CGE\_38)}$$

$$iena_{r,ca}^{t} = iene_{r,c,a}^{"base\_year"} \cdot \sum_{c \in ENE} iene_{r,c,a}^{"base\_year"} \cdot aeei_{r,c,a}^{t} \quad , \forall r \in R, a \in ACES\_ENE \qquad \text{(CGE\_39)}$$

$$\gamma_{r,c,h}^{mt} = \gamma_{r,c,h}^{mt-1} \cdot aeei_{r,c,h}^{t} \quad , \forall r \in R, c \in ENE, h \in H \qquad \text{(CGE\_40)}$$

Where:

$iene_{r,c,a}^{t}$: energy commodity consumption ratio

$iena_{r,ca}^{t}$: quantity of aggregate energy input per activity unit

$aeei_{r,c,ac}^{t}$: annual AEEI rate of energy commodity *c*, sector *ac*, time *t*, region *r*

$\gamma_{r,c,h}^{m}$: subsistence consumption of marketed commodity *c* for household *h*

3.2.3 Estimation of AIDADS parameters and its integration in AIM/CGE[basic] model

3.2.3.1 Overview

Economic development as usual has strong effect on income change, household consumption behavior, and energy consumption that lead to higher GHG emissions. When climate change mitigation policies are taken into account, economic development would be lower than usual, people tends to change their lifestyles, particularly in term of energy consumption and technological device usages, leading to possible smaller GHG emissions. If the climate change mitigation policies are implemented successfully, hopefully we can achieve the vision of sustainable development, low carbon lifestyle, energy security, and finally is low carbon society.

Therefore, it is important to predict how people in different income levels in developing countries, especially lowest income households, spend their income for energy, goods and services (reference lifestyle) and compare with their consumption change under climate mitigation measures (low carbon lifestyle).

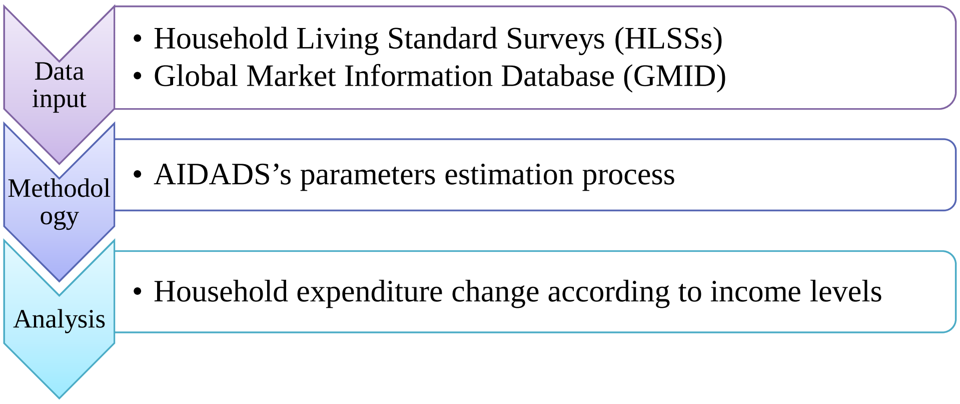


Figure 3.7: Overview of AIDADS function estimation

Data from HLSS and GMID for the household's consumption is used to estimate the AIDADS's parameters performing the change of final consumption when income changes (as described in Figure 3.7 above).

3.2.3.2 Description

The aim of AIDADS function study, with detail of household consumption pattern, is to support AIM/CGE[basic] model in simulating and analyzing the implication of climate change mitigation policies on the social and economic aspects of a nation. In which, change in goods and services consumption, especially energy consumption, will have strong effect on the GHG emissions and therefore reflect the effectiveness of climate change policies and their implications to the socio-economic.

The originality of this estimation is that the historical data of HLSS is used together with GMID data to estimate the AIDADS's parameters in order to perform the characteristic of historical consumption preference. Moreover, these parameters must also satisfy the condition of re-producing the 2005's SAM. Therefore, the calibration process is needed to constraint the estimated parameters under the condition of 2005's SAM. Firstly, HLSSs (1993-2010) of Vietnam together with GMID (1990-2010) data are used to estimate the AIDADS's parameters. Secondly, these AIDADS parameters are calibrated under the constraints of 2005's SAM information (minimizing the residual between HLSS-based estimated and SAM-based estimated parameters). Thirdly, calibrated AIDADS parameters are used to simulate future household final consumption.

The AIDADS parameters are estimated for different households groups (as shown in Table 3.7). However, later only AIDADS parameters of TOT are used for AIM/CGE[basic] model since currently the AIM/CGE[basic] model has only 1 representative for household.

Table 3.7: Households classification for AIDADS parameters estimation

Group		Code	Household disaggregation	Income level
1 group	1	TOT	Total	-
2 groups	1	HURB	Urban	-
	2	HRUR	Rural	-
5 groups	1	QT1	Lowest income	Quintile 1
	2	QT2	Low income	Quintile 2
	3	QT3	Middle income	Quintile 3
	4	QT4	High income	Quintile 4
	5	QT5	Highest income	Quintile 5

In general, the commodity in this research is classified into 3 main groups (as shown in Table 3.8): agriculture and foods, industry and services, and energy; in which energy sector is disaggregated in detail. Detail description of sectors and commodities are written in Appendices C and D. In AIDADS estimation, the commodity classification is same as AIM/CGE[basic] model, except five commodities that household does not directly consume (do not exist in 2005's SAM). These excluded commodities are forestry (COM_FRS), gas manufacturing distribution (COM_GDT), crude oil (COM_OIL), mineral mining and other quarrying (COM_OMN), and non-ferrous products (COM_NFM).

Therefore, the AIDADS budget share coefficient parameters (alpha, beta) and subsistence minima (theta) are estimated for 16 commodities of totally 8 household groups.

Table 3.8: Group of sector and commodity classification

Main group	Sector and commodity classification	Code
Agriculture and foods	Agriculture, fishery, forestry, food production	AGR, FSH, FRS, FPR
Industry and services	Mineral mining, textile, paper and pulp, chemical, manufacturing, iron and steel, transportation, services	OMN, TEX, PPP, CRP, OMF, I_S, TRS, CSS
Energy	Coal, crude oil, gas, petroleum products, electricity	COA, OIL, GAS, P_P, ELY

3.2.3.3 Data input

The main sources of database used for the estimation of AIDADS parameters are GMID and HLSSs (as listed in Table 3.9).

- The observed values for $\overline{EH\_HLSS_h^y}$ (monthly), $\overline{CE\_HLSS_{h,i}^y}$, $\overline{POP_h^y}$ are in ../data/HLSS.xls

- The observed values for $\overline{EH_{"TOT"}^y}$ annual), $\overline{CE_{"TOT",c}^y}$, $\overline{POP_{"TOT"}^y}$, $\overline{CPI\_org_c^y}$ are in ..data/GMID.xls

Table 3.9: Availability of observations

Category	Code	Available observation	Unit	Period	Source
Total expenditure	$\overline{EH\_HLSS_h^y}$	Total expenditure per capita per month by households	thous. VND	1993-2010	1993-2010 HLSS (GSO, 2011)
	$\overline{EH_{"TOT"}^y}$	Total expenditure per year (1 household representative - TOT)	mil. USD (2009)	1990-2020	GMID (Euromonitor, 2010)
Expenditure by commodities	$\overline{CE\_HLSS_{h,i}^y}$	Expenditure per capita per month by commodity i & households	thous. VND	1993-2010	1993-2010 HLSS (GSO, 2011)
	$\overline{CE_{"TOT",c}^y}$	Expenditure per year by commodity c	mil. USD (2009)	1990-2020	GMID (Euromonitor, 2010)
Price by commodities	$\overline{CPI\_org_c^y}$	Consumer Price Index (year 1990=100)	-	1990-2009	GMID (Euromonitor, 2010)
Total population	$\overline{POP_h^y}$	Total population (TOT, HURB, HRUR)	thous. pers.	1990-2010	2010 SYB (GSO, 2011)
	$\overline{POP_{"TOT"}^y}$	Total population (TOT)	thous. pers.	1990-2020	GMID (Euromonitor, 2010)

Since HLSS provides $\overline{EH\_HLSS_h^y}$ and $\overline{CE\_HLSS_{h,i}^y}$ for all household groups rather than GMID data with only 1 representative (TOT), the HLSS data is used to estimate the expenditure ratio (or share) between TOT and other household groups ($\overline{EH\_share_h^y}$ and $\overline{CE\_share\_agg_{h,c\_a}^y}$).

➢ **Pre-calibrated calculation**

The aggregated calculation for $\overline{EH\_share_h^y}$, $\overline{CE\_share\_agg_{h,c\_a}^y}$, $\overline{EH_h^y}$, $\overline{CE\_agg_{h,c\_a}^y}$, $\overline{CPI\_agg_{c\_a}^y}$, $\overline{QH\_obs\_agg_{h,c\_a}^y}$ are in ..data/calculation.xls. Detail equations of pre-calibration (name is started with letter "P") are listed in subsections below:

- Household expenditure ratio among household groups ($\overline{EH\_share_h^y}$) is calculated from HLSS data:

$$\overline{EH\_share_h^y} = \frac{\overline{EH\_HLSS_h^y}}{\overline{EH\_HLSS_{"TOT"}^y}} \tag{P1}$$

- Share of commodity expenditure by households ($\overline{CE\_share\_agg_{h,c\_a}^y}$) is calculated from HLSS data:

$$\overline{CE\_share_{h,i}^y} = \frac{\overline{CE\_HLSS_{h,i}^y}}{\sum_{i'} \overline{CE\_HLSS_{h,i'}^y}} \tag{P2a}$$

$$\overline{CE\_share\_agg_{h,c\_a}^y} = \sum_{i} \overline{CE\_share_{h,i}^y} \qquad \forall i \in C\_map(c\_a,i) \tag{P2b}$$

- Total expenditure per capita per year of households $\overline{EH_h^y}$ (constant 2005 price) is calculated from $\overline{EH\_share_h^y}$ and $\overline{EH_{"TOT"}^y}$ (constant 2009 price):

$$\overline{EH_h^y} = \overline{EH\_share_h^y} \cdot \frac{\overline{EH_{"TOT"}^y}}{\overline{POP_{"TOT"}^y} / 1000} \cdot \frac{\overline{def^{2005}}}{\overline{def^{2009}}} \qquad \text{(P3)}$$

- Consumer Price Index $\overline{CPI\_agg_{c\_a}^y}$ (2005=100) is calculated from $\overline{CPI\_org_c^y}$ (1990=100). We assume that all household groups are under the same $\overline{CPI\_agg_{c\_a}^y}$:

$$\overline{CPI_c^y} = \frac{\overline{CPI\_org_c^y}}{\overline{CPI\_org_c^{2005}}} \qquad \text{(P4a)}$$

$$\overline{CPI\_agg_{c\_a}^y} = \min_c \left\{ \overline{CPI_c^y} \right\} \qquad \forall c \in C\_map(c\_a,c) \qquad \text{(P4b)}$$

- The observed consumption $\overline{QH\_obs\_agg_{h,c}^y}$ is calculated from $\overline{CE\_agg_{h,c\_a}^y}$, $\overline{EH_h^y}$ and $\overline{CPI\_agg_{c\_a}^y}$:

$$\overline{CE\_agg_{h,c\_a}^y} = \overline{CE\_share\_agg_{h,c\_a}^y} \cdot \overline{EH_h^y} \qquad \text{(P5a)}$$

$$\overline{QH\_obs\_agg_{h,c\_a}^y} = \frac{\overline{CE\_agg_{h,c\_a}^y}}{\sum_{c\_a'} \overline{CE\_agg_{h,c\_a'}^y}} \cdot \frac{\overline{EH_h^y}}{\overline{CPI\_agg_{c\_a}^y}} \qquad \text{(P5b)}$$

3.2.3.4 Integration of AIDADS function in AIM/CGE[basic] model

After being estimated (as explained in previous parts of this subsection), the AIDADS parameters are calibrated under the constraints of 2005's SAM information (minimizing the residual between HLSS-based estimated and SAM-based estimated parameters). After that, the calibrated AIDADS parameters are used to form the new consumption function in AIM/CGE[basic] model in order to simulate future household final consumption (as shown in Figure 3.8).

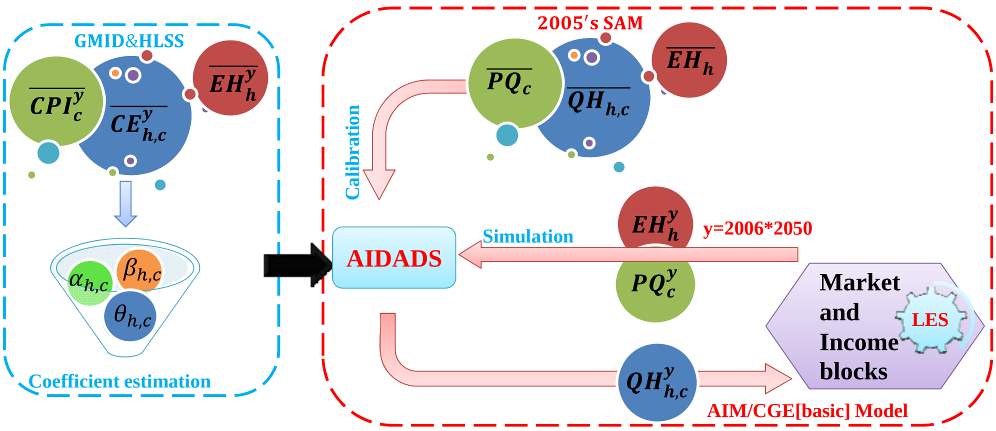


Figure 3.8: Overview of integrating AIDADS function into AIM/CGE[basic] model

In the estimation and calibration of AIDADS function, the price (use Consumer Price Index - CPI) and total household expenditure of commodities are known as exogenous parameters. However, once the AIDADS function is integrated into AIM/CGE[basic] model, these parameters are endogenously determined according to the simulation results from the model, in which one of the most important results from AIM/CGE[basic] model is price of commodities.

3.2.3.5 Main mathematical equations

- **AIDADS Function**

In AIDADS function, utility u_h^y is described with the following equation:

$$u_h^y = \sum_{c\_a} \mu_{h,c\_a}^y \cdot \ln\left(QH_{h,c\_a}^y - \theta_{h,c\_a}\right) - (\ln A + 1) \qquad (\mathrm{EQ\_U})$$

Where:

u_h^y : utility level

μ_{h,c_a}^y : budget share parameter of commodity *c_a*

QH_{h,c_a}^y : household consumption demand of commodity *c_a*

θ_{h,c_a} : subsistence minima of commodity *c_a*

A : constant value determining the absolute value of u_h^y

(for convenience, $\ln(A)+1$ is written κ (≥ 1) here after)

Budget share parameter μ_{h,c_a}^y is written by two parameters α_{h,c_a}, β_{h,c_a} and utility u_h^y.

$$\mu_{h,c\_a}^y = \frac{\left[\alpha_{h,c\_a} + \beta_{h,c\_a} \cdot e^{u_h^y}\right]}{\left[1 + e^{u_h^y}\right]} \qquad (\mathrm{EQ\_MU})$$

$$\sum_{c\_a} \alpha_{h,c\_a} = 1 \qquad (\mathrm{EQ\_ALPHA})$$

$$\sum_{c\_a} \beta_{h,c\_a} = 1 \qquad (\mathrm{EQ\_BETA})$$

Where: α_{h,c_a} and β_{h,c_a} : budget share coefficients

Consumption demand QH_{h,c_a}^y, which maximizes u_h^y, is calculated:

$$QH_{h,c\_a}^y = \theta_{h,c\_a} + \frac{\mu_{h,c\_a}^y}{\overline{CPI\_agg_{c\_a}^y}} \cdot \left(\overline{EH_h^y} - \sum_{c\_a'} \overline{CPI\_agg_{c\_a'}^y} \cdot \theta_{h,c\_a'}\right) \qquad (\mathrm{EQ\_QH})$$

In which: $(\alpha_{h,c\_a} \geq 0 \text{ and } \beta_{h,c\_a} \geq 0)$

$$\theta_{h,c\_a} \geq 0$$

$$QH^{y}_{h,c\_a} \geq \theta_{h,c\_a}$$

Where:

$\overline{CPI\_agg^{y}_{c\_a}}$: Consumer Price Index of commodity *c_a* (2005=100)

$\overline{EH^{y}_{h}}$: total expenditure per capita per year

The restrictions involving relative prices and differences in the parameters are needed to define the region over with AIDADS is regular (i.e. utility is strictly increasing in the level of consumption of each good and the upper level sets for utility are convex).

- Global regularity condition:

$$\sum_{c\_a}(\beta_{h,c\_a} - \alpha_{h,c\_a}) \cdot \ln \overline{CPI\_agg^{y}_{c\_a}} \geq -\frac{(1-e^{u^{y}_{h}})^2}{e^{u^{y}_{h}}} + \sum_{c\_a}(\beta_{h,c\_a} - \alpha_{h,c\_a}) \cdot \ln \mu^{y}_{h,c\_a} \quad (\text{EQ\_Greg})$$

- Local regularity condition:

$$\sum_{c\_a}(\beta_{h,c\_a} - \alpha_{h,c\_a}) \cdot \ln\left(QH^{y}_{h,c\_a} - \theta_{h,c\_a}\right) \leq \frac{(1-e^{u^{y}_{h}})^2}{e^{u^{y}_{h}}} \quad (\text{EQ\_Lreg})$$

- Error term:

$$\varepsilon^{y}_{h,c\_a} = \frac{\overline{CPI\_agg^{y}_{c\_a}}}{\overline{\overline{EH^{y}_{h}}}} \cdot \left(QH^{y}_{h,c\_a} - \overline{QH\_obs\_agg^{y}_{h,c\_a}}\right) \quad (\text{EQ\_eps})$$

Where:

$\overline{QH\_obs\_agg^{y}_{h,c\_a}}$: observed consumption per capita per month of commodity *c_a* (unit/capita/year)

➢ **Calibration**

In the calibration, $\overline{QH\_obs\_agg^{y}_{h,c\_a}}$: consumption of commodity *c_a* in household *h* in year *y* are used as referenced values. Estimated parameters are: α_{h,c_a}, β_{h,c_a}, θ_{h,c_a}, and κ.

Estimation equations, which are (EQ_U), (EQ_MU), (EQ_ALPHA), (EQ_BETA), (EQ_QH), (EQ_Greg), and (EQ_Lreg) are used to calculate parameters subject to minimizing objective function.

Chosen objective function: Minimizing Log-Likelihood Φ_h *(follow Rimmer and Powell, 1996)*:

$$\Phi_h = \sum_{y,c\_a}\left(\varepsilon^{y}_{h,c\_a} \cdot \varepsilon^{y}_{h,c\_a}\right) \quad (\text{EQ\_RESIDUAL})$$

- **Estimation of initial values and bounds**

The equations of estimating initial values are named with letter "E". Initial values $\alpha.l_{h,c\_a}$, $\beta.l_{h,c\_a}$, $\theta.l_{h,c\_a}$, $u.l_h^y$ are estimated based on $\overline{CPI\_agg_{c\_a}^y}$, $\overline{EH_h^y}$, and $\overline{QH\_obs\_agg_{h,c\_a}^y}$:

$$\alpha.l_{h,c\_a} = \mu.l_{h,c\_a}^y = \min_y \left\{ 1/3 \cdot \overline{CPI\_agg_{c\_a}^y} \cdot \frac{\overline{QH\_obs\_agg_{h,c\_a}^y}}{\overline{EH_h^y}} \right\} \qquad (E1-2)$$

$$\beta.l_{h,c\_a} = \min_y \left\{ 1/5 \cdot \overline{CPI\_agg_{c\_a}^y} \cdot \frac{\overline{QH\_obs\_agg_{h,c\_a}^y}}{\overline{EH_h^y}} \right\} \qquad (E3)$$

$$\theta.l_{h,c\_a} = 0.1 \cdot \min_y \left(\overline{QH\_obs\_agg_{h,c\_a}^y} \right) \qquad (E4)$$

$$QH.l_{h,c\_a}^y = \theta.l_{h,c\_a} + \frac{\mu.l_{h,c\_a}^y}{\overline{CPI\_agg_{c\_a}^y}} \cdot \left(\overline{EH_h^y} - \sum_{c\_a'} \overline{CPI\_agg_{c\_a'}^y} \cdot \theta.l_{h,c\_a'} \right) \qquad (E5)$$

$$u.l_h^y = \sum_{c\_a} \mu.l_{h,c\_a}^y \cdot \ln\left(\overline{QH\_obs\_agg_{h,c\_a}^y} - \theta.l_{h,c\_a} \right) - \kappa \qquad (E6)$$

(In which: $\kappa = 1$)

Bounds of parameters adopted in the estimation procedure are:

$\alpha_{h,c\_a} = [0,\ 1]$ and $\beta_{h,c\_a} = [0,\ 1]$

$$\theta_{h,c\_a} = \left[0,\ 0.5 \cdot \min_y \left(\overline{QH\_obs\_agg_{h,c\_a}^y} \right) \right]$$

$$\mu_{h,c\_a}^y = [0,\ 1]$$

$$QH_{h,c\_a}^y = \left[0.0001, \frac{\overline{EH_h^y}}{\overline{CPI\_agg_{c\_a}^y}} \right]$$

$$u_h^y = \left[\ln\left(0.01 \cdot \min_{c\_a} \left(\overline{QH\_obs\_agg_{h,c\_a}^y} \right) \right), \sum_{c\_a} \ln QH.up_{h,c\_a}^y \right]$$

The setting of initial value and the bounds is crucial for the calibration process. Once they are changed, the values of calibrated parameters will be different. Setting of initial value and bounds for the calibration process is summarized in Table 3.10).

The estimation of AIDADS parameters is programed by GAMS with CONOP solver.

Table 3.10: Summary of Setting initial values and bounds

Parameter	Lower bound	Upper bound	Initial value
α_{h,c_a}	0	1	$\min_y \left\{ \frac{1}{3} \cdot \overline{CPI\_agg_{c\_a}^y} \cdot \frac{\overline{QH\_obs\_agg_{h,c\_a}^y}}{\overline{EH_h^y}} \right\}$
β_{h,c_a}	0	1	$\min_y \left\{ \frac{1}{5} \cdot \overline{CPI\_agg_{c\_a}^y} \cdot \frac{\overline{QH\_obs\_agg_{h,c\_a}^y}}{\overline{EH_h^y}} \right\}$
μ_{h,c_a}^y	0	1	$\min_y \left\{ \frac{1}{3} \cdot \overline{CPI\_agg_{c\_a}^y} \cdot \frac{\overline{QH\_obs\_agg_{h,c\_a}^y}}{\overline{EH_h^y}} \right\}$
θ_{h,c_a}	0	$0.5 \cdot \min_y \left(\overline{QH\_obs\_agg_{h,c\_a}^y} \right)$	$0.1 \cdot \min_y \left(\overline{QH\_obs\_agg_{h,c\_a}^y} \right)$
u_h^y	$\ln\left(0.01 \cdot \min_{c\_a} \left(\overline{QH\_obs\_agg_{h,c\_a}^y} \right)\right)$	$\sum_{c\_a} \ln QH.up_{h,c\_a}^y$	$\sum_{c\_a} \mu.l_{h,c\_a}^y \cdot \ln\left(\overline{QH\_obs\_agg_{h,c\_a}^y} - \theta.l_{h,c\_a} \right) - \kappa$
QH_{h,c_a}^y	0.0001	$\frac{\overline{EH_h^y}}{\overline{CPI\_agg_{c\_a}^y}}$	$\theta.l_{h,C\_a} + \frac{\mu.l_{h,c\_a}^y}{\overline{CPI\_agg_{c\_a}^y}} \cdot \left(\overline{EH_h^y} - \sum_{c\_a'} \overline{CPI\_agg_{c\_a'}^y} \cdot \theta.l_{h,c\_a'} \right)$

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Chapter 4 REVIEW OF VIETNAMESE OUTLOOK TOWARDS LOW CARBON DEVELOPMENT

Chapter 4 reviews the governmental outlook of Vietnam based on the national development targets and plans. This review is the background for the national-based scenario development conducted in Chapter 5 of this dissertation.

In this chapter, "review" does not only mean gathering information of current governmental socio-economic outlook (Section 4.2) but also include back-casting the historical development of Vietnam from the LCD viewpoint (Section 4.1).

Energy development outlook including the energy pricing system and detail content of latest Vietnam Power Development Plan (PDP7) is reviewed in Section 4.3.

4.1 Analysis of Vietnam historical development and energy consumption

Studies on the future potential for CO_2 emissions reduction in Vietnam require the use of reliable information on economic development, energy consumption, and CO_2 emissions, topics that also tend to be incompletely monitored in other developing countries. Therefore, the accounting principle for data reconciliation and CGE model are applied with calibrated parameters to estimate SAM and EIOT. They are used to analyze the economic, energy consumption, and CO_2 emissions structures of Vietnam from 1986 to 2005 (Tran *et al.*, 2010).

4.1.1 Economic structure

The industrial value added increases drastically, effectively tripling from 13,030 mil.USD in 1986 to 46,730 mil.USD in 2005 (as illustrated in Figure 4.1).

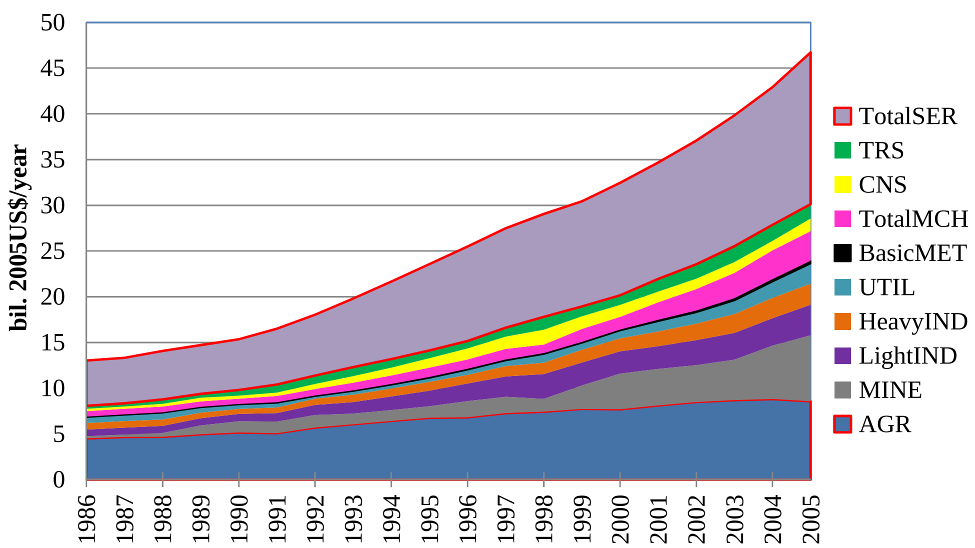

Figure 4.1: GDP change by sectors

The two main contributors are total services (TotalSER) (contributes steadily at the same rate of about 40%) and agriculture (AGR) (decreases from 35% to 20%). The contributions from the mining and quarrying (MINE), light industry (LightIND), and total machinery (TotalMCH) increase softly; while those of the transport (TRS), construction (CNS), basic metal (BasicMET), and utility (UTIL) show little change.

4.1.2 Energy consumption

The total energy consumption of Vietnam begins to increase from 1986-1987, then loses ground from 1988 to 1990, eventually returning to the 1986 level of around 4,700 kTOE. After this two-year retraction, the energy consumption begins a rapid ascent, climbing from 4,974 kTOE in 1990 to 22,668 kTOE in 2005.

Increases in all sectors contribute to this growth in energy consumption. The main contributors are transport (TRS), utility (UTIL), industry (HeavyIND and LightIND), residential (HURB), basic metal (BasicMET), and total services (TotalSER), making up 20%, 22%, 25%, 12%, 9%, and 6% of the total consumption, respectively, in 2005. The energy consumption of machinery (TotalMCH), agriculture (AGR), mining (MINE), and construction (CNS) is still very small compared to the other consumption sources during this period (as shown in Figure 4.2).

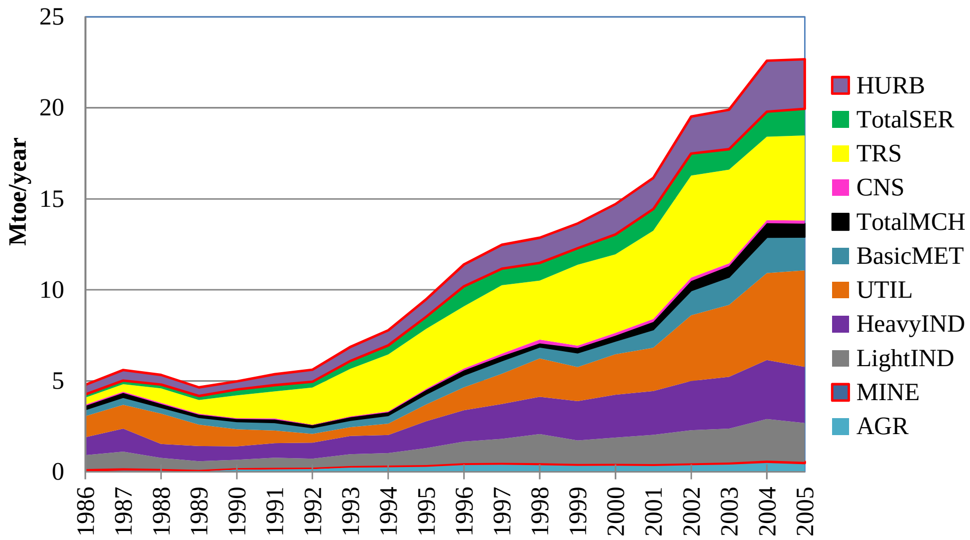

Figure 4.2: Energy consumption change by sectors

4.1.3 CO_2 emissions

The CO_2 emissions of each sector follow the same trend as energy consumption, climbing more than four-fold from 4,086 (in 1986) to 16,378 thousand tons of carbon (in 2005). The change in percentage contribution to CO_2 emissions by sector is also very close to the percentage change of energy consumption, increasing rapidly from 1990 onward (see Figure 4.3).

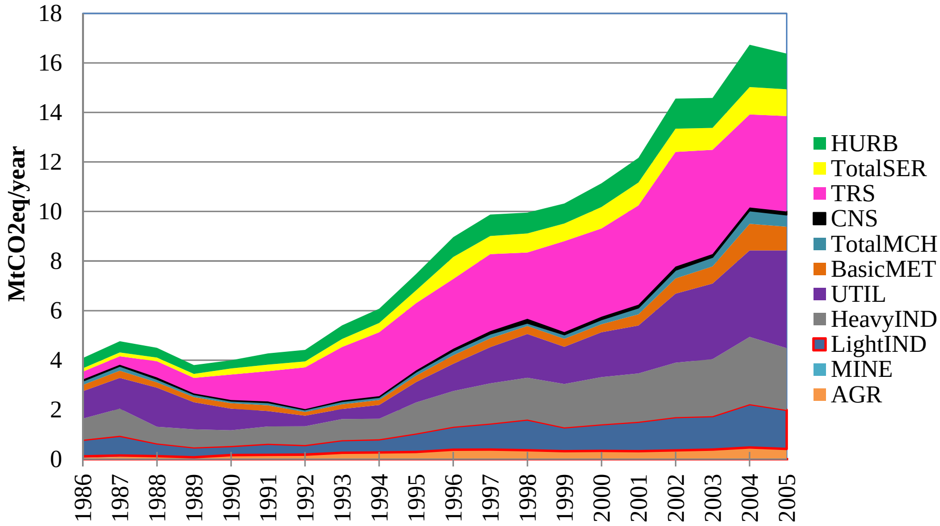

Figure 4.3: CO_2 emissions by sectors

4.1.4 Main drivers of CO_2 emissions

An accurate analysis of the CO_2 emissions reduction potential requires an understanding of the main drivers behind the CO_2 emissions changes. Figure 4.4 shows the changes of the population, GDP, energy consumption, and CO_2 emissions in the other years of the period, compared to the base-year 1986. The population increases much more slowly than the GDP, energy consumption, and CO_2 emissions. The gaps among these parameters increase rapidly, especially from 1995 onward, marking the start of rapid development in Vietnam.

CO_2 emissions are decomposed into economic activity (GDP), energy intensity, and carbon intensity, in order to determine the main drivers behind them (see equations below). The GDP, meanwhile, is decomposed into population and GDP per capita.

$$CO_2 = Pop \cdot {GDP}/{Pop} \cdot {EC}/{GDP} \cdot {CO_2}/{EC}$$

$$\Delta CO_2 = \Delta Pop + \Delta\left({GDP}/{Pop}\right) + \Delta\left({EC}/{GDP}\right) + \Delta\left({CO_2}/{EC}\right)$$

Where: CO_2: CO_2 emissions

Pop: total population

GDP: Gross Domestic Production

EC: total energy consumption

${GDP}/{Pop}$: GDP per capita

${EC}/{GDP}$: energy intensity

${CO_2}/{EC}$: carbon intensity

Figure 4.5 shows the contribution of decomposed factors affecting the CO_2 emissions changes over each 5-year period from 1986 to 2005. Our macroeconomic analysis identifies the energy intensity as the main driver behind the decrease of CO_2 emissions in the first period, 1986-1990, when energy consumption is decreasing. The other three factors contribute in almost the same proportions during this period. This can be explained by the hyperinflation in 1986, together with the shock from the Soviet Union collapse in 1989.

In the second period, 1991-1995, the main driver behind the increase in CO_2 emissions switches to GDP per capita, though the contribution of energy consumption remains high. Over the next two periods, 1996-2000 and 2001-2005, the GDP per capita remains the main driver behind the CO_2 emissions changes, while the contribution of carbon intensity slightly rises and the contribution of industrial value slightly falls.

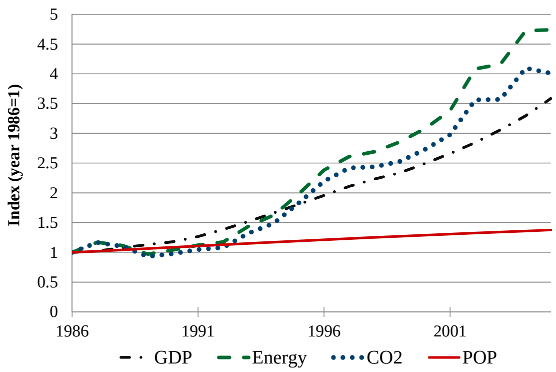

Figure 4.4: Changes of population, GDP, energy consumption, and CO_2 emissions

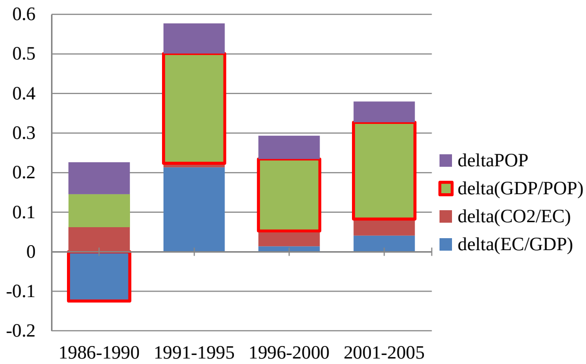

Figure 4.5: CO_2 emissions changes by decomposed factors

Meanwhile, the main driver in the transport sector is energy intensity, except during the period from 1996 to 2000 (see Figure 4.6) while main driver of utility sector is GDP even energy intensity remains a very strong contributor to income from the utility sector, a major contributor to the CO_2 emissions changes (see Figure 4.7).

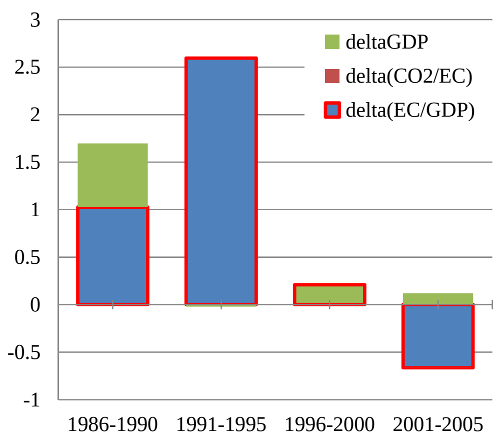

Figure 4.6: CO_2 emissions changes by decomposed factors in transport sector

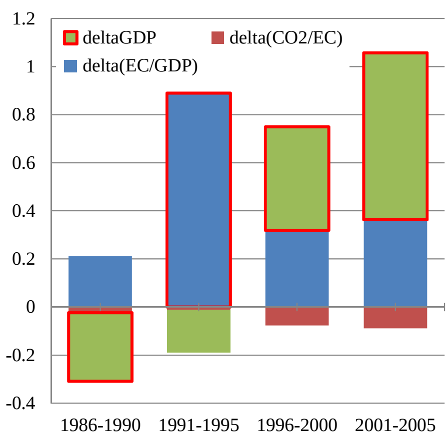

Figure 4.7: CO_2 emissions changes by decomposed factors in utility sector

Heavy industry (HeavyIND) and light industry (LightIND) are aggregated. GDP persists as the main driver for heavy industry throughout the whole study period (see Figure 5.4), just as it does for light industry during all periods, except the plateau period from 1986 to 1990 (see Figure 5.7). CO_2 emissions from light industry from 1986 to 1990 are strongly affected by the energy intensity.

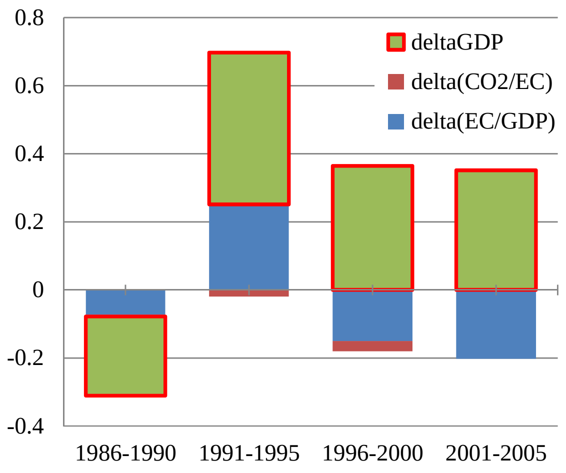

Figure 4.8: CO_2 emissions changes by decomposed factors in heavy industry sector

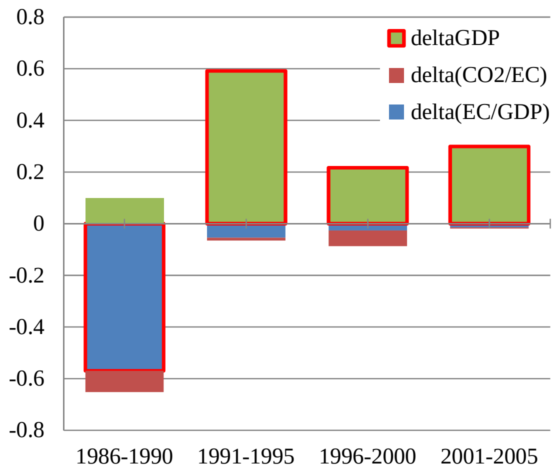

Figure 4.9: CO_2 emissions changes by decomposed factors in light industry sector

4.2 Socio-economic outlook of Vietnam

4.2.1 Population and urbanization

Vietnam is still relatively un-urbanized by Asian standards. In 2001, the urban population was only 25% and reached 30% in 2009. Annual growth projections vary but Government accepts that the urbanization rate will be high. Around one million people per year are being added, which would lead to a doubling of the urban population by 2020.

The percentage of people in poverty is lower in urban areas in Vietnam than in rural areas. However, the poverty density is greater in urban areas i.e. there are more poor per square kilometer. This applies equally to the rapidly urbanizing areas in the hinterlands of the large cities and the intensively cultivated Red River and Mekong deltas. The economies of scale and agglomeration that underpin the existence and growth of cities mean that poor people can be raised out of poverty more cost effectively in urban areas than in rural areas. The extent to which urban areas are going to be home to an increasing percentage of the population of Vietnam calls for more investment in their infrastructure. It is estimated that the urban population growth would be 3%/year that leads to the urban ratio in 2030 is around 42% of total population (twice of the year 2001).

In 2011, General Statistics Office (GSO) of Vietnam published the projection for Vietnam population in the period 2009-2049 (Vietnamese GSO, 2011). According to GSO's projections, the population of Vietnam in the year 2049 will be 108.7 mil. people (medium variant), 119.8 mil. people (high variant), 98.3 mil. people (low variant) and 111.8 mil. people (constant variant). The total population and population growth rate projection of urban and rural Vietnam is shown in Figure 4.10.

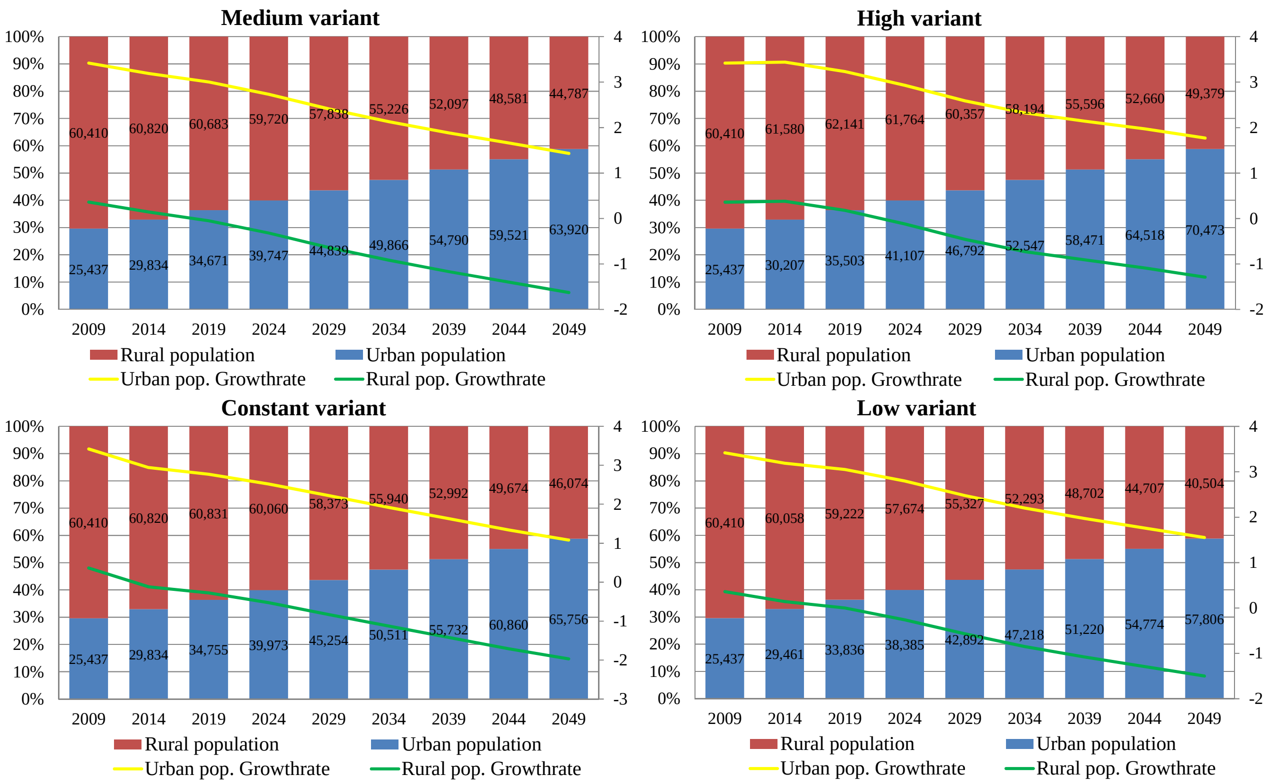

Figure 4.10: Projection of Vietnam total population and population growth rate

Source: Vietnamese GSO (2011)

4.2.2 Economic status and development targets

Vietnam's economy was in a state of constant flux from 1977 to 2003. This situation began with a sharp decline of the GDP, from 1977 to 1980, then followed with a rapid GDP recovery from 1980 to 1986 and another slowdown in the late eighties (Pham *et al.*, 2007). In 1986, the Vietnamese Government introduced Doi Moi, a policy of radical reform to promote economic development and trade liberalization. Since then the economic structure has been more closely interconnected with regional and even global forces, with a growing reliance on foreign direct investment (Tarp *et al.*, 2003). According to Pham *et al.* (2007), the collapse of the Soviet Union in 1989 incited a frantic search for changing ideas and development models in Vietnam from 1986 to 1990. Vietnam's economy settled into a period of smoother progress from 1990 to 1996, then faltered and lost ground again from 1996 to 1999. Since 2000, the economy has been steadily growing.

According to Ministry of Planning and Investment (Vietnamese MOPI, 2011), Vietnam is trying to achieve the 7-8% GDP growth per year that makes the GDP in 2020 more than double that of 2010, and the GDP per capita in 2020 will be around 3,000USD. Table 4.1 summarizes the economic development targets of Vietnam towards 2050. In which, the country will continue to shift from agriculture-based to industry-and-service-based economy.

Table 4.1: Economic development targets of Vietnam

Major targets	1996-2000	2005	2010	2011-2020	2021-2030	2031-2040	2041-2050
GDP growth (%/year)	**6.9**	**7.5**	**6.5**	**7**	**7**	**7**	**6**
AGR-FRS-FSH	4.4	3.83	3.5	3	2.5	2	2
IND-CNS	10.6	10.23	10	10	8.5	7	6
CSS	5.7	7	7	8.4	8.3	7.5	6.9
Shift in economic structure (% of total)							
AGR-FRS-FSH	24.5	21	17.1	10.8	6.9	4.6	3.2
IND-CNS	36.7	40.9	45	50.1	51.1	49.7	46.6
CSS	38.8	38.2	37.9	39	42	45.8	50.2

Source: Vietnamese MOIT (2011)

4.3 Energy outlook of Vietnam

4.3.1 Energy development in Vietnam

While the Vietnamese economy has grown fast over recent years, energy demand has expanded even faster. GDP per capita of Vietnam reach 724 USD in 2006, though the country is still among the late developing group of the ASEAN countries. Annual energy consumption per capita is also small with 0.3 TOE compared with ASEAN countries. Vietnam has rich energy resources such as coal, oil, natural gas, hydropower and renewable energies, maintaining energy self-sufficiency. Vietnam was net energy export country but recently has to import coal and electricity from neighbor countries due to the high economic growth and the energy inefficiency situation.

Table 4.2: Primary energy demand and domestic production outlook

Primary energy demand and supply (KTOE)	2005	2010	2015	2020	2030
Primary energy demand	**43,832**	**63,023**	**110,627**	**171,828**	**317,391**
Domestic production	**61,145**	**76,237**	**93,780**	**103,994**	**121,792**
Coal	18,271	25,440	30,960	35,482	42,000
Crude Oil	18,120	20,217	20,360	21,073	20,360
Gas	6,205	7,759	12,772	14,040	18,000
Hydro Power	3,762	7,259	12,614	12,919	14,586
Small Hydro Power		428	904	2,104	6,042
Renewable energy	14,788	15,134	16,170	18,378	20,805
Remain/Import	17,313	13,214	16,847	67,834	195,599

Source: Vietnamese Institute of Energy (Pham, 2007)

Table 4.2 shows the change in primary energy demand and domestic production of energy in recent years as well as projection from Institute of Energy (Pham, 2007) in order to support Vietnamese Government in developing appropriate energy development plan. Similarly, the final energy demand outlook of Vietnam is shown in Table 4.3.

Table 4.3: Final energy demand outlook

Final energy demand (KTOE)	2005	2010	2015	2020	2025	2030
Industry	11,454	15,875	25,579	39,496	52,946	65,996
Agriculture	532	728	941	1,085	1,189	1,348
Transport	6,401	10,423	17,437	26,665	40,738	52,120
Commerce	2,009	3,112	5,261	7,687	10,136	12,084
Residence	319	4,390	13,088	21,748	31,927	41,518
Total	**20,715**	**34,528**	**62,306**	**96,681**	**136,936**	**173,066**

Source: Vietnamese Institute of Energy (Pham, 2007)

4.3.1.1 Coal

In 2008, the Vietnamese Government approved the strategy on development of coal industry up to 2015 with the vision to 2025 (Vietnamese Government, 2008c). The main strategy is to develop Vietnam's coal industry into a developed and highly competitive industry with advanced technological level compared to the regional level in all stages of coal exploration, mining, sieving, sorting, processing and use, which will be capable of basically meeting the domestic demand and ensuring national energy security.

Main objectives of coal industry development program in Vietnam are:

a) *Coal exploration*: To strive to completely explore and assess the northeastern coal basin's natural resources below the -300m level and thoroughly explore part of natural resources of the Red River delta's coal basin by 2010; to completely explore and assess natural resources of the Red River delta's coal basin by 2015. To step up exploration for increasing verified coal reserves and upgrading existing reserves in order to ensure sufficient reliable coal reserves to be mined during 2008-2025.

b) *Coal mining*: To strive for the target that the output of clean coal of the northeastern coal basin and other coal mines (other than the Red River delta's coal basin) will reach 48-50 mil. tons by 2010; 60-65 mil. tons by 2015; 70-75 mil. tons by 2020; and over 80 mil. tons by 2025. The target up to 2010 is to invest on a pilot basis in some projects in the Red River delta's coal basin with traditional mining technologies such as pit mining, coal gasification and liquefaction, serving as a basis for post-2010 development investment.

c) *Coal sieving, sorting and processing*: From now to 2015, to strive to develop coal processing in the direction of diversifying products (instant fuel, coal used for metallurgy, gasified coal, liquid fuel from coal, raw materials for the chemical industry, etc.).

d) *Environmental protection*: To strive to basically prevent environmental and water source pollution by 2010; by 2015, principal environmental indicators must basically be improved in sensitive areas (urban centers, residential areas, tourist sites, etc.), and mines must satisfy environmental standards; by 2020, environmental standards must be fully satisfied in the entire mine region.

e) *Coal market*: The coal industry will switch to operate under the State-controlled market mechanism integrated into regional and international markets.

4.3.1.2 Oil, gas and Petroleum products

Vietnam, though producing crude oil, previously had no oil refinery that has to import petroleum products. The Dung Quoc refinery with crude capacity of 148,000 barrels/day was completely constructed at Central of Vietnam in Feb. 2009. The second oil refinery is under construction as a joint venture (named Nghi Son refinery and Petrochemical Limited Liability Company). The joint venture is considering the basic design and economy of the complex and fundraising methods in a bid to launch the complex in 2013, with around 70% of the total cost is covered by Japan Bank for International Cooperation. The third oil refinery is planned in BaRia-VungTau Province, southern Vietnam. Even the three refineries are completed; they may fall short of meeting all petroleum product demand in Vietnam.

Vietnam has had a short history for gas development. Its gas industry emerged through the development of associated gas from the Bach Ho oilfield in mid-1990 and an offshore gas field in Nam Con Son in 2001. Vietnam features a larger number of small gas fields, forcing a great number of wells to be dug at higher costs. But Vietnam’s gas prices are the lowest in Southeast Asia excluding Malaysia that has implemented a policy to limit gas prices.

4.3.1.3 Electricity

Figure 4.11 displays the zoning power system from Northern to Central and Southern regions of Vietnam in order to meet the National power master plan VII.

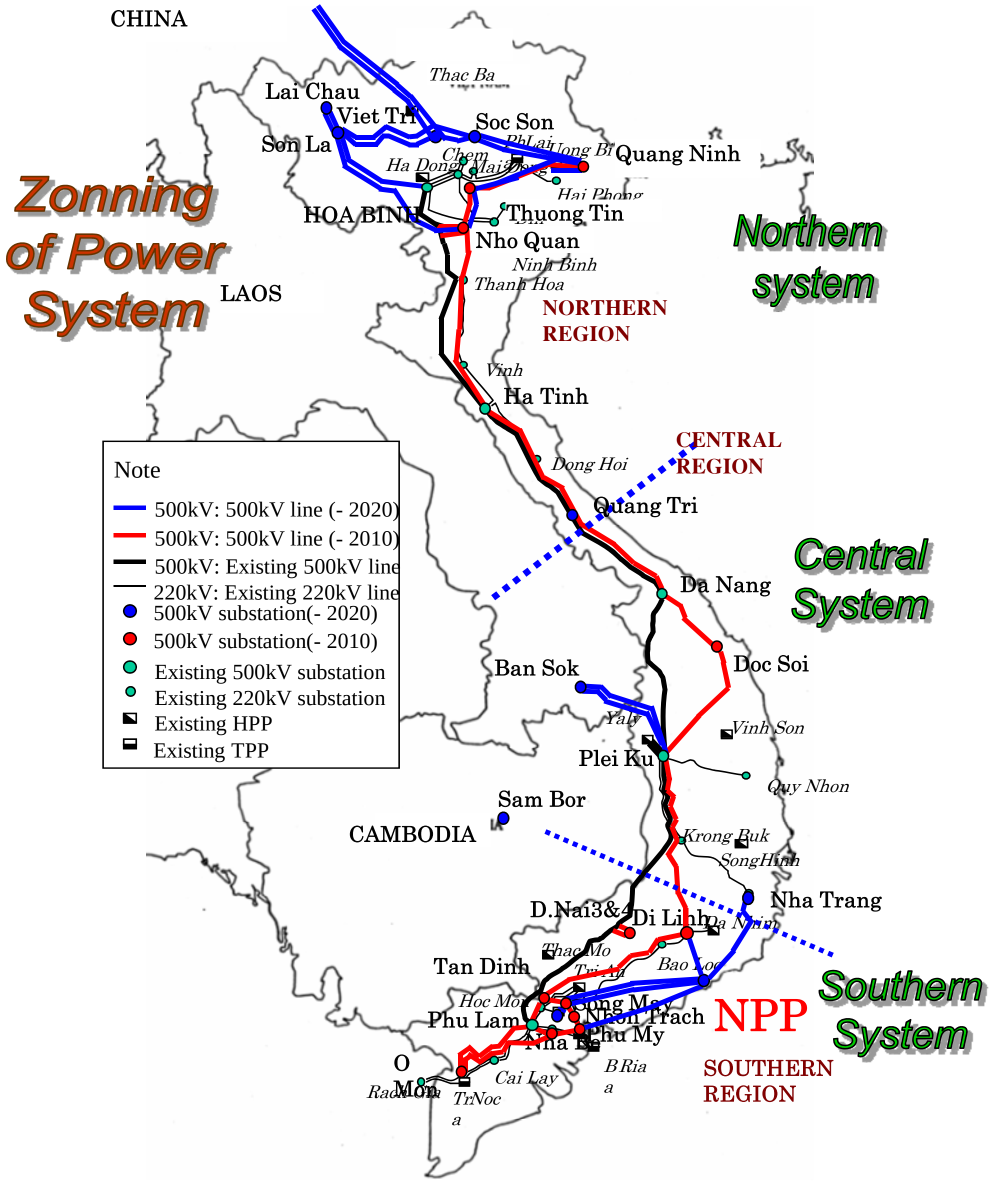

Figure 4.11: Map of Zoning power system in Vietnam

Source: Vietnamese Institute of Energy (Pham, 2007)

Thanks to this zoning system, the electrification level of Vietnam is very high, almost 100% in urban area and around 95% in rural areas (in the year 2010). The whole country power system consists of 3 regional power systems:

- Northern power system: including Northern provinces from Ha Tinh to the North.
- Central power system: including central provinces from Quang Binh to Khanh Hoa and four provinces in Highlands: Kon Tum, Gia Lai, Dac Lac, Dac Nong.
- Southern power system: including southern provinces and provinces of Binh Thuan, Ninh Thuan, Lam Dong. Ninh Thuan is the province where NPP 1 and 2 are located (as shown in the map below).

➢ **Summary of Vietnam Power Master Plan VII** (Vietnamese Government, 2011a)**:**

The Power Master Plan VII sets out four specific targets for Vietnam's power development in the next 20 years:

1. Increase the aggregate output of imported and produced electricity from 194-210 bil. kWh by 2015 to 330-362 bil. kWh by 2020 and 695-834 bil. kWh by 2030.
2. Give priority to the development of power generation from the renewable energy so that the proportion of electricity generated from the renewable energy will be increased from the present 3.5% of the total electricity production to 4.5% in 2020 and 6% in 2030.
3. Reduce the average energy elasticity ratio (the ratio between the growth rate of energy consumption and the growth rate of GDP in the same period) from the current 2.0 to 1.5 in 2015 and 1.0 in 2020.
4. Promote the rural electrification program in rural, mountainous and island areas so that most of the rural households will have access to the electricity by 2020.

The Power Master Plan VII emphasizes a balanced development of power sources in each region of the country (North, Central and South Vietnam) to ensure the power source reserve capacity is shared effectively and the power supply in each region of the country is reliable. It envisages that the aggregate power generation capacity of all the power plants in Vietnam will be increased to about 75,000 MW by 2020 (with produced and imported electricity reaching 330 bil. kWh) and 146,800 MW by 2030 (with produced and imported electricity reaching 695 bil. kWh). Table 4.4 shows the detail of electricity production by energy types.

Table 4.4: Summary of targeted electricity production capacity of Vietnam

National Power Master Plan VII	Targeted Electricity Production Capacity								
	2010	**by 2020**				**by 2030**			
	Electricity Output	**Power Capacity**		**Electricity Output**		**Power Capacity**		**Electricity Output**	
	% of total	(MW)	% of total	(bil. kWh)	% of total	(MW)	% of total	(bil. kWh)	% of total
Wind Power	-	2,775	3.7	9.9	3	10,423	7.1	31.3	4.5
Biomass Power	-	1,425	1.9	5.0	1.5	3,376	2.3	10.4	1.5
Hydro Power	38	17,325	23.1	58.8	17.8	17,322	11.8	43.8	6.3
Pumped Storage Hydropower	-	1,800	2.4	5.9	1.8	5,725	3.9	20.9	3
Gas-fired Thermal Power	2.2	10,425	13.9	66.1	20	10,716	7.3	73.0	10.5
Coal-fired Thermal Power	18.5	36,000	48	154.6	46.9	75,749	51.6	392.0	56.4
Nuclear Power	-	975	1.3	6.6	2	10,700	7.3	70.2	10.1
LNG Power	2.7	1,950	2.6	13.2	4	6,019	4.1	27.1	3.9
Gas turbine	31.4	-	-	-	-	-	-	-	-
Diesel	2.5	-	-	-	-	-	-	-	-
Imported Electricity	4.7	2,325	3.1	9.9	3	6,753	4.6	26.4	3.8
TOTAL	**100**	**75,000**	**100**	**330**	**100**	**146,800**	**100**	**695**	**100**

Source: Decision No. 1208/QD-TTg (Vietnamese Government, 2011a)

Coal-fired power plants will still remain the most important source of electricity in Vietnam. To secure the supply of coal, Vietnam will speed up its negotiations with other nearby countries to import coals from them on a long-term and stable basis. On the other hand, the State will give its top priority to the development of power sources from renewable energies such as hydropower, wind power, solar power and biomass power in the next decade, especially hydropower projects with multiple functions (e.g., flood control, water supply, and power production). Financial incentives will also be given to enterprises that develop new and renewable energy from agricultural wastes and garbage of the cities. The State targets to put the first nuclear power plant into operation in 2020 and develops more NPPs going forward with the hope that electricity generated from nuclear energy will account for about 10.1% of the total power output by 2030.

Table 4.5: Vietnam Power demand forecast

Power demand forecast	2005		2010		2015		2020		2025	
	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%
Low case										
Sale	45,603	**100**	91,948	**100**	146,898	**100**	216,433	**100**	308,511	**100**
Generation	53,462		106,669		169,238		247,352		349,390	
Peak (MW)	9,255		18,100		28,046		40,052		55,395	
Consumption per cap. (kWh/cap.annum)	548		1,048		1,579		2,189		2,997	
Base case										
Sale	45,603	**100**	97,111	**100**	164,961	**100**	257,260	**100**	381,160	**100**
Generation	53,462		112,658		190,047		294,012		431,664	
Peak (MW)	9,255		19,117		31,495		47,607		68,440	
Consumption per cap. (kWh/cap.annum)	548		1,106		1,774		2,629		3,703	
High case										
Agriculture-Forest-Fishery	574	1.26	1,272	1.26	1,672	0.97	2,109	0.79	2,658	0.67
Industry-Construction	21,302	46.71	48,201	47.65	84,958	49.29	135,398	50.60	204,149	51.76
Commercial-Service	2,162	4.74	6,354	6.28	10,828	6.28	17,719	6.62	28,750	7.29
Household-Management	19,831	43.49	39,654	39.21	62,412	36.21	88,692	33.15	123,089	31.21
Others	1,734	3.80	5,665	5.60	12,485	7.24	23,643	8.84	35,741	9.06
Sale	45,603	100.00	101,148	100.00	172,354	100.00	267,561	100.00	394,388	100.00
T&D losses		12.00		10.80		9.60		8.50		7.50
Plant use		2.70		3.00		3.60		4.00		4.20
Generation	53,462		117,341		198,565		305,784		446,645	
Peak (MW)	9,255		19,911		32,906		49,513		70,815	
Consumption per cap. (kWh/cap.annum)	548		1,152		1,853		2,734		3,831	

Source: Vietnamese Institute of Energy (Pham, 2007)

The reduction of energy elasticity ratio from the current 2.0 to 1.0 by 2020 as highlighted as a specific target in the plan will also considerably cut the investment required to accelerate the power generation after 2015 and help solve the problem of coal supplies to thermal power plants. The State's attitude to gradually abolish the price subsidies on electricity tariffs will also exert a considerable pressure on household consumers and companies in Vietnam to use electricity more efficiently. With a combination of efforts on balanced development of power sources, investment in energy efficiency and power market liberalization, the Power Master Plan VII will hopefully show a higher possibility of satisfying the power need of the fast-growing economy of

Vietnam. The Institute of Energy of Vietnam also provides forecast for the power demand (as shown in Table 4.5).

<u>4.3.1.4 Nuclear Power</u>

On November 25th 2009, Viet Nam's National Assembly approved the Government Plan on the implementation of the Ninh Thuan Nuclear Power Project composed of two NPP called Ninh Thuan 1 and Ninh Thuan 2. According to the Power Master Plan VII (Vietnamese Government, 2011a):

- Ninh Thuan 1 NPP consists of 4 units x 1,000 MW, the first two units will be put into operation in the 2020-2021, the units 3 and 4 in 2024-2025;
- Ninh Thuan 2 NPP consists of 4 units x 1,000 MW, the first two units will be put into operation in 2021-2022, the units 3 and 4 in 2026-2027.

Thus, from 2020 to 2027, there will be 1,000 MW of nuclear power being put into operation each year. Two other NP units x 1,350 MW in the Central planned to put into operation in 2028-2029. By 2030, there will be 10 NP units with total capacity of 10,700 MW. Nuclear power capacity of Vietnam will increase from 1,000 MW (1.5%) in 2020 to 6,000 MW (6.2%) in 2025 and 10,700 MW (7.3%) in 2030. As a newcomer – country embarking on nuclear power, Vietnam is facing many challenges (Le, 2011):

- *First*, the shortage of human resources necessary to almost relevant aspects, such as law and regulation, management, science and technology, etc., while capacities of Vietnam's education and training institutions are still limited;
- *Second*, nuclear power development from a low level of infrastructure, including legal framework, competent regulatory body, Technical Support Organization, research & development organizations;
- *Third*, Assessment and selection of reactor technology meeting criteria put by the Government (Generation III, III+, proven, affordable to transmission grid, etc.);
- *Fourth*, Financing and investment, including infrastructure development, work force training, resettlement;
- *Fifth*, Assuring safety, security, and non – proliferation requires to become parties of some international instruments (Additional Protocol-AP, Convention on the Physical Protection of Nuclear Material-CPPNM and the Amendment, Vienna Convention, Joint Convention);
- *Sixth*, Fukushima accident raises more public concern, requests re-view of nuclear safety and related issues, at the results, licensing time and construction period will be prolonged and project cost will increase, etc.;

- *Seventh*, implementing two projects with two partners of different technical regulations and standards on sitting, technologies, etc. also cause difficulties to formulation of regularity documents.

4.3.1.5 Renewable energy

Vietnam is endowed with a relatively large amount of renewable energy resources distributed throughout the country. Biomass from agricultural products and residues is available at equivalent to 10 million tons of oil a year. Biogas energy potential is approximately 10 bil. m^3 a year, which can be collected from landfills, animal excrements and agricultural residues. The technical potential of small hydropower (<30 MW) is larger than 4,000 MW. Solar energy is abundant with average solar radiation at $5kWh/m^2$ per day throughout the country. Vietnam's geographic orientation with approximately 3400km of coastline also provides abundant wind energy at an estimated potential of 500-1000 kWh/m^2 per year. These alternative sources of energy can be harnessed to meet Vietnam's rapidly increasing demand for energy. While there has been some early success, deployment of renewable energy has not reached the country's potentials yet.

Vietnam's renewable energy policies are driven by the needs to supply sufficient energy for economic development and ensure environmental protection. Since energy demand is expected to increase dramatically in the future, developing renewable capacity will help Vietnam reduce its reliance on foreign sources of energy and ensuring ample energy security.

For biofuels, the Government has targeted an annual output of 100,000 tons of E5 and 50,000 tons of B5 by 2010 which is equivalent to 0.4% of the country's projected oil and gasoline demand; 1.8 million tons of ethanol and vegetable oil, or 5% of oil and gasoline demand by 2025 (Decision No. 177/2007/QD-TTg) (Vietnamese Government, 2007b). E5 is gasoline with a 5% volumetric of bio-ethanol content; B5 is diesel with a 5% volumetric of biodiesel content.

In order to achieve these targets, the Government has provided various incentives to investors. Renewable energy power plants will receive incentives for investment, electricity tariffs and taxes. Investors can enjoy advantages such as import tax exemption and land fee exemption over a certain period of time. The existing incentives however are not sufficient yet to create the appropriate conditions for planning and implementing numerous renewable projects as well as the sale of renewable energy products in Vietnam. These incentives are beneficial to small hydropower projects only and not to other forms of renewable energy.

Biomass is a major component of non-commercial energy in Vietnam. It has more than 50% share in national energy balance in the past and will continue in the same status in the future (at least until 2020). It is the main energy source in rural area where 70-80% of the population still uses biomass mostly for heating and cooking with the share of about 98% of energy consumption in this area. Currently, biomass energy use is mainly for rural household cooking, and small industries. The use of biomass energy for households includes: meal cooking, pigfeed preparation, heating and food processing at household scale, which accounts for the major rate (about 76%) of total biomass energy consumption. The remaining rate (24%) is used for small industries such as food processing, agro-processing, building materials production, porcelain and pottery.

➢ **Energy conversion technologies for biomass use in Vietnam:**

- Household cookstoves:
    - It is estimated that about 80% of households use traditional cooking stoves (or tripod stoves) for meal cooking. The efficiencies of these stove types vary from 8 to 15%, depending on how they are used. The popular use of tripod stoves with low efficiencies is one of major reasons for depletion of the local biomass resources in Vietnam rural areas. The solutions to improve the heat efficiency of stoves have been carried out in many years that can result in saving the time needed for fuelwood collection or in terms of money-for the population who buy fuelwood and also in environmental protection. Many types of improved cooking stoves are being performed in rural areas, especially the less smoke improved cooking stove program that was carried out in Ninh Binh province with number of over 20 thousands of chimneyed improved cooking stoves being used. The efficiency of these stoves is around 25% that can save 30- 40% of fuelwood.
- Small-scale industries:
    - *Food Processing*: With regard to technologies and equipment used by the food processing sector, a little information on the small-scale noodle and tofu making is available. Stoves used in restaurants and for small-scale food-processing such as noodle and tofu making, sometimes are similar to ones used by the domestic sector, only the sizes are larger. Processing is manual: grinding of rice into flour for noodles and of soy beans for tofu making. Fuel used varies depending on the availability, but noodle making requires a well and long-burning fuel (such as fuel wood).
    - *Agro-processing* is done both on large and small scales. Again, not much information has been available. Most of the crude sugar is processed by small to

medium-sized units. The fuel used is bagasse which is available during cane crushed.

- *Tea* is an important export crop of Vietnam. The export qualities are processed in larger factories. Many farmers in the north grow tea for domestic consumption. Unlike black tea, which needs heat for drying after the leaves have been cut and twisted, the green tea widely used in Vietnam is only dried. The tea leaves, after picking, are spread out on a thick metal plate which the sizes are about 1.5 m. This metal plate is supported at walls, which enclose at the same time the furnace, at a height of about 70 cm above ground level. Fuels consist of anything (such as wood, leaves, etc.) that is burnt in this combustion space. Care is taken that the metal plate does not get too hot to avoid the tea leaves from the burning.
- *Brick and tile production* are the larger consumers of biomass energy in this sector that use different types of kilns depending on the type of fuel used. Wood-fired kilns for bricks and tiles, which mainly used in the south and south-central part of Vietnam. In general, the brick and tile kilns have low or medium efficiency.

4.3.2 Energy price in Vietnam

As Vietnam depends on imports of oil and petroleum products from international market, prices of these products in the country are based on international levels. But domestic coal and gas prices for power plants are set at lower levels. In 2006, coal prices for domestic power plants stood at some 20 USD per ton against export prices around 35 USD. Associated gas prices are separated from natural gas prices. Domestic gas prices for power plants are far lower than the international standard of 7-8 USD/mmBtu. Domestic coal prices for power plants, though planned to shift to market levels, are now 30% lower than domestic market prices and 50% less than export prices.

Table 4.6: Energy price of Vietnam (in 2006)

Energy type	Unit	Price (in 2006)	
		VND	USD
Domestic coal	ton	336,800	21.05
Exported coal	ton		35.7
Natural gas	mil. Btu		3.2
Oil-associated gas	mil. Btu		2.1
Gasoline	liter	10,279	0.64
Diesel oil	liter	8,029	0.5
Kerosene	liter	8,029	0.5
Fuel oil	liter	5,400	0.34
LPG	kg	14,842	0.93
Agricultural electricity	kWh	660	0.04
Industrial electricity	kWh	829	0.05
Commercial electricity	kWh	1,359	0.08
Household electricity	kWh	695	0.04
Average electricity price	kWh	789	0.05

Source: Vietnamese Institute of Energy (Pham, 2007)

Electricity prices are limited under government policy to as low as 0.05 $/kWh on average. Summary of Vietnam energy price (for the year 2006) is in Table 4.6. The energy price change is very sensitive since it affects the change in price of other goods and services in the whole economy.

- **Electricity price in Vietnam:**

In Vietnam, the government sets electricity prices while providing no subsidies to electricity utilities. But the government has led fuel suppliers to supply fuels (coal and gas) for power plants at lower-than-market price levels. Since 2009, Vietnamese Government has introduced a progressive pricing system for different utilizers, in which the latest pricing system is from the Regulation No. 42/2011/TT-BCT (Vietnamese MOIT, 2011).

Vietnam is considering introducing a market mechanism for electricity prices. The MOIT plans to introduce a market-based electricity price adjustment mechanism in consideration of electricity utilities' generation levels, business performances and average prices while consulting with the Ministry of Finance (MOF). Under the mechanism, an electricity sales price control task force may examine the adjustment level for approval by MOIT if the level is within 5% of the average electricity sales price approved for the previous year. If the adjustment level exceeds 5% of the previous year's average price, the level may be considered by the MOIT and examined by MOF before approval by the premier. Table 4.7 and Table 4.8 show the electricity pricing system in Vietnam in recent years, by household areas and by purpose, respectively. In which, rural households have lower electricity price compared with urban areas.

Table 4.7: Household electricity pricing system of Vietnam

Electricity price (VND/kWh)	Dec. 2006	Feb. 2009	Feb. 2010	Mar. 2011	Dec. 2011
1. For rural households					
First 50 kWh	390	420	432	807	807
51 - 100 kWh	390	605	753	981	981
101 - 150 kWh	713	795	886	988	1,054
151 - 200 kWh	1,005	1,120	1,227	1,279	1,335
201 - 300 kWh	1,090	1,215	1,326	1,384	1,455
301 - 400 kWh	1,171	1,305	1,420	1,477	1,556
From 401 kWh	1,207	1,345	1,455	1,515	1,607
2. For urban households					
First 50 kWh	550	600	600	993	993
51 - 100 kWh	550	865	1,004	1,242	1,242
101 - 150 kWh	1,110	1,135	1,214	1,304	1,369
151 - 200 kWh	1,470	1,495	1,594	1,651	1,734
201 - 300 kWh	1,600	1,620	1,722	1,788	1,877
301 - 400 kWh	1,720	1,740	1,844	1,912	2,008
From 401 kWh	1,780	1,790	1,890	1,962	2,060

Source: Regulations on electricity prices in Vietnam (Vietnamese MOIT, 2011)

Table 4.8: By-purpose electricity pricing system of Vietnam

Electricity price (VND/kWh)	Dec. 2006	Feb. 2009	Feb. 2010	Mar. 2011	Dec. 2011
1. For production					
Above 110kV					
Normal hours	785	835	898	1,043	1,102
Low-peak hours	425	455	496	646	683
High-peak hours	1,590	1,690	1,758	1,862	1,970
22kV - 110kV					
Normal hours	815	870	935	1,068	1,128
Low-peak hours	445	475	518	670	710
High-peak hours	1,645	1,755	1,825	1,937	2,049
6kV - 22kV					
Normal hours	860	920	986	1,093	1,164
Low-peak hours	480	510	556	683	727
High-peak hours	1,715	1,830	1,885	1,999	2,049
Below 6kV					
Normal hours	895	955	1,023	1,139	1,216
Low-peak hours	505	540	589	708	767
High-peak hours	1,775	1,900	1,938	2,061	2,185
2. For irrigation					
Above 6kV					
Normal hours	600	645	690	956	1,013
Low-peak hours	240	255	281	497	526
High-peak hours	1,140	1,220	1,269	1,415	1,500
Below 6kV					
Normal hours	630	670	717	1,023	1,084
Low-peak hours	250	265	292	521	553
High-peak hours	1,200	1,280	1,331	1,465	1,553

Electricity price (VND/kWh)	Dec. 2006	Feb. 2009	Feb. 2010	Mar. 2011	Dec. 2011
3. For public organization/services					
Hospital, kindergarten, schools					
Above 6kV	875	950	1,009	1,117	1,184
Below 6kV	920	1,000	1,063	1,192	1,263
Public lighting					
Above 6kV	965	1,060	1,124	1,217	1,290
Below 6kV	1,005	1,110	1,177	1,291	1,369
Governmental offices					
Above 6kV	990	1,090	1,159	1,242	1,316
Below 6kV	1,030	1,135	1,207	1,291	1,369
4. For business					
Above 22kV					
Normal hours	1,410	1,540	1,648	1,713	1,808
Low-peak hours	770	835	902	968	1,022
High-peak hours	2,615	2,830	2,902	2,955	3,117
6kV - 22kV					
Normal hours	1,510	1,650	1,766	1,838	1,939
Low-peak hours	885	960	1,037	1,093	1,153
High-peak hours	2,715	2,940	3,028	3,067	3,226
Below 6kV					
Normal hours	1,580	1,725	1,846	1,862	1,965
Low-peak hours	915	995	1,065	1,142	1,205
High-peak hours	2,855	3,100	3,193	3,193	3,369

Source: Regulations on electricity prices in Vietnam (Vietnamese MOIT, 2011)

4.3.3 Energy saving, efficiency and conservation in Vietnam

Vietnam has been preparing energy efficiency and conservation law since 2003 for different utility purposes. With the latest Law in 2010 (Vietnamese Government, 2010c), the energy efficiency and conservation goals are a 3-5% cut in cumulative energy consumption between 2006-2010 and a 5-8% cut in cumulative energy consumption between 2011-2015. Energy conservation centers have been established by the government or provincial peoples' committees in Hanoi, Ho Chi Minh City, Phu Tho and other cities. Unlike similar centers in Japan, these centers have not been unified. These energy conservation centers implement energy conservation promotion operations and "energy conservation diagnoses" for nearby factories and business offices.

The specific targets of energy efficiency program in Vietnam are:

- Establishing and putting model of managing energy savings and effective use in operation including activities of state administration, management in enterprises, in buildings and social life.
- Popularizing high-efficiency equipment and gradually replacing the low efficiency ones, and then remove out-of-date equipment; reducing energy intensity in production; saving energy in all activities of social life.

- Exploiting maximally capacity of equipment and means of transportation; minimizing fuel consumption in transportation, carrying out pilot model of using alternative fuel in some big cities and provinces, restricting gas emission volume of means of transportation and protecting environment.

Moreover, Vietnamese Government also approved the Electricity saving program (Vietnamese Government, 2006b):

- Mobilizing the entire population to participate in electricity saving;
- Electricity saving at public offices, head-quarters of agencies;
- Electricity saving in daily life and service business;
- Electricity saving in industrial production;
- Electricity saving by units engaged in electricity production and business;
- Electricity saving for electric equipment;
- Economical and efficient lighting program;
- To disseminate the use of water heating equipment operated by solar energy and the use of other substitute energies.

4.3.4 Carbon Capture and Storage (CCS) in Vietnam

At the current stage, none of CDM projects is for a coal-fired power plant with CCS but there have been at least three proposals to include CCS projects under the CDM including the White Tiger Field project in Vietnam (IEA, 2008). It will involve the collection of CO_2 gas from combined cycle natural gas power plants in the Phu My power complex, and its transport, via a 144 km pipeline, to the injection site at While Tiger Oil Field (WTOF) with enhanced oil recovery.

The CCS project will have a high sustainable development value since it is likely to become the first commercial CCS project in Asia. It is expected to generate emissions reduction of approximately 7.7 mil. tCO_2 per year and the recovery of an average of 50 thous. barrels of crude oil per day as well as employment opportunities for the country (Nguyen, 2011). Therefore, the adoption of CCS technology for Vietnamese electric-power generation industry, which has high CO_2 emissions source from coal-fired generation plants, would be not an implausible scenario that allows for a better balance between industry expansion and environmental protection and potentially brings sustainable opportunities to the country through the Clean Development Mechanism or other like-CDM mechanism if any.

Domestic coal reserves, geological potential, rapid expansion of coal-fired electricity generation and pronounced climate change vulnerability all make CCS technology highly interesting mitigation options for Vietnam. The ability and prospects to capture and sequester CO_2 emissions offers a promising technology of significant CO_2 reduction in a way that is compatible with the future's fossil-fuel power generation industry while also allowing coal to meet the pressing needs for energy. Vietnam is expected to be heavily dependent on coal usage to fuel the development of power sector within next 30 years for meeting the increasing electricity needs. Moreover, Vietnam is estimated to have significant potential for underground geological storage of CO_2 emissions, a part through Enhanced Oil Recovery (EOR) and Enhanced Coal Bed Methane (ECBM). This explicitly provides opportunities to increase the CCS deployment in Vietnam's power sector.

In Vietnam, several investigations have been recently made by the Research Department of Geology and Mines of TKV, Ministry of Natural Resource and Environment, Vietnam (MONRE), and Bureau de Recherches Geologiques et Minieres (BRMG), France to estimate the potential for geological storage of CO_2. The estimates are using the following criteria:

- All formations of sediment whose thickness should be beyond 1,000 meters
- They should be 10 km away from the major faults
- Not more than 100 km away from CO_2 emitting sources (generation plants)

As results, there are promising opportunities for geologically storing the emissions of CO_2 under various forms:

- Enhanced Oil Recovery (EOR) in the river basin area of Cuu Long.
- Injection of CO_2 emissions into the oil fields already fully exploited in the river basin areas of Cuu Long and Song Hong, the North end.
- Enhanced Coal Bed Methane Recovery (ECBM) in Quang Ninh coal basin.
- The existing of hydrocarbon sources could potentially improve the added economic of CO_2 emissions in conjunction with EOR and EGR production

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Chapter 5 VIETNAM'S FUTURE LOW CARBON SOCIETY AND ITS IMPLICATIONS

Chapter 5 discusses the research results. Section 5.1 describes the vision of future society in Vietnam with a Scenario-for-Low-Carbon-Society (SLCS) and a Scenario-of-rather-STAGnant-Society (SSTAG). Section 5.2 analyzes the economic implications and Vietnamese climate change mitigation measures by 2050. Detail analysis of social implications is described in Section 5.3 while the energy and environmental issues of low carbon development in Vietnam is discussed in Section 5.4.

5.1 Visions of future society in Vietnam

Main socio-economic indicators are assumed for the future of Vietnam to be inputted in AIM/CGE[basic] model based on national projections. This national-based projection (Tran *et al.*, 2011a) is important in order to check and compare them with the results from AIM/CGE[basic] model which is under the same assumption of macroeconomic development.

5.1.1 National-based scenario for main socio-economic indicators

According to the Vietnam Ministry of Planning and Investment, the national development strategy focuses on utilizing the growth factors in large, including employment, capital and land. In order to go ahead in a sustainable manner, a sharp qualitative step forward in depth must be generated, especially in terms of transforming the economic structure, upgrading the level of technology and management, both at macro and micro levels. Vietnam targets that the production development should correspond to the market demand, strongly oriented to export, and at the same time oriented to an effective import substitution; as well as viewed to expand the domestic markets in order to improve the competitiveness and efficiency. The composition of exportable articles should be sharply moved from raw materials to after processing products, of which there are more and more articles with recognized trademarks in the world market.

In urban areas and in industrial estates, stress is placed in the development processing industries with new no-pollution technologies. As for industrial products specified both for consumption and export, it is required to rapidly increase the domestic content and improve their competitiveness. Moreover, energy industry and selected industries producing capital goods and technical equipment for economic and defense purposes will be developed to effectively implement programs on infrastructure building. In agriculture, the activities of agricultural extension and the application of new technologies, particularly biological technologies, should be promoted in order to improve both the productivity and the quality of products. Moreover, the Government also wants to ensure the macro-economic stability and make the nationals financial system healthy, both in terms of public finances and corporate finances, as well as people's financial situation.

5.1.1.1 Socio-economic indicators

Data for total population of Vietnam is collected from National Statistics Yearbook 2009 (SYB_2009) (for years before 2010). Some other national institutes also provide projections for population of Vietnam, but mainly up to year 2030 (as illustrated in Figure 5.1). The trend of each reference is not so much different compared to the others. After year 2030, the population growth rate is assumed to be decreased due to the current population development policy of the Vietnamese Government. The total population for this period is also estimated based on the assumed growth rate. The population of Vietnam in 2050 is projected to be about 120 mil., almost twice of the total population in year 2000. This assumption is almost same as projection from Vietnam General Statistics Office for the population projections for Vietnam 2009-2049 (MOPI, 2011b).

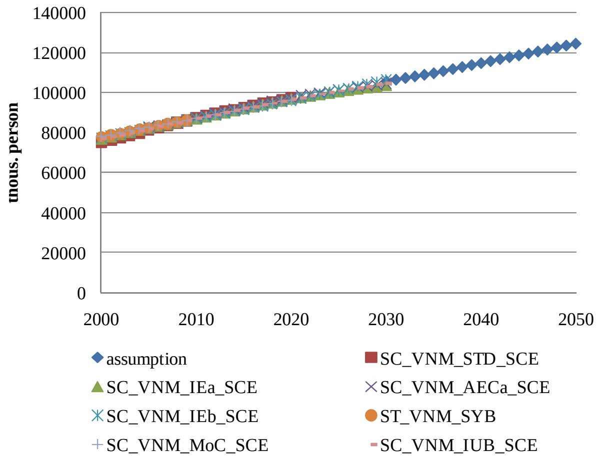


Figure 5.1: Total population scenarios of Vietnam

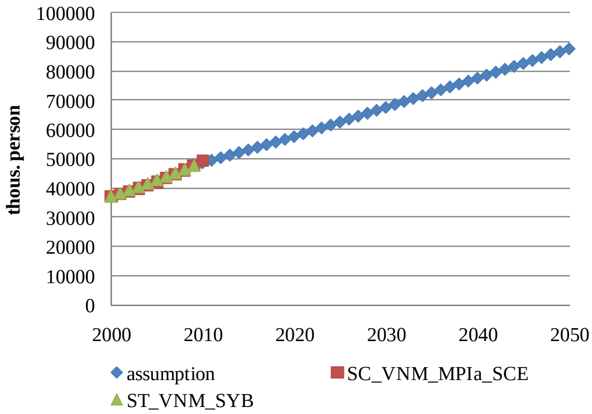


Figure 5.2: Total employment scenarios of Vietnam

In term of total employment, based on data from GSO (2009), it is estimated that each year, there are 1 mil. jobs generated. This is consistent with the target of Vietnamese Government development plan (8 mil. jobs shall be generated in 2010) (as shown in Figure 5.2). The total employment is projected to be about 90 mil. in 2050, nearly 2.5 times of year 2000. The shares of employment in economic sectors strongly affect the contribution to GDP. Therefore, it would be large transfer from agriculture sector to industrial and service sectors, especially to services. It is estimated that each 5-year period since 2015, 2% and 3% of employment from agriculture will move to industry and services, respectively. This assumption is used to estimate the employment in agricultural, industrial and service sectors.

The data for GDP is collected from SYB_2009 for historical information. Instead of having projection for GDP, most of references give targets for GDP growth rate and sectoral GDP contribution. We use these growth rate projections to assume the future GDP (see Figure 5.3). However, these growth rate scenarios are still very high compared to international projections. Among the references, only the Institute of Energy (SC_VNM_IEc_SCE) provides total GDP projection for the years up to 2050, however, this is very challenging projection that affect the contribution of economic sectors in the total GDP. Historical and projected data up to year 2030 show similar contribution of industries and services to the GDP at high level while that from agriculture is very low. According to the projection, the main contributor to GDP in the year 2050 would be commercial activities due to the governmental policy in investment on services.

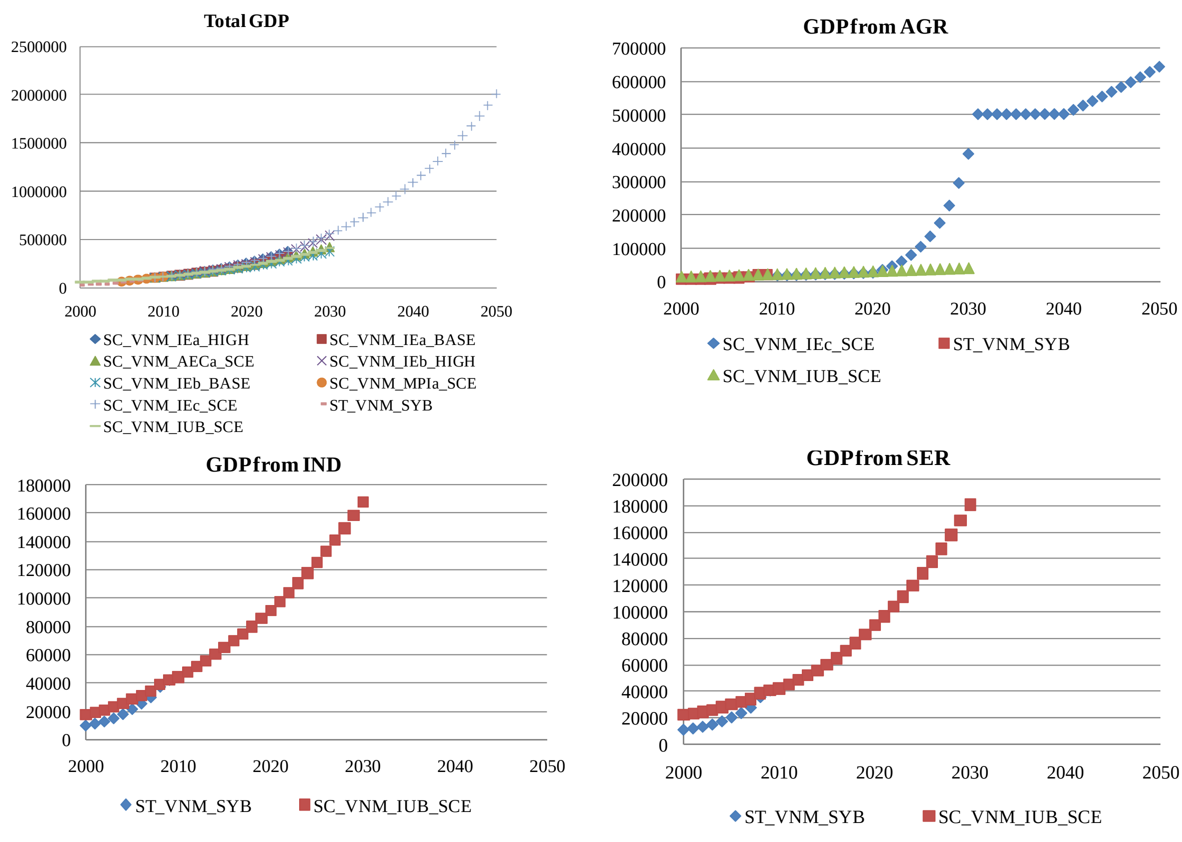


Figure 5.3: GDP scenarios of Vietnam (mil. 2005US$)

5.1.1.2 Housing and Transportation

The housing demand is projected to be driven by the increase of population and their income. The more income people can gain, the larger area people want to live in. It is assumed that the housing demand in Vietnam will be increased 4 times in 2030 compared to 2000. The projection of household floor demand is necessary for the simulation of household electricity consumption, especially for purposes of lighting, space cooling and heating.

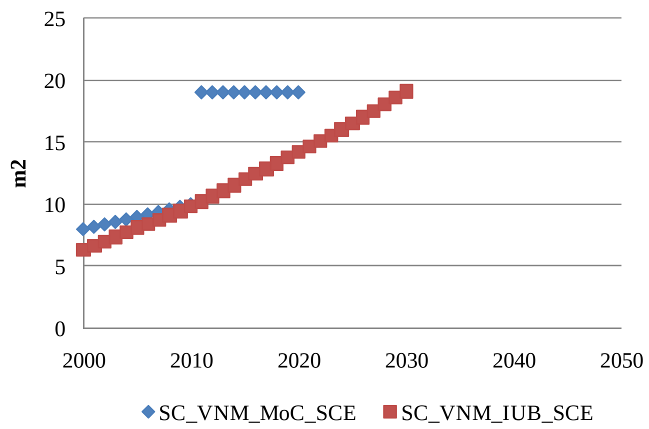


Figure 5.4: Floor area per person scenarios of Vietnam

Currently we can only obtain the projection of transportation demand up to year 2030 (as shown in Figure 5.5 and Figure 5.6). As illustrated in Figure 5.5, the passenger transportation demand is increasing in all transport modes, especially in road and aviation. The projection of year 2030 is about 3.5 times compared to 2000, average for all passenger transport modes.

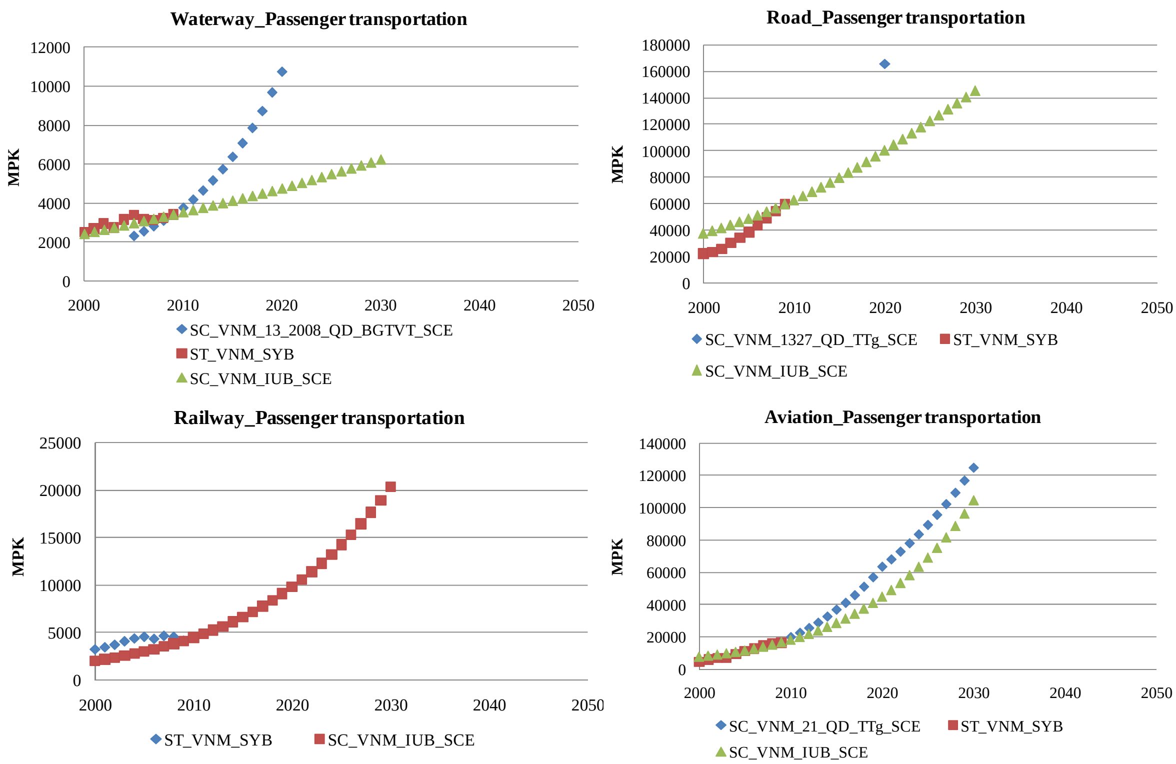


Figure 5.5: Passenger transportation volume (mil.passenger-km)

The freight transportation demand is also increasing in which road and waterway modes are still dominated. The increase of freight transport is higher than that of passenger. Increase of transportation demand, especially road transport as projected, may cause an increase in the consumption of petroleum products since they are main sources for road transportation in Vietnam.

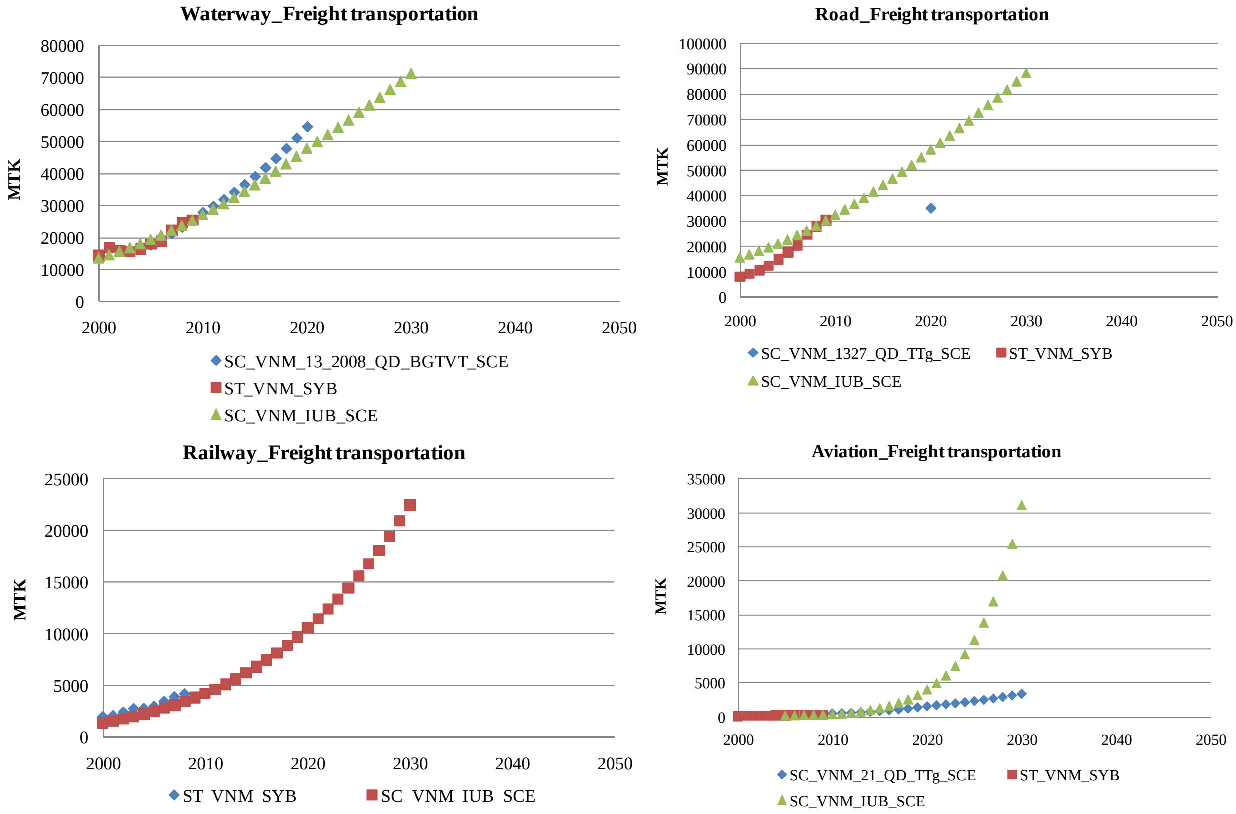
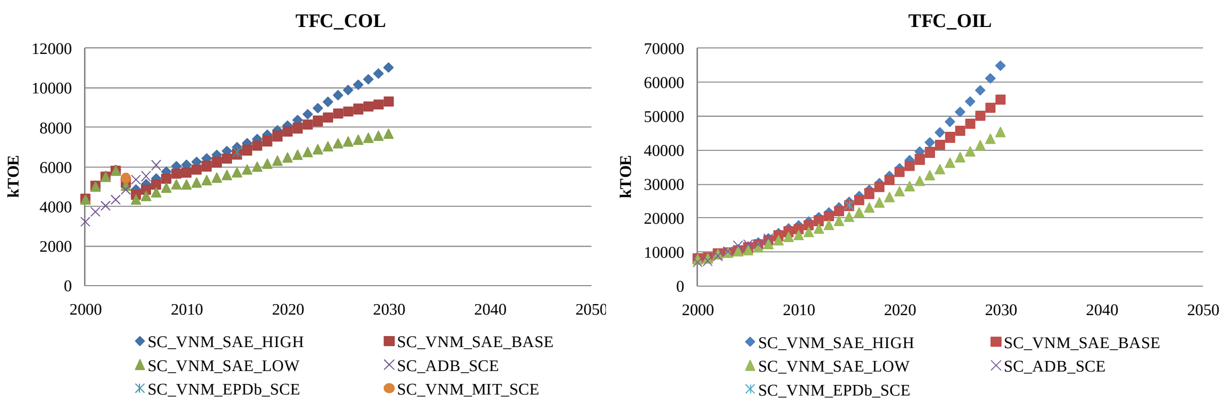


Figure 5.6: Freight transportation volume (mil.ton-km)

5.1.1.3 Energy consumption

Only projections up to year 2030 are obtained for energy consumption. Coal (TFC_COL) and oil (TFC_OIL) still dominate the energy mix of final consumption, followed by electricity consumption (TFC_ELY) while natural gas consumption (TFC_NGS) also increases same as other energy types but still keep very small proportion (as illustrated in Figure 5.7). The final consumption of oil is mainly for transportation, meanwhile part of the oil consumption and coal consumption are for industrial activities.



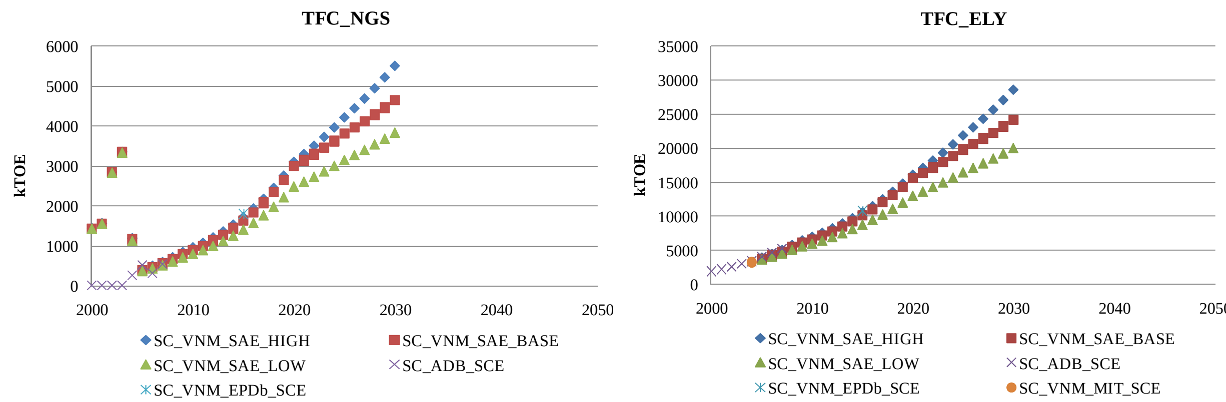
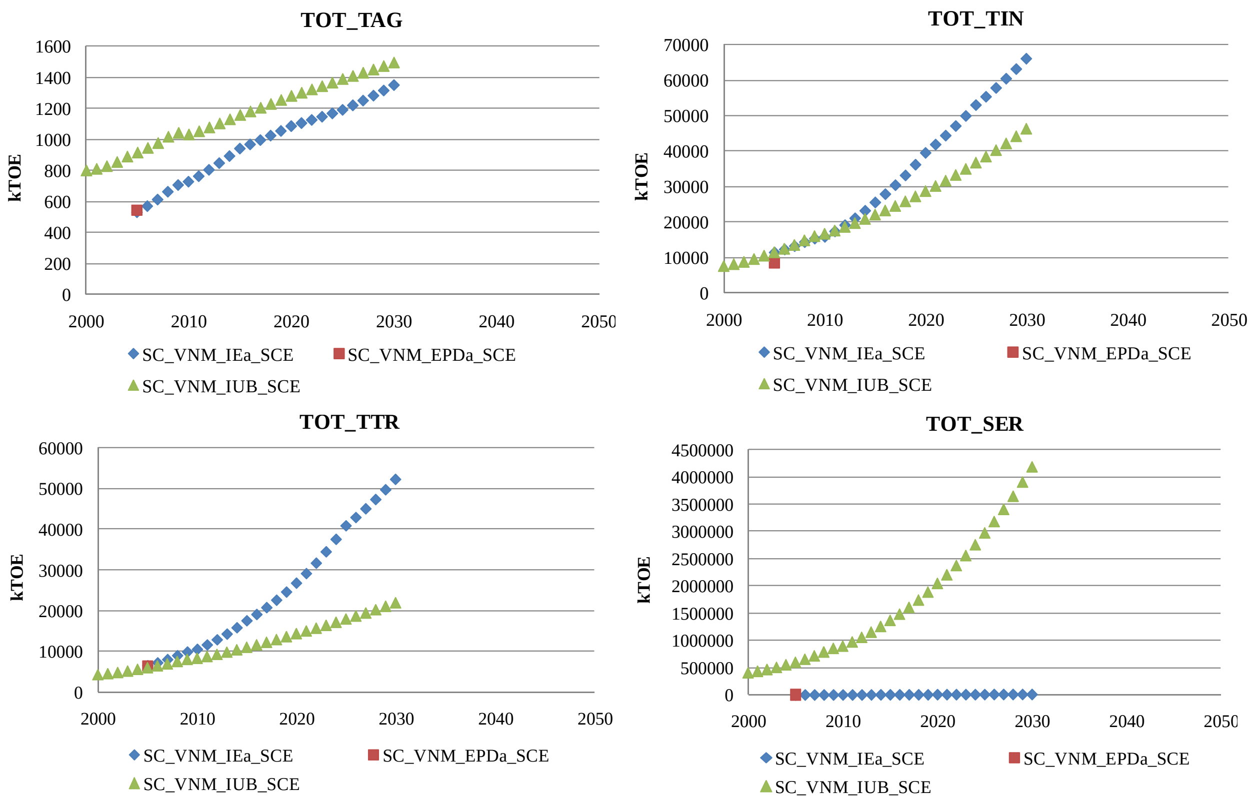


Figure 5.7: Total final energy consumption by energy types

According to Figure 5.8, industrial (TOT_TIN) and transport (TOT_TTR) sectors dominate the final energy consumption while agricultural (TOT_TAG) and residential sectors (TOT_RSD) have very small proportions. The service sector (TOT_SER) is projected to consume smaller than industrial and transport sectors, except one reference provides very high projection for it due to the assumption that tertiary sector will rapidly increase its share in total GDP of Vietnam in the future.



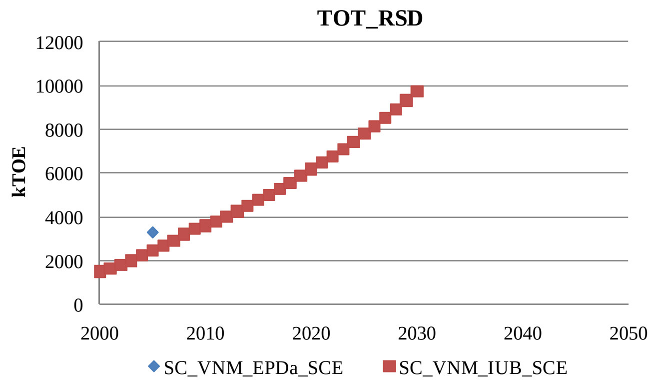


Figure 5.8: Total energy consumption by economic sectors

In summary, the above projection of housing and transportation demand, total final energy consumption by economic sectors and by energy types is based on the dramatic assumption of GDP growth without considering the effects from rest of the world especially the economic crisis in some countries. Therefore, at this point forwards, in simulating the future scenarios, a milder-than-this-GDP-growth-rate will be assumed for future development in Vietnam.

5.1.2 Description of future societies

Two societies for the future of Vietnam are drawn based on main indicators such as socio-economic and political factors; dependency on imported energy; energy diversity; advanced technology progress; household consumption behavior towards environmental-friendly products; and lastly is the CO_2 emissions reduction target. The level of these scenario indicators, except emission reduction target, varies from low to high for SSTAG and SLCS societies, respectively (as shown in Figure 5.9).

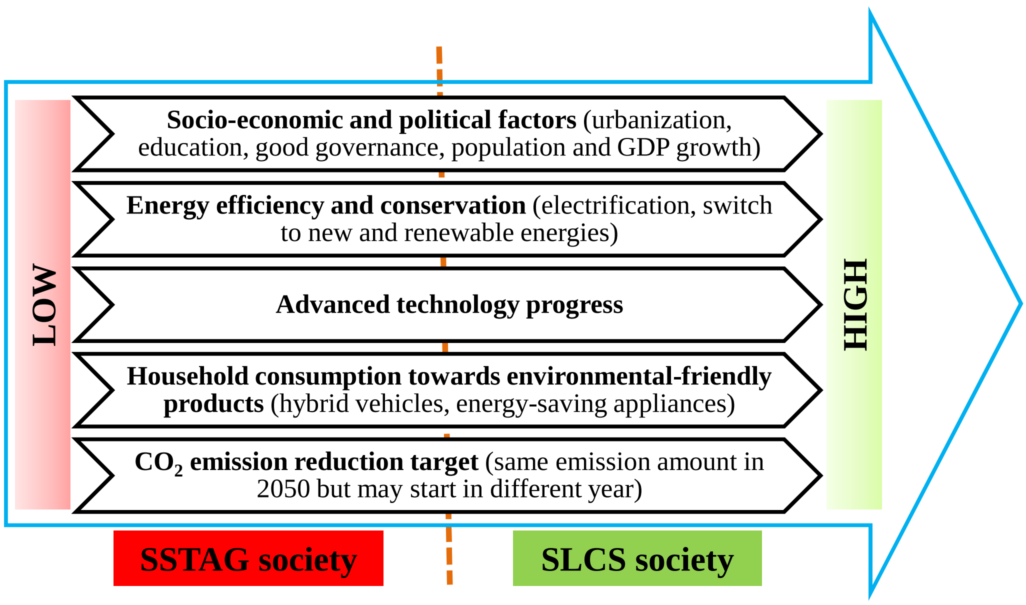


Figure 5.9: Key scenario indicators of SSTAG and SLCS societies

➢ **Socio-economic and political indicators**

- The GDP growth rate for SSTAG and SLCS is taken from the international projection after comparing with Vietnam Government development target (Kawase and Matsuoka, 2012). Specifically, the average annual economic growth rate during the period 2005-2050 for the SSTAG and SLCS are 4.6% and 6.6%, respectively (as shown in Figure 5.10). Both SLCS and SSTAG puts more effort in increasing the share of tertiary sector in economic structure, however, secondary sector still occupies the economy.
- The population growth rate is same for both SSTAG and SLCS. Annual growth rate of population and GDP for SSTAG and SLCS are illustrated in Figure 5.11, which is around 0.66% per annum. Moreover, it is assumed that people in SLCS have higher education and skill compared to SSTAG. The difference in education and skill affects the ability to adopt new and advanced technologies in both societies.
- The SLCS has better governance compared to SSTAG. Therefore, government in SLCS has higher efficiency in decision-making process towards LCD, as well as in the resource management. The accessibility and affordability of energy especially for the low-income people, in other word, energy-for-all, is critical factor in energy policy formulation. Moreover, better governance also helps SLCS to manage the price change, especially of energy commodities, better than SSTAG since change in energy price (fuels, electricity) sensitively affects price of other goods and services in the economy.

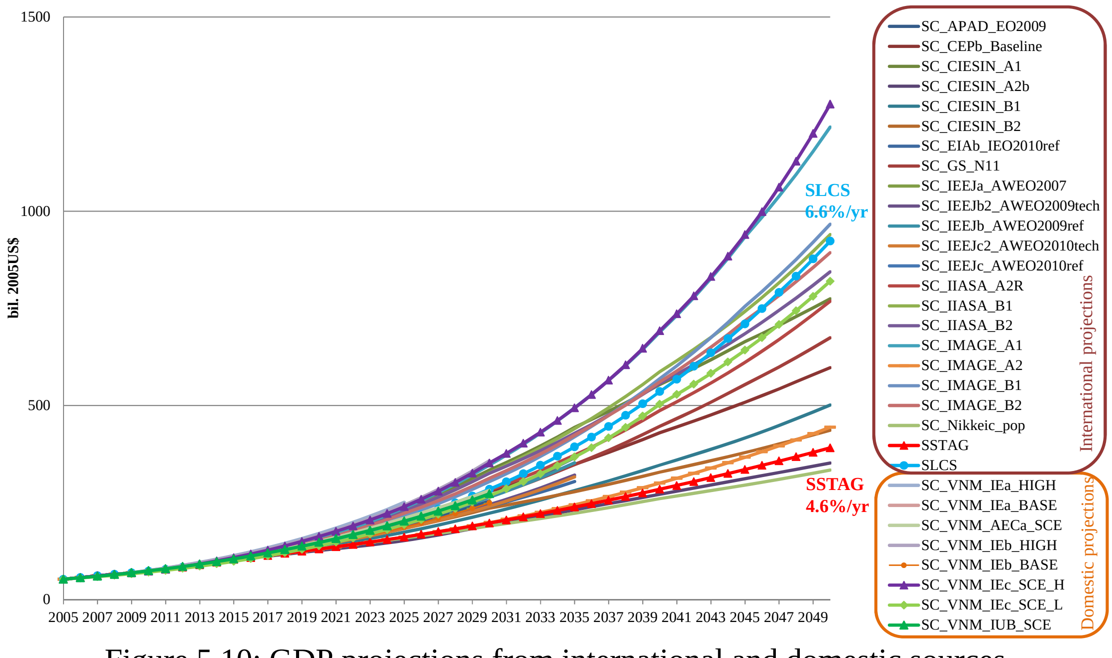


Figure 5.10: GDP projections from international and domestic sources

(Note: The purple line indicates the GDP growth rate assumed by Institute of Energy, Vietnam in order to project the future energy consumption demand shown in Figure 5.7 *and* Figure 5.8 *above)*

The chosen GDP growth rates for SSTAG and SLCS are based on the comparison of different references, both international and national sources (as shown in Figure 5.11). In which, the growth rate of SSTAG is almost same as some low projections from international sources. Meanwhile, assumption for SLCS is consistent with the expectation of Vietnamese Government.

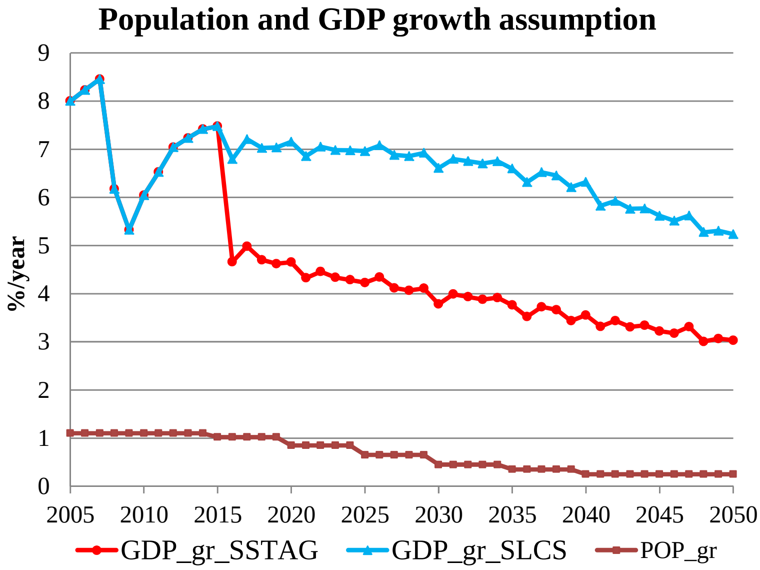


Figure 5.11: Annual population and GDP growth rate of SSTAG and SLCS

- **Energy efficiency and conservation**

- This indicator consists of energy resources, conversion and end-use which are specified in terms of percentages of energy savings, shares of new and renewable energy for power generation and final consumption, as well as alternative fuels in road transport and economic sectors, especially industrial sector.
- Currently, Vietnam is still an exporter in term of traditional fuels (coal, crude oil) and an importer of petroleum products. However, in the next few years, it is projected that Vietnam has to import not only electricity but also coal and crude oil in order to fulfill the needs of energy consumption for economic development. Therefore, the amount of imported energy in SSTAG and SLCS would be different due to the difference in their economic targets.
- Since end-use energy efficiency (EEE) has high potential in GHG emissions reduction in most of developing countries, it is important to create realistic scenarios for energy efficiency achievement and different speeds.

- **Advanced technology progress**

- Technology in general and energy technologies in particular, can play an important role in improving energy efficiency and hence enhance energy security and reduce negative impacts on the environment. It is, therefore, worth to examine how advanced technologies, such as power generation technologies (from new and renewable energies) and end-use technologies (e.g. transportation with hybrid, hydrogen and bio-fuel, household consumption with energy-saving appliances).

- Each society has different assumption for the level of adopting advanced technologies, penetration of advanced technologies in both supply and demand sides, which are high for SLCS and lower for SSTAG.
- The Carbon Capture and Storage (CCS) technology is available since 2020 SLCS as one of the mitigation measures. Meanwhile, this countermeasure is not available in SSTAG. Moreover, the starting year of implementing CCS technology is depended on the carbon price. So far, it is assumed that the maximum ability to implement CCS technology SLCS is 4% per annum, respectively high speed.

➢ **Household consumption behavior**

- It is important to understand how the society becomes environmentally conscious and begins to accept more efficient and environmental-friendly appliances, such as solar water heater and hybrid vehicles, would influence the evolution of the energy system, including the introduction of new and renewable energy technologies in power generation, to reduce fossil fuels consumption and therefore GHG emissions.
- In SLCS, people are willing to buy new products which are energy-saving and environmental-friendly even they are more expensive. People in SLCS believe that even the investment cost for new capitals (vehicles, cooking stoves, lights, heater/cooler, etc.) is high, their energy efficiency is also high and the lifetime is longer. Meanwhile, even being convinced similar good characteristic of new products, people in SSTAG still hesitate to invest new capitals.

➢ **Environmental indicator**

- In term of CO_2 emissions reduction target, both SSTAG and SLCS set the emission amount for target year 2050 which is around 0.37 $GtCO_2eq$ (1.7 times that of 2005) since Vietnam does not have to reduce the GHG emissions stringently. This targeted value is calculated based on the burden share estimation following C&C scheme (Meyer, 2000) in which each person in the world, if necessary, need to reduce the same amount of their owns emission in order to reach the global target of 50% reduction compared to the total global emission in 1990. The quantity emission target in C&C scheme for Vietnam is around 0.196 $GtCO_2eq$ (12% reduction of the total emission in 2005).
- Depending on the characteristic of each society, the co-benefit of air pollutants reduction is different between SSTAG and SLCS. Due to different characteristics as

described above, the SSTAG is relatively stagnant to change towards LCD. Unlike in the SSTAG, the SLCS is more eager to change towards LCD.

Table 5.1: Key features of SSTAG and SLCS and their scenarios

Indicators	BaU_SSTAG	BaU_SLCS	CM_SSTAG	CM_SLCS
Main characteristic	Cautious and careful to change social system, institution and technology, putting more focus on transition cost for realizing next societies	Positive and willing to innovate the social system, institution and technology for realizing next societies	Even the potential of implementing countermeasure to reduce emission is lower, they are still utilized towards low carbon development	The high potential of implementing countermeasure to reduce emission is utilized towards low carbon development
1. Socio-economic and political				
1.1 Population growth	0.66	0.66	0.66	0.66
1.2 Economy				
a. GDP growth (%/year)	4.6	6.6	4.6	6.6
b. Economic structure	secondary sector dominates		secondary sector still dominates even tertiary sector increases its share	
1.3 Good governance	moderate	high	moderate	high
1.4 Education/skill	moderate	high	moderate	high
2. Energy				
2.1 Energy resouces (TPES)	- Fossil fuel in total energy mix: 5% in 2050 - Has low potential and not yet attemp to promote alternative fuels - Renewable energy in total energy mix: 15% in 2050 - Still relies on imported energy	- Fossil fuel in total energy mix: 4% in 2050 - Has high potential but not yet attemp to promote alternative fuels - Renewable energy in total energy mix: 15% in 2050 - Minimize dependence on imported energy	- Fossil fuel in total energy mix: 5% in 2050 - Renewable energy in total energy mix: 20% in 2050 - No introduction of CCS technology	- Fossil fuel in total energy mix: 4% in 2050 - Renewable energy in total energy mix: 25% in 2050 - Introduction of CCS technology at high speed (3.5% per annum) (available since 2020 with higher speed of advanced technology)
2.2 Electricity generation	- Share of renewable energy in generation mix: 15% in 2050 - Share of nuclear power in generation mix: 10% in 2050	- Share of renewable energy in generation mix: 15% in 2050 - Share of nuclear power in generation mix: 10% in 2050	- Share of renewable energy in generation mix: 25% in 2050 - Share of nuclear power in generation mix: 15% in 2050	- Share of renewable energy in generation mix: 25% in 2050 - Share of nuclear power in generation mix: 20% in 2050
3. Advanced technology progress				
	- Has low potential to promote advanced technologies and not yet implement	- Has high potential to promote advanced technologies but not yet implement	- Promotion of advanced technologies at low speed for: power generation, energy intensive in industry and transport sectors	- Promotion of advanced technologies at high speed for: power generation, energy intensive in industry and transport sectors
4. Household consumption behavior				
	- People hesitate to buy new products which are energy-saving and environmental-friendly due to higher cost	- People are willing to buy new products which are energy-saving and environmental-friendly even they are more expensive	- People hesitate to buy new products which are energy-saving and environmental-friendly due to higher cost	- People are willing to buy new products which are energy-saving and environmental-friendly even they are more expensive
5. Environment				
Emission reduction target	No CO_2 emissions reduction target		The emission amount for target year 2050 is around 0.37GtCO_2eq (1.7times of 2005)	

Table 5.1 summarizes the quantitative characteristics of SSTAG and SLCS and their BaU and CM scenarios, while the quantitative characteristics are described in below sub-sections.

These two societies are targeted towards GHG emissions reduction in order to analyze the socio-economic implications and energy-environmental issues of LCD (through comparing the Business-as-Usual (BaU) and Counter-Measure (CM) scenarios of each society). In which, BaU_SSTAG and BaU_SLCS do not consider the emission reduction target while CM_SSTAG and CM_SLCS have to take into account some mitigation measures in order to achieve the reduction target with the minimum compromising to their societies. In both societies, the underlying hypothesis of carbon tax (or emission price) is that by internationalizing externalities, high-emissions fuels become less attractive.

5.1.2.1 A Scenario of rather STAGnant Society (SSTAG)

- **Overview:** As shown in Table 5.2, SSTAG has relatively lower economic development target of around 4.6% per annum (2005-2050) with moderate level of good governance and education/skill, as well as the low technological breakthroughs, therefore more stagnant to change towards LCD. SSTAG government puts effort to increase the share of tertiary sector, however secondary sector still dominate the economy. The demand of energy in SSTAG is still high because of lower energy efficiency. Under the condition of lacking resources, SSTAG still relies on the imported energy.

The BaU_SSTAG scenario represents a continuation of the current trends in socio-economic and energy development of Vietnam without any major changes. In which, the main bottleneck of economic development and energy provision is the lack of resources and capital investment. This also precludes the development of a cleaner and more efficient energy system. These conditions explain why the current levels of commitments to climate-friendly-energy production and consumption, as well as the technological breakthroughs in SSTAG are low.

- **Socio-economic condition:** The population growth rate of Vietnam is projected to be reduced; from 1.1% per annum currently to around 0.3% per annum in the last period (2041-2050), even this rate is still high for some developed countries where the total population is being decreased. The total population of Vietnam is projected to be around 112 mil. people in 2050, increased 1.34 times compared to 2005. Economic factors play important roles not only in energy development (end-use energy demand) but also environmental protection and investment in energy-related technologies. At the current 7% per annum growth rate (2005-2010), BaU_SSTAG puts target for its economic development at low rate (5.9% per annum in 2011-2020) due to the fact that most of countries in the world are now facing many challenges to maintain their development due to economic crisis. This growth is still kept at lower rate in longer term (4.2% per annum in 2021-2030) and reaches 3.7% per annum (2031-2040) before declining to 3.2% per annum in the last period (2041-2050). With the average growth rate around 4.6% per annum, the economic structure in SSTAG is maintained to be dominated by secondary sector even the government provides more investment for tertiary sector.

- **Energy resources:** Vietnam is expected to face no constraint on fossil fuel including coal, oil and gas to meet its energy needs, even the government recognizes the importance of new and renewable energies, particularly in power generation. Having low potential and not yet attempt to promote alternative fuels, Vietnam may face an increase in dependency on imported energy, especially traditional fuels due to limited reserves that will be depleted within next 15 years. The contribution of renewable energy in total energy mix of BaU_SSTAG is 15% in 2050; particularly for power generation, while in CM_SSTAG is 20% in 2050. Meanwhile, the contribution of nuclear energy for power generation in 2050 is around 10% to 15% in BaU_SSTAG and CM_SSTAG, respectively.

- **Energy conversion:** It is assumed that Vietnam still keeps the current trends of fossil fuel dominance and low energy efficiency. Lacking of policies on promoting clean generation technologies would make new technologies become less competitive compared to conventional ones; thus delay their implementation in power generation sector. Gas, hydro and renewable energy are promising sources in reducing the CO_2 emissions, however due to their limited indigenous reserves, their shares in total generation mix are low. Currently, the Vietnamese Government also ratified the development of nuclear power for electricity generation since 2020, with even higher share in the generation mix by 2050 compared to renewable energy. The low share of new and renewable energies is due to the fact that the unit cost of investment of these energies in power plants is higher than the fossil-based power plants.

- **End-use energy sectors** include agriculture, industry, transportation, commercial, and residential. The energy consumption and CO_2 emissions patterns in each sector are depended on its structure and technologies employed. Furthermore, the administrative framework for implementing energy efficiency and conservation policy is not appropriate. As a result, the energy consumption in end-use sectors is assumed to remain high due to the prevalence of energy intensive technologies, especially in the fast growing sub-sectors like industry and transportation. Besides, the residential sector also become a big consumer due to the income growth as well as the increasing accessibility to energy, particularly is the electrification in both urban and rural of Vietnam is reaching 100% in the next few years.

At the slow implementation of EEE programs, SSTAG does not represent technological potential rather than a more pragmatic *"maximum cost-effective efficiency"*. In other words, it is not realistic in the SSTAG to require their citizens to purchase equipment or obtain technologies that is currently not on the domestic market and is much more expensive than presently available products. Consequently, people in SSTAG hesitate to buy new products which are energy-saving and environmental-friendly due to high cost.

- **Concern on environmental issues:** In order to achieve the emission reduction target in 2050, which is around 0.37 $GtCO_2eq$ (1.7 times that of 2005), SSTAG has to implement some mitigation countermeasures, as represented by CM_SSTAG scenario, including reducing the share of fossil fuel consumption. This reduction of fossil fuel is substituted by the contribution of new and renewable energies, particularly for power generation sector.

Table 5.2: Key features of BaU_SSTAG and CM_SSTAG

Indicators	BaU_SSTAG			CM_SSTAG		
Main characteristic	Cautious and careful to change social system, institution and technology, putting more focus on transition cost for realizing next societies			Even the potential of implementing countermeasure to reduce emission is lower, they are still utilized towards low carbon development		
Period	2005-2010	2011-2020	2021-2030	2031-2040	2041-2050	2005-2050
1. Socio-economic and political						
1.1 Population growth (%/year)	1.1	1.0	0.7	0.4	0.3	0.66
1.2 Economy						
a. GDP growth (%/year)	7.0	5.9	4.2	3.7	3.2	4.6
b. Economic structure	secondary sector still dominates even tertiary sector increases its share					
1.3 Good governance	moderate					
1.4 Education/skill	moderate					
2. Energy						
2.1 Energy resouces (TPES)	- Fossil fuel in total energy mix: 5% in 2050 - Has low potential and not yet attemp to promote alternative fuels - Renewable energy in total energy mix: 15% in 2050 - Still relies on imported energy			- Fossil fuel in total energy mix: 5% in 2050 - Renewable energy in total energy mix: 20% in 2050 - No introduction of CCS technology		
2.2 Electricity generation	- Share of renewable energy in generation mix: 15% in 2050 - Share of nuclear power in generation mix: 10% in 2050			- Share of renewable energy in generation mix: 20% in 2050 - Share of nuclear power in generation mix: 15% in 2050		
3. Advanced technology progress						
	- Has low potential to promote advanced technologies and not yet implement			- Promotion of advanced technologies at low speed for: power generation, energy intensive in industry and transport sectors		
4. Household consumption behavior						
	- People hesitate to buy new products which are energy-saving and environmental-friendly due to high cost					
5. Environment						
Emission reduction target	No CO_2 emission reduction target			The emission amount for target year 2050 is around 0.37$GtCO_2eq$ (1.7times of 2005)		

Due to low potential of promoting advanced technologies, CM_SSTAG scenario shows slow speed of introducing advanced technologies in power generation, energy intensive in industry and transport sectors. Since CCS technology is not available in SSTAG, CM_SSTAG considers the contribution of new and renewable energies for its emission reduction.

5.1.2.2 A Scenario for Low Carbon Society (SLCS)

- **Overview:** Having same population growth rate as SSTAG, which is around 0.66% per annum, SLCS has higher economic growth compared to SSTAG of average around 6.6% per annum during 2005-2050 period. There is high level of good governance and education/skill, as well as the high technological breakthroughs in SLCS; thus this society is more eager to change towards LCD compared to SSTAG. SLCS government successes in making tertiary sector become the domination of its economy. With high economic development target, the energy demand in SLCS is also high but its energy efficiency is higher than SSTAG. Believe in the diversity of energy, SLCS tries to minimize its dependency on imported energy (as shown in Table 5.3).

The BaU_SLCS scenario represents a higher trend in socio-economic and energy development of Vietnam compared to BaU_SSTAG. There is higher potential of resources and capital investment that encourage the development of a cleaner and more efficient energy system. This scenario reflects the situation where levels of commitments to climate-friendly-energy production and consumption, as well as the technological breakthroughs in SLCS are high. The contribution of renewable energy in total energy mix of BaU_SLCS is 15% and 25% by 2025 and 2050, respectively, particularly for power generation. The share is higher than CM_SSTAG in order to reduce the CO_2 emissions.

- **Socio-economic condition:** The population growth rate of Vietnam assumed in SLCS is the same as assumption in SSTAG, which is reduced from 1.1% per annum currently to around 0.3% per annum in 2041-2050, reach 112 mil. people in 2050 (1.34 times of total population in 2005). Economic factors play even higher roles compared to SSTAG, in term of end-use energy demand, environmental protection and investment in energy-related technologies. At the current growth rate 7% per annum (2005-2010), BaU_SLCS increases highly its economic development target to 7.1% per annum (2011-2020), and 6.9% per annum (2021-2030) before starting the decline to 6.5% per annum (2031-2040) and finally reaches 5.6% per annum in the last period (2041-2050). The economic growth in SLCS is much higher than that of SSTAG, in which secondary sector is still the dominant and tertiary sector increases its share.

- **Energy resources:** Vietnam is still expected not to face the constraints of traditional fuels, in which the contribution of new and renewable energies is also well-recognized, especially in power generation sector. Having high potential and the willingness to promote the alternative fuels, the government would have policies to promote new and renewable energies in order to minimize the dependency on imported energy, even the traditional fuels reserves may be depleted within next 15 years. Therefore, the alternative fuels would be more competitive with the conventional ones.

- **Energy conversion:** It is assumed that there is no restriction on fossil fuel use and the energy efficiency is high. Due to the urgent need for power supply security and growing concern about pollution from generation, the contribution of renewable energy in total energy mix of BaU_SLCS is around 15% in 2050, same as BaU_SSTAG. This contribution in CM_SLCS is 25% in 2050, which is higher than CM_SSTAG. Meanwhile, the contribution of nuclear energy for power generation in 2050 is around 10% to 20% in BaU_SLCS and CM_SLCS, respectively. With high indigenous reserves; gas, hydro and renewable energy are very promising sources of power generation in order to reduce the CO_2 emissions. Therefore, their shares in total generation mix are higher compared to SSTAG, and the introducing phase is also earlier. Even the Vietnamese Government still keeps implementing nuclear power plant since 2020, the share of renewable energy is assumed to be higher than nuclear power. Even the unit cost of investing new and renewable energy-based power plants is much more expensive than the current ones.

- **End-use energy sectors:** In SLCS, the end-use sectors are characterized by a high level of energy efficiency improvement. Under pressure from energy resources constraints and public concern on environmental issues; substitution of fuels, from traditional fuels to new and renewable energy, to improve energy efficiency and therefore reduce CO_2 emissions is promoted. BaU_SLCS assumes that fossil fuels consumption by these end-use sectors would be around 4% in 2050.

SLCS implements the EEE programs as early as possible, starting since 2015 that represent technologies *"available and cost-effective now"*. In other words, government and people in SLCS are willing to adopt green technologies whatsoever exist on either domestic or global market. People in SLCS have optimizing consumer behavior towards energy-saving and environmental-friendly products with a belief that these products would be more energy efficient even their prices are higher than existing ones.

- **Concern on environmental issues:** In order to achieve the emission reduction target in 2050, which is around 0.37 $GtCO_2eq$ (1.7 times that of 2005), SLCS also has to implement some mitigation countermeasures, as represented in CM_SLCS scenario, including reducing fossil fuel consumption. This reduction of fossil fuel is also substituted by the contribution of new and renewable energies, especially for power generation sector, which is higher than the contribution of renewable energy in CM_SSTAG scenario. Thanks to high potential of promoting advanced technologies, CM_SLCS scenario shows high speed of introducing advanced technologies in power generation, energy intensive in industry and transport sectors. CCS technology is also one of the main measures contributing to emission reduction in CM_SLCS at high speed of 4% per annum. The availability of CCS technology is from 2020, which is same time as SSTAG. Similarly, the starting year of implementing CCS in SLCS can be earlier than SSTAG, which is also depended on the price of carbon.

Table 5.3: Key features of BaU_SLCS and CM_SLCS

Indicators	BaU_SLCS			CM_SLCS		
Main characteristic	Positive and willing to innovate the social system, institution and technology for realizing next societies			The high potential of implementing countermeasure to reduce emission is utilized towards low carbon development		
Period	2005-2010	2011-2020	2021-2030	2031-2040	2041-2050	2005-2050
1. Socio-economic and political						
1.1 Population growth (%/year)	1.1	1.0	0.7	0.4	0.3	0.66
1.2 Economy						
a. GDP growth (%/year)	7.0	7.1	6.9	6.5	5.6	6.6
b. Economic structure	secondary sector still dominates even tertiary sector increases its share					
1.3 Good governance	high					
1.4 Education/skill	high					
2. Energy						
2.1 Energy resouces (TPES)	- Fossil fuel in total energy mix: 4% in 2050 - Has high potential but not yet attemp to promote alternative fuels - Renewable energy in total energy mix: 15% in 2050 - Minimize the dependence on imported energy			- Fossil fuel in total energy mix: 4% in 2050 - Renewable energy in total energy mix: 25% in 2050 - Introduction of CCS technology at high speed (3.5% per annum) (available since 2020 with higher speed of advanced technology)		
2.2 Electricity generation	- Share of renewable energy in generation mix: 15% in 2050 - Share of nuclear power in generation mix: 10% in 2050			- Share of renewable energy in generation mix: 25% in 2050 - Share of nuclear power in generation mix: 20% in 2050		
3. Advanced technology progress						
	- Has high potential to promote advanced technologies but not yet implement			- Promotion of advanced technologies at high speed for: power generation, energy intensive in industry and transport sectors		
4. Household consumption behavior						
	- People are willing to buy new products which are energy-saving and environmental-friendly even they are more expensive					
5. Environment						
Emission reduction target	No CO_2 emission reduction target			The emission amount for target year 2050 is around 0.37GtCO_2eq (1.7times of 2005)		

5.2 Economic implications of future LCD

This section analyzes the economic implications (technology change and energy efficiency; transportation; change in economic structure and trade; price change; and GDP loss) (Tran *et al.*, 2011b) of LCD by comparing BaU and CM scenarios of SSTAG and SLCS. Moreover, the results of CM target (0.37 GtCO_2eq) are compared with the results of more stringent emission reduction (C&C target – 0.196 $GtCO_2eq$) in order to discuss about the potential of LCD in Vietnam under different emission targets.

5.2.1 Technology change and energy efficiency

In SSTAG, the energy consumption efficiency of industry (AEEI – Autonomous Energy Efficiency Improvement, except for energy transformation sector and household energy consumption) is lower than SLCS. Moreover, the energy efficiency improvement for energy consumption in power generation, household passenger transportation, and industry passenger transportation of SSTAG is also lower than SLCS.

- In SSTAG, there is very low level of energy efficiency improvement in power sector is around 0.2% per annum. In term of transportation, the household passenger transport energy efficiency improvement (the usage of energy in private vehicles) is around 0.1% per annum while that of industry passenger transport (truck, bus, railways, domestic and international aviation) is around 0.5% per annum. Among different modes for industry passenger transport, truck has highest efficiency improvement, which is around 0.6% per annum.
- In SLCS, the energy efficiency improvement in industrial sector (AEEI) is much higher than that of SSTAG. Moreover, the average energy improvement in power sector is 1.5 times of SSTAG, reach 0.3% per annum. Besides, transportation in SLCS has very high average efficiency improvement compared to SSTAG, which is 2% and 1.5% per annum for household passenger transport and industry passenger transport, respectively. In post-2020, the energy improvement in SLCS is even twice that of pre-2020 due to the rapid introduction of advanced technology. In term of industry passenger transport, truck also has highest efficiency improvement compared to other modes, which is around 3.5% per annum. Indirectly it implies that SLCS has to invest more for technology improvement in most of the sectors (industry, residential, and transportation) in order to achieve the same emission reduction target as SSTAG. This investment can be accounted as indirect economic loss, which is assumed to be higher than SSTAG due to rapid economic development in SLCS.
- The reason of high energy efficiency improvement for truck is because of the rapid increase of transport demand by truck compared to other modes, while the main energy source for this transport mode is petroleum, a high emission energy type. In order to minimize the GHG emissions from this sector without compromising the transport demand, efficiency improvement is one of the solutions. It can be understood in the way that in future, the transport modes are developed to be more efficient in consuming energy, in other word, the technology improvement in producing transport vehicles, both for public and private.

5.2.2 Transportation

Transportation is one of the sectors consuming large amount of energy, in which truck (TC) consumes highest share in total energy supplied for transportation. The demand of transportation is changed according to income and GDP increases. In SLCS, this transport demand coefficient is 2 times that of SSTAG. It means that when the GDP and people income are increased, the demand for transportation is also increased, for transporting goods and services, as well as for traveling and movement. Therefore, in reducing the GHG emissions, beside the increase of energy improvement and advanced technology, transport demand will be decreased, in which SLCS has to reduce more than SSTAG (as shown in Figure 5.12).

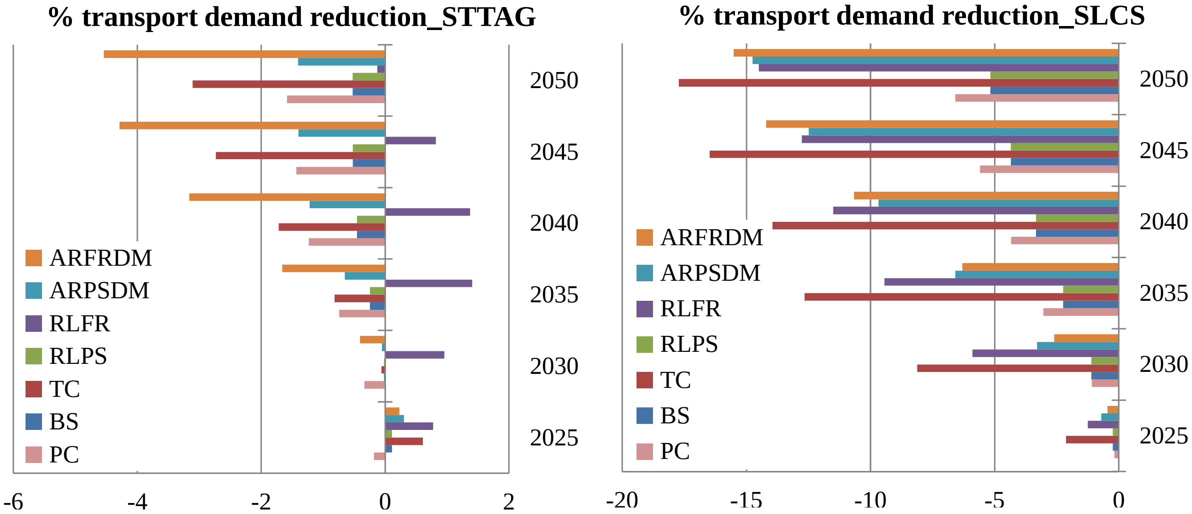


Figure 5.12: Reduction of transport demand in CM cases (% of demand in BaU)

- The total transportation demand in SSTAG is around 420 mil. passenger.km/year in 2050, increases 3 times compared to 2005. In which, truck transport (TC) dominates 46%, followed by bus transport (BS) with 31% of total transport demand. In reducing the GHG emissions (CM_SSTAG), transport demand starts to reduce since 2030, with highest reduction domestic aviation (ARFRDM and ARPSDM), truck (TC), and passenger transport (PC). The transport demand reduction in 2050 for domestic aviation is 6%, followed by truck and passenger transport with 3% and 1.5%, respectively. On the other hand, the demand of freight railway transport (RLFR) is increased in most of the period and starts to reduce at very small percentage in 2050. Under more stringent emission reduction (C&C target), SSTAG has to reduce its transport demand much more, around double of the reduction in CM target. Especially, even the demand of freight railway will be decreased significantly.
- The total transportation demand in SLCS is around 1,014 mil. passenger.km/year in 2050, increases 7.2 times compared to 2005. In which, truck transport (TC) dominates 44%, followed by bus transport (BS) with 20% of total transport demand. In reducing

the GHG emissions (CM_SLCS), transport demand starts to reduce since 2025, earlier than SSTAG, with highest reduction for domestic aviation (ARFRDM and ARPSDM), truck (TC), and railway freight transport (RLFR). The transport demand reduction in 2050 for domestic aviation, truck, and railway freight transport is 30%, 18% and 15%, respectively; followed by passenger transport (PC) with 6% and other transport modes with 5% for each. In general, the total transport demand and energy for transportation of SLCS is 2.4 times compared to STTAG. Under more stringent emission reduction (C&C target), SLCS also have to reduce more than double of the reduction in CM target.

Figure 5.13 shows the truck transport demand (TC) and its energy consumption in CM_SSTAG and CM_SLCS (when considering the emission reduction target). Due to strong promotion of advanced technology, SLCS implements electric truck more than SSTAG. In SLCS, the technology improvement in truck transport increases the share of electricity consumption (COM_ELY) in this sector. Meanwhile, in SSTAG, the share of petroleum (COM_P_P) in consuming for truck transport still dominates and there is no electric vehicle is used. The ratio of energy consumption and truck transport demand shows the technology change and energy efficiency in which the truck transport demand increases rapidly faster than energy consumption. Under more stringent emission reduction (C&C target), both SSTAG and SLCS have to introduce the electric truck in order to reduce the dependence on petroleum products. In which, SSTAG introduces electric truck since 2031 with total share of electric truck in 2050 is around 50%. Meanwhile, SLCS introduces electric truck earlier, since 2027 with nearly 95% of the total truck energy consumption in 2050.

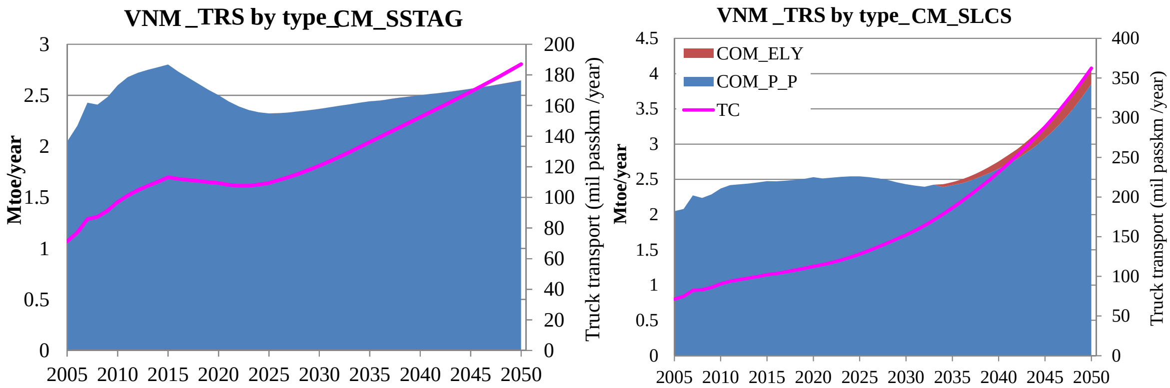


Figure 5.13: Truck transport demand and its energy consumption

The total passenger transport demand (Pass_car) (includes industry passenger transport and household passenger transport) and its energy consumption are illustrated in Figure 5.14 for CM_SSTAG and CM_SLCS when considering the emission reduction target. The total passenger transport demand in SLCS is more than double that of SSTAG.

In both SLCS and SSTAG, the electric vehicle for passenger transport (such as car and motorbike) is not introduced. However, under more stringent emission reduction (C&C target), both SSTAG and SLCS have to introduce the electric vehicles for passenger transport at 5% and 3% of total energy for passenger transport in 2050, respectively.

In general, the usage of electric vehicles for industry and household transportation is depended on the technology change and also the price of electricity. In AIM/CGE[basic] model, it is treated that goods and energy are chosen and consumed based on their prices. Except external drivers such as governmental policies and extreme preferences, the cheaper goods and energy are preferred in the market.

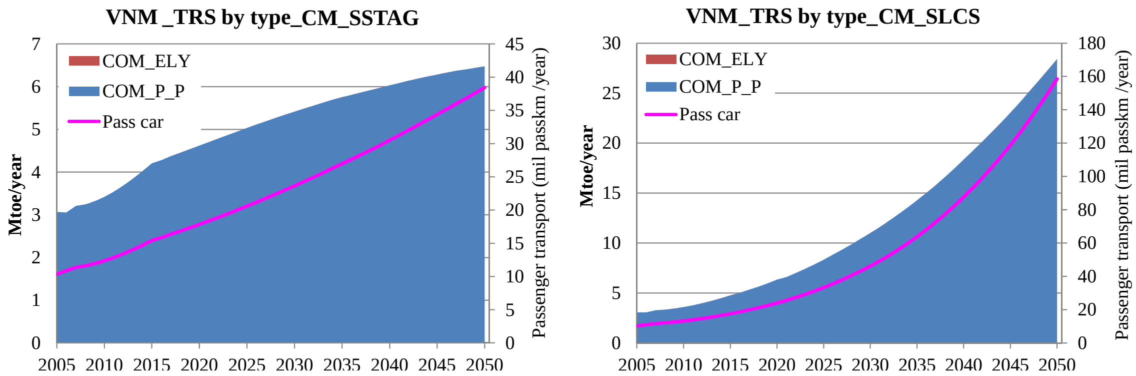


Figure 5.14: Total passenger transport demand and its energy consumption

5.2.3 Economic structure and trade

As descripted earlier, in 2005, the economic structure is occupied by secondary sector, followed by tertiary. In AIM/CGE[basic] definition, primary sector includes agriculture and forestry; tertiary sector includes transport and services; and secondary sector includes all remaining economic activities defined in this model. The Vietnamese Government would like to increase the share of tertiary sector to be dominant of the economy; however, both SSTAG and SLCS show the trend that in 2050 secondary sector still occupies with more than 40% of total GDP. In SSTAG, there is not much different in the economic structure between BaU_SSTAG and CM_SSTAG. However, in SLCS, the CM_SLCS has higher share of secondary sector compared to its share in BaU_SLCS (as shown in Table 5.4). This economic structure is maintained even Vietnam follow more stringent emission reduction (C&C target).

Table 5.4: Economic structure SSTAG of and SLCS

Economic sector	2005	2050			
		BaU_SSTAG	CM_SSTAG	BaU_SLCS	CM_SLCS
Primary	0.22	0.29	0.30	0.29	0.24
Secondary	0.41	0.42	0.41	0.42	0.49
Tertiary	0.38	0.29	0.29	0.29	0.27

Figure 5.15 illustrates the total import and export of goods and services in SSTAG and SLCS, in which, the main goods for trading in Vietnam are machinery and other manufacturing (COM_OMF), light industrial products (COM_LIN), chemical products (COM_CRP), services (COM_CSS), and petroleum products (COM_P_P, imported only). Compared to base-year 2005, the trading of these goods increases rapidly especially in SLCS. There are changes in trading of goods and services when STTAG and SLCS take into account the emission reduction countermeasures (the difference between BaU and CM cases).

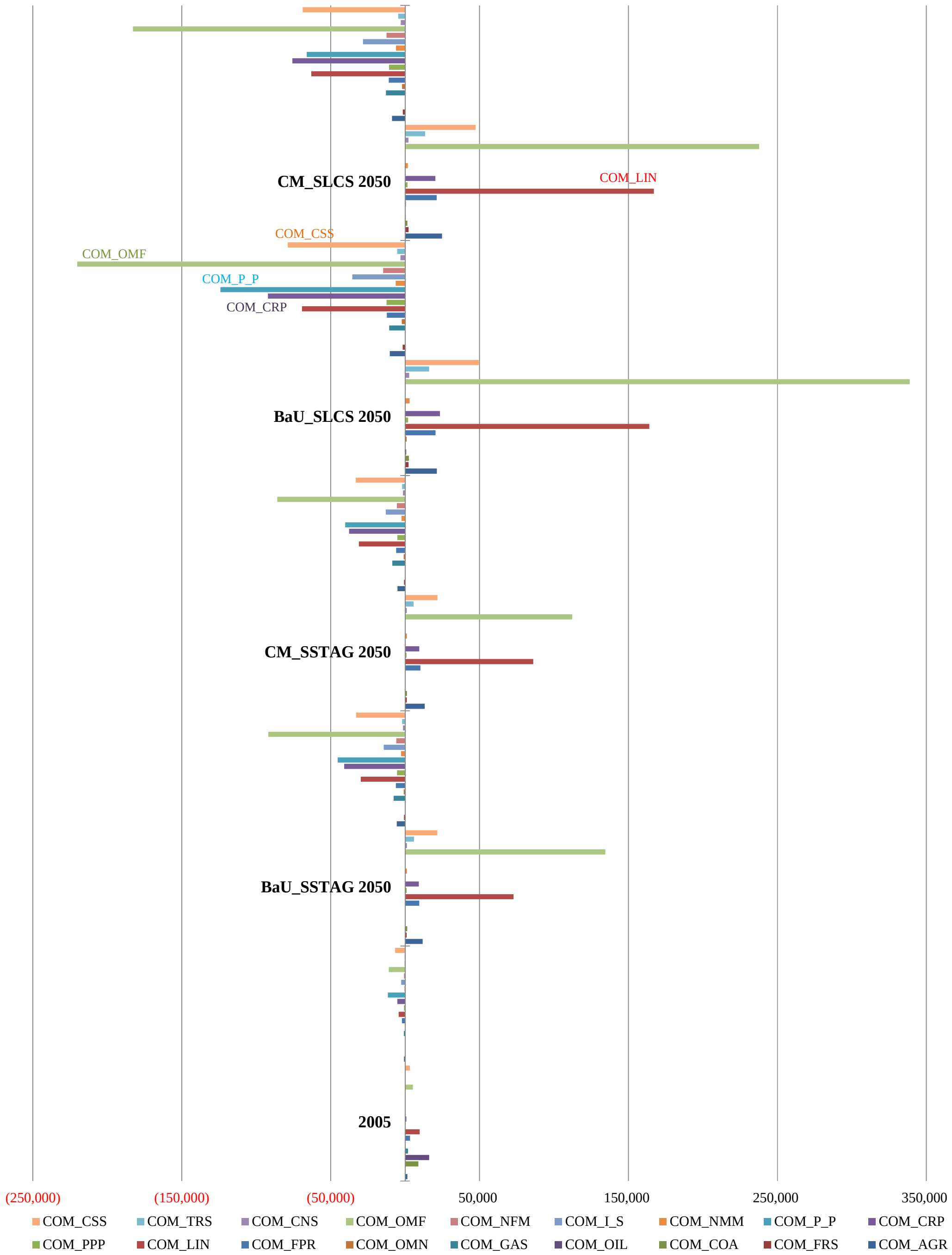


Figure 5.15: Total import (-) and export (+) of goods and services (mil. 2005USD)

The main imported goods in Vietnam are still manufactured products, petroleum, chemical products, light industry and services with rapid increasing rate. In BaU_SSTAG and BaU_SLCS, Vietnam still relies on imported petroleum products; however, in CM cases the imported amount of petroleum is reduced due to the introduction of renewable energy and nuclear power. It is projected that the total import of goods and services in 2050 of BaU_SLCS is 2.4 times that of BaU_SSTAG and this ratio is around 2.0 times for [CM_SLCS/CM_SSTAG]. Under more stringent emission reduction (C&C target), these ratio for [BaU_SLCS/BaU_SSTAG] and [CM_SLCS/CM_SSTAG] are 2.8 times and 2.1 times, respectively.

Figure 5.16 shows the increase (+) and decrease (-) of import of goods and services in CM_SSTAG and CM_SLCS compared to BaU_SSTAG and BaU_SLCS, respectively.

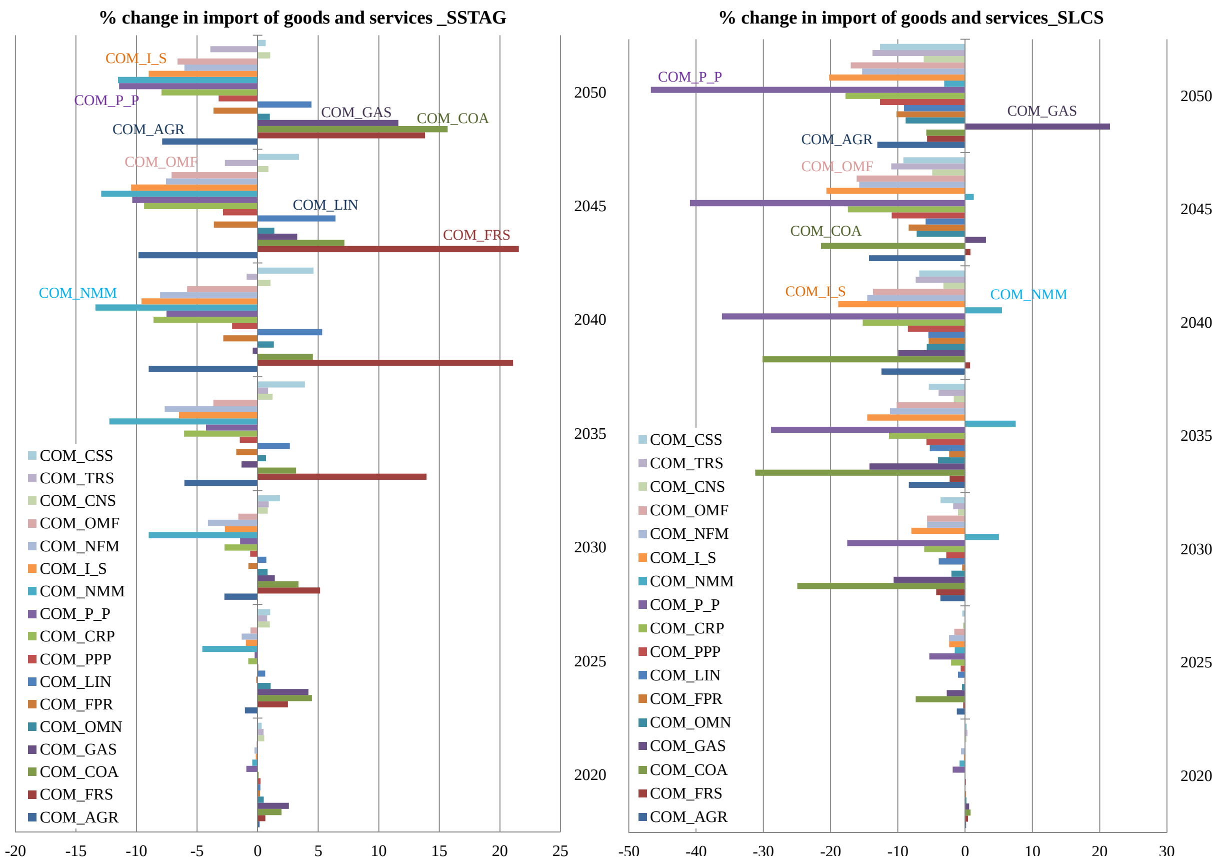


Figure 5.16: Change in import of goods and services in CM cases (% of total in BaU)

- In SSTAG, the large difference between BaU_SSTAG and CM_SSTAG starts since 2020, and increase greatly onwards. In 2050, CM_SSTAG reduce the import of mineral products (COM_NMM), petroleum products (COM_P_P), coal and iron-steel (COM_I_S), and agriculture (COM_AGR) around 12%, 11.5%, 9% and 8% of total import in BaU_SSTAG, respectively. Other imported categories reduce around 6% in CM_SSTAG compared to BaU_SSTAG; except coal (COM_COA), gas (COM_GAS), forestry products (COM_FRS), and light industrial products (COM_LIN) show the increase of import compared to BaU_SSTAG, especially forestry products which is around 14% increase compared to BaU_SSTAG. It means that CM_SSTAG reduces the dependence on imported goods and services, especially energy and heavy industry products. Meanwhile there is higher dependence on imported forestry products.

- In SLCS, the large difference between BaU_SLCS and CM_SLCS starts since 2025, with higher difference compared to SSTAG. The change of petroleum products (COM_P_P) import is highest compared to other categories during these period, which is around 47% reduction of total coal imported in BaU_SLCS in 2050. Other imported categories reduce around 20% in CM_SLCS compared to BaU_SLCS. Opposite to CM_SSTAG, CM_SLCS increases its dependence on imported mineral products (COM_NMM) (such as non-metallic mineral, stone, sand, grave, clay, etc.), which is increased 8% of total imported mineral in BaU_SLCS, before reducing this dependence in 2050. Especially, in 2050, CM_SLCS increase the import of gas (COM_GAS) around 22% of total gas imported in BaU_SSTAG, indicating the more dependence on natural gas. In both SSTAG and SLCS, under more stringent emission reduction (C&C target); the behavior is similar to CM target, however, the reduction percentage of import is double that of CM target, with very high reduction in the dependence on petroleum products.

On the other hand, Figure 5.17 illustrated the change (increase (+) and decrease (-)) in export of goods and services of SSTAG and SLCS when emission reduction countermeasures are implemented. The main exported goods in Vietnam are machinery products (COM_OMF) (metal products, machinery, electric equipment, motor vehicles, etc.), light industrial products (COM_LIN) (textiles, apparel and leather, and wood products), coal (COM_COA) and gas (COM_GAS). When considering the emission reduction, CM_SSTAG and CM_SLCS show that Vietnam will export more light industrial products rather than machinery in order to reduce the energy consumption from heavy industry. It is projected that the total export of goods and services in 2050 of BaU_SLCS is 2.6 times that of BaU_SSTAG and this ratio is around 2.1 times for [CM_SLCS/CM_SSTAG]. Under more stringent emission reduction (C&C target), these ratio for [BaU_SLCS/BaU_SSTAG] and [CM_SLCS/CM_SSTAG] are 2.9 times and 2.1 times, respectively.

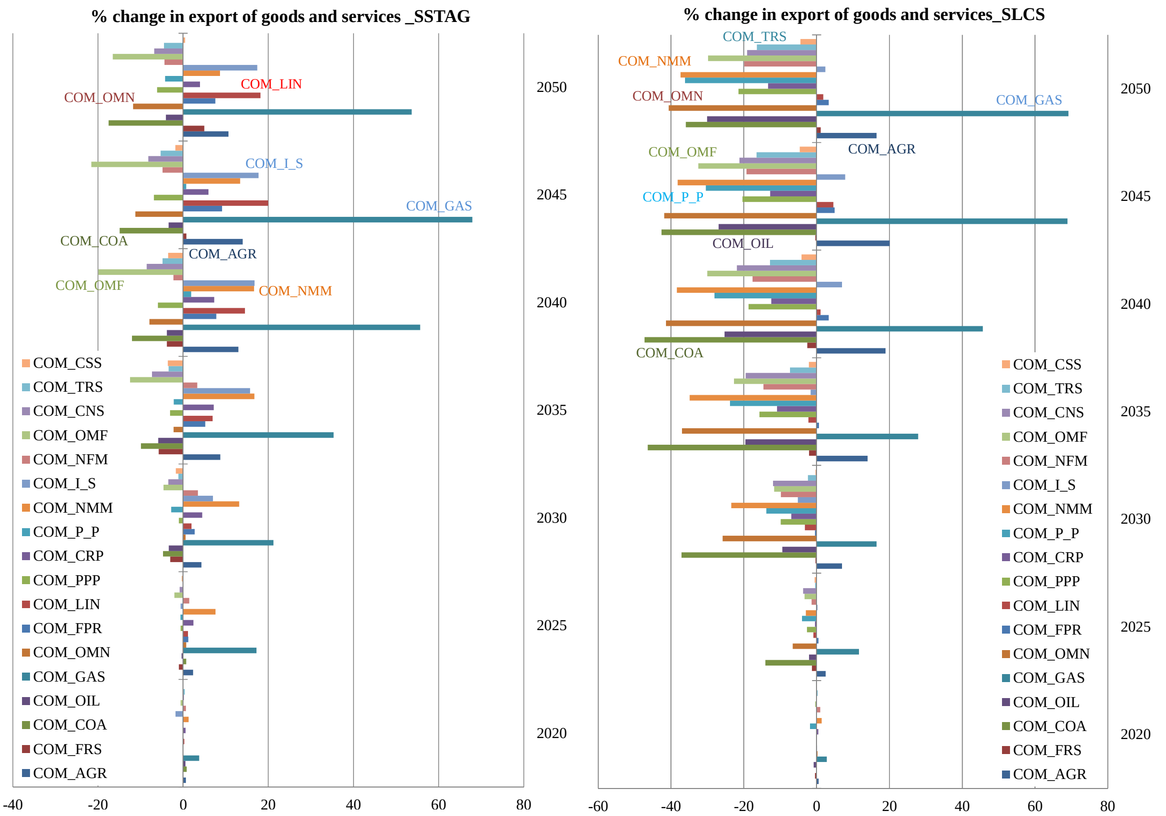


Figure 5.17: Change in export of goods and services in CM cases (% of total in BaU)

- In SSTAG, the large difference between BaU_SSTAG and CM_SSTAG starts since 2025, and increase greatly onwards. In 2050, CM_SSTAG reduce the export of coal (COM_COA), machinery products (COM_OMF), and mineral and quarrying (COM_OMN) around 17.5%, 16.5% and 11.7% of total export in BaU_SSTAG, respectively. Other exported categories reduce around 6% in CM_SSTAG compared to BaU_SSTAG; except gas (COM_GAS), light industrial products (COM_LIN), iron-steel (COM_I_S), and agricultural products (COM_AGR) show the increase of export compared to BaU_SSTAG, especially gas with more than 50% increase compared to BaU_SSTAG.

- In SLCS, the large difference between BaU_SLCS and CM_SLCS also starts since 2025, with higher difference compared to SSTAG. Most of goods are reduced in their exports. The change of mineral and quarrying (COM_OMN) exported is highest compared to other categories during these period, which is around 40.6% reduction of total coal exported in BaU_SLCS in 2050. Other exported categories reduce around 25% in CM_SLCS compared to BaU_SLCS. Similar to CM_SSTAG, CM_SLCS also shows the increase in export of gas (COM_GAS) and agricultural products (COM_AGR). In both SSTAG and SLCS, under more stringent emission reduction (C&C target); the behavior is similar to CM target, however, the reduction percentage of export is nearly double that of CM target, with very high increase in the export of gas.

5.2.4 Price change

Similar to other CGE models, in AIM/CGE[basic] mode, price is the main factor determining the change of demand and supply in market, therefore controlling activities of the whole economy. Price of energy and non-energy commodities is analyzed in more detail for SSTAG and SLCS, especially the price change when emission reduction countermeasures are taken into actions.

Figure 5.18 and Figure 5.19 show the change in price of energy commodities (including for power generation) and non-energy commodities for economic activities in SSTAG and SLCS, respectively.

As illustrated in Figure 5.18, in BaU_SSTAG, the price change of energy commodities raise moderately, except for petroleum products (P_P) which price increases dramatically and the price in 2050 reaches 15 times that of 2005. In 2050, petroleum product is the most expensive energy, followed by oil (E_OIL), coal (E_COL), hydro (E_HYD) and gas (E_GAS) for power generation. Some energy commodities for power generation such as coal (E_COL), gas (E_GAS), hydro (E_HYD) also have increasing price while other energy sources for power generation has stable price, especially renewable energies (wind and solar) and biomass. Specifically, nuclear power (E_NUC) has very high price in pre-2020 due to the unavailability of this energy in Vietnam. However, since 2020 the price of nuclear power for electricity generation is dramatically decreased due to the operation of nuclear power plants in central of Vietnam.

- Generally, there is a little change in the price of non-energy commodities in BaU_SSTAG, which are divided into 2 groups. The first group of non-energy commodities has slight declines in the price, including light industry (LIN), chemical, plastic and rubber products (CRP), machinery and other manufacturing (OMF), construction (CNS), services (CSS), and transport (TRS). In which transport has the most significant decrease within this group. The second groups of non-energy commodities has quite increase in the price, including agriculture (AGR), forestry (FRS), mineral mining and other quarrying (OMN), food production (FPR), paper and pulp (PPP), mineral products (NMM), non-ferrous products (NFM). In which iron-steel (I_S) has vastest increase within this group.
- When considering the emission reduction countermeasures, the economy of SSTAG will be affected performing by the different change of price in CM_SSTAG compared to BaU_SSTAG. In overall, almost all energy commodities in CM_SSTAG has higher price compared to BaU_SSTAG. Among these energy commodities for power

generation, petroleum products (P_P) also has huge increase, followed by coal (E_COL), gas (E_GAS), hydro (E_HYD), while other energy sources for power generation has lower increase rate. While there is not much change in the price of coal (COA), oil (OIL), and gas (GAS and GDT) compared to BaU_SSTAG, petroleum products has increasing price and become the most expensive energy. Price of nuclear power keeps similar behavior as in BaU_SSTAG with very high price in pre-2020 and dramatically decreases since 2021 and become cheaper than other energy sources. The top most expensive energies are still petroleum product (P_P), followed by oil (E_OIL), coal (E_COL), hydro (E_HYD) and gas (E_GAS). Meanwhile, cheapest energies are coal (COA) and gas (GAS).

- In CM_SSTAG, the price of non-energy commodities are also affected and keep similar trend as in BaU_SSTAG, especially for the price-increasing group in which price of non-ferrous products increases substantially and reach 2.5 times in 2050 compared to 2005. However, under more stringent emission reduction (C&C target), the price is more sensitive with the increasing price of energy-commodities, especially coal (E_COL) and hydro (E_HYD) for power generation.

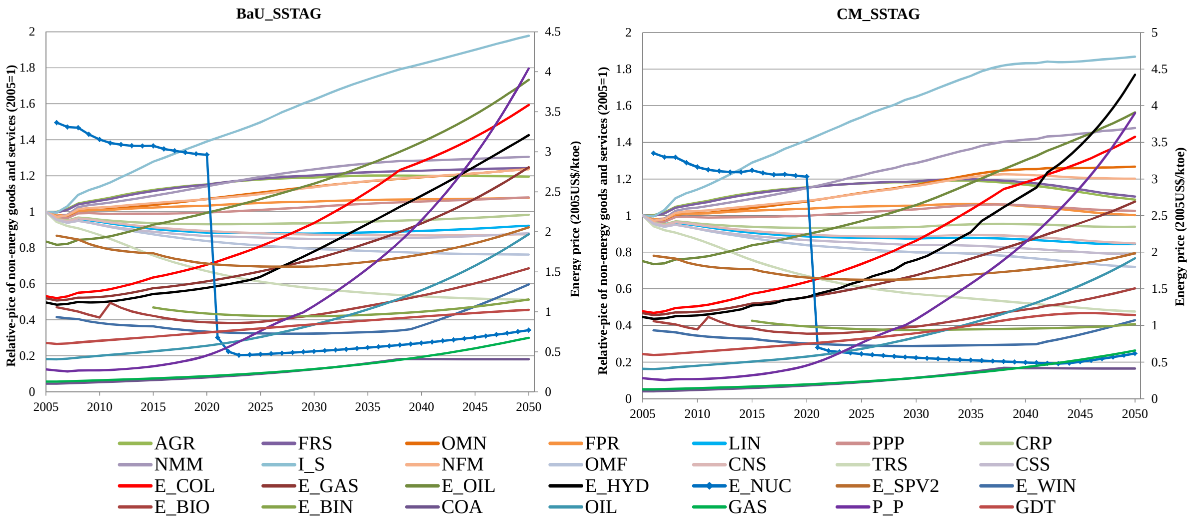


Figure 5.18: Change in price of energy and non-energy commodities in SSTAG

Generally, in SLCS the price of all commodities is higher than those in SSTAG, which is around 1.5-2 times of SSTAG in 2050, except for petroleum product of which price in SLCS is cheaper than in SSTAG. The increase speed of commodity's price in SLCS is also higher than those in SSTAG (as shown in Figure 5.19).

- In BaU_SLCS, the price change of energy commodities raise substantially, especially coal (E_COL) and hydro (E_HYD) which price increases dramatically and the price in 2050 reaches 6 times that of 2005. Price of petroleum products increases at higher speed and in 2050 reaches 13 times of 2005. However, generally, price of energies for power generation (E_COL, E_HYD, E_OIL, E_GAS, E_BIO) is higher than other energy commodities with higher increasing speed. Price of renewable energies such as wind (E_WIN) and solar (E_SPV) in BaU_SLCS is also higher than in BaU_SSTAG. In pre-2020 of BaU_SLCS, the price of nuclear power (E_NUC) is higher than other energies due to the unavailability and rapidly decreases since 2021 and become cheap energy in the future due to the operation of nuclear power plants in central of Vietnam.

- In overall, similar to BaU_SSTAG, there is also a little change in the price of non-energy commodities in BaU_SLCS, which are also divided into 2 groups. The first group of non-energy commodities has slight declines in the price, including light industry (LIN), chemical, plastic and rubber products (CRP), machinery and other manufacturing (OMF), construction (CNS), services (CSS), and transport (TRS). In which transport also has the most significant decrease within this group. The second groups of non-energy commodities has quite increase in the price, including agriculture (AGR), forestry (FRS), mineral mining and other quarrying (OMN), food production (FPR), paper and pulp (PPP), mineral products (NMM), non-ferrous products (NFM). In which iron-steel (I_S) has vastest increase within this group, and even higher increase than in BaU_SSTAG.
- When considering the emission reduction countermeasures, the interesting point is that the price in CM_SLCS is decreased compared to BaU_SLCS. In overall, all energy commodities for power generation (E_COL, E_GAS, E_OIL, E_HYD, etc.) and most of other energy commodities and non-energy commodities in CM_SLCS has lower price compared to BaU_SLCS, except price of mineral products (NMM) in 2050 of CM_SLCS is double that of BaU_SLCS. The increase of these commodities compared to 2005 is also at lower speed than the speed in CM. In CM_SLCS, coal for power generation (E_COL) becomes the most expensive energy, followed by E_OIL, E_HYD, and E_GAS. The increasing speed of these energies for power generation is more rapid than the others. In CM_SLCS, there is also not much change in the price of coal (COA), oil (OIL), and gas (GAS and GDT) compared to BaU_SLCS, the most expensive energies are for power generation (E_COL, E_HYD, E_OIL, E_GAS, E_BIO). Price of nuclear power keeps similar behavior as in BaU_SSTAG with very high price in pre-2020 and dramatically decreases since 2021 and become cheaper than other energy sources. Beside, cheapest energies are still coal (COA) and gas (GAS).
- The price of non-energy commodities are also affected especially forestry (FRS) and food production (FPR) switch to price-decreasing group while chemical, plastic and rubber products (CRP) move to price-increasing group. Within the price-increasing group, iron-steel (I_S) and mineral products (NMM) have swift increase compared to

other non-energy commodities; especially I_S is no longer the highest price change commodity as in BaU_SLCS but NMM occupies the position. After 2037, there is a decline curve in the price increase of NMM due to the decrease in the demand for this sector in order to reduce the GHG emissions since this mineral mining and other quarrying (NMM) activities are the highest emitter of carbon dioxide (CO_2) and carbon monoxide (CO). Similar to SSTAG, in SLCS, under more stringent emission reduction (C&C target), price of coal and hydro for power generation increase higher than under CM target. Especially, in 2050, coal for power generation (E_COL) becomes the most expensive energy, follow by hydro for power generation.

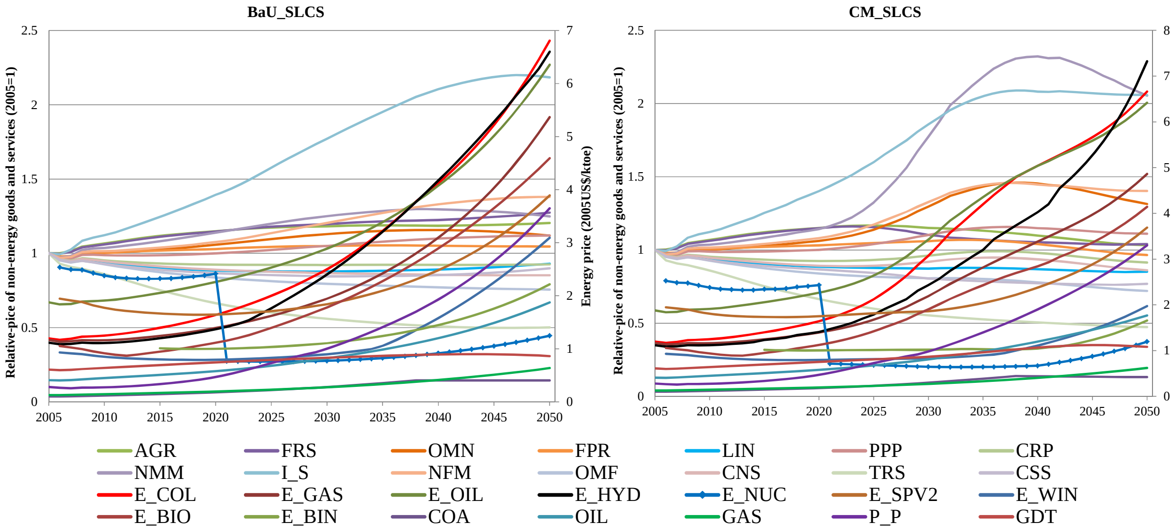


Figure 5.19: Change in price of energy and non-energy commodities in SLCS

5.2.5 GDP loss

Figure 5.20 shows the total GDP and GDP per capita (at Market Exchange Rate – MER) of SSTAG and SLCS. In overall, the total GDP in 2050 of SLCS is around 2.3 times that of SSTAG. The total GDP of SSTAG in 2050 is around 7.4 times compared to 2005 while this ratio in SLCS is around 17 times. Under the same population projection for both SSTAG and SLCS, the GDP per capita follows similar trend as total GDP.

The difference between BaU and CM indicates the loss of GDP when considering the GHG emissions constraint. In SSTAG, the GDP loss is around 1.2% of its total GDP in 2050. Meanwhile, in 2050 SLCS has higher GDP loss of around 10% of its total GDP. It means that the total direct cost of implementing climate change mitigation measures in SLCS is much higher than in SSTAG. This is due to the percentage of GHG emissions reduction in 2050 of CM_SLCS and CM_SSTAG compared to BaU_SLCS and BaU_SSTAG, respectively, which is 53% in SLCS and only 12% in SSTAG, in order for both societies to reach the same emission reduction target (0.37 $GtCO_2eq$ in 2050).

However, under more stringent emission reduction (C&C target - 0.196 $GtCO_2eq$), the speed of increasing GDP loss in SSTAG is faster than SLCS.

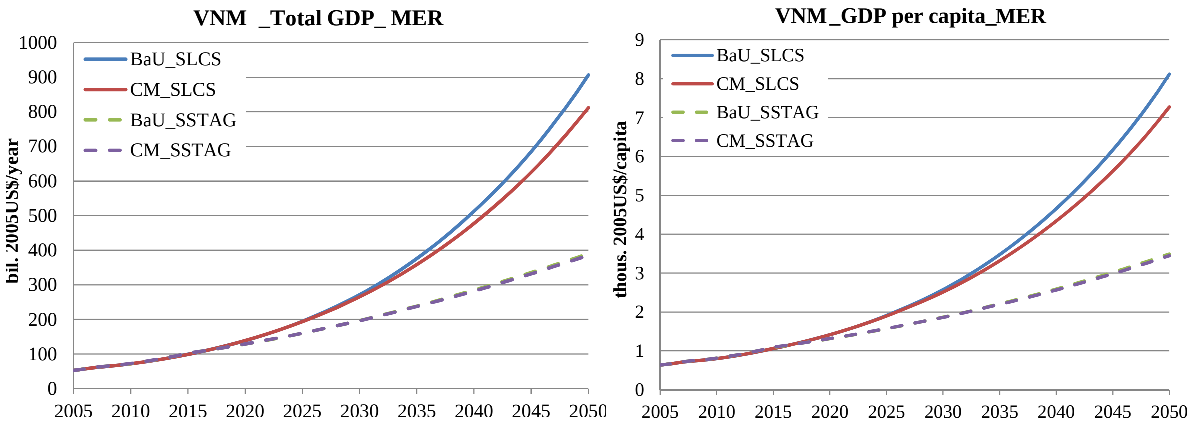


Figure 5.20: Total GDP and GDP per capita (at Market Exchange Rate, MER)

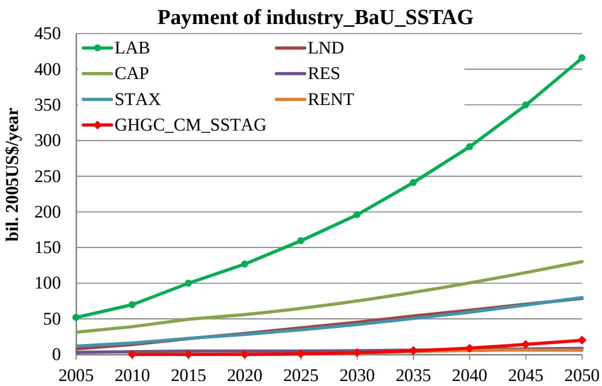
Table 5.5 summarizes the loss of GDP in SSTAG and SLCS during 2030-2050 when Vietnam starts to implement climate change mitigation actions since post-2020. At much higher economic development, SLCS has to suffer more GDP loss compared to SSTAG in order to reach the same emission amount in 2050 (CM target - 0.37 $GtCO_2eq$ in 2050). Under more stringent emission reduction (C&C target - 0.196 $GtCO_2eq$), the GDP loss in 2050 of SSTAG and SLCS is 7.1% and 14.5%, respectively.

Table 5.5: GDP loss (-) of reducing GHG emissions (% of total GDP in BaU)

	2030	2035	2040	2045	2050
CM_SSTAG	-0.1	-0.6	-1.0	-1.2	-1.2
CM_SLCS	-2.4	-4.7	-6.8	-8.8	-10.4

The possible reason leading to the GDP loss when implementing climate change mitigation actions is that when take into account the emission constraint, industries have to increase their payment for energy consumption under constraint budget. Therefore the income of capital and labor paid by industries would be reduced, leading to the reduction in savings, and thus, investment and next year's capital stock are also reduced. Even though the revenue from emission tax is given to households (as assumed in AIM/CGE[basic] model), this revenue cannot fulfill the income loss supposed to be paid by the industry. Therefore, the payment of industry to different sectors of the economy is analyzed in more detail. In general, the payment from industry is mainly for labor (LAB), capital (CAP), taxes (STAX), land (LND), natural resources (RES), and rent (RENT), in which payment for labor force is the main factor and increase dramatically compared to other sectors. Generally, the payment of industry for each factor in SLCS is 2.3 times compared to SSTAG. Red solid line in the figure indicates the cost of reducing GHG emissions (GHGC) which only occurs in CM cases of SSTAG and SLCS (as illustrated in Figure 5.21).

- In BaU_SSTAG, the payment of industry to labor force (LAB) in 2050 increases and reaches around 8 times compared to 2005. Capital (CAP) is the second factor consuming the industry's payment, followed by payment for land (LND) and taxes (STAX). Natural resources (RES) and renting (RENT) share small part of the payment from industry. However, the increase of payment for land and taxes is higher than the speed of payment for capital. When emission reduction countermeasures are implemented (CM target), the total direct cost paid for reducing emission (GHG emissions cost – GHGC) occurs in CM_SSTAG since 2025 and slightly increase. Similar behavior occurs when SSTAG follow more stringent emission reduction (C&C target).
- In BaU_SLCS, the payment of industry to labor force (LAB) also increases rapidly and in 2050 reaches around 21 times compared to 2005. Capital (CAP) is the second factor consuming the industry's payment, followed by payment for taxes (STAX) and land (LND). Similar to BaU_SSTAG, natural resources (RES) and renting (RENT) also share small part of the payment from industry. Besides, the increase of payment for land and taxes is also higher than the speed of payment for capital. When emission reduction countermeasures are implemented, the total direct cost paid for reducing emission (GHG emissions cost - GHGC) occurs in CM_SLCS earlier than in CM_SSTAG, since 2020 and slightly increase. In 2050, the GHG emissions cost paid in CM_SLCS is 1.1 times compared to that in CM_SSTAG. Similar behavior occurs when SLCS follow more stringent emission reduction (C&C target).



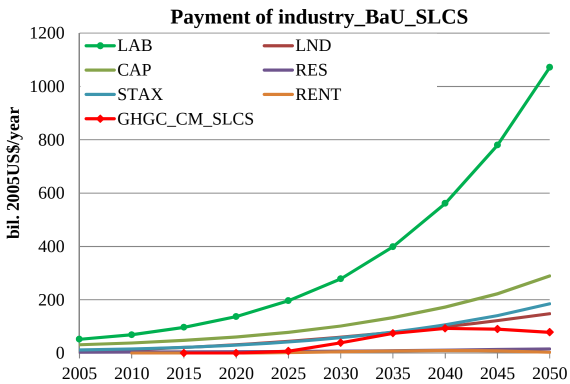


Figure 5.21: Payment of industry in BaU_SSTAG and BaU_SLCS

Figure 5.22 represents the percentage change in payment of industry in SSTAG and SLCS through comparing the BaU and CM cases. In order to pay for the GHG emissions reduction cost under constraint budget, industry in SSTAG has to reduce its payment to other sectors. Payment to labor (LAB) is reduced significantly; followed by reduction in payment for capital (CAP), land (LND), and taxes (STAX). In 2050, the reduction of industry's payment in CM_SSTAG for labor, land, capital, and taxes is around 15.2%, 12.5%, 9.9%, and 8.3% of total payment in BaU_SSTAG, respectively. These reductions are performed through the decrease of industrial production. However, in order to reduce the total emission in 2050, industry in SSTAG has to increase the payment for resource (RES) such as renewable energy since CCS technology is not available in SSTAG as one of the emission reduction countermeasure. Under more stringent emission reduction (C&C target), the reduction of industry's payment in CM_SSTAG for labor, land, capital, taxes, and natural resources is around 27.7%, 21.9%, 21.8%, 13.7% and 5.2% of total payment in BaU_SSTAG, respectively.

Similarly, industry in SLCS also has to decrease its payment to labor (LAB), followed by reduction in capital (CAP), land (LND), taxes (STAX), and natural resources (RES). In 2050, the reduction of industry's payment in CM_SLCS for capital, labor, taxes, land, and natural resources is around 26.5%, 23.9%, 19.6%, 19.4% and 2% of total payment in BaU_SLCS, respectively. There is no increase in payment for resource since CCS is implemented at high speed as one of the main countermeasure for emission reduction in SLCS. The reduction of payment to factors leads to the decrease in production that may be counted as one of the reason for GDP loss. Under more stringent emission reduction (C&C target), the reduction of industry's payment in CM_SLCS for capital, labor, taxes, land, and natural resources is around 37.8%, 32.9%, 32.3%, 31.6% and 7% of total payment in BaU_SLCS, respectively.

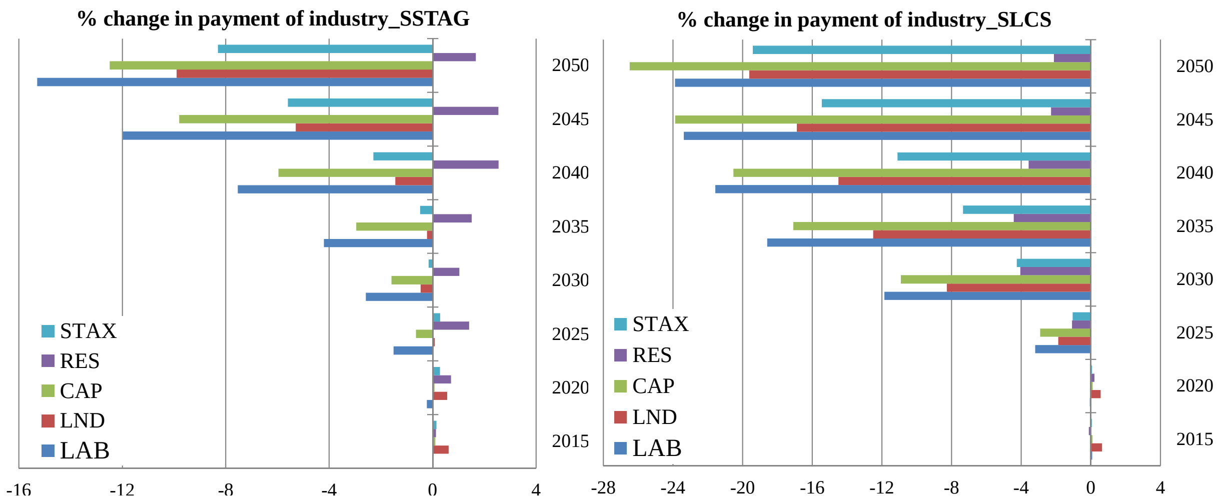


Figure 5.22: Change in payment of industry in CM cases (% of total payment in BaU)

5.3 Social implications of future LCD

This section analyzes the social implications (population, employment, income; change in price of goods and services for household consumption, and the household expenditure) of LCD by comparing BaU and CM scenarios of SSTAG and SLCS.

5.3.1 Employment and income

Assuming the same growth rate of total population for SSTAG and SLCS, which is around 0.66 %/year within 2005-2050; the population of Vietnam will reach approximately 112 mil. people in 2050. In 2050, the total population increases 1.34 times compared to the base-year 2005 (which is around 83.2 mil. people). There is no difference in total population between SSTAG and SLCS, even when Vietnam takes into account the GHG emissions reduction measures.

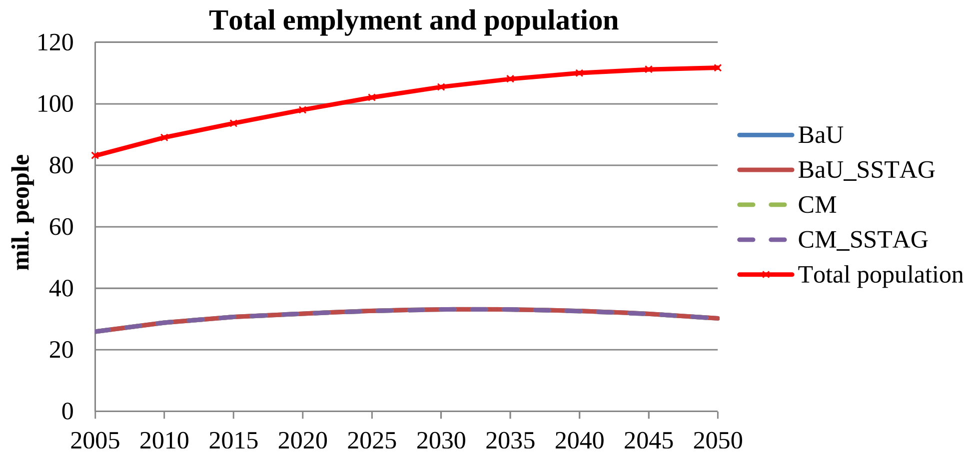


Figure 5.23: Total population and total employment in Vietnam

In Figure 5.23, the total population is indicated by red solid line while the other lines indicate the total employment of the whole economy. In all period, the total employment is around 27-33% of total population which provides a stable labor force for the economy. Generally, in both STTAG and SLCS, the employment for each sector is varying, with the highest employment supplied for service sector (CSS); followed by agriculture activities (AGR) (as shown in Figure 5.24). Other economic sector requires large number of labor are power generation from gas (E_GAS), machinery and other manufacturing (OMF), power generation from hydro (E_HYD), and transportation (TRS).

- In BaU_SSTAG, service sector (CSS) and agriculture activities (AGR) occupy the employment, which is 29% and 20% in 2050, respectively. However, the employment demand of these two sectors, together with light industry (LIN), has declining shape compared to 2005. Other sectors including machinery and manufacturing (OMF), power generation from gas and hydro (E_GAS, E_HYD), and transportation (TRS) has increasing demand in employment.
- In BaU_SLCS, the total employment is also mainly occupied by service sector (CSS) and agriculture activities (AGR) with 29% and 15% of total employment, respectively. Similar to BaU_SSTAG, the total employment demand for these two sectors and light industry (LIN) fall slightly. The demand of employment for other sectors is almost same as that of BaU_SSTAG, except there is a moderate increase in the demand of

employment in power generation by gas (E_GAS), which is 8 times in 2050 compared to 2005. This increase is due to the increase of power generation in the future.

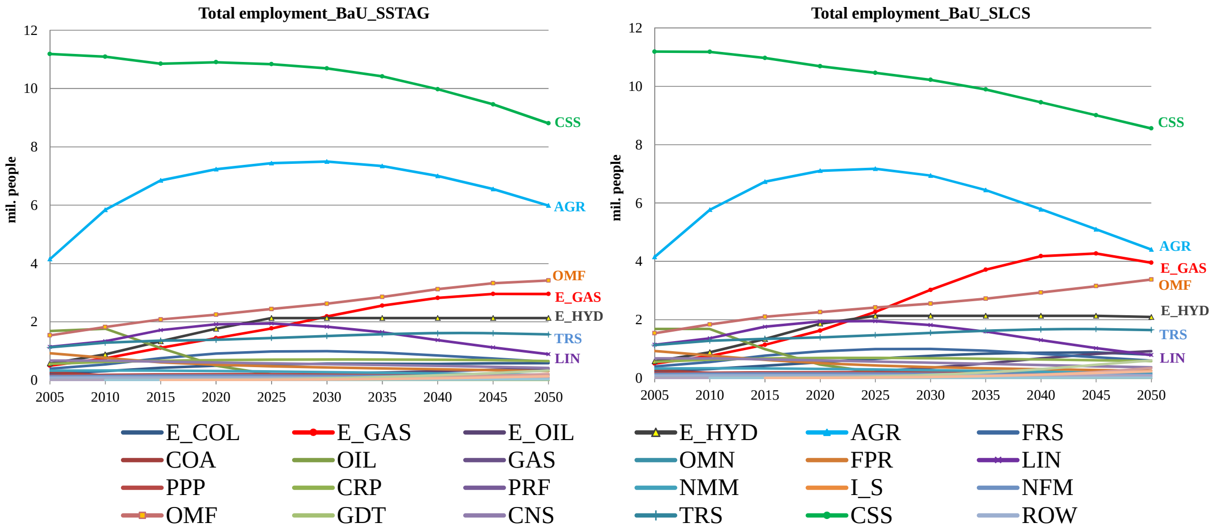


Figure 5.24: Total employment by economic sectors in SSTAG and SLCS

Figure 5.25 represents the percentage change in total employment demand of economic sectors in SSTAG and SLCS through comparing the BaU and CM cases. For those sectors that is not available in BaU cases (including new and renewable energy for power generation), the employment demand is suddenly increase in CM cases and even higher than some other sectors in the economy (gas distribution - GDT, iron-steel - I_S).

- In CM_SSTAG, employment demand in some energy sectors decreases compared to BaU_SLCS, especially high reduction in hydro for power generation (E_HYD); gas distribution (GDT); petroleum refinery (PRF) due to the reduction in production of these sectors. For non-energy sectors, mainly there is large reduction in employment demand in machinery and other manufacturing (OMF). Increasing employment demand sectors in CM_SSTAG are gas extraction (GAS), light industry (LIN), forestry (FRS), gas for electricity generation (E_GAS), etc. This behavior is maintained when SSTAG considers more stringent emission reduction (C&C target).

- In CM_SLCS, employment demand in most of sectors are decreased, especially the energy sectors; except the increasing demand in gas (GAS) and power generation from hydro (E_HYD) due to the increase in power demand. Light industry (LIN) and forestry (FRS) also increase their demand on employment. This behavior is maintained when SLCS considers more stringent emission reduction (C&C target).

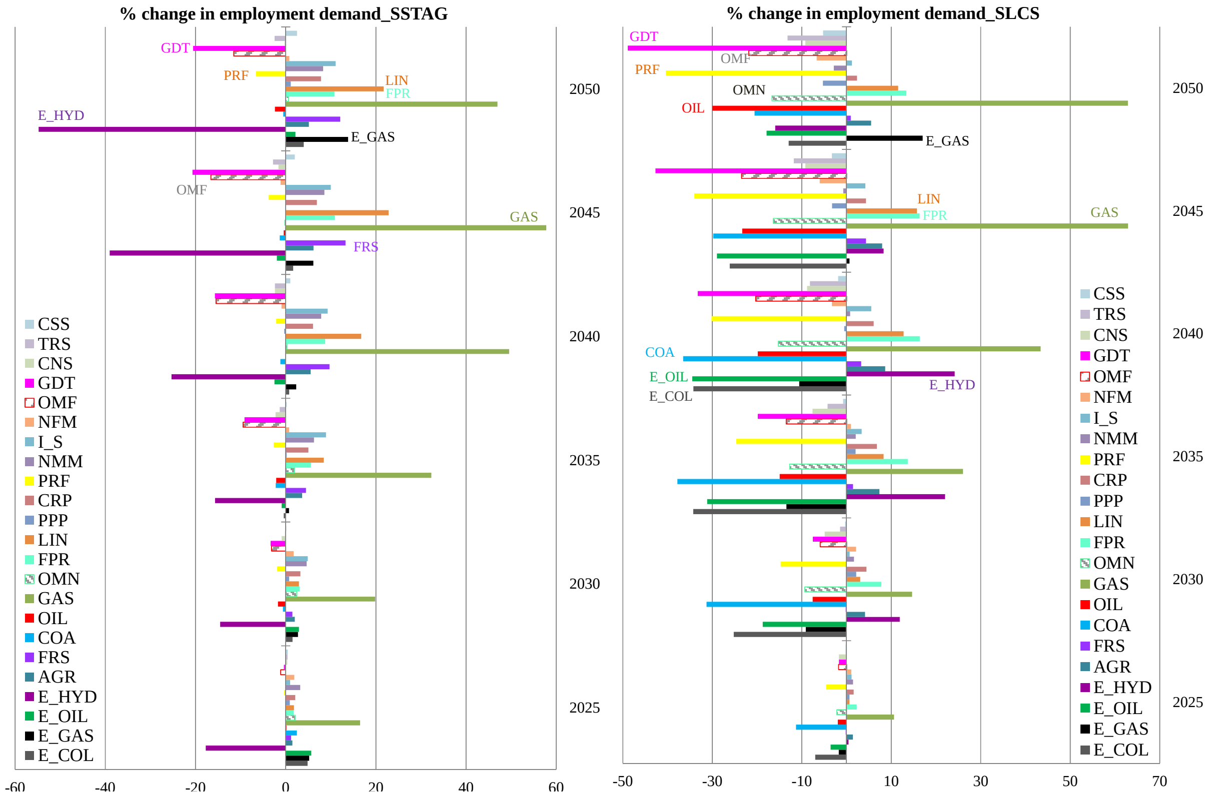
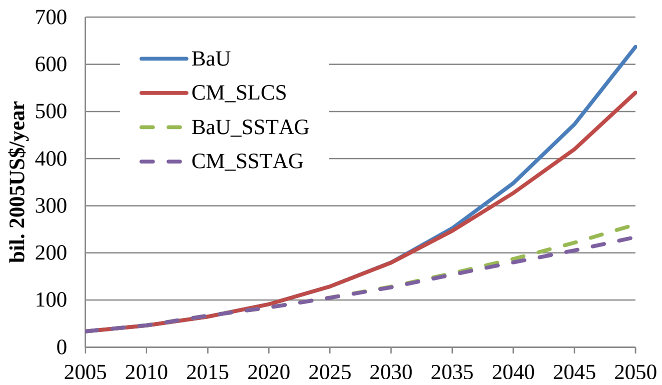


Figure 5.25: Change in employment demand in CM cases (% of total demand in BaU)

Similar to GDP, the total income of household is also different in SSTAG and SLCS. In overall, the total household income of SLCS is around 2 times that of SSTAG (as shown in Figure 5.26). The total household income of SSTAG in 2050 is around 7 times compared to 2005 while this ratio in SLCS is around 19 times. The difference between BaU and CM indicates the implication to household income when considering the GHG emissions constraint. In SSTAG, the household income loss starts since 2030 with 0.2% and reaches around 10% of its total income in 2050. Meanwhile, SLCS starts to suffer the income loss since 2025 with very small lost and dramatic increase and reach more than 15% of its total income. Under more stringent emission reduction (C&C target), both SSTAG and SLCS face higher income loss compared to CM target.



Total income loss (-)

	CM_SSTAG	CM_SLCS
2025	-0.7	0.0
2030	-1.0	-0.2
2035	-1.7	-2.2
2040	-4.0	-6.0
2045	-7.4	-11.3
2050	-10.3	-15.3

Figure 5.26: Total household income and the implications

The possible reason leading to total income loss when Vietnam takes into account low carbon development is that the payment from industry to household will be reduced, together with payment to other sectors (as analyzed in the GDP loss above) in order to spend more budget for the energy consumption. The household receives payment from industry through labor (LAB), capital (CAP) and others (OTH). Moreover, as treated in this AIM/CGE[basic] model, the revenue from emission tax (GHGC) and Carbon Capture and Storage (CCS) is given to household, which only occur when the society considers GHG emissions reduction measures (CM cases) (as shown in Figure 5.27). However, this revenue could not fulfill the decrease of industry payment to household.

- In BaU_STTAG, the income of household is mainly from labor (LAB) which increases 8 times in 2050 compared to 2005. The second source of household income is from land and resources (OTH), while capital (CAP) is also share a small part of total household income. When SSTAG implements emission reduction countermeasures, household can receive revenue from GHG emissions cost (GHGC) slightly increases since 2025.
- In BaU_SLCS, labor (LAB) is also main income source of household which increases rapidly and nearly 21 times in 2050 compared to 2005. Land and resources (OTH) is the second income source with slightly increase in the future; followed by capital (CAP). Similar to CM_SSTAG, when CM_SLCS implements emission reduction actions, the revenue from GHG emissions cost (GHGC) starts since 2020 and the small revenue from carbon capture and storage (CCS) occurs since 2030, earlier than in CM_SSTAG. The revenue from GHG emissions cost in CM_SLCS is around 4 times that of in CM_SSTAG.

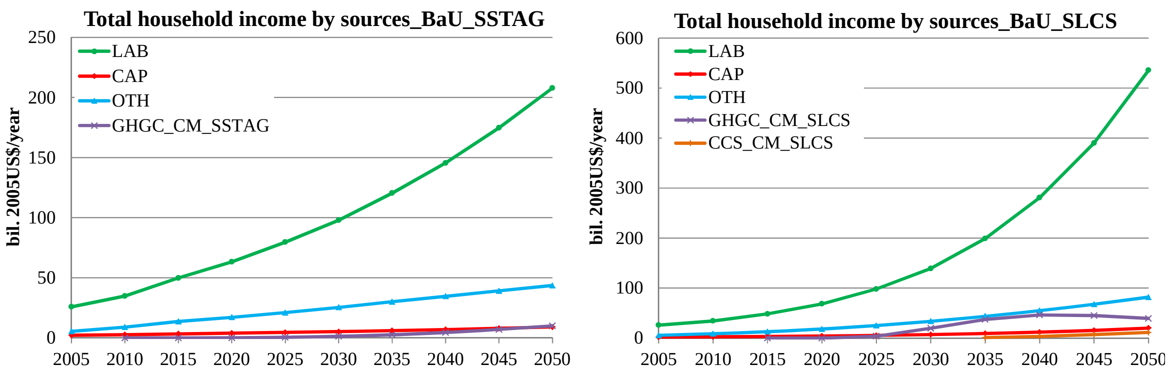


Figure 5.27: Total household income by sources

Figure 5.28 illustrates the percentage change in total household income by sources in SSTAG and SLCS by comparing the BaU and CM cases. In SSTAG, the income loss starts since 2025, in which income from labor (LAB) is decreased hugely since industries decrease their payment to labor by reducing the number of employees. Income from land, resources (OTH) and capital (CAP) is also reduced. In 2050, the reduction of household income in CM_SSTAG compared to BaU_SSTAG is around 15.3%, 12.5%, and 8.8% for labor (LAB), capita (CAP), and land and resources (OTH), respectively.

Similarly, household in SLCS also has to suffer the income loss, even earlier than SSTAG since 2020; from labor (LAB), capital (CAP), and other sources such as land and resources (OTH), with average reduction amount is around 23% of total income in BaU_SLCS. In 2050, the reduction of household income in CM_SLCS compared to BaU_SLCS is around 26.5%, 23.9% and 18% for capita (CAP); labor (LAB); and land and resources (OTH), respectively.

In both SSTAG and SLCS, under more stringent emission reduction (C&C target), the revenue from GHG emissions cost increases more than that of CM target. However, the reduction of household income is also higher, leading to more income loss if more stringent emission reduction is considered.

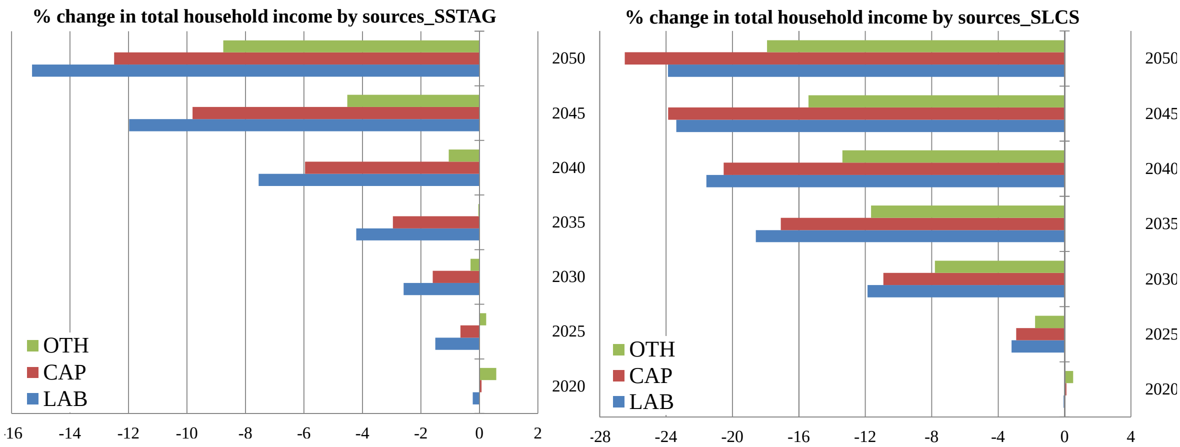


Figure 5.28: Change in total household income by sources in CM cases (% of BaU)

5.3.2 Change in price of goods and services for household consumption

Except some preference-related reasons, people consume commodities based on the necessity of each commodity and its price. In general, prices of most of energy commodities are increased, especially oil (COM_OIL) price. In SLCS, price of oil is cheaper than in SSTAG, both without or with considering the GHG emissions reduction. Non-energy commodities are also divided into 2 groups, one is price-decreasing and the other is price-increasing.

As illustrated in Figure 5.29, in BaU_SSTAG, the price of energy commodities increases slightly, except for oil products (COM_OIL) which price increases dramatically and the price in 2050 reaches 29 times that of 2005. In 2050, oil (COM_OIL) is the most expensive energy; followed by gas (COM_GDT), electricity (COM_ELY), petroleum products (COM_P_P) and coal (COM_COA). In the first group of non-energy commodities (price-decreasing group), there are products from light industry, machinery, construction, transportation, and services (COM_LIN, COM_OMF, COM_CNS, COM_TRS, and COM_CSS, respectively). The most price-decreasing is transportation. Meanwhile, price-increasing group includes products from agriculture, forestry, mineral mining, food production, paper and pulp, chemicals, mineral, iron-steel, and non-ferrous (COM_AGR, COM_FRS, COM_OMN, COM_FPR, COM_PPP, COM_CRP, COM_NMM, COM_I_S, and COM_NFM, respectively). Among the price-increasing non-energy commodities, mineral products (COM_NMM) have highest increasing rate.

- When SSTAG considers the emission reduction target, price of commodities for household consumption is also affected. For energy commodities, most of the price is decreased in CM_SSTAG, compared to BaU_SSTAG, including oil (COM_OIL), and in 2050 the oil price is higher than BaU_SSTAG. Since 2046, oil becomes the most expensive energy in household consumption; followed by gas (COM_GDT), electricity (COM_ELY), petroleum (COM_P_P), and coal (COM_COA). There is less change in the price on non-energy commodities in CM_SSTAG compared to BaU_SSTAG, meaning that the price of non-energy commodities is also cheaper than BaU_SSTAG, except for mineral products with the price-increasing rate is even much higher than in BaU_SSTAG.
- In summary, when SSTAG implements countermeasures to reduce the GHG emissions, price of commodities for household consumption would be decreased, except for mineral products (COM_NMM).

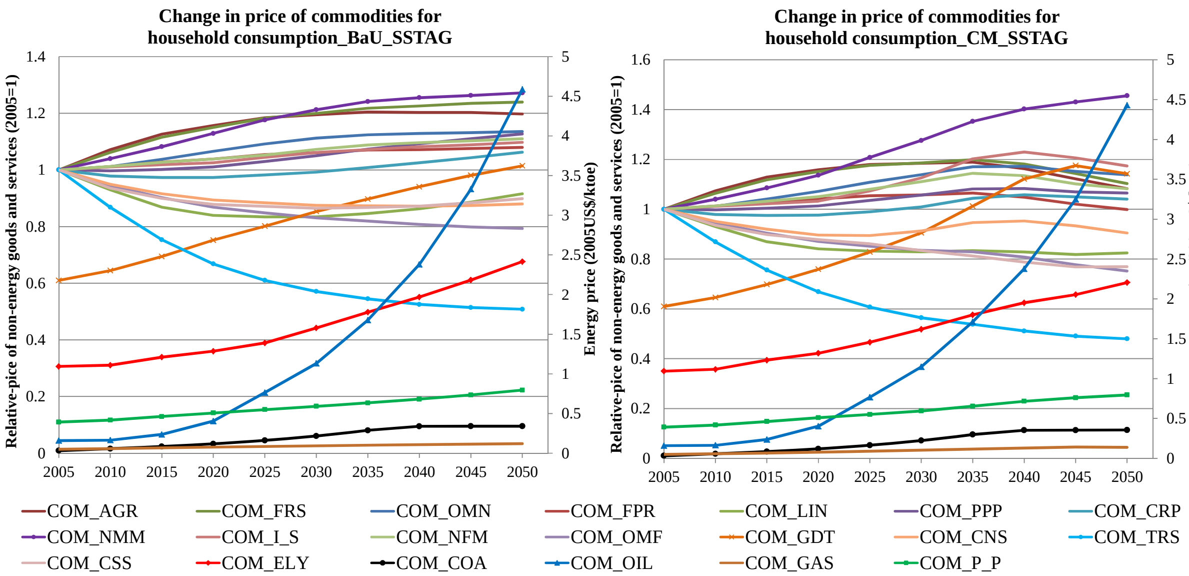


Figure 5.29: Change in price of commodities for household consumption in SSTAG

Generally, there is a bit different behavior in price of commodities in SLCS compared to SSTAG. Most of the energy commodities, except electricity (COM_ELY) in SLCS are cheaper than those in SSTAG. Non-energy commodities are also divided into 2 groups of decrease and increase price, in which the increasing rate is also lower than that of SSTAG (as shown in Figure 5.30).

- In BaU_SLCS, price of electricity (COM_ELY) and oil (COM_OIL) increase substantially, in which electricity becomes the most expensive energy since 2041. There is not much different in price of petroleum products (COM_P_P) and coal (COM_COA) compared to BaU_SSTAG, however, price of gas (COM_GDT) and oil (COM_OIL) is lower and the price of electricity in BaU_SLCS is more than twice of its price in BaU_SSTAG. Price of non-energy commodities in BaU_SLCS is also similar to that in BaU_SSTAG, which does not increase too much compared to base-year 2005. Among non-energy commodities, mineral products (COM_NMM) has the highest increase rate and machinery and transportation (COM_TRS) has the highest decrease rate.
- When SLCS considers the emission reduction target, price of commodities for household consumption is also affected. For all energy commodities, the price decreases in CM_SLCS compared to BaU_SLCS, and the price of electricity (COM_ELY) in CM_SLCS is still higher than CM_SSTAG. In 2050, oil (COM_OIL) occupies the position of electricity and becomes the most expensive energy in household consumption; followed by electricity (COM_ELY), gas (COM_GDT), petroleum (COM_P_P), and coal (COM_COA). There is also less change in the price on non-energy commodities in CM_SLCS compared to BaU_SLCS, meaning that the price of non-energy commodities is also cheaper than BaU_SLCS, except for mineral products with the price-increasing rate is even much higher than in BaU_SLCS before reducing its growth since 2040.

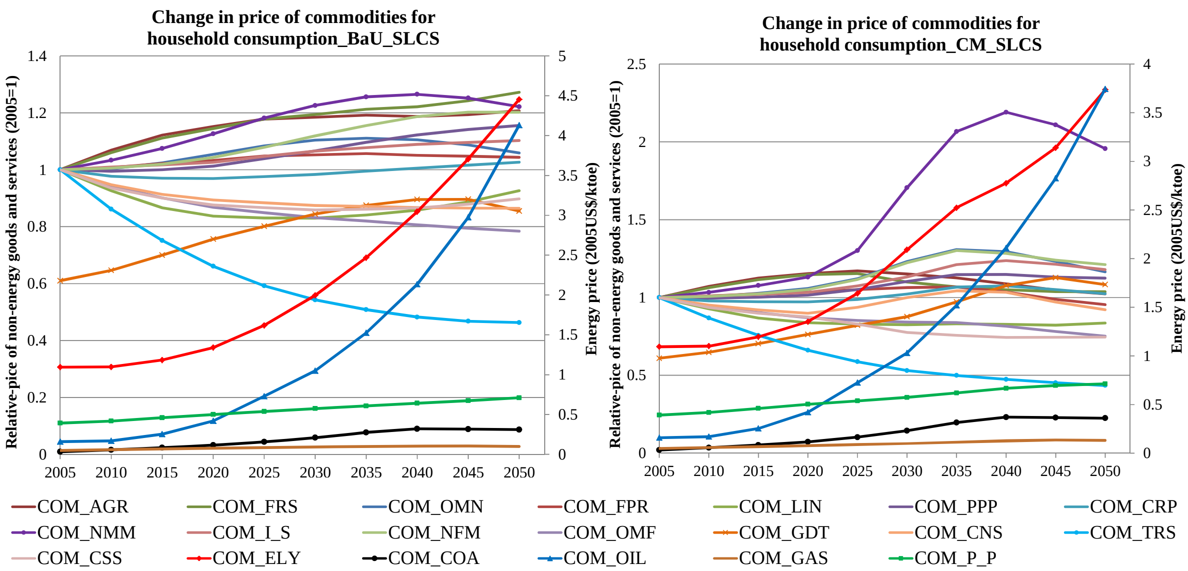


Figure 5.30: Change in price of commodities for household consumption in SLCS

In summary, when countermeasures to reduce the GHG emissions are implemented in SLCS, price of all energy commodities and almost all non-energy for household consumption would be decreased, except for mineral products (COM_NMM). Under more stringent emission reduction (C&C target), households in both SSTAG and SLCS experience more expensive commodities compared to CM target, except the cheaper price of electricity.

5.3.3 Household expenditure

The expenditure of household is depended on their income, their preferences, as well as the price of commodity itself. Moreover, consumption preference is also affected by income. The household expenditure of non-energy commodities is treated by AIDADS function, which is also depended on the total household expenditure (or total income). Meanwhile, household expenditure of energy commodities is treated by Logit function through the income elasticity. It is assumed that in SLCS, people are much eager to increase their consumption on transportation and energies. The income elasticity for transport demand of household in SSTAG is 1 while that of SLCS is 1.3. Similarly, income elasticity for household energy demand is 1.4 and 1.5 in SSTAG and SLCS, respectively. In general, people are much eager to consume energy (especially electricity) for different purposes such as lighting, heating, cooking, etc. compared to transportation (travelling) within a constraint budget (as shown in Figure 5.31).

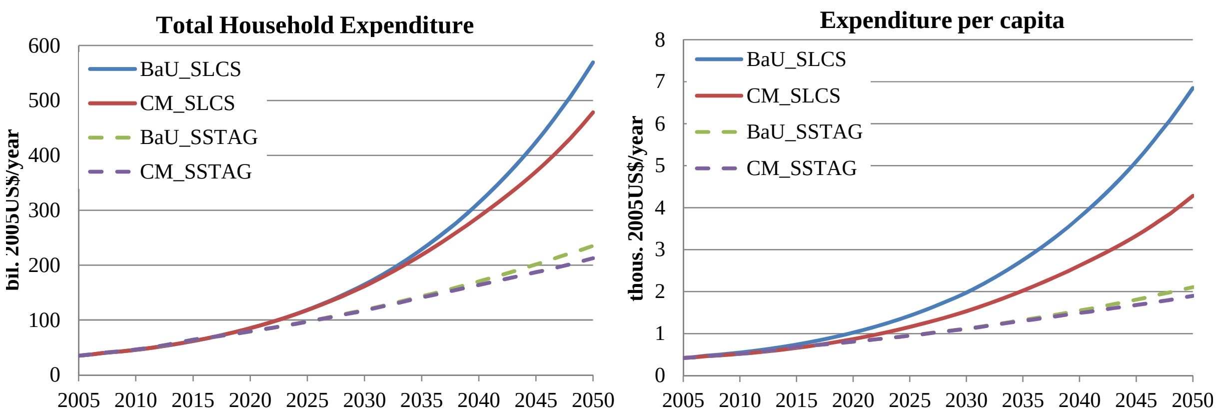


Figure 5.31: Total household expenditure and expenditure per capita

- In BaU_SSTAG (see Figure 5.32), the total household expenditure increases substantially to around 6.7 times in 2050 compared to 2005. Spending on foods (COM_AGR) is still highest share, which is around 40% of total household expenditure in 2050, followed by spending on services (COM_CSS), electricity (COM_ELY), machinery and other manufacturing (COM_OMF), transportation (COM_TRS), and food products (COM_FPR) at the share of 18%, 10.5%, 9%, 7%, 4%, respectively. There is not much change in the household consumption share when SSTAG implements emission reduction measures since there is not much change in the price of these commodities between BaU_SSTAG and CM_SSTAG. In general, the share of most of commodities increases except the large decrease in share of services (COM_CSS), and small decrease in share of food productions (COM_FPR) (such as coffee, drinks, tobacco), light industrial products (COM_LIN) (textiles, furniture), and petroleum products (COM_P_P).

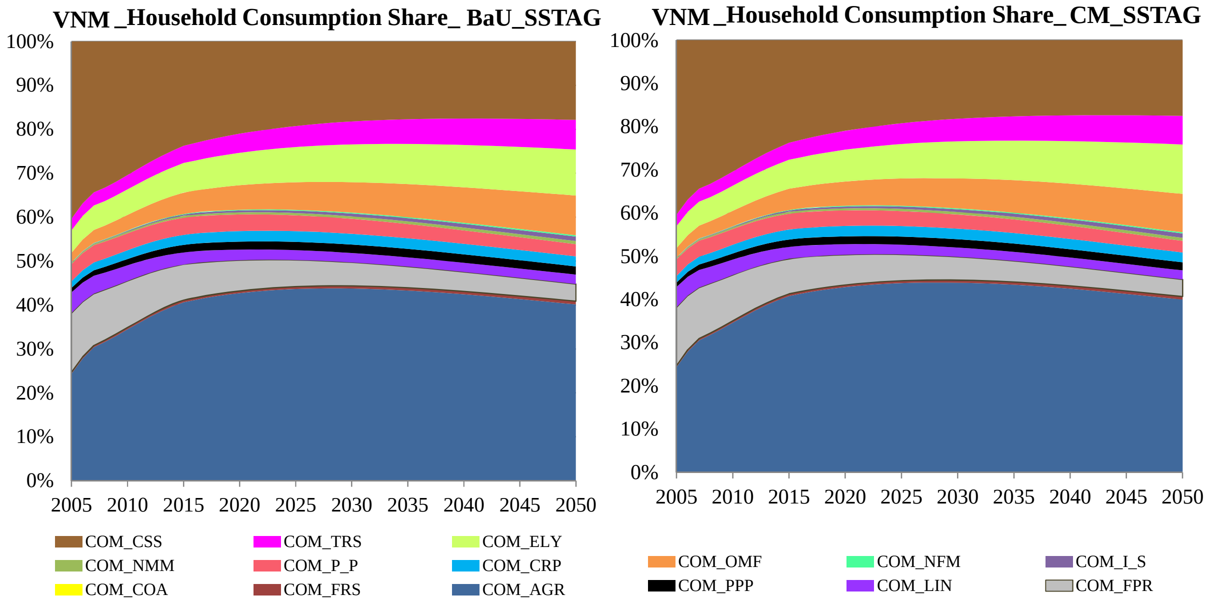


Figure 5.32: Household expenditure share of commodities in SSTAG

- In BaU_SLCS (see Figure 5.33), the total household expenditure increases substantially to around 16.3 times in 2050 compared to 2005, much higher than the increase in BaU_SSTAG. Spending on foods (COM_AGR) is still highest share, which is around 29% of total household expenditure in 2050, followed by spending on services (COM_CSS), electricity (COM_ELY), machinery and other manufacturing (COM_OMF), transportation (COM_TRS), and petroleum products (COM_P_P) at the share of 18.5%, 14.5%, 10.4%, 7.7%, 7.7%, respectively. There is not much change in the household consumption share when SLCS takes into account the emission reduction measures, except in the reduction of share for petroleum products (COM_P_P) and increasing share of electricity (COM_ELY) consumption since people in CM_SLCS prefer to use more electricity for cooking, lighting, and heating, etc. Similar to SSTAG, the share of most of commodities increases except the large decrease in share of services (COM_CSS), and small decrease in share of food productions (COM_FPR) (such as coffee, drinks, tobacco), light industrial products (COM_LIN) (textiles, furniture), and petroleum products (COM_P_P).

Under more stringent emission reduction (C&C target), the share of household expenditure in both SSTAG and SLCS is similar to that of CM target, except there is the increase in the household consumption on electricity due to the lower electricity price compared to CM target.

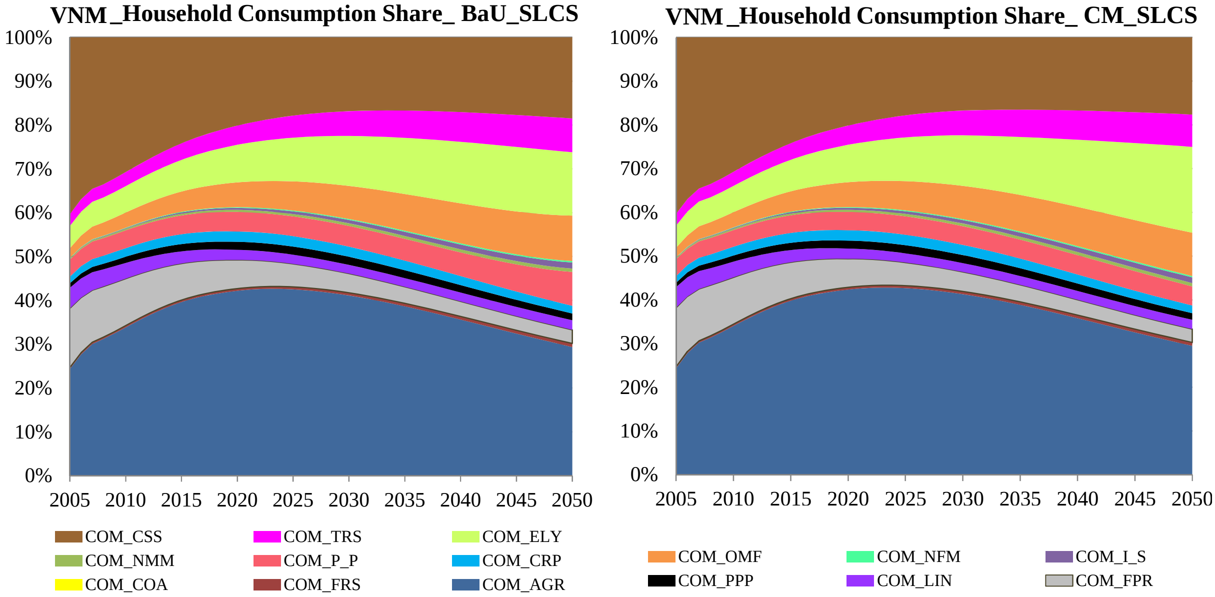


Figure 5.33: Household expenditure share of commodities in SLCS

5.4 Energy and environmental issues of LCD in Vietnam

This section analyzes the energy supply and consumption, power generation of SSTAG and SLCS, and the role of new and renewable energies. In term of environmental issue, this section analyzes the role of mitigation measures in reducing the CO_2 emissions. Emission price in SSTAG_CM and SLCS_CM is important factor determining appropriate time to introduce CCS technology as one of main mitigation measures in Vietnam.

5.4.1 Energy supply and consumption

(a) Total primary energy supply (TPES)

In SSTAG (Figure 5.34), the total primary energy supply (TPES) increases slowly with almost stable supply for coal (EB_F_COL) and natural gas (EB_F_NGS) and the decrease supply of crude oil (EB_F_CRU) due to the limited resource. The supply of hydro power (EB_F_HYD) increases slightly together with the contribution of wind (EB_F_WIN) and solar power (EB_F_SPV). Meanwhile, supply of oil and petroleum products (EB_F_OIL) increases gradually together with the contribution of nuclear power (EB_F_NUC) since 2020. The oil and petroleum in Vietnam is mainly imported, therefore, this energy source will be imported more in the future. On the other hand, the nuclear power share in TPES in 2050 is around 10%, which almost reach the nuclear power development plan of Vietnamese Government (10%-20% of total primary energy supply in the future). The contribution of biomass (EB_F_BIO) is high in base-year and gradually decreases in the future due to the change in the future energy consumption preference.

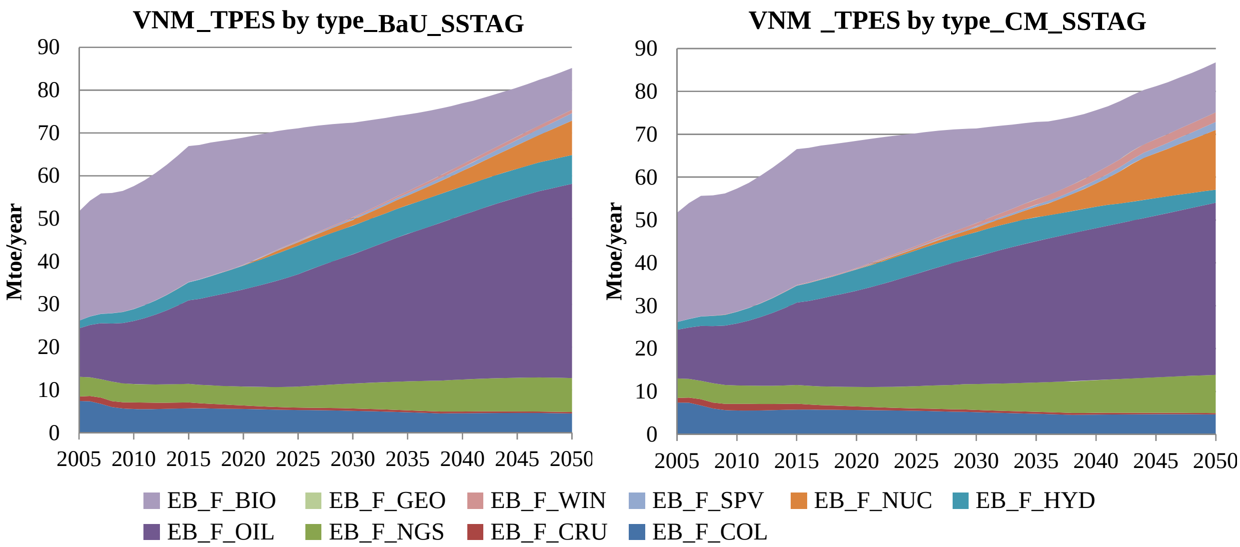


Figure 5.34: Total primary energy supply in STTAG

When considering the reduction of GHG emissions, the TPES in CM_SSTAG is almost same as in BaU_SSTAG. Moreover, nuclear power will be promoted more in the future in order to replace the supply of oil and petroleum. The share of nuclear power in CM_SSTAG is around 16% of TPES in 2050 (10%-20% of total primary energy supply, as planned by the Vietnamese Government). Follow the Vietnamese Government energy development plan, the supply of coal and natural gas is maintained for some industrial activities. Some organizations such as International Energy Agency (IEA, 2010) and Institute of Energy Economics Japan (IEEJ, 2010) project the future primary energy supply in Vietnam which is higher than the results from AIM/CGE[basic] model because they do not consider the reduction of biomass consumption in Vietnam. Moreover, IEA and IEEJ assume future energy supply in Vietnam under very high GDP growth, if compared to SSTAG. However, under more stringent emission reduction (C&C target), the primary energy supply of petroleum products will be partly replaced by the contribution of renewable energies (wind, solar, and biomass), leading to nearly 45% contribution of renewable energies in TPES.

In SLCS (Figure 5.35), the total primary energy supply (TPES) increases rapidly with a small increase in supply of coal (EB_F_COL) and natural gas (EB_F_NGS). The supply of hydro power (EB_F_HYD) also increases slightly together with the contribution of wind (EB_F_WIN) and solar power (EB_F_SPV). Meanwhile, supply of oil and petroleum products (EB_F_OIL) increases dramatically with the contribution of nuclear power (EB_F_NUC) since 2020. The oil and petroleum in Vietnam is mainly imported, therefore, this energy source will be imported more in the future, even Vietnam operates the Dung Quoc oil-gas refinery. Having similar nuclear capacity as BaU_SSTAG, in BaU_SLCS the nuclear power share in TPES in 2050 is around 11% to follows the nuclear power development plan of Vietnamese Government. The contribution of biomass (EB_F_BIO) is also reduced in the future of BaU_SLCS.

When considering the reduction of GHG emissions, the TPES in CM_SLCS is reduced around 16% of total TPES in BaU_SLCS. Moreover, nuclear power will be promoted more in the future, even more than in SSTAG, in order to replace the supply of oil and petroleum. The share of nuclear power in CM_SSTAG is around 20% of TPES in 2050, at the highest share in Vietnamese Government plan as one of the measure to reduce the GHG emissions towards LCD. Follow the Vietnamese Government energy development plan, the supply of coal and natural gas is maintained, and even increase a little for some industrial activities. The results of TPES from AIM/CGE[basic] model is similar to some projections of IEA due to similar GDP growth assumption, even they also do not separate the contribution of biomass in total primary supply. However, under more stringent emission reduction (C&C target), the supply of petroleum products is also decreased and replaced by the increasing supply of biomass.

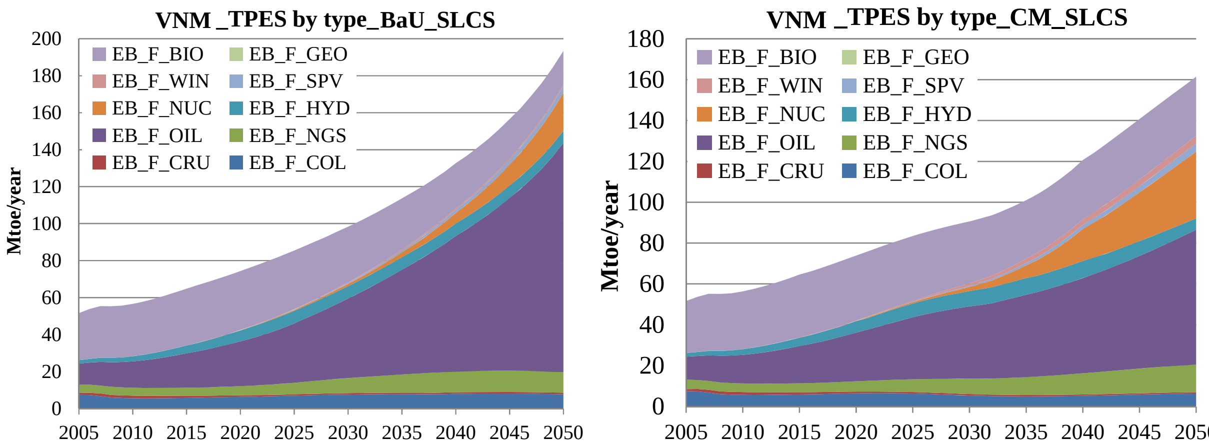


Figure 5.35: Total primary energy supply in SLCS

(b)Total final energy consumption by energy types (TFC)

Generally, in final energy consumption, oil and petroleum (EB_F_OIL) is the main source with the gradual increase, together with the increase in total final consumption of electricity (EB_F_ELY). Meanwhile, biomass consumption (EB_F_BIO) is reduced significantly due to the switch of household energy consumption from biomass to electricity as treated in this AIM/CGE[basic] model. The final consumption of crude oil (EB_F_CRU) and coal (EB_F_COA) decrease dramatically in both SSTAG and SLCS.

- In SSTAG (Figure 5.36), the final energy consumption with the account of biomass (which is high in base-year and assumed to be decreased dramatically in the future) seems not increase. However, non-biomass final energy consumption increases significantly, especially in the consumption of petroleum products and electricity. When considering the emission reduction measures, CM_SSTAG has a little less final energy consumption compared to BaU_SSTAG due to the decline of petroleum consumption. In 2050, the final consumption share of CM_SSTAG is 49%, 40% and 8.2% for electricity (EB_F_ELY), petroleum products (EB_F_OIL), and biomass (EB_F_BIO), respectively. Under more stringent emission reduction (C&C target), SSTAG reduces its consumption on petroleum products by half (in 2050) while the consumption of biomass and electricity is almost same as in CM target. The total final energy consumption under C&C target is lower than that of CM target.

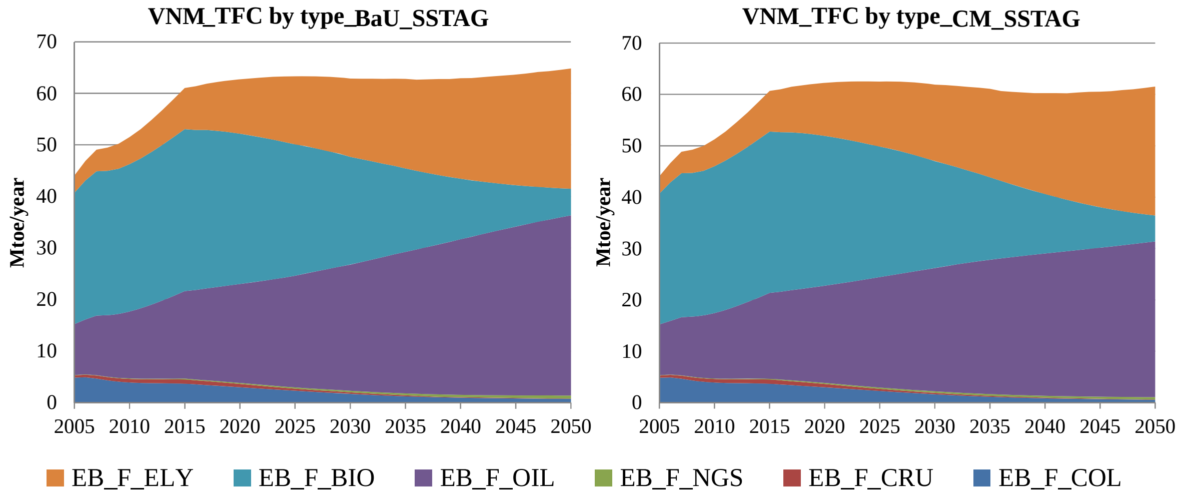


Figure 5.36: Total final energy consumption (by energy types) in SSTAG

- In SLCS (Figure 5.37), the total final energy consumption is much higher than in SSTAG. The total final energy consumption in BaU_SLCS is more than 2.3 times that of BaU_SSTAG in 2050. The main energy source for final consumption is also petroleum product, which is mainly for the consumption of industry and transportation. Similar to BaU_SSTAG, the final consumption of non-biomass energies, especially petroleum products and electricity also increases dramatically in BaU_SLCS while there is reduction in final consumption of biomass, crude oil, and coal. When GHG emissions reduction measures are considered, the electricity consumption increases much higher in CM_SLCS compared to BaU_SLCS while there is reduction in the consumption of petroleum products. The total final energy consumption in CM_SLCS is only 70% of total final consumption in BaU_SLCS. In 2050, the final consumption share of CM_SLCS is 45%, 43% and 10% for electricity (EB_F_ELY), petroleum products (EB_F_OIL), and biomass (EB_F_BIO), respectively. Under more stringent emission reduction (C&C target), LSCS also reduces its consumption on petroleum products and there is a small increase in the consumption of electricity instead. The total final energy consumption under C&C target is almost same as that of CM target.

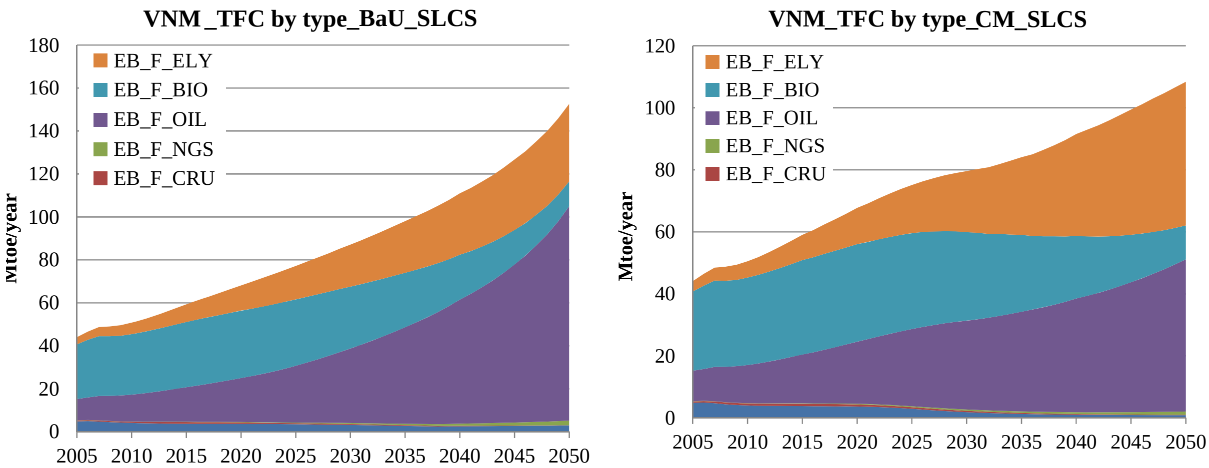


Figure 5.37: Total final energy consumption (by energy types) in SLCS

The total final energy consumption assumed in SLCS is similar to IEA and IEEJ since their assumptions of GDP growth is similar to SLCS rather than SSTAG.

(c) Total final energy consumption by sectors

The consumption of final energy is mainly for total industry (EB_TIN), residential sectors (EB_RSD), and transportation (EB_TRS). Services (EB_SER), agriculture (EB_AGR), and final non-energy consumption (EB_NEU) (energy is used as material for chemical industry and other sectors) share small part of the final energy consumption.

In SSTAG (Figure 5.38), in pre-2040 the highest final energy consumer of is residential sector due to the counting of biomass in the final energy consumption. However, since post-2040, SSTAG will reduce the consumption of biomass in households (while the consumption of electricity and other types of energy does not increase so much); therefore industry sector is the dominant of final energy consumption. There is small increase in the final energy consumption of transport sector in SSTAG.

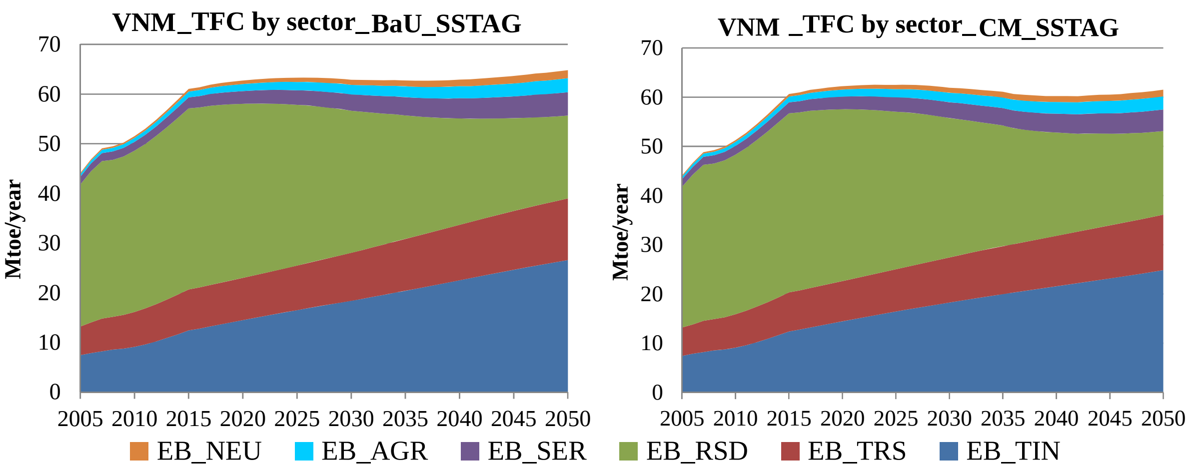


Figure 5.38: Total final energy consumption (by sectors) in SSTAG

The behavior of final energy consumption in CM_SSTAG when emission reduction countermeasures are implemented is almost same as BaU_SSTAG, even there is a decrease in total final energy consumption in 2050 of CM_SSTAG compared to BaU_SSTAG. The total final energy consumption share of industry (EB_TIN), residential (EB_RSD), and transportation (EB_TRS) in CM_SSTAG is 40.4%, 27.6%, and 18.3%, respectively.

In SLCS (Figure 5.39), in all period the highest final energy consumer of is residential sector due to the increasing consumption of electricity even the reduction of biomass consumption is accounted. There is rapid increase in the final energy consumption of transport sector in SSTAG due to the increasing demand and becomes second dominant while industry also increases its final energy consumption moderately. The behavior of final energy consumption in CM_SLCS when emission reduction countermeasures are implemented is similar to BaU_SLCS, and there is nearly half reduction in total final energy consumption in 2050 of CM_SLCS compared to BaU_SLCS. The total final energy consumption share of transportation, residential, and industry in CM_SLCS is 34.8%, 34.4%, and 25.2%, respectively.

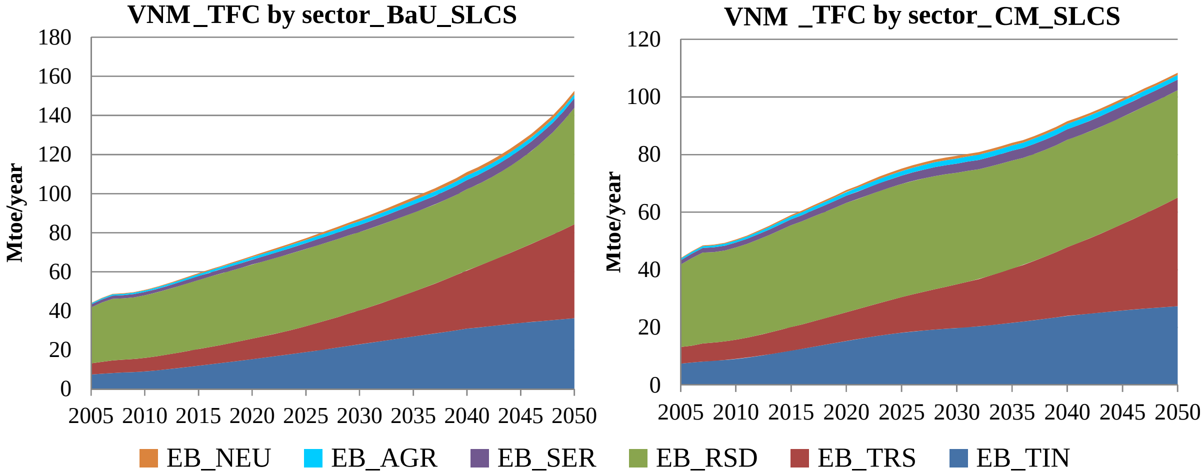


Figure 5.39: Total final energy consumption (by sectors) in SLCS

In both SSTAG and SLCS, under more stringent emission reduction (C&C target), the share of sectors in total final energy consumption is almost same as under CM target.

(d) Energy intensity

Figure 5.40 illustrates the energy efficiency in Vietnam, which is the ratio of total energy supply and total GDP (TPES/GDP), and total final energy consumption per total GDP (TFC/GDP). The lower energy intensity is, the higher energy efficiency is. Basically, the energy efficiency increases moderately in Vietnam, around 5 times in 2050 compared to 2005. Furthermore, the energy efficiency when considering the reduction of GHG emissions must be higher than without the consideration, in order to achieve the reduction target. There is similar energy efficiency in both SSTAG and SLCS due to the big difference between total GDP in SSTAG and SLCS, as analyzed previously. In both SSTAG and SLCS, under more stringent emission reduction (C&C target), there is not much change in the energy intensity compared to CM target.

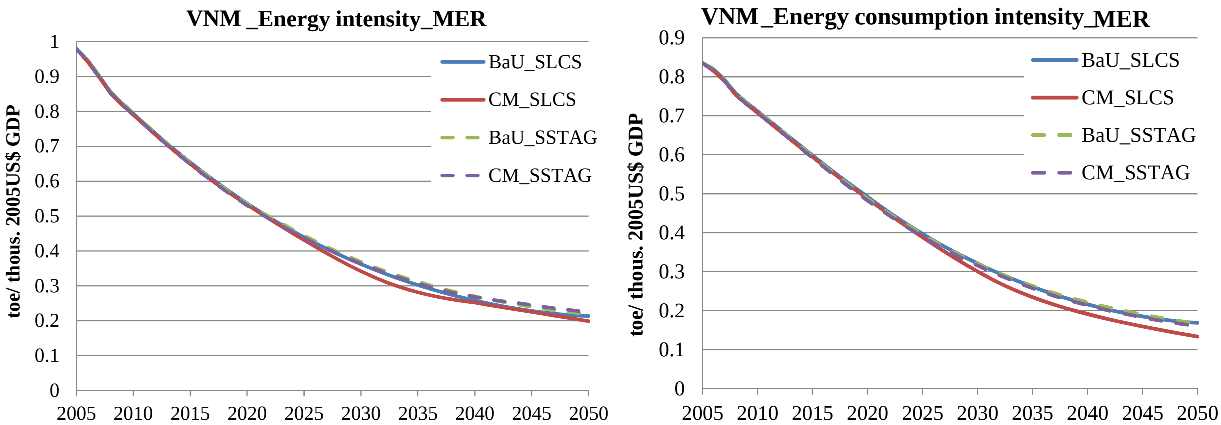


Figure 5.40: Energy intensity (at Market Exchange Rate, MER)

5.4.2 Power generation

As analyzed earlier, besides the increase of petroleum consumption for industry and transportation, the electricity consumption is also increased drastically. Therefore, it is important to analyze the future power generation in Vietnam. Currently, gas (E_GAS) and hydro (E_HYD) are the two main sources of power generation in Vietnam, together with small contribution of coal (E_COL) and oil (E_OIL). Recently, small part of electricity is produced from renewable energies such as wind (E_WIN) and solar (E_SPV), however at small scale due to the limitation of capacity and high investment and operation cost. In the future, nuclear power will contribute to the production of electricity according to the power development plan of Vietnamese Government. The total power generation resulted from AIM/CGE[basic] model is almost same as projections from IEA and IEEJ.

In BaU_SSTAG (Figure 5.41), the electricity is mainly produced by gas (E_GAS) with rapid increasing share; followed by hydro power (E_HYD). There is not much increase in electricity generation from hydro due to the limited capacity in the future. Meanwhile, oil (E_OIL) and coal (E_COL) slightly increase their contribution to the total electricity generation. Since 2020, the contribution of new and renewable energies in power generation increases slightly, including nuclear power (E_NUC), biomass (E_BIO), solar power (E_SPV), and wind power (E_WIN). Especially, the contribution of nuclear power increases substantially since the Vietnamese Government will start the construction of nuclear power plants in central of Vietnam since 2020. In 2050, the share of gas (E_GAS), hydro (E_HYD), nuclear (E_NUC), biomass (E_BIO), coal (E_COL), solar (E_SPV), and oil (E_OIL) in total electricity generation is 37.7%, 23.8%, 9.5%, 7.1%, 7%, 6.1%, and 5.8%, respectively.

- In CM_SSTAG, the total power generation is higher than in BaU_SSTAG. However, there is a reduction of contribution from gas (E_GAS), hydro (E_HYD), oil (E_OIL), and coal (E_COL) due to the limitation in GHG emissions. Since CCS technology is not available in SSTAG, the contribution of biomass and renewable energies (solar and wind) in power generation of CM_SSTAG is increased higher than those in BaU_SSTAG. Especially, nuclear power increases its contribution to power generation in the future. In 2050, the share of gas (E_GAS), nuclear (E_NUC), hydro (E_HYD), biomass (E_BIO), coal (E_COL), and solar (E_SPV) is 40%, 15.3%, 10%, 8.9%, 6.8%, and 6.2%, respectively. In order to achieve the GHG emissions reduction target, CCS technology, contribution of nuclear power and renewable energies are some countermeasures in order not to compromise the energy supply for future demand in Vietnam. The contribution of biomass in power generation is still high because of its cheap price compared to other energies. However, under more stringent emission reduction (C&C target), SSTAG has to introduce more renewable energies (especially wind, solar, and biomass) in the energy mix for power generation, leading to nearly 55% contribution of renewable energies in total power generation.

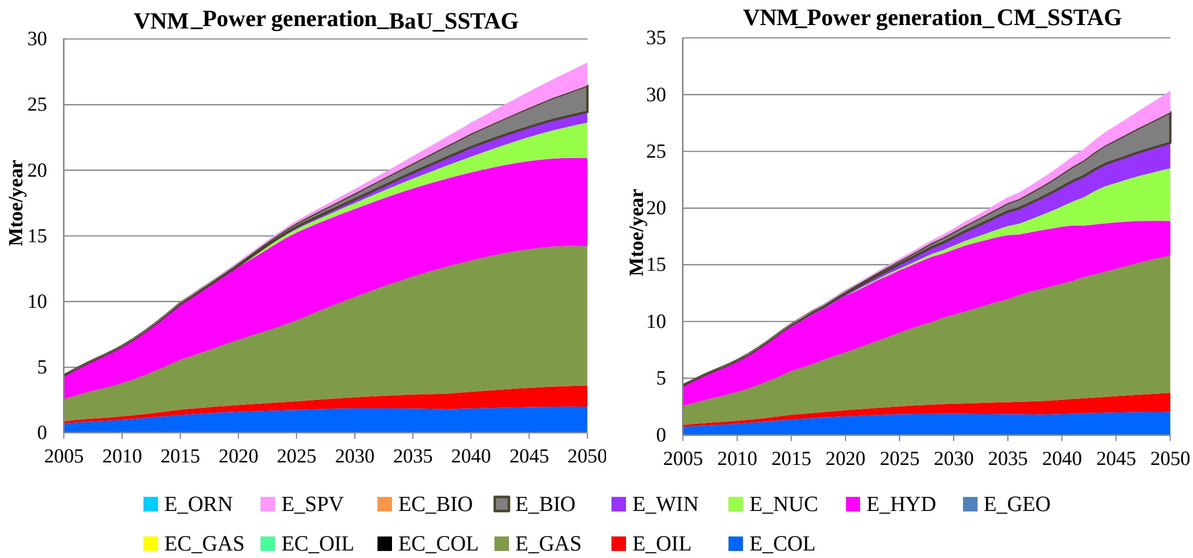


Figure 5.41: Power generation by energy types in SSTAG

In BaU_SLCS (Figure 5.42), the electricity is also mainly produced by gas (E_GAS) with rapid increasing share (even higher than in BaU_SSTAG); follow by hydro power (E_HYD). Similar to BaU_SSTAG, there is not much increase in electricity generation from hydro while oil (E_OIL) and coal (E_COL) increase their contribution to the total electricity generation. Since 2020, new and renewable energies also increase their share in power generation slightly, including nuclear power (E_NUC), biomass (E_BIO), solar power (E_SPV), and wind power (E_WIN). Especially, the contribution of nuclear power increases substantially, following the national power development plan. In 2050, the share of gas (E_GAS), nuclear (E_NUC), hydro (E_HYD), oil (E_OIL), solar (E_SPV), coal (E_COL), and biomass (E_BIO) in total electricity generation is 37%, 15.9%, 15.3%, 9.1%, 8%, 6.4%, and 6.2%, respectively.

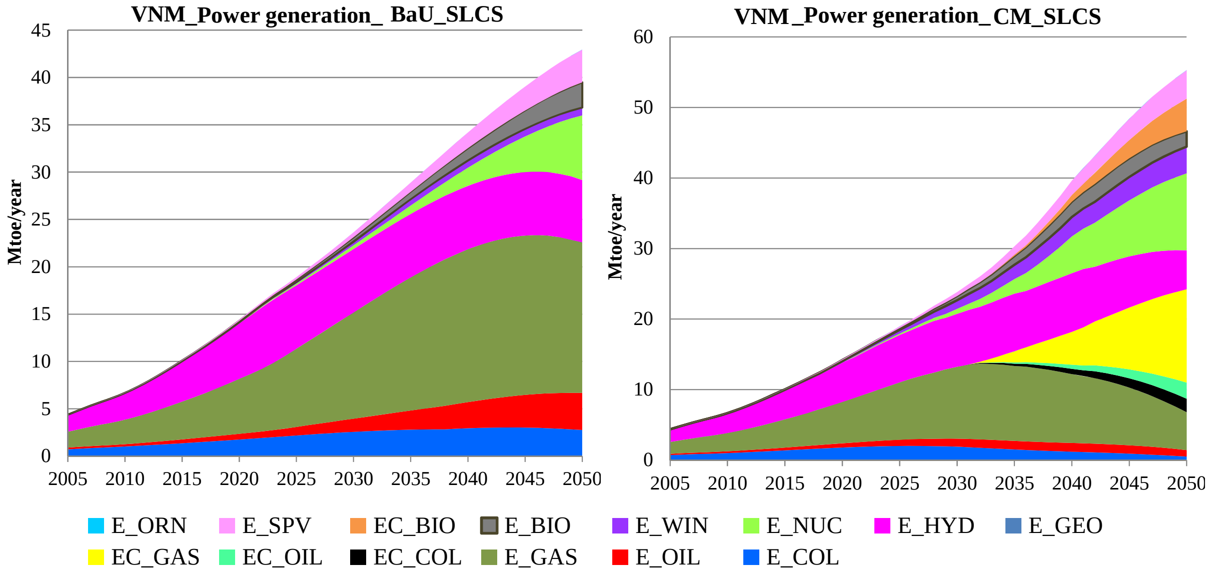


Figure 5.42: Power generation by energy types in SLCS

- In CM_SLCS, the total power generation is higher than in BaU_SLCS. Gas (E_GAS), hydro (E_HYD), oil (E_OIL), and coal (E_COL) reduce their contributions to power generation. Meanwhile, CCS technology is also introduced in power generation at very high speed; especially from gas (EC_GAS) and biomass (EC_BIO). The contribution of biomass and renewable energies (solar and wind) in power generation of CM_SLCS is also higher than those in BaU_SLCS. Especially, nuclear power has larger contribution to power generation in the future. In 2050, the share of CCS in gas (EC_GAS), nuclear (E_NUC), hydro (E_HYD), gas (E_GAS), CCS in biomass (EC_BIO), solar (E_SPV), and wind (E_WIN) is 24%, 19.7%, 10%, 9.7%, 8.4%, 7.3%, and 6.9%, respectively. In order to achieve the GHG emissions reduction target, CCS technology, contribution of nuclear power and renewable energies are also main countermeasures in order fulfill the future electricity demand in Vietnam. Due to cheaper price compared to other energies, the contribution of biomass in power generation is still high. However, under more stringent emission reduction (C&C target), SLCS has to increase the share of CCS technology in power generation, especially in the use of biomass (EC_BIO).

5.4.3 GHG emissions and reduction measures

High economic development leads to increasing energy consumption and GHG emissions in Vietnam. Therefore, total GHG emissions from SLCS are much higher than in SSTAG due to the large different in GDP growth rate (as shown in Figure 5.43).

- In BaU_SSTAG, the total GHG emissions in 2050 is around 1.9 times compared to 2005 while total GDP is nearly 7.4 times together with 1.6 times increase in total primary energy supply; 1.5 times increase in total final energy consumption; and 6.4 times increase in total electricity generation. In order to achieve the GHG emissions reduction target in 2050 (around 0.37 GtCO_2eq), SSTAG has to reduce 12.4% of its total emission in BaU_SSTAG. The GHG emissions intensity (total emission per total GDP) in 2050 of CM_SSTAG is around 89% of that in BaU_SSTAG. On the other hand, under more stringent emission reduction (C&C target - 0.196 GtCO_2eq), SSTAG has to reduce more than 54% of its total emission, with the emission intensity in 2050 is only nearly 50% of that in BaU_SSTAG.
- In BaU_SLCS, the total GHG emissions in 2050 is nearly 3.6 times compared to 2005, which is also much higher compared to the emission in 2050 of BaU_SSTAG. Meanwhile, the increase of total GDP in 2050 is more than 17 times compared to 2005; together with 3.7 times increase in total primary energy supply, 3.5 times increase in total final energy consumption, and nearly 10 times increase in total electricity generation. With the target of total GHG emissions in 2050 around 0.37 GtCO_2eq, SLCS has to reduce nearly 53% of its total emission in BaU_SLCS. The GHG emissions intensity in CM_SLCS is also decreased, to nearly half of that in 2050 of BaU_SLCS. On the other hand, under more stringent emission reduction (C&C target - 0.196 GtCO_2eq), SLCS has to reduce more than 75% of its total emission, with the emission intensity in 2050 is only nearly 29% of that in BaU_SLCS.

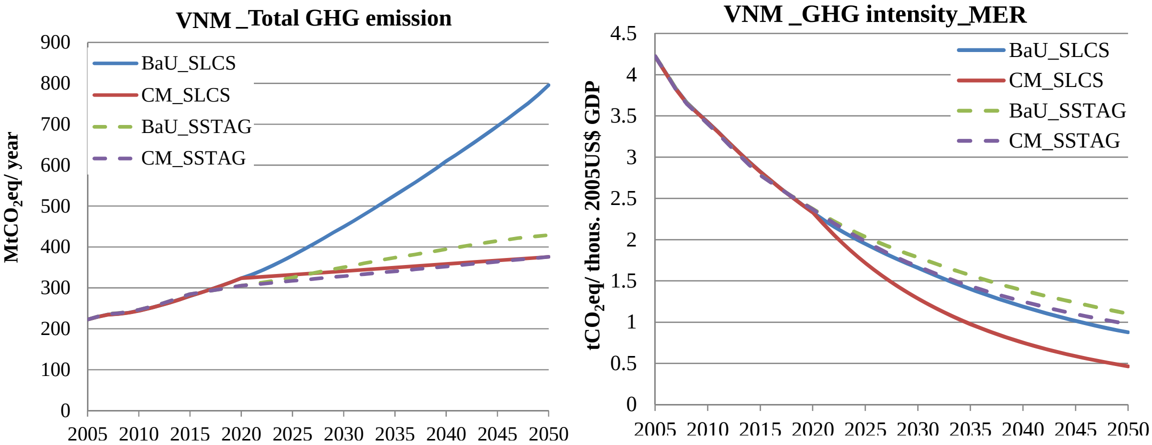


Figure 5.43: Total GHG emissions and emission intensity

In order to achieve GHG emissions reduction target in 2050, both SSTAG and SLCS have to implement appropriate countermeasures (as listed in Table 3.6). The main countermeasures contributed to the reduction of GHG emissions in Vietnam are: CCS technology in power generation (CCS); reduction of non-energy final consumption (non-energy GHG); increase the share of nuclear power (Nuclear) and new-renewable energies (Renewable) in energy mix; as well as end-use the energy fuel switch (Enduse_fuel_switch) and end-use energy efficiency (Enduse_efficiency). In which, CCS is not available in SSTAG.

As shown in Figure 5.44, GHG emissions from non-energy consumption (Non-energy GHG) is one of the most important reduction measures for both SSTAG and SLCS. This measure includes the reduction of emissions from industrial processes, waste (e.g. landfills), agriculture, land use change and forestry.

- In SSTAG, the reduction of non-energy GHG emissions is the biggest contributor to the total GHG emissions reduction, with nearly 90% share in 2050; followed by the total emission reduction potential from end-use (fuel switch, efficiency, structure change). Renewable energy also contributes around 18% to the total reduction amount. Under more stringent emission reduction (C&C target), SSTAG has to rely more on renewable energy due to the unavailability of CCS technology.

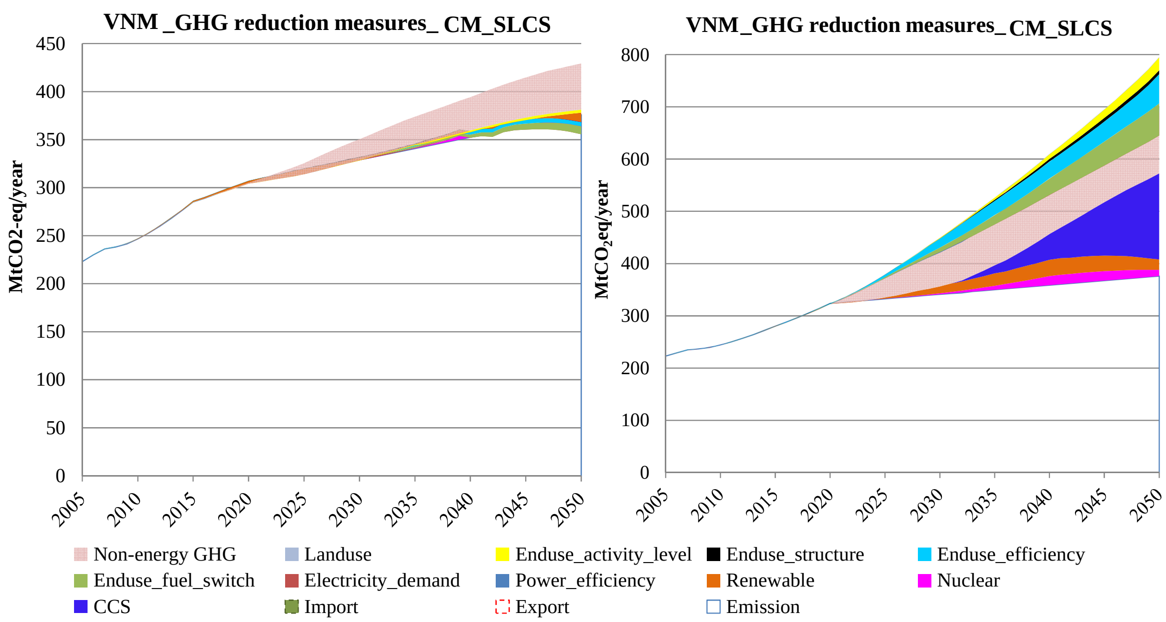


Figure 5.44: GHG emissions reduction measures

- In SLCS, the total emission reduction potential from the implementation CCS technology in power generation becomes the biggest contributor to the total GHG emissions reduction, with nearly 40% share in 2050; followed by end-use (fuel switch, efficiency, structure change; in which fuel switch has highest potential) and non-energy GHG emissions, with nearly 35.7% and 30% of total reduction potential in 2050, respectively. Meanwhile, renewable energy and nuclear power share nearly 8% of total reduction potential in the target year. Under more stringent emission reduction (C&C target), SLCS increases the contribution of CCS technology, making this technology becomes the most important countermeasure in order to reduce the GHG emissions in SLCS.

Main technologies for reducing non-energy related emissions are listed in Table 5.6 (Jolley, 2010).

Table 5.6: Technologies for reducing non-energy-related emissions

Non-energy related emission sources	Emission reduction method
Industrial processes	- incremental improvements in process technology (higher product yields leads to lower emisisons per unit of output) - minimize the likages of emissions associated with equipment use (use sensors and controls in monitoring and maintenance) - reduce the halocaron production and consumption (SF6 consumption) in metals industry and mineral products
Waste	- minimize the waste - diversion of solid waste away from landfills - efficiency improvement in waste management (in landfills)
Agriculture	- reduce the emission from enteric fermentation (use of vaccine) - minimize the manure production (ensure energy requirements of the animals) - reduce the emissions from soil disturbance (reduced tillage, changes in rotations and cover crops, fetility managenent, etc.) - reduce methan emissions from rice cultivation (adopt advanced water and nitrogen management strategies to improve the trade-off between rice production yields and GHGs emission)
Land use change and forestry	- improve the productivity of forestry industries - increase the productivity on existing land in order to reduce the incentive to clear additional land for agricultural purposes

Souce: Jolley (2010)

5.4.4 CCS technology and carbon price

Since the final consumption of electricity in Vietnam is projected to be increased drastically in the future, it is important to analyze the power generation by energy type that may affect the total GHG emissions. CCS technology is considered as one of effective mitigation options. However, since CCS is still in the experiment stage for most countries including Vietnam, we do not have specific information about the future cost of CCS in Vietnam. Therefore, the price of CCS technology for Vietnam is borrowed from

IEA (2008) (as shown in Table 3.4). This CCS technology cost is kept to be constant in all simulated periods.

Figure 5.45 shows the GHG emissions reduction potential of CCS technology in SSTAG and SLCS, in which SLCS introduce CCS technology at very high speed (available since 2020) while this technology is not available in SSTAG. In SLCS, the potential of CCS technology is around 0.16 $GtCO_2eq$ in 2050. Under more stringent emission reduction (C&C target), the contribution of CCS technology in SLCS increases to more than 0.25 $GtCO_2eq$ in 2050, higher than under CM target.

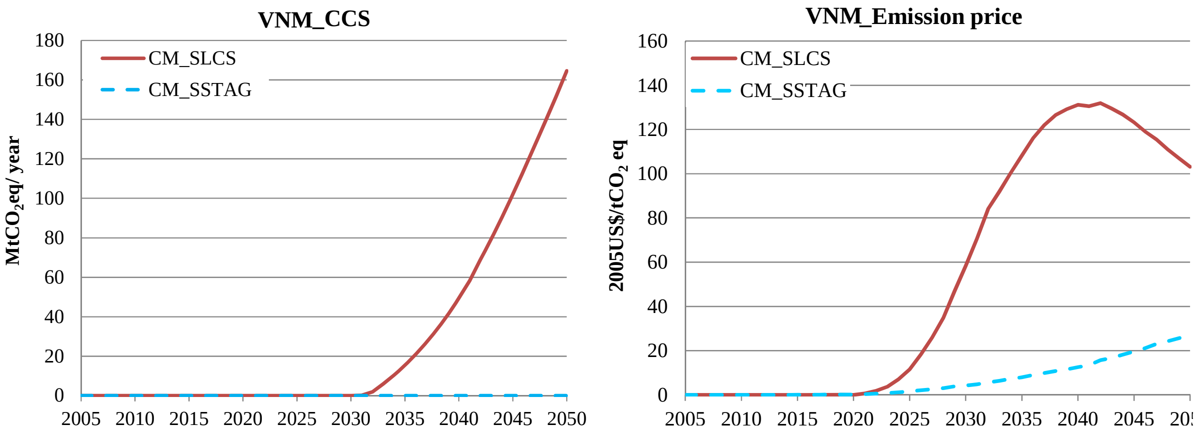


Figure 5.45: Carbon Capture and Storage (CCS) technology and carbon price

There is a cost when implementing GHG emissions countermeasures, which is called carbon price. In SSTAG, carbon price increases gradually since 2025 and reaches around 27 US$/$tCO_2eq$ (in 2005 price). Meanwhile, the carbon price in SLCS increases dramatically since 2020, earlier than in SSTAG, and reaches maximum around 132 US$/$tCO_2eq$ (in 2005 price) before starting the decline significantly and finally drops at 103 US$/$tCO_2eq$ in 2050. This fall of carbon price in SLCS is due to the huge contribution of CCS technology in post 2040.

Under more stringent emission reduction (C&C target), both SSTAG and SLCS have to face more expensive emission price. In which, in 2050; the emission price of SSTAG is very high, around 400 US$/$tCO_2eq$, while the maximum emission price in SLCS is around 306 US$/$tCO_2eq$ (in 2038) before falling down to around 150 US$/$tCO_2eq$ (in 2050). The emission price of SSTAG is higher than that of SLCS since 2043 and become more than twice of SLCS in 2050 due to the unavailable CCS technology in SSTAG.

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Chapter 6 CONCLUDING REMARKS AND DISCUSSIONS

Chapter 6 summarizes main findings of this research through the concluding remarks in Section 6.1 for the characteristic of future society in Vietnam; the implications of low carbon development on social and economic aspects; as well as the energy and environmental issues of low carbon society in Vietnam.

Section 6.2 discusses the reliability of the results analyzed in this study and the limitation of the applied methodology, therefore provides suggestion for future direction.

6.1 Concluding remarks

The two great challenges of the 21st century are the battle against poverty and the management of climate change. On both we must act strongly now and expect to continue that action over the coming decades. Our response to climate change and poverty reduction will define our generation. If we fail on either one of them, we will fail on the other. The current crisis in the financial markets and the economic downturn is new and immediate, although some years in the making. All three challenges require urgent and decisive action, and all three can be overcome together through determined and concerted efforts across the world. But whilst recognizing that we must respond, and respond strongly, to all three challenges, we should also recognize the opportunities: a well-constructed response to one can provide great direct advantages and opportunities for the other.

Two societies for the future of Vietnam are drawn based on main indicators such as socio-economic and political factors; dependency on imported energy; energy diversity; advanced technology progress; household consumption behavior towards environmental-friendly products; and lastly is the CO_2 emissions reduction target. Specifically, the average annual economic growth rate during the period 2005-2050 for the SSTAG and SLCS are 4.6% and 6.6%, respectively, in which the assumption for SLCS is similar to the expectation of Vietnamese Government. Both SLCS and SSTAG puts more effort in increasing the share of tertiary sector in economic structure, however, secondary sector still occupies the economy.

- The SSTAG represents a continuation of the current trends in socio-economic and energy development of Vietnam without any major changes. In which, the main bottleneck of economic development and energy provision is the lack of resources and capital investment. This also precludes the development of a cleaner and more efficient energy system. These conditions explain why the current levels of commitments to climate-friendly-energy production and consumption, as well as the technological breakthroughs in SSTAG are low.

- The SLCS represents a higher trend in socio-economic and energy development of Vietnam compared to SSTAG. There is higher potential of resources and capital investment that encourage the development of a cleaner and more efficient energy system. This scenario reflects the situation where levels of commitments to climate-friendly-energy production and consumption, as well as the technological breakthroughs in SLCS are high.

The population growth rate is same for both SSTAG and SLCS. Annual growth rate of population and GDP for SSTAG and SLCS is around 0.66% per annum. Moreover, it is assumed that people in SLCS have higher education and skill compared to SSTAG. The difference in education and skill affects the ability to adopt new and advanced technologies in both societies. Another difference is that SLCS has better governance compared to SSTAG. Therefore, government in SLCS has higher efficiency in decision-making process towards LCD, as well as in the resource management. In SLCS, people are willing to buy new products which are energy-saving and environmental-friendly even they are more expensive.

6.1.1 Summary of economic implications

➢ ***Technology change and energy efficiency***

In SSTAG, the energy consumption efficiency of industry (AEEI – Autonomous Energy Efficiency Improvement, except for energy transformation sector and household energy consumption) is much lower than SLCS. Moreover, the energy efficiency improvement for energy consumption in power generation, household passenger transportation, and industry passenger transportation of SSTAG is also lower than SLCS.

In conclusion, in order to achieve the GHG emissions reduction target in a very high GDP growth like SLCS, Vietnam has to improve the energy system and technology system dramatically at similar speed as the economic growth, which is around 6% per annual. With less efficiency improvement speed, Vietnam may have to face more economic loss.

➢ ***Transportation***

Beside industry sector, transportation is one of the sectors consuming large amount of energy, in which truck consumes highest share in total energy supplied for transportation. The demand of transportation is changed according to income and GDP increases. In general, the total transport demand and energy for transportation of SLCS is 2.4 times those of STTAG.

Due to strong promotion of advanced technology, SLCS implements electric truck more than SSTAG. In SLCS, the technology improvement in truck transport increases the share of electricity consumption in this sector. Meanwhile, in SSTAG, the share of petroleum in consuming for truck transport dominates and there is no contribution of electric vehicle in truck transportation.

Moreover, the total passenger transport demand in SLCS is more than double that of SSTAG. In both SSTAG and SLCS, electric vehicles haven't been used for passenger transportation. In general, the usage of electric vehicles for industry and household transportation is depended on the technology change and also the price of electricity.

Under more stringent emission reduction (C&C target), SSTAG has to reduce its transport demand much more, around double of the reduction in CM target. Especially, even the demand of freight railway will be decreased significantly. Meanwhile, SLCS has to reduce more than double of the reduction in CM target. SSTAG introduces electric truck since 2031 with total share of electric truck in 2050 is around 50%. Besides, SLCS introduces electric truck earlier, since 2027 with nearly 95% of the total truck energy consumption in 2050. Both SSTAG and SLCS have to introduce the electric vehicles for passenger transport at 5% and 3% of total energy for passenger transport in 2050, respectively.

In general, the role of electric vehicles is important for Vietnam to achieve LCD in the way of switching from conventional alternatives to electricity which emit less GHG due to the contribution of renewable energies, nuclear power, and CCS technology in power generation mix.

- ***Economic structure and trade***

The Vietnamese Government would like to increase the share of tertiary sector to be dominant of the economy; however, both SSTAG and SLCS show the trend that in 2050 secondary sector still occupies with more than 40% of total GDP. In SLCS, the share of tertiary sector is higher than primary sector; meanwhile, the share of these two sectors in SSTAG is similar at 29% of total GDP. This economic structure is maintained even Vietnam follow more stringent emission reduction (C&C target).

The main imported goods in Vietnam are still manufactured products, petroleum, chemical products, light industry and services with rapid increasing rate. In BaU_SSTAG and BaU_SLCS, Vietnam still relies on imported petroleum products; however, in CM cases the imported amount of petroleum is reduced due to the introduction of renewable energy and nuclear power. It is projected that the total import of goods and services in 2050 of BaU_SLCS is 2.4 times that of BaU_SSTAG and this ratio is around 2.0 times for [CM_SLCS/CM_SSTAG]. Under more stringent emission reduction (C&C target), these ratio for [BaU_SLCS/BaU_SSTAG] and [CM_SLCS/CM_SSTAG] are 2.8 times and 2.1 times, respectively. In both SSTAG and SLCS, the behavior is similar to CM target, however, the reduction percentage of import is double that of CM target, with very high reduction in the dependence on petroleum products.

Meanwhile, the main exported goods in Vietnam are machinery products (metal products, machinery, electric equipment, motor vehicles, etc.) and light industrial products (textiles, apparel and leather, and wood products). When considering about the emission reduction, CM_SSTAG and CM_SLCS show that Vietnam will export more light industrial products rather than machinery in order to reduce the energy consumption from heavy industry. It is projected that the total export of goods and services in 2050 of BaU_SLCS is 2.6 times that of BaU_SSTAG and this ratio is around 2.1 times for [CM_SLCS/CM_SSTAG]. Under more stringent emission reduction (C&C target), these ratio for [BaU_SLCS/BaU_SSTAG] and [CM_SLCS/CM_SSTAG] are 2.9 times and 2.1 times, respectively. In both SSTAG and SLCS, the behavior is similar to CM target, however, the reduction percentage of export is nearly double that of CM target, with very high increase in the export of gas.

- ***Price change***

Generally, in SLCS the price of all commodities is higher than those in SSTAG, which is around 1.5-2 times of SSTAG in 2050, except for petroleum product whose price in SLCS is cheaper than in SSTAG. The increase speed of commodity's price in SLCS is also higher than those in SSTAG. Most of energy commodities have increasing price, except for renewable energies. On the other hands, non-energy commodities are grouped into price-increasing and price-decreasing, with highest representative is transport and iron-steel, respectively.

Price of renewable energies such as wind and solar in SLCS is also higher than in SSTAG. In pre-2020 of SLCS, the price of nuclear power is higher than other energies due to the unavailability and rapidly decreases since 2021 and become cheap energy in the future due to the operation of nuclear power plants in central of Vietnam. Beside, cheapest energies are still coal and gas.

However, under more stringent emission reduction (C&C target), the price is more sensitive with the increasing price of energy-commodities, especially coal (E_COL) and hydro (E_HYD) for power generation. Similar to SSTAG, in SLCS, price of coal and hydro for power generation increase higher than under CM target. Especially, in 2050, coal for power generation (E_COL) becomes the most expensive energy, follow by hydro for power generation.

- ***GDP loss***

In overall, the total GDP of SLCS is around 2.3 times that of SSTAG. The total GDP of SSTAG in 2050 is around 7.4 times compared to 2005 while this ratio in SLCS is around

17 times. Under the same population projection for both SSTAG and SLCS, the GDP per capita follows similar trend as total GDP.

In SSTAG, the GDP loss is around 1.2% of its total GDP in 2050. Meanwhile, in 2050 SLCS has higher GDP loss of around 10% of its total GDP. It means that the total direct cost of implementing climate change mitigation measures in SLCS is much higher than in SSTAG. Generally, the payment of industry for each factor in SLCS is 2.3 times compared to SSTAG. However, under more stringent emission reduction (C&C target – 0.196 $GtCO_2eq$), the speed of increasing GDP loss in SSTAG is faster than SLCS. The GDP loss in 2050 of SSTAG and SLCS is 7.1% and 14.5%, respectively.

The possible reason leading to the GDP loss when implementing climate change mitigation actions is that when take into account the emission constraint, industries have to increase their payment for energy consumption under constraint budget. Therefore the income of capital and labor paid by industries would be reduced, leading to the reduction in savings, and thus, investment and next year's capital stock are also reduced. Even though the revenue from emission tax is given to households, this revenue cannot fulfill the income loss supposed to be paid by the industry.

In order to pay for the GHG emissions reduction cost under constraint budget, industry in SSTAG has to reduce its payment to other sectors. Payment to labor is reduced significantly; followed by reduction in payment for land, capital, taxes, and natural resources. In 2050, the reduction of industry's payment in CM_SSTAG for labor, land, capital, and taxes is around 15.2%, 12.5%, 9.9%, and 8.3% of total payment in BaU_SSTAG, respectively. These reductions are performed through the decrease of industrial production.

Similarly, industry in SLCS also has to decrease its payment to labor, followed by reduction in capital, land, taxes, and natural resources. In 2050, the reduction of industry's payment in CM_SLCS for capital, labor, taxes, land, and natural resources is around 26.5%, 23.9%, 19.6%, 19.4% and 2% of total payment in BaU_SLCS, respectively. The reduction of payment to factors leads to the decrease in production that may be counted as one of the reason for GDP loss.

Similar behavior occurs when both SSTAG and SLCS follow more stringent emission reduction (C&C target). The reduction of industry's payment in CM_SSTAG for labor, land, capital, taxes, and natural resources is around 27.7%, 21.9%, 21.8%, 13.7% and 5.2% of total payment in BaU_SSTAG, respectively. Meanwhile, the reduction of industry's payment in CM_SLCS for capital, labor, taxes, land, and natural resources is around 37.8%, 32.9%, 32.3%, 31.6% and 7% of total payment in BaU_SLCS, respectively.

6.1.2 Summary of social implications

➢ ***Employment and income***

In all period, the total employment is around 27-33% of total population which provides a stable labor force for the economy. Generally, in both STTAG and SLCS, the employment for each sector is varying, with the highest employment supplied for service sector; followed by agriculture activities. Other economic sector requires large number of labor are power generation from gas, machinery and other manufacturing, power generation from hydro, and transportation. This behavior is maintained when SSTAG considers more stringent emission reduction (C&C target). This behavior is maintained when SLCS considers more stringent emission reduction (C&C target).

Similar to GDP, the total income of household is also different in SSTAG and SLCS. In overall, the total household income of SLCS is around 2 times that of SSTAG. The total household income of SSTAG in 2050 is around 7 times compared to 2005 while this ratio in SLCS is around 19 times.

In SSTAG, the household income loss starts since 2030 with 0.2% and reaches around 10% of its total income in 2050. Meanwhile, SLCS starts to suffer the income loss since 2025 with very small lost and dramatic increase and reach more than 15% of its total income. The possible reason leading to total income loss when Vietnam takes into account low carbon development is that the payment from industry to household will be reduced, together with payment to other sectors (as analyzed in the GDP loss above) in order to spend more budget for the energy consumption. The household receives payment from industry through labor, capital and others. Moreover, the revenue from emission tax and Carbon Capture and Storage is given to household, which only occur when the society considers GHG emissions reduction measures. However, this revenue could not fulfill the decrease of industry payment to household.

In SSTAG, the income loss starts since 2025, in which income from labor (LAB) is decreased hugely since industries decrease their payment to labor by reducing the number of employees. Income from land, resources (OTH) and capital (CAP) is also reduced. In 2050, the reduction of household income in CM_SSTAG compared to BaU_SSTAG is around 15.3%, 12.5%, and 8.8% for labor (LAB), capita (CAP), and land and resources (OTH), respectively. Similarly, household in SLCS also has to suffer the income loss, even earlier than SSTAG since 2020; from labor (LAB), capital (CAP), and other sources such as land and resources (OTH), with average reduction amount is around 23% of total income in BaU_SLCS. In 2050, the reduction of household income in CM_SLCS compared to BaU_SLCS is around 26.5%, 23.9% and 18% for capita (CAP); labor (LAB); and land and resources (OTH), respectively.

Under more stringent emission reduction (C&C target), both SSTAG and SLCS face higher income loss compared to CM target. In both SSTAG and SLCS, , the revenue from GHG emissions cost increases more than that of CM target. However, the reduction of household income is also higher, leading to more income loss if more stringent emission reduction is considered.

- ***Change in price of goods and services for household consumption***

In general, prices of most of energy commodities are increased, especially oil price. In SLCS, price of oil is cheaper than in SSTAG, both without or with considering the GHG emissions reduction. Non-energy commodities are also divided into 2 groups, one is price-decreasing and the other is price-increasing.

In BaU_SSTAG, the price of energy commodities increases slightly, except for oil products which price increases dramatically and the price in 2050 reaches 29 times that of 2005. In 2050, oil is the most expensive energy; followed by gas, electricity, petroleum products and coal. In the first group of non-energy commodities (price-decreasing group), there are products from light industry, machinery, construction, transportation, and services. The most price-decreasing is transportation. Meanwhile, price-increasing group includes products from agriculture, forestry, mineral mining, food production, paper and pulp, chemicals, mineral, iron-steel, and non-ferrous. Among the price-increasing non-energy commodities, mineral products have highest increasing rate. When SSTAG implements countermeasures to reduce the GHG emissions, price of commodities for household consumption would be decreased, except for mineral products.

Generally, there is a bit different behavior in price of commodities in SLCS compared to SSTAG. Most of the energy commodities, except electricity in SLCS are cheaper than those in SSTAG. In SLCS, price of electricity and oil increase substantially, in which electricity becomes the most expensive energy since 2041. There is not much different in price of petroleum products and coal compared to SSTAG, however, price of gas and oil is lower and the price of electricity in SLCS is more than twice of its price in SSTAG. When SLCS considers the emission reduction target, price of commodities for household consumption is also affected. For all energy commodities, the price decreases in CM_SLCS compared to BaU_SLCS, and the price of electricity in CM_SLCS is still higher than CM_SSTAG. In 2050, oil occupies the position of electricity and becomes the most expensive energy in household consumption; followed by electricity, gas, petroleum, and coal.

Under more stringent emission reduction (C&C target), households in both SSTAG and SLCS experience more expensive commodities compared to CM target, except the cheaper price of electricity.

- ***Household expenditure***

The expenditure of household is depended on their income, their preferences, as well as the price of commodity itself. Moreover, consumption preference is also affected by income. It is assumed that in SLCS, people are much eager to increase their consumption on transportation and energies. The income elasticity for transport demand of household in SSTAG is 1 while that of SLCS is 1.3. Similarly, income elasticity for household energy demand is 1.4 and 1.5 in SSTAG and SLCS, respectively. In general, people are much eager to consume energy (especially electricity) for different purposes such as lighting, heating, cooking, etc. compared to transportation (travelling) within a constraint budget.

In SSTAG, the total household expenditure increases substantially to around 6.7 times in 2050 compared to 2005. Spending on foods is still highest share, which is around 40% of total household expenditure in 2050, followed by spending on services, electricity, machinery and other manufacturing, transportation, and petroleum products at the share of 18%, 10.5%, 9%, 7%, 4%, respectively. In general, the share of household expenditure for most of commodities increases except the large decrease in share of services, and small decrease in share of food productions (such as coffee, drinks, tobacco), light industrial products (textiles, furniture), and petroleum products.

In SLCS, the total household expenditure increases substantially to around 16.3 times in 2050 compared to 2005, much higher than the increase in SSTAG. Spending on foods is still highest share, which is around 29% of total household expenditure in 2050, followed by spending on services, electricity, machinery and other manufacturing, transportation, and petroleum products at the share of 18.5%, 14.5%, 10.4%, 7.7%, 7.7%, respectively. There is also not much change in the household consumption share when SLCS takes into account the emission reduction measures, except in the reduction of share for petroleum products and increasing share of electricity consumption since people in SLCS prefer to use more electricity for cooking, lighting, and heating, etc. Similar to SSTAG, the share of most of commodities increases except the large decrease in share of services, and small decrease in share of food productions (such as coffee, drinks, tobacco), light industrial products (textiles, furniture), and petroleum products.

Under more stringent emission reduction (C&C target), the share of household expenditure in both SSTAG and SLCS is similar to that of CM target, except there is the increase in the household consumption on electricity due to the lower electricity price compared to CM target.

6.1.3 Summary of energy and environmental issues of LCD in Vietnam

➢ ***Energy supply and consumption***

In SSTAG, the total primary energy supply increases slowly with almost stable supply for coal and natural gas and the decrease supply of crude oil due to the limited resource. The supply of hydro power increases slightly together with the contribution of wind and solar power. Meanwhile, supply of oil and petroleum products increases gradually together with the contribution of nuclear power since 2020. The nuclear power share in total primary energy supply in 2050 is around 10%, which almost reach the nuclear power development plan of Vietnamese Government (10%-20% of total primary energy supply in the future). The contribution of biomass is high in base-year and gradually decreases in the future due to the change in the future energy consumption preference. When considering the reduction of GHG emissions, the total primary energy supply in CM_SSTAG is almost same as in BaU_SSTAG. Moreover, nuclear power will be promoted more in the future in order to replace the supply of oil and petroleum. The share of nuclear power in CM_SSTAG is around 16% of TPES in 2050

In SLCS, the total primary energy supply increases rapidly with a small increase in supply of coal and natural gas. The supply of hydro power also increases slightly together with the contribution of wind and solar power. Meanwhile, supply of oil and petroleum products increases dramatically with the contribution of nuclear power since 2020. Having similar nuclear capacity as SSTAG, in SLCS the nuclear power share in total primary energy supply in 2050 is around 11%. The contribution of biomass is also reduced in the future of SLCS.

When considering the reduction of GHG emissions, the total primary energy supply in SLCS is reduced around 16%. Moreover, nuclear power will be promoted more in the future, even more than in SSTAG, in order to replace the supply of oil and petroleum. The share of nuclear power in CM_SSTAG is around 20% of TPES in 2050. However, under more stringent emission reduction (C&C target), the primary energy supply of SSTAG from petroleum products will be partly replaced by the contribution of renewable energies (wind, solar, and biomass), leading to nearly 45% contribution of renewable energies in TPES. Moreover, the supply of petroleum products in SLCS is also decreased and replaced by the increasing supply of biomass.

Generally, in final energy consumption, oil and petroleum is the main source with the gradual increase, together with the increase in total final consumption of electricity. Meanwhile, biomass consumption is reduced significantly due to the switch of household energy consumption from biomass to electricity. The final consumption of crude oil and coal decreases dramatically in both SSTAG and SLCS. In 2050, the final consumption share of CM_SSTAG is 49%, 40% and 8.2% for electricity, petroleum products, and biomass, respectively. In SLCS, the total final energy consumption is much higher than in SSTAG. The total final energy consumption in BaU_SLCS is more than 2.3 times that of BaU_SSTAG in 2050.When GHG emissions reduction measures are considered, the electricity consumption increases much higher in CM_SLCS compared to BaU_SLCS while there is reduction in the consumption of petroleum products. The total final energy consumption in CM_SLCS is only 70% of total final consumption in BaU_SLCS. In 2050, the final consumption share of CM_SLCS is 45%, 43% and 10% for electricity, petroleum products (EB_F_OIL), and biomass, respectively.

Under more stringent emission reduction (C&C target), SSTAG reduces its consumption on petroleum products by half (in 2050) while the consumption of biomass and electricity is almost same as in CM target. The total final energy consumption under C&C target is lower than that of CM target. Furthermore, LSCS also reduces its consumption on petroleum products and there is a small increase in the consumption of electricity instead. The total final energy consumption under C&C target is almost same as that of CM target.

The consumption of final energy is mainly for total industry, residential sectors, and transportation. Services, agriculture, and final non-energy consumption (energy is used as material for chemical industry and other sectors) share small part of the final energy consumption. In SSTAG, in pre-2040 the highest final energy consumer of is residential sector due to the counting of biomass in the final energy consumption. However, since post-2040, SSTAG will reduce the consumption of biomass in households (while the consumption of electricity and other types of energy does not increase so much); therefore industry sector is the dominant of final energy consumption. There is small increase in the final energy consumption of transport sector in SSTAG. The total final energy consumption share of industry, residential, and transportation in CM_SSTAG is 40.4%, 27.6%, and 18.3%, respectively. In SLCS, in all period the highest final energy consumer of is residential sector due to the increasing consumption of electricity even the reduction of biomass consumption is accounted. There is slightly increase in the final energy consumption of transport sector in SSTAG and becomes second dominant while industry also increases its final energy consumption moderately. Moreover, there is nearly half reduction in total final energy consumption in 2050 of CM_SLCS compared to BaU_SLCS. The total final energy consumption share of transportation, residential, and industry in CM_SLCS is 34.8%, 34.4%, and 25.2%, respectively. In both SSTAG and SLCS, under more stringent emission reduction (C&C target), the share of sectors in total final energy consumption is almost same as under CM target.

Basically, the energy efficiency increases moderately in Vietnam, around 5 times in 2050 compared to 2005. Furthermore, the energy efficiency when considering the reduction of GHG emissions must be higher than without the consideration, in order to achieve the reduction target. There is similar energy efficiency in both SSTAG and SLCS due to the big difference between total GDP in SSTAG and SLCS. In both SSTAG and SLCS, under more stringent emission reduction (C&C target), there is not much change in the energy intensity compared to CM target.

- ***Power generation***

Recently, small part of electricity is produced from renewable energies such as wind and solar, however at small scale due to the limitation of capacity and high investment and operation cost. In the future, nuclear power will contribute to the production of electricity according to the power development plan of Vietnamese Government.

In SSTAG, the electricity is mainly produced by gas with rapid increasing share; followed by hydro power. There is not much increase in electricity generation from hydro due to the limited capacity in the future. Meanwhile, oil and coal increase their contribution to the total electricity generation. When considering GHG emissions reduction, there is a reduction of contribution from gas, hydro, oil, and coal. Therefore, in order to meet the electricity demand, CCS technology is introduced in power generation, especially from gas, biomass, oil and coal. Especially, nuclear power increases its contribution to power generation in the future. In 2050, the share of gas, nuclear, hydro, biomass, coal, and solar is 40%, 15.3%, 10%, 8.9%, 6.8%, and 6.2%, respectively.

In SLCS, the electricity is also mainly produced by gas with rapid increasing share (even higher than in SSTAG), follow by hydro power. Since 2020, new and renewable energies also increase their share in power generation slightly, including nuclear power, biomass, solar power, and wind power. The total power generation is increased when SLCS consider the emission reduction target, in which gas, hydro, oil, and coal reduce their contributions to power generation. Meanwhile, CCS technology is also introduced in power generation at higher speed compared to SSTAG; especially from gas and biomass. The contribution of biomass and renewable energies (solar and wind) in power generation of SLCS is also higher. In 2050, the share of CCS in gas, nuclear, hydro, gas, CCS in biomass, solar, and wind is 24%, 19.7%, 10%, 9.7%, 8.4%, 7.3%, and 6.9%, respectively. In order to achieve the GHG emissions reduction target, CCS technology, contribution of nuclear power and renewable energies are also main countermeasures in order fulfill the future electricity demand in Vietnam. Due to cheaper price compared to other energies, the contribution of biomass in power generation is still high.

However, under more stringent emission reduction (C&C target), SSTAG has to introduce more renewable energies (especially wind, solar, and biomass) in the energy mix for power generation, leading to nearly 55% contribution of renewable energies in total power generation. Meanwhile, SLCS has to increase the share of CCS technology in power generation, especially in the use of biomass (EC_BIO).

- ***GHG emissions and reduction measures***

High economic development leads to increasing energy consumption and GHG emissions in Vietnam. Therefore, total GHG emissions from SLCS are much higher than in SSTAG due to the large different in GDP growth rate.

In SSTAG, the total GHG emissions in 2050 is around 1.9 times compared to 2005 while total GDP is nearly 7.4 times together with 1.6 times increase in total primary energy supply; 1.5 times increase in total final energy consumption; and 6.4 times increase in total electricity generation. In order to achieve the GHG emissions reduction target in 2050 (around 0.37 $GtCO_2eq$), SSTAG has to reduce 12.4% of its total emission.

In SLCS, the total GHG emissions in 2050 is nearly 3.6 times compared to 2005, which is also much higher compared to the emission in 2050. Meanwhile, the increase of total GDP in 2050 is more than 17 times compared to 2005; together with 3.7 times increase in total primary energy supply, 2.5 times increase in total final energy consumption, and nearly 10 times increase in total electricity generation. With the target of total GHG emissions in 2050 around 0.37 $GtCO_2eq$, SLCS has to reduce nearly 53% of its total emission in SLCS.

On the other hand, under more stringent emission reduction (C&C target - 0.196 $GtCO_2eq$), SSTAG has to reduce more than 54% of its total emission, with the emission intensity in 2050 is only nearly 50% of that in BaU_SSTAG. On the other hand, SLCS has to reduce more than 75% of its total emission, with the emission intensity in 2050 is only nearly 29% of that in BaU_SLCS.

In order to achieve GHG emissions reduction target in 2050, both SSTAG and SLCS have to implement appropriate countermeasures. The main countermeasures contributed to the reduction of GHG emissions in Vietnam are: CCS technology in power generation; reduction of non-energy final consumption; increase the share of nuclear power and new-renewable energies in energy mix; as well as end-use the energy fuel switch and end-use energy efficiency. In which, CCS technology is only available in SLCS, while SSTAG has to rely on renewable energy and nuclear power in order to reduce the total GHG emissions.

Under more stringent emission reduction (C&C target), SSTAG has to rely more on renewable energy due to the unavailability of CCS technology. Meanwhile, SLCS increases the contribution of CCS technology, making this technology becomes the most important countermeasure in order to reduce the GHG emissions in SLCS.

➢ ***CCS technology and carbon price***

SLCS introduce CCS technology at very high speed (available since 2020) while this technology is not available in SSTAG. In SLCS, the potential of CCS technology is around 0.16 $GtCO_2eq$ in 2050. Under more stringent emission reduction (C&C target), the contribution of CCS technology in SLCS increases to more than 0.25 $GtCO_2eq$ in 2050, higher than under CM target.

There is a cost when implementing GHG emissions countermeasures, which is called carbon price. In SSTAG, carbon price increases gradually since 2025 and reaches around 27 US$/$tCO_2eq$ (in 2005 price). Meanwhile, the carbon price in SLCS increases dramatically since 2020, earlier than in SSTAG, and reaches maximum around 132 US$/$tCO_2eq$ (in 2005 price) before starting the decline significantly and finally drops at 103 US$/$tCO_2eq$ in 2050. This fall of carbon price in SLCS is due to the huge contribution of CCS technology in post 2040.

Under more stringent emission reduction (C&C target), both SSTAG and SLCS have to face more expensive emission price. In which, in 2050; the emission price of SSTAG is very high, around 400 US$/$tCO_2eq$, while the maximum emission price in SLCS is around 306 US$/$tCO_2eq$ (in 2038) before falling down to around 150 US$/$tCO_2eq$ (in 2050). The emission price of SSTAG is higher than that of SLCS since 2043 and become more than twice of SLCS in 2050 due to the unavailable CCS technology in SSTAG.

6.2 Discussions

This study proposes a scientific and methodological framework to support policy-makers on scenario studies and long-term LCD plans to promote the adoption of aggressive climate and clean energy targets. Moreover, it provides background for establishing the implication assessment of LCD to the society and economy of Vietnam, under the context that Vietnamese Government is developing the strategic framework for green growth.

The results of this research may assist local governments to develop comprehensive low-carbon action plans that promote the adoption and implementation of sustainable energy policies under uncertainty with minimum compromising to the socio-economic targets.

- Firstly, the chosen GDP growth rates for SSTAG and SLCS are based on the comparison of different references, both international and national sources, after comparing with Vietnam Government development target. In which, the growth rate of SSTAG is almost same as some low projections from international sources.

Meanwhile, assumption for SLCS is similar to the expectation of Vietnamese Government.

- Secondly, some organizations such as International Energy Agency (IEA) and Institute of Energy Economics Japan (IEEJ) project the future primary energy supply in Vietnam which is higher than the results from AIM/CGE[basic] model because they do not consider the reduction of biomass consumption in Vietnam. Moreover, IEA and IEEJ assume future energy supply in Vietnam under very high GDP growth, if compared to SLCS and SSTAG.
- Thirdly, the results of TPES from AIM/CGE[basic] model is similar to some projections of IEA due to similar GDP growth assumption, even they also do not separate the contribution of biomass in total primary supply.
- Fourthly, in this AIM/CGE[basic] model, biomass consumption (EB_F_BIO) is treated to be reduced significantly due to the switch of household energy consumption from biomass to electricity. The final consumption of crude oil (EB_F_CRU) and coal (EB_F_COA) decrease dramatically in both SSTAG and SLCS. The total final energy consumption assumed in SLCS is similar to IEA and IEEJ since their assumptions of GDP growth is similar to SLCS rather than SSTAG. Moreover, the total power generation resulted from AIM/CGE[basic] model is almost same as projections from IEA and IEEJ.
- Lastly, the CCS technology is considered as one of effective mitigation options. However, since CCS is still in the experiment stage for most countries including Vietnam, we do not have specific information about the future cost of CCS in Vietnam. Therefore, the price of CCS technology for Vietnam is borrowed from IEA (2010). This CCS technology cost is kept to be constant in all simulated periods.

Few simulations have been done in order to determine the rank of feasible LCS for Vietnam under the context of SLCS characteristics. At very high economic growth, SLCS may face different levels of economic loss at different GHG emissions reduction targets. Figure 6.1 illustrates the possibility of feasible LCS in Vietnam described by the relationship between total GDP and the emission reduction target (% of total emission in BaU) under the constraint of not more than 12% GDP loss. The red-solid line separates the possibility of LCS in Vietnam into 2 areas: feasible (lower part of the line) and infeasible (upper part of the line). Small blue-dot represents BaU_SLCS and small orange-triangle represents CM_SLCS that are analyzed in this dissertation.

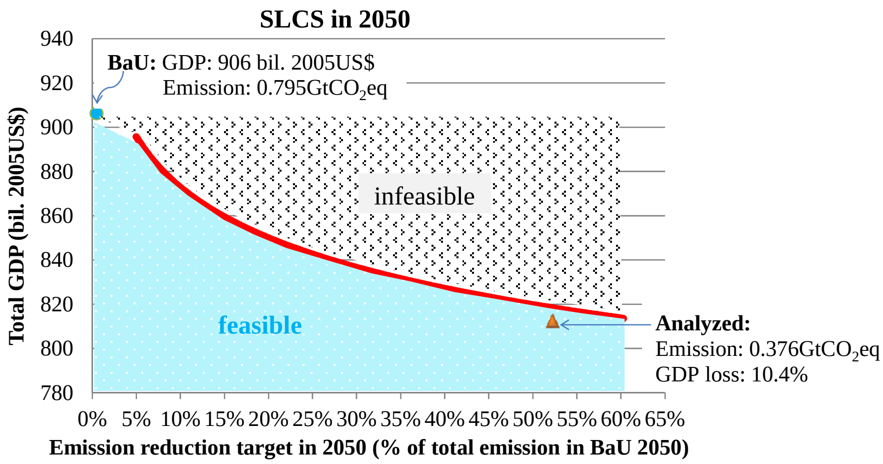

Figure 6.1: Possibility of feasible LCS in Vietnam

The feasible area indicates that, under the context of SLCS characteristics, Vietnam can achieve high economic development. However, the more stringent Vietnam wants to reduce its total GHG emissions, the less economic development the country can achieve due to possible economic loss (as summarized in Table 6.1). It is infeasible that Vietnam still want to reach very high economic development with very small GHG emissions at very low trade-off in economy (less than 5% GDP loss), but could achieve if the country accept around 12% GDP loss. However, it will be possible if suddenly Vietnam can implement very advanced technology and extremely high energy efficiency that may be available in the market.

Table 6.1: Summary of GHG emissions target and GDP loss

Simulation	1st	2nd	3rd	4th	5th	6th
Targeted emission in CM cases ($GtCO_2eq$)	**0.196**	**0.316**	**0.376**	**0.436**	**0.496**	**0.556**
% reduction compared to BaU_SSTAG 2050 (0.429$GtCO_2eq$)	-54.3	-26.4	-12.4			
GDP loss of SSTAG (% of total GDP in 2050)	7.1	3.0	1.2			
% reduction compared to BaU_SLCS 2050 (0.795$GtCO_2eq$)	-75.3	-60.3	-52.7	-45.2	-37.7	-30.1
GDP loss of SLCS (% of total GDP in 2050)	14.5	11.8	10.4	9.1	8.1	7.4

The first simulation (1^{st}) shows the most stringent emission target, which follow exact C&C target (emission in 2050 equals to 12% reduction in the total emission in 2005), for Vietnam. Under this constraint, both SSTAG and SLCS have to face very high GDP loss. At less stringent emission target, the GDP loss is reduced accordingly. The third simulation (3^{rd}) shows the case of emission target where both SSTAG and SLCS still have to reduce their emissions (as analyzed in Chapter 5). Meanwhile, in later simulations, only SLCS has to reduce its emission while SSTAG does not have to reduce; therefore, there is no GDP loss in SSTAG compared to SLCS which still has high GDP loss.

In term of methodology, even CGE model is one of the powerful tools to describe the whole economy of a nation, as well as the interaction of one nation with the rest of the world; so far it cannot perform the real flexibility of the country in term of improvement in energy system and technology system. For example, in reality, developing country like Vietnam can take the advantage of energy improvement and technology innovation at very rapid speed thanks to current innovation in energy and technology from developed countries; which is not allowable in this AIM/CGE[basic] model.

On the other hand, in order to propose more appropriate climate change mitigation options and the well-designed scenarios for future low carbon development, the methodology in this research should:

- Extend the study to more detail household disaggregation (such as urban and rural, and by income levels)
- The simulation of household energy consumption should be in more detail by coupling with bottom-up energy models, especially for households.
- The AIDADS parameters should be estimated based on more detail surveys, such as the updated GMID and HLSS and the household energy consumption (electronic appliances, lighting, cooking, heating/cooling, etc.)

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Drawing back the story of life is always interesting since it recalls all the memories of me and those people I have known so far.

My story of three years staying in Japan and studying at Kyoto University is full of surprises. There are many new things first time I experienced; new language which I am still very bad at it until now; new culture that is not so different from Vietnam culture, but somehow unique; new weather and lifestyle that I day by day get used to. New things in Japan replaces those things I may missed back in Vietnam, where there is Ho Chi Minh City with only two seasons of sunny and rainy. In that city, there are my family, cousins, and friends who always support me unconditionally. It would be my big mistake not to remember how I could end up in Japan until now and write this acknowledgement.

Firstly, it's deep reputation to **my parents** who took my brother and I (at the age of 5 and 3 years old, respectively) from a poor hometown in Binh Dinh province (central of Vietnam) to Ho Chi Minh City in order to find chance for a new life. My parents tried all their bests to raise my brother and I so that both of us had no worry except putting efforts for studying. Life is still difficult but I really appreciate my parents for what they have done to give me chance in finding my own way.

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To all of us, secretary is very important since she help us to manage many things. To me, **Taniguchi-san** and **Hatanaka-san** are more than secretaries because I would not be able to adapt to new life in Japan without them. I am so sorry that I could not communicate with Taniguchi-san much because of my bad Japanese language. Even though Taniguchi-san is no longer working in Matsuoka Lab, I will think of her as a very kind and warm aunt with smiles always on her face. On the other hand, I can talk a lot with Hatanaka-san, not because my Japanese skill has been improved, but thanks to her kindness and "sugoi" English skill.

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The last moment I want to recall is the introduction seminar for new students where I got one question from Hasegawa-san: "Why did you choose Matsuoka Lab?". My answer to her question was that actually I did not have a chance to choose a lab due to the screening process of the scholarship. However, I will always appreciate that selection-by-chance since it brought me to many kind Sensei and lab-mates who made my life in Japan more meaningful. I wish them all the bests and hope to have chance meeting them all again.

***

“I do not know anyone who has gotten to the top without hard work. That is the recipe. It will not always get you to the top, but it will get you pretty near.”

___Margaret Thatcher___

“True wisdom comes to each of us when we realize how little we understand about life, ourselves, and the world around us.”

___Socrates___

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APPENDICES

Appendix A – List of Vietnamese legal documents

Appendix A-1: List of Vietnamese socio-economic and infrastructure legal documents

Name	Year	Organization	Title
06/2002/QD-TTg	2002	Vietnamese Government	Master Plan on the development of Vietnam Railways transport sector till 2020
76/2004/QD-TTg	2004	Vietnamese Government	approval of the Housing development plan up to 2020
Master Plan	2007	Ministry of Investment and Trade (MOIT)	Master plan for the development of Vietnam's motorcycle industry in the period of 2006-2015, with a vision to 2020
13/2008/QD-BGTVT	2008	Ministry of Transportation	approval of the Master plan to develop the domestic waterway transportation in Vietnam up to 2020
48/2008/QD-BCT	2008	Ministry of Finance	approval of the Planning on Development of Electric Equipment-Manufacturing Industry in the 2006-2015 period with a Vision towards 2025
1686/QD-TTg	2008	Vietnamese Government	approval of the Master plan to develop the railway transportation in Vietnam up to 2020, with a vision to 2050
21/QD-TTg	2009	Vietnamese Government	approval of the Strategy for airway transportation development up to 2020, with a vision to 2030
35/2009/QD-TTg	2009	Vietnamese Government	approval of the Strategy for transportation development up to 2020, with a vision to 2030
1327/QD-TTg	2009	Vietnamese Government	approval of the Strategy for road transportation development up to 2020, with a vision to 2030
1436/QD-TTg	2009	Vietnamese Government	approval of the Master plan to develop the railway transportation in Vietnam up to 2020, with a vision to 2030
2190/QD-TTg	2009	Vietnamese Government	approval of the Master plan to develop the seaport/habor in Vietnam up to 2020, with a vision to 2030
129/QD-TTg	2010	Vietnamese Government	approval of the Master plan to develop the seaside roadway in Vietnam
Socio-economic strategy 2020	2011	Ministry of Planning and Investment (MOPI)	Strategies for socio-economic development 2011-2020

Appendix A-2: List of Vietnamese energy legal documents

Name	Year	Organization	Title
40/2003/QD-TTg	2003	Vietnamese Government	Adjusting a number of contents of the planning on Vietnam's electricity development in the 2001-2010 with prospect till 2020 taken into account
102/2003/ND-CP	2003	Vietnamese Government	Decree on thrifty and efficient use of energy
28/2004/QH11	2004	Vietnamese Government	Electricity Law
176/2004/QD-TTg	2004	Vietnamese Government	approval of the Strategy on Development of Vietnam Electricity Industry in the 2004-2010 period, with Orientations towards 2020
26/2006/QD-TTg	2006	Vietnamese Government	approval of the Roadmap and conditions for formation and development of different levels of the electricity market in Vietnam
79/2006/QD-TTg	2006	Vietnamese Government	approval of the National target program on energy efficiency and effectiveness
80/2006/QD-TTg	2006	Vietnamese Government	approval of the 2006-2010 Electricity-saving Program
110/2007/QD-TTg	2007	Vietnamese Government	approval of the Master plan of national power development in 2006-2015, with a vision to 2025 (PDP6)
114/2007/QD-TTg	2007	Vietnamese Government	approval of the "Master plan to implement the Nuclear Power development strategy for peaceful purposes by 2020"
PDP6	2007	Electricity of Vietnam (EVN)	Vietnam Power Development Plan 6
177/2007/QD-TTg	2007	Vietnamese Government	approval of The scheme on development of biofuel up to 2015, with a vision to 2025
1855/2007/QD-TTg	2007	Vietnamese Government	approval of The National Power development strategy of Vietnam up to 2020 with outlook to 2050
18/2008/QH12	2008	Vietnamese Government	Vietnam Law on Nuclear Power
Strategy of EVN	2008	Electricity of Vietnam (EVN)	Strategies to develop electricification technology of EVN up to 2015, with a vision to 2025
89/2008/QD-TTg	2008	Vietnamese Government	Approval of the Strategy on Development of Vietnam's Coal industry up to 2015 and orientations towards 2025
45/2010/QD-TTg	2010	Vietnamese Government	promulgation the regulation on nuclear control
50/2010/QH12	2010	Vietnamese Government	Vietnam Law on Energy efficiency and effectiveness
906/QD-TTg	2010	Vietnamese Government	approval of the Master plan of nuclear power development in Vietnam up to 2030
07/2010/ND-CP	2010	Vietnamese Government	Decree on Detailing and guiding a number of articles of the Law on Atomic Energy
70/2010/ND-CP	2010	Vietnamese Government	detail instruction for Law on Atomic Energy regarding Nuclear Power Plants
05/2011/TT-BCT	2011	Ministry of Industry and Trade (MOIT)	about the electricity sale price in 2011 and instruction
37/2011/QD-TTg	2011	Vietnamese Government	about the supports for wind-power development projects in Vietnam
1208/QD-TTg	2011	Vietnamese Government	approval of the National Master plan for Power development for the 2011-2020 period with the vision to 2030 (PDP7)
42/2011/TT-BCT	2011	Ministry of Industry and Trade (MOIT)	about the electricity sale price and instruction

Appendix A-3: List of Vietnamese environment protection and climate change mitigation legal documents

Name	Year	Organization	Title
Environmental Law	1993	Vietnamese Government	Vietnam Law on Environmental Protection
51/2001/NQ-QH10	2001	Vietnamese Government	About change and improvement of Vietnamese Law in 1992
256/2003/QD-TTg	2003	Vietnamese Government	approval of the National strategies for environmental protection up to 2010, with a vision to 2020
153/2004/QD-TTg	2004	Vietnamese Government	promulgation of the Strategic Orientation for Sustainable Development in Vietnam (Vietnam Agenda 21)
35/2005/CT-TTg	2005	Vietnamese Government	suitable mechanism to adjust the operations related to Convention of Climate and Kyoto Protocol for the period from now to 2012
52/2005/QH11	2005	Vietnamese Government	Vietnam Law on Environmental Protection (support Resolution No. 51/2001/QH10)
10/2006/TT-BTNMT	2006	Ministry of Natural Resources and Environment (MONRE)	encourage wide participation of organizations, domestic and foreign investors in the activities of Clean development mechanism, encourage to renovate the technology, receive and apply clean technology for sustainable development in line with the adaptation and mitigation of the climate change
47/2007/QD-TTg	2007	Vietnamese Government	support instruction No. 35/2005/CT-TTg
130/2007/QD-TTg	2007	Vietnamese Government	about some financial measures and policies towards green investment
60/2007/NQ-CP	2007	Vietnamese Government	National Target Program on Climate Change (NTP)
Document of Energy Efficiency Program	2008	Ministry of Industry and Trade (MOIT)	Climate change mitigation support to the Vietnam Energy Efficiency Program
National Target Program (NTP)	2008	Ministry of Natural Resources and Environment (MONRE)	National Target Program to respond to Climate Change

Appendix B - Mathematical summary statements in National Scenarios Development System

- **Sets**

t	a year which does not have value in the reference
tmax	a year which has value in the reference, bigger than the year *t*, and the closest to the year *t*
tmin	a year which has value in the reference, smaller than the year *t*, and the closest to the year *t*
tref	observed year

- **Parameters**

GDP_comp	complemented GDP scenario
GDP_org	original GDP scenario (described in the reference)
GDP_ref	observed GDP data
POP	population scenario (from UN prospects)
SCL	scale index (GDP, POP, GDPCAP)
TGT_comp	complemented target scenario
TGT_org	original target scenario (described in the reference)
TGT_ref	observed target parameter data
Xo	ratio of target scenario and scale index
Xo_itp	interpolated *Xo*
X	adjusted *Xo*
Xref	ratio of observed GDP and population

List of data source for National-based scenario development

Scenario Code	Year	Organization	Author	Title
SC_VNM_GSO_SCE	2009	General Statistic Office		"Statistic Yearbook of Vietnam 2008"
SC_VNM_STD_SCE	2005	Science and Technology Dept. – Ministry of Industry and Trade, Vietnam	Phong, L.T.	"Current status and activities on energy conservation and energy efficiency in Vietnam"
SC_VNM_IEa_SCE SC_VNM_IEa_HIGH SC_VNM_IEa_BASE SC_VNM_IEa_LOW	2007	Institute of Energy, Vietnam	Toan, P.K.	"Vietnam energy review and power development plan period 2006-2015 with outlook to 2025"
SC_VNM_AECa_SCE SC_VNM_AECa_HIGH SC_VNM_AECa_BASE	2008	Vietnam Atomic Energy Commission-Council of Science and Technology	Phat, T.H.	"The status of the Vietnam nuclear power program"
SC_UN2008_SCE	2008	Population division, department of economic and social affairs, UN		World Population Prospects: The 2008 revision population database (http://esa.un.org/unpp)
SC_VNM_IEb_SCE SC_VNM_IEb_HIGH SC_VNM_IEb_BASE	2008	Institute of Energy, Vietnam	Bao, N.M.	"Vietnam Energy Outlook"
SC_VNM_MPIa_SCE	2006	Ministry of Planning and Investment		"The Five-year Socio-economic Development Plan 2006-2010"
8_IEC_VNM	2005	Institute of Economics, Vietnam Economic Research Network	Trung, T.Q. and Tung, N.T.	"Effect of trade liberalization on non-farm household enterprises in Vietnam"
SC_VNM_IEc_SCE	2006	Institute of Energy		"Vietnamese Power Development Plan VI" (in Vietnamese)
SC_VNM_SAE_SCE SC_VNM_SAE_HIGH SC_VNM_SAE_BASE SC_VNM_SAE_LOW	2005	Vietnam's Society of Automobile Engineers	Chuan, N.X.	"Vietnam's Biofuels project targeting 2015 vision 2020"
SC_ADB_SCE	2009	Asian Development Bank		"Country report – Energy and Climate change in Vietnam"
SC_VNM_HUT_SCE	2006	Hanoi University of Technology, Vietnam	Luong, P.H.	"State-of-the-Art coal combustion technology in the power sector of Vietnam"
SC_VNM_MPIb_SCE	2007	Ministry of Planning and Investment		"Socio-economic strategies" (in Vietnamese)
SC_VNM_GSRa_SCE	2009	Government of Socialist Republic of Vietnam		"Transportation development strategy towards 2020 – vision to 2030" (35/2009/QD-TTg) (in Vietnamese)
SC_VNM_GSRb_SCE	2007	Government of Socialist Republic of Vietnam		"National energy development strategy of Vietnam towards 2020 – vision to 2050" (1855/2007/QD-TTg) (in Vietnamese)
SC_VNM_GSRc_SCE	2006	Government of Socialist Republic of Vietnam		"National target program on Energy Conservation and Efficiency" (79/2006/QD-TTg) (in Vietnamese)
SC_VNM_IEd_SCE	2006	Institute of Energy		"Renewable Energy Development Policies" (in Vietnamese)
SC_VNM_GSRd_SCE	2007	Government of Socialist Republic of Vietnam		"Master plan to implement nuclear power application strategy for peaceful purposes towards 2020" (114/2007/QD-TTg) (in Vietnamese)
SC_VNM_EPDc_SCE	Feb 2007	Energy and Petro Department, Ministry of Insustry, Vietnam	Can, T.V.	Outlook of domestic COA demand and capacity of future COA supply in Vietnam
SC_VNM_EPDa_SCE SC_VNM_EPDa_HIGH SC_VNM_EPDa_BASE	Mar 2007	Energy and Petro Department, Ministry of Insustry, Vietnam	Hung, N.M.	Energy efficiency in industry in Vietnam
SC_VNM_EPDb_SCE	Jun 2007	Energy and Petroleum Department, Ministry of Industry, Vietnam	Trung, M.D.	Vietnam country report on Cleaner coal
SC_VNM_PM_SCE	Dec 2007	Prime Minister	PrimeMinister	National Energy Development Plan by 2020 – Vision to 2050 (Vietnamese)
SC_VNM_MIT_BASE	Mar 2008	Ministry of Industry and Trade (MOIT)	Phong, L.T.	Renewable energy potential, status of RE use for off-rid rural Electrification and policy for Electrification
SC_VNM_MIT_SCE	Apr 2009	Ministry of Industry and Trade (MOIT)	MOIT	Energy balance of Vietnam by 2020
SC_VNM_AEC_sta		Vietnam Atomic Energy Commission	Hong, L.V. and Tuan, H.A.	Preparation studies for introduction of nuclear power to Vietnam
SC_VNM_MOI_SCE	Nov 2004	Ministry of Industry	Thai, V.V.	Long-term Energy demand-supply: Role of Renewable and nuclear energy in Vietnam
SC_VNM_1436_QD_TTg_SCE	2009	Prime Minister		Decree for the railway transportation development plan in 2020, vision to 2030 (in Vietnamese)
SC_VNM_1686_QD_TTg_SCE	2008	Prime Minister		Decree for the railway transportation development plan in 2020, vision to 2050 (in Vietnamese)
SC_VNM_1327_QD_TTg_SCE	2009	Prime Minister		Decree for the road transportation development plan in 2020, vision to 2030 (in Vietnamese)
SC_VNM_35_2009_QD_TTg_SCE	2009	Prime Minister		Decree for the approval of transportation development strategy in 2020, vision towards 2030 (in Vietnamese)
SC_VNM_2190_QD_TTg_SCE	2009	Prime Minister		Decree for the port transportation development plan in 2020, vision to 2030 (in Vietnamese)
SC_VNM_21_QD_TTg_SCE	2009	Prime Minister		Decree for the airway transportation development plan in 2020, vision to 2030 (in Vietnamese)
SC_VNM_13_2008_QD_BGTVT_SCE	2008	Ministry of Transportation		Decree for the approval, revision of inland waterway transportation development strategy in 2020 (in Vietnamese)
ST_VNM_TRS	2008	National traffic safety committee	Binh, P.L.	statistic data on transport sector in vietnam
ST_VNM_SYB	2010	Gereral Statistics Office		Statistical Yearbook of Vietnam 2009
SC_VNM_MoC_SCE	1998	Ministry of Construction		Important pathways for the construction development in Vietnam towards 2010 and 2020
SC_VNM_INEST_SCE		Institute for Environmental Science and Technology	Tuyet, N.T.A and Tam, N.T.	National case study on Renewable Energy for Vietnam
SC_VNM_AECb_SCE	2009	Vietnam Atomic Energy Commission	Phat, L.D.	The IAEA technical supports in capacity building for long term energy and nuclear power assessment and planning in Vietnam
SC_VNM_IUB_SCE	2005	International University of Bremen	Quoc Khanh Nguyen	Long term optimization of energy supply and demand in Vietnam with special reference to the potential of renewable energy

Appendix C - Mathematical summary statements in AIM/CGE[basic] model

➢ SETS

$a \in A$: a set of activities

$a \in ACES(\subset A)$: a set for non-energy transformation

$a \in ALEA(\subset A)$: a set for energy transformation

$a \in ALEO\_ENE(\subset A)$: a set of activities with a CES function at energy nest

$a \in ACES\_ENE(\subset A)$: a set of activities with a CES function at energy nest

$aagg \in Aagg$: a set of aggregated activity

$c \in C$: a set of commodities (also referred as *c'* and *C'*)

$c \in CE(\subset C)$: a set of exported commodities (with domestic production)

$c \in CM(\subset C)$: a set of imported commodities

$c \in CD(\subset C)$: a set of commodities with domestic sales of domestic output

$c \in CX(\subset C)$: a set of commodities with domestic output

$c \in CNEN$: a set of non-energy commodities

$c \in ENE$: a set of energy commodities (COA, OIL, GAS, P_P, ELY, GDT)

$c \in CEN(\subset C)$: non-exported commodities (complement of *CE*)

$c \in CDN(\subset C)$: commodities without domestic market sales of domestic output (complement of *CD*)

$c \in CMN(\subset C)$: a set of non-imported commodities

$c \in C\_TRS$: a set of transport service

$emcm \in EMCM$: a set of emission reduction counter measures (such as CCS)

$emcm \in EMCM0(\subset EMCM)$: a subset of emission reduction counter measures which are for non-energy related emissions

$emcm \in EMCM1(\subset EMCM)$: a subset of emission reduction counter measures which are for energy related emissions

$emcm \in EMCM2(\subset EMCM)$: a subset of emission reduction counter measures which are for biomass power plant absorption

$f \in F(=F')$: a set of factors

$f \in FCAP(=F)$: a set of capital (new and old; *"ncap"* and *"cap"*)

$g \in G$: a set of emission gases

$g \in G^{CO2}$: a set of CO_2

$h \in H\left(\subset INSDNG\right)$: a set of households

$i \in INS$: a set of institutions (domestic and rest of the world)

$i \in INSD\left(\subset INS\right)$: a set of institutions (domestic and rest of the world)

$i \in INSDNG\left(\subset INSD\right)$: a set of domestic nongovernment institutions

$r \in R$: a set of regions

$ragg \in Ragg$: a set of aggregated regions

$tr \in TR$: a set of transport mode (including FRT and PAS for freight and passenger, respectively)

- **PARAMETERS**

✓ **Latin letters**

$aeei_{r,c,ac}^{t}$: annual AEEI rate of energy commodity *c*, sector *ac*, time *t*, region *r*

$bioc_{r,ac}$: biomass consumption coefficient to the activity level of sector *ac*

$biod_{r,ac}$: decreasing rate of biomass consumption of sector *ac*

$capital\_stock_{r}^{t}$: capital stock in time *t* and region *r*

$careneeff_{r,h}$: household passenger transport energy coefficient

CPI_base_{r} : base-year's CPI

crt_in_{r} : transfer from rest of the world

crt_out_{r} : transfer to rest of the world

$cwts_{r,c}$: weight of commodity *c* in the consumer price index

dep_{r}^{t} : capital depreciation rate in time *t* and region *r*

$dis\_imp_{r,c}$ and $dis\_exp_{r,c}$: price difference of the import and export commodity *c*

$dwts_{r,c}$: weight of commodity *c* in the producer price index

$efacl_{r,a,g}$: emission factors for emissions related to activity level by sector *ac*

$efbio_{r,a,g}$: emission factors for emissions related to biomass combustion by sector *ac*

$efffc_{r,c,ac,g}$: emission factors for emissions related to fossil fuel combustion by sector *ac* consuming of goods *c*

$efit_c$	: emission coefficient of international bankers
$EH\_base_{r,h}$	: household expenditure of base-year
$el_{r,c,a}^{inden}$	: price elasticity parameter of Logit function for industrial activity energy source selection
$el_{r,tr}^{pssincome}$	: passenger transport income elasticity
$el_{r,tr}^{trspr}$	: transport energy demand price elasticity
$el_{r,c,a}^{trsen}$	: price elasticity parameter of Logit function for transport mode energy source selection
$el_{r,c,h}^{carh}$	: price elasticity parameter of Logit function for transport mode energy source selection
$el_{r,h}^{eneincome}$	: income elasticity for energy demand in household
$el_{r,h}^{eneagpr}$	: price elasticity for energy demand in household
$enur_{r,c,ac}$	: energy-used ratio (1-non-energy-use ratio)
$ewts_{r,c}$	: weight of commodity *c* in the export price index
$fac\_gr_{r,f}^{t}$	: expected factor input growth rate
$gdp\_gr_{r}^{t*}$	: GDP growth target (annual growth rate)
gwp_g	: Global Warming Potential of gas *g*
$gwts_{r,c}$	: weight of commodity *c* in the government price index
$HEHE\_base_{r,h}$	: energy demand of household except for car energy use in base-year
$ica_{r,c,a}$	: quantity of *c* per unit of aggregate intermediate input *a*
$iena_{r,ca}^{t}$	: quantity of aggregate energy input per activity unit
$iene_{r,c,a}^{t}$	: energy commodity consumption ratio
$ivfa_{r,f,a}$	: input coefficient of factors for Leontief inputs
$inta_{r,a}$	: quantity of aggregate non-energy intermediate input per activity unit
$ires_{r,a}$	: quantity of aggregate resource input per activity unit
$iva_{r,a}$	: quantity of value-added per activity unit
$ivae_{r,a}$	: quantity of value-added energy composite per activity unit
$iwts_{r,c}$	: weight of commodity *c* in the capital formation price index
$lab\_gr_{r}^{t}$	: labor stock (annual) growth rate in time *t* and region *r*
$labor\_stock_{r}^{t}$	: labor stock in time *t* and region *r*

$loss_{r,c}$	: distribution loss rate
$mwts_{r,c}$	: weight of commodity *c* in the import price index
$mps01_{r,i}$	: 0-1 parameter with 1 for institutions with potentially flexed direct tax rates
$pasch_{r,h}$	: income elasticity of passenger transport service demand
pc_c	: carbon fraction
$pco2_c$	: CO_2 emissions coefficient
$pdd_{r,c}^{pre}$	: previous year's domestic demand price of commodity *c*
$pds_{r,c}^{pre}$	: previous year's domestic supply price of commodity *c*
$pe_{r,c}^{pre}$	: previous year's export price of commodity *c*
$pene\_tr\_base_{r,tr}$	: energy price of transport mode *tr* in base-year
$pflag_{c,a}$	: flag for fossil fuel transformation
$pfdq_{r,c,ac}$	: price differences of commodity price among inputs sectors
$pm_{r,c}^{pre}$	: previous year's import price of commodity *c*
$pxac_{r,a,c}^{pre}$	: previous year's producer price of commodity *c* for activity *a*
$PENE\_H\_base_{r,h}$	: energy price of household in base-year
$quotaqa_{ragg,aagg}$	: quota of aggregated region *ragg* and aggregated activity *aagg*
$renew\_up_{r,a}$	: capacity of the activity level *a* (for power sector energy)
$sh\_ely\_up_{r,a}$	: power generation share of activity *a*
$stch_{r,c}$	: stock change of commodity *c* (positive)
$stch2_{r,c}$	: stock change of commodity *c* (negative)
$shif_{r,i,f}$	: share of domestic institution *i* in income of factor *f*
$shii\_resource_{r,i}$	: ratio of transfer to institution *i* of total transfer in a country
$shii\_use_{r,i}$	: share of net income of *i*
$shincome_{r,i}$	: total income share of GHG emissions cost for institution *i*
$shres_{r,i}$	: resource income share of institution *i*
$ta_{r,a}$	: tax rate for activity
$tf_{r,f}$	: direct tax rate for factor *f*

$tins01_{r,i}$	: 0.1 parameter with 1 for institutions with potentially flexed direct tax rates
$tm_{r,c}$ and $te_{r,c}$	: import tariff and export tax rates
$tqd_{r,c,ac}$	: rate of sales tax (as share of composite price inclusive of sales tax). Suffix *ac* includes activity *a* and institution *i*
$transfr\_crt\_in_{r}$	: current transfer from rest of the world
$transfr\_crt\_out_{r}$	: current transfer to rest of the world
$transfr\_f_{r,f}$	: factor transfer from abroad
$transfr_{r,f}$	: factor transfer to abroad
$trspss\_base_{r,tr}$	: passenger transport demand in base-year
$trscvf_{r,tr,ac}$	: transport service demand by modes
$trseneeffi_{r,tr}$	: transport energy efficiency
tsh_{c}	: share of international trade service to world total trade service
$tva_{r,a}$	: rate of value-added tax for activity *a*
$tw_{r,c}$	: international trade cost ratio

✓ **Greek letters**

$\alpha_{r,a}^{vae}$	: efficiency parameter in the CES energy and value-added function
$\alpha_{r,a}^{va}$	: efficiency parameter in the CES value-added function
$\alpha_{r,a}^{va\,*}$	: efficiency parameter in the CES value-added function
$\alpha_{r,c}^{ac}$	: shift parameter for domestic commodity aggregation function
$\alpha_{r,c}^{t}$	: a CET function shift parameter
$\alpha_{r,c}^{q}$	: an Armington function shift parameter
$\beta_{r,c,h}^{m}$	: marginal share of consumption spending on marketed commodity *c* for household *h*
$\beta_{r,c,a}^{inden}$	: share parameter of Logit function for industrial activity energy selection
$\beta_{r,c,tr}^{trsen}$	: share parameter of Logit function for transport mode energy selection
$\beta_{r,c,h}^{carh}$	: share parameter of Logit function for transport mode energy selection
$\gamma_{r,c,h}^{m}$	: subsistence consumption of marketed commodity *c* for household *h*

λ_c^w	: depreciation rate of traded commodity *c*
$\rho_{r,a}^{vae}$	: CES energy and value-added function exponent
$\rho_{r,a}^{va}$	: CES value-added function exponent
$\rho_{r,c}^{ac}$	: domestic commodity aggregation function exponent
$\rho_{r,c}^{t}$	: a CET function exponent
$\rho_{r,c}^{q}$	: an Armington function exponent
$\delta_{r,a}^{vae}$	: CES energy and value-added function share parameter in activity *a*
$\delta_{r,a}^{va}$	: CES value-added function share parameter for factor *f* in activity *a*
$\delta_{r,a,c}^{ac}$	: shift parameter for domestic commodity aggregation function
$\delta_{r,c}^{t}$	: a CET function share parameter
$\delta_{r,c}^{q}$	: an Armington function share parameter
$\theta_{r,a,c}$	: yield of output *c* per unit of activity *a*
$\psi_{r,a,c}^{ac}$	: share parameter of the commodity *c* produced by activity *a*
$\psi_{r,c}^{t}$	: previous year's share of export to domestically produced commodity *c*
$\psi_{r,c}^{m}$	: previous year's share of import to domestically produced commodity *c*
$\eta_{r,a,c}^{ac}$	: elasticity of domestic commodity aggregation
$\eta_{r,c}^{t}$	: elasticity of domestic produced commodity aggregation
$\eta_{r,c}^{m}$	: elasticity of domestic consumption commodity aggregation
$\chi_{r,a,g}$	: reference case emission reduction coefficient
$\sigma_{r,a,g}^{ghg}$	: elasticity of additional emission reductions of non-energy related emissions
$\varsigma_{r,a}$	: a parameter for operation ratio
$\alpha h_{r,c,h}$	: a parameter for AIDADS function
$\beta h_{r,c,h}$	: a parameter for AIDADS function
$\theta h_{r,c,h}$	: subsistence consumption of commodity *c* for household *h* (AIDADS)
$uh_{r,h}$	: utility of household *h* (AIDADS)
$\mu h_{r,c,h}$	: marginal share of consumption spending on marketed commodity *c* for household *h* (AIDADS)

- **Exogenous variables**

CPI_r and CPI_base_r : CPI of year *y* and base-year

$\overline{DTINS_{r,i}}$	: change in domestic institution tax share (= 0 for base-year)
$\overline{EXR_r}$	: currency exchange rate of country *r*
$\overline{FSAV_r}$	: foreign savings (FCU)
$\overline{GADJ_r}$	: government consumption adjustment factor
$\overline{ghgc_r}$	: GHG emissions constraint
$\overline{ghgt\_imp\_cap_r}$	: GHG emissions trading (import) limit
$\overline{ghgt\_exp\_cap_r}$	: GHG emissions trading (export) limit
$\overline{ghgtot\_c}$	: global GHG emissions constraint
$IADJ_r$	: investment adjustment factor
$\overline{mps_{r,i}}$	: base savings rate for domestic institution *i*
$MPS_{r,i}$	: marginal propensity to save for domestic nongovernment institution
$\overline{MPSADJ_r}$	: savings rate scaling factor (= 0 for base-year)
$pcaru_{r,h}$	: household passenger transport service demand in base-year
$pene\_tr\_base_{r,tr}$	: energy price of transport mode *tr* in base-year
$\overline{QFS_{r,f}}$	: quantity supplied of factor
$\overline{qg_{r,c}}$	: government consumption adjustment factor
$\overline{qinv_{r,c}}$	: base-year quantity of fixed investment demand
$\overline{tins_{r,i}}$	: rate of direct tax on domestic institutions *i*
$\overline{TINSADJ_r}$	: direct tax scaling factor (= 0 for base)
$\overline{trnsfr\_CRT_{r,"gov"}}$	: governmental transfer in base-year

- **Endogenous variables**

$ADEEI_{r,a}$	: Additional Energy Efficiency Improvement coefficient
$COPR_{r,a}$	: operation ratio
$DMPS_r$	: 0-1 parameter with 1 for institutions with potentially flexed direct tax rates
DPI_r	: producer price index for domestically marketed output

EG_r : government expenditures

$EH_{r,h}$ and $EH\_base_{r,h}$: total household expenditure of year *y* and base-year

$EMALH_{r,h,g}$: emissions related to activity level by household *h*

$EMALI_{r,a,g}$: emissions related to industrial activity *a*

$EMBIH_{r,h,g}$: emissions related to biomass combustion emitted by household *h*

$EMBII_{r,a,g}$: emissions related to biomass combustion emitted by industrial activity

$EMFFH_{r,c,h,g}$: emissions related to fossil fuel combustion emitted by household *h* consumption of goods *c*

$EMFFI_{r,c,a,g}$: emissions related to fossil fuel combustion emitted by industrial activity *a* consuming of goods *c*

$EMFFINT$: emission from international bankers

EPI_r : export price index

$GHGCA\_ENE_{r,a,c}$: GHG emissions cost related to energy consumption

$GHGCA\_NENE_{r,a}$: GHG emissions cost related to biomass burning and CCS negative emissions of activity *a* in region *r*

$GHGCH_{r,h}$: GHG emissions cost of household *h* in region *r*

GHG_IMP_r : GHG emissions credit import (net)

$GHGT\_CT_r$: GHG emissions from region *r* includes imported emission permit

$GHGT_r$: GHG emissions from region *r* (CO_2 equivalent)

$GHGTCOST_r$: GHG emissions cost

GPI_r : government price index

$GSAV_r$: government savings

IPI_r : capital formation price index

MPI_r : import price index

$NERED_{r,a,g}$: emission reduction caused by the GHG emissions price

$PA_{r,a}$: activity price (gross revenue per activity unit)

$PDD_{r,c}$: demand price for commodity produced and sold domestically

$PDS_{r,c}$: supply price for commodity produced and sold domestically

$PE_{r,c}$: export price of commodity *c*

$PENE_{r,a}$: price of (aggregate) energy input

$PENE_{r,h}^{bau}$: energy price (BaU case)

$PENE\_H_{r,h}$ and $PENE\_H\_base_{r,h}$: energy price for household in year *y* and base-year

$PENE\_TR_{r,tr}$: energy price of transport mode *tr*

$PGHG_r$: GHG emissions price in region *r* (2005US$/t$CO_2$)

$PGHG\_EXP\_QUO_r$: GHG emissions price generated by export quota

$PGHG\_G_r$: global GHG emissions price

$PGHG\_IMP\_QUO_r$: GHG emissions price generated by import quota

$PINTA_{r,a}$: aggregated intermediate input price for activity *a*

$PBIOF_{r,e,a}$: price of biomass for activity *a*

$PM_{r,c}$: composite commodity price (including import tax and transaction costs)

$PQ_{r,c}$: composite commodity price excluding sales tax

$PQD_{r,c}$: composite commodity price excluding sales tax

$PRES_{r,a}$: price of resource input

$PTRS_c$: price of international trade service

$PVA_{r,a}$: price of (aggregate) value-added

$PVAE_{r,a}$: price of (aggregate) energy and value-added bundle (non-energy transformation sector)

PWM_c and PWE_c : world import price *(c.i.f)* and *(f.o.b.)* export price of commodity *c*

$PX_{r,c}$: aggregate producer price for commodity

$PX2_{r,c}$: aggregate producer price for commodity including stock change effects

$PXAC_{r,a,c}$: producer price of commodity *c* for activity *a*

$QA_{r,a}$: quantity (level) of activity

$QBIOF_{r,e,a}$: biomass consumption of activity *a*

$QCARU_{r,h}$: household passenger transport service demand

$QCARUENE_{r,h,c}$: energy use for household passenger transport (by energy sources)

$QCARUENET_{r,h}$: household passenger transport energy use

$QD_{r,c}$: quantity sold domestically of domestic output

$QDTRS_{r,tr,ac}$: freight transport service demand by sector *ac* and modes

$QDTRST_{r,tr}$	: total transport service demand by modes
$QENE_{r,a}$	: quantity of (aggregate) energy input
$QF_{r,f,a}$	: quantity demanded of factor *f* from activity *a*
$QG_{r,c}$	: government consumption demand for commodity
$QH_{r,c,h}$	: quantity of consumption of marketed commodity *c* for household *h*
$QHENE_{r,h}$	: energy demand in household except for car energy use
$QINT_{r,c,a}$	: quantity of commodity *c* as intermediate input to activity *a*
$QINTA_{r,a}$	: quantity of aggregate intermediate input
$QINV_{r,c}$	: quantity of fixed investment demand for commodity
$QM_{r,c}$ and $QE_{r,c}$	: import and export quantities of commodity
$QQ_{r,c}$	: quantity of goods supplied to domestic market (composite supply)
$QRED_{r,emcm,a}$	: input of emission reduction counter measures of activity *a* and measure *emcm*
$QRES_{r,a}$	: quantity of resource input
$QTRS_{c}$	: quantity of international trade service
$QVA_{r,a}$	: quantity of (aggregate) value-added
$QVAE_{r,a}$	: quantity of (aggregate) energy and value-added bundle (non-energy transformation sector)
$QWM_{r,c}$	: quantity of imports of commodity
$QWE_{r,c}$	: quantity of exports of commodity
$QX_{r,c}$	: aggregated marketed quantity of domestic output of commodity
$QX2_{r,c}$	: aggregated marketed quantity of domestic output of commodity including stock change
$QXAC_{r,a,c}$	: marketed output quantity of commodity *c* from activity *a*
$RPBIOF_{r,e,a}$	: reduction rate of the price of biomass for activity *a*
$RQUOQA_{r,a}$	: shadow subsidies of the fixed activity level
$SHAC_{r,a,c}$	: share of the commodity *c* produced by activity *a*
$SHQE_{r,c}$	: share of domestically sold and export commodity *c*
$SHQM$	: share of domestically sold and imported commodity *c*

$SURGHG_{r,emcm,a}$	: complementary variable for the upper boundary of the counter measure installation
$TBH_{r,h}$	: total biomass consumption by household *h*
$TBI_{r,a}$	: total biomass consumption by activity *a*
$TINS_{r,i}$	: direct tax rate for institution *i*
$TRII\_Resource_{r,i}$	: transfers to institution *i*
$TRII\_Use_{r,i}$	: transfers from institution *i*
$TRS\_ENE_{r,tr}$	: transport energy demand by modes
$TRS\_ENE\_FL_{r,c,tr}$	: transport energy demand by modes and energy sources
$VRENCAP_{r,a}$	: rent of electricity capacity activity *a* in region *r*
$VRENCAPTOT_{r}$	: rent related to electricity capacity
$WF_{r,f}$	: average price of factor *f*
$WFDIST_{r,f,a}$	: factor price distortion factor for factor *f* in activity *a*
$YF_{r,f}$	: income of factor *f*
YG_{r}	: government revenue
$YI_{r,i}$	: income of institution *i* (in the set *INSDNG*)
$YIF_{r,i,f}$	: income to domestic institution *i* from factor *f*

- **EQUATION**

Import price:

$$PM_{r,c} = PWM_{c} \cdot dis\_imp_{r,c} \cdot \left(1+tm_{r,c}\right) \cdot EXR_{r} \qquad , \forall c \in CM$$

Export price:

$$PE_{r,c} = PWE_{c} \cdot dis\_exp_{r,c} \cdot \left(1-te_{r,c}\right) \cdot \overline{EXR_{r}} \qquad , \forall r \in R, c \in CE$$

Demand price of domestic non-traded goods:

$$PDD_{r,c} = PDS_{r,c} \qquad , \forall r \in R, c \in CD$$

Absorption:

$$PQ_{r,c} \cdot QQ_{r,c} = PDD_{r,c} \cdot QD_{r,c} + PM_{r,c} \cdot QM_{r,c} \qquad , \forall r \in R, c \in \left(CD \cup CM\right)$$

Commodity market monetary balance:

$$PQ_{r,c} \cdot QQ_{r,c} = PQD_{r,c} \cdot \begin{pmatrix} \sum_{a \in A} pfdq_{r,c,a} \cdot QINT_{r,c,a} + \sum_{h \in H} pfdq_{r,c,h} \cdot QH_{r,c,h} \\ + pfdq_{r,c,"gov"} \cdot QG_{r,c} + pfdq_{r,c,"S-I"} \cdot QINV_{r,c} \end{pmatrix} \quad , \forall r \in R, c \in CX$$

Marketed Output with stock change:

$$QX2_{r,c} = QX_{r,c} + stch_{r,c} \qquad , \forall r \in R, c \in CX$$

Marketed output value with stock change:

$$PX2_{r,c} \cdot QX2_{r,c} = PX_{r,c} \cdot QX_{r,c} \qquad , \forall r \in R, c \in CX$$

Marketed output value:

$$PX2_{r,c} \cdot QX2_{r,c} = PDS_{r,c} \cdot QD_{r,c} + PE_{r,c} \cdot QE_{r,c}, \qquad \forall r \in R, c \in CX$$

Activity price:

$$PA_{r,a} \cdot QA_{r,a} \cdot \left(1 + RQUOQA_{r,a}\right) = \sum_{c \in C} PXAC_{r,a,c} \cdot QXAC_{r,a,c}, \quad \forall r \in R, a \in A$$

Aggregate non-energy intermediate input price:

$$PINTA_{r,a} = \sum_{c \in CNEN} PQ_{r,c} \cdot pfdq_{r,c,a} \cdot QINT_{r,c,a} \left(1 + tqd_{r,c,a}\right) \cdot ica_{r,c,a}, \quad \forall r \in R, a \in A$$

Activity revenue and costs (Non-energy transformation sector):

$$\begin{aligned} PA_{r,a} \cdot \left(1 - ta_{r,a}\right) \cdot QA_{r,a} &= PVAE_{r,a} \cdot QVAE_{r,a} + PINTA_{r,a} \cdot QINTA_{r,a} + PRES_{r,a} \cdot QRES_{r,a} \\ &+ GHGCA\_NENE_{r,a} + VRENCAP_{r,a} \cdot QA_{r,a} + \sum_{emcm \in EMCM} QRED_{r,emcm,a} \\ &, \forall r \in R, a \in ACES \end{aligned}$$

Activity revenue and costs (Energy transformation sector):

$$\begin{aligned} PA_{r,a} \cdot \left(1 - ta_{r,a}\right) \cdot QA_{r,a} &= PVA_{r,a} \cdot QVA_{r,a} + PINTA_{r,a} \cdot QINTA_{r,a} + PENE_{r,a} \cdot QENE_{r,a} \\ &+ PRES_{r,a} \cdot QRES_{r,a} + GHGCA\_NENE_{r,a} + VRENCAP_{r,a} \cdot QA_{r,a} \sum_{emcm \in EMCM} QRED_{r,emcm,a} \\ &, \forall r \in R, a \in ALEO \end{aligned}$$

Resource input price:

$$PA_{r,a} = PRES_{r,a} \qquad , \forall r \in R, a \in A$$

Consumer price index:

$$CPI_r = \sum_{c \in C} PQD_{r,c} \cdot dfpq_{r,c,"hurb"} \cdot \left(1 + tqd_{r,c,"hurb"}\right) \cdot cwts_{r,c} \qquad , \forall r \in R$$

Producer price index for non-traded market output:

$$DPI_r = \sum_{c \in C} PDS_{r,c} \cdot dwts_{r,c} \qquad , \forall r \in R$$

Export price index:

$$EPI_r = \sum_{c \in C} PE_{r,c} \cdot ewts_{r,c} \qquad , \forall r \in R$$

Import price index:

$$MPI_r = \sum_{c \in C} PM_{r,c} \cdot mwts_{r,c} \qquad , \forall r \in R$$

Governmental consumption price index:

$$GPI_r = \sum_{c \in C} PQD_{r,c} \cdot dfpq_{r,c,"gov"} \cdot \left(1 + tqd_{r,c,"gov"}\right) \cdot gwts_{r,c} \qquad , \forall r \in R$$

Capital formation price index:

$$IPI_r = \sum_{c \in C} PQD_{r,c} \cdot dfpq_{r,c,"S-I"} \cdot \left(1 + tqd_{r,c,"gov"}\right) \cdot iwts_{r,c} \qquad , \forall r \in R$$

Leontief Technology - Demand for aggregate value-added (energy transformation sector):

$$QVA_{r,a} = iva_{r,a} \cdot QA_{r,a} \qquad , \forall r \in R, a \in ALEO$$

Leontief Technology - Demand for aggregate energy input (energy transformation sector):

$$QENE_{r,a} = iena_{r,a} \cdot QA_{r,a} \qquad , \forall r \in R, a \in ALEO$$

Energy and Value added Bundle (Non-energy transformation sector)

$$QVAE_{r,a} = ivae_{r,a} \cdot QA_{r,a} \qquad , \forall r \in R, a \in ACES$$

Leontief Technology - Demand for aggregate Non-energy intermediate input:

$$QINTA_{r,a} = inta_{r,a} \cdot QA_{r,a} \qquad , \forall r \in R, a \in A$$

Leontief Technology - Demand for Resource Input:

$$QRES_{r,a} = ires_{r,a} \cdot QA_{r,a} \qquad , \forall r \in R, a \in A$$

Energy and Value-added composite:

$$QVAE_{r,a} = \alpha_{r,a}^{vae} \cdot \left(\delta_{r,a}^{vae} \cdot QVA_{r,a}^{-\rho_{r,a}^{vae}} + \left(1 - \delta_{r,a}^{vae}\right) \cdot \left(\frac{QENE_{r,a}}{1 - ADEEI_{r,a}} \right)^{-\rho_{r,a}^{vae}} \right)^{-\frac{1}{\rho_{r,a}^{vae}}} \qquad , \forall r \in R, a \in ACES$$

Energy and Value-added Input CES Technology (Energy - Value-added input ratio):

$$QVA_{r,a} = \left(\frac{QENE_{r,a}}{1 - ADEEI_{r,a}} \right) \cdot \left(\frac{\delta_{r,a}^{vae}}{1 - \delta_{r,a}^{vae}} \cdot \frac{PENE_{r,a}}{PVA_{r,a}} \right)^{\frac{1}{1+\rho_{r,a}^{vae}}} \qquad , \forall r \in R, a \in ACES$$

Energy and Value-added composite balance:

$$QVAE_{r,a} \cdot PVAE_{r,a} = QENE_{r,a} \cdot PENE_{r,a} + QVA_{r,a} \cdot PVA_{r,a} \qquad , \forall r \in R, a \in ACES$$

Additional energy efficiency improvement (Industry):

$$ADEEI_{r,a} = 1 - \left(\frac{PENE_{r,a}}{PENE_{r,a}^{bau}} \right)^{-\sigma_{r,a}^{eff}} \qquad , \forall r \in R, a \in ACES$$

Energy and Value-added composite (Non-energy use sector):

$$QVAE_{r,a} = QVA_{r,a} \qquad , \forall r \in R, a \in ACES$$

Value-Added and Factor demands (Non-power supply activities):

$$QVA_{r,a} = \alpha^{va}_{r,a} \cdot \left(\sum_{f \in F} \delta^{va}_{r,a} \cdot QF_{r,f,a}{}^{-\rho^{va}_{r,a}} \right)^{-\frac{1}{\rho^{va}_{r,a}}} \qquad , \forall r \in R, a \in A$$

Value-Added and Factor demands (Power supply activities):

$$PVA_{r,a} \cdot \left(1 - tva_{r,a}\right) \cdot QVA_{r,a} = \sum_{f \in F} WF_{r,f} \cdot WFDIST_{r,f,a} \qquad , \forall r \in R, a \in A$$

Factor demand (Non-power supply activities):

$$WF_{r,f} \cdot WFDIST_{r,f,a} = PVA_{r,a} \cdot \left(1 - tva_{r,a}\right) \cdot QVA_{r,a} \cdot \left(\sum_{f \in F'} \delta^{va}_{r,a} \cdot QF_{f\ r,a}{}^{-\rho^{va}_{r,a}} \right)^{-1} \cdot \delta^{va}_{r,a} \cdot QF_{r,f,a}{}^{-\rho^{va}_{r,a}-1}$$
$$, \forall r \in R, a \in A, f \in F$$

Factor demand: Power supply activities:

$$QF_{r,f,a} = ivfa_{r,f,a} \cdot QVA_{r,a} \qquad , \forall r \in R, a \in A, f \in F$$

Factor demand:

$$WF_{r,f} \cdot WFDIST_{r,f,a} = PVA_{r,a} \cdot \left(1 - tva_{r,a}\right) \cdot QVA_{r,a} \cdot \left(\sum_{f \in F'} \delta^{va}_{r,a} \cdot QF_{f\ r,a}{}^{-\rho^{va}_{r,a}} \right)^{-1} \cdot \delta^{va}_{r,a} \cdot QF_{r,f,a}{}^{-\rho^{va}_{r,a}-1}$$
$$, \forall r \in R, a \in A, f \in F$$

Capital aggregation - Perfect substitution:

$$QF_{r,"ccap",a} = QF_{r,"ncap",a} + QF_{r,"cap",a} \cdot COPR_{r,a} \qquad , \forall r \in R, a \in A$$

Capital rate of return for new and old:

$$WF_{r,"ncap"} \cdot WFDIST_{r,"ncap",a} \geq WF_{r,"cap"} \cdot WFDIST_{r,"cap",a} \quad \perp \quad QF_{r,"ncap",a} \geq 0 \qquad , \forall r \in R, a \in A$$

Capital Operation ratio:

$$COPR_{r,a} = \left(\frac{WF_{r,"cap"} \cdot WFDIST_{r,"cap",a}}{WF_{r,"ncap"} \cdot WFDIST_{r,"ncap",a}} \right)^{\varsigma_{r,a}} \qquad , \forall r \in R, a \in A$$

Disaggregated intermediate input demand:

$$QINT_{r,c,a} = ica_{r,c,a} \cdot QINTA_{r,a} \qquad , \forall r \in R, a \in A, c \in CNEN$$

Energy inputs aggregation:

$$QENE_{r,a} = \sum_{c \in ENE} QINT_{r,c,a} \qquad , \forall r \in R, a \in A$$

Energy input technology share:

$$QINT_{r,c,a} = QENE_{r,a} \cdot \frac{\beta^{inden}_{r,c,a} \cdot \left\{ PQD_{r,c} \cdot \left(1+tqd_{r,c,a}\right) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g} \right\}^{el^{inden}_{r,c,a}}}{\sum_{cp \in ENE} \beta^{inden}_{r,cp,a} \cdot \left\{ PQD_{r,cp} \cdot \left(1+tqd_{r,cp,a}\right) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,cp,a} \cdot efffc_{r,cp,a,g} \right\}^{el^{inden}_{r,cp,a}}}$$

$$, \forall r \in R, c \in ENE, a \in A$$

Energy input costs:

$$PENE_{r,a} \cdot QENE_{r,a} = \sum_{c \in C\_ENE} \left\{ PQD_{r,c,a} \cdot \left(1+tqd_{r,c,a}\right) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g} \right\} \cdot QINT_{r,c,a}$$

$$, \forall r \in R, a \in A$$

Energy consumption of energy transformation sector:

$$QINT_{r,c,a} = QENE_{r,a} \cdot iene_{r,c,a} \qquad , \forall r \in R, a \in ALEO\_ENE, c \in ENE$$

Freight transport generated by industrial activity:

$$QDTRS_{r,tr,a} = QINT_{r,"COM\_TRS",a} \cdot trscvf_{r,tr,a} \qquad , \forall r \in R, a \in A, tr \in TR\_FRT$$

Freight transport generated by household consumption:

$$QDTRS_{r,tr,h} = QH_{r,"COM\_TRS",h} \cdot trscvf_{r,tr,h} \qquad , \forall r \in R, h \in H, tr \in TR\_FRT$$

Total freight transport:

$$QDTRST_{r,tr} = \sum_{ac \in AC} QDTRS_{r,tr,ac} \qquad , \forall r \in R, tr \in TR\_FRT$$

Passenger transport (excluding household passenger transport):

$$QDTRST_{r,tr} = trspss\_base_{r,tr} \cdot \left(\frac{GDP_r}{GDP\_base_r} \right)^{el^{pssincome}_{r,tr}} \qquad , \forall r \in R, tr \in TR\_PSS$$

Transport energy demand:

$$TRS\_ENE_{r,tr} = QDTRST_{r,tr} \cdot trseneeffi_{r,tr} \cdot \left(\frac{PENE\_TR_{r,tr}}{pene\_tr\_base_{r,tr}} \right)^{el^{trspr}_{r,tr}} \qquad , \forall r \in R, a \in A, tr \in TR\_FRT$$

Transport energy source:

$$TRS\_ENE\_FL_{r,c,tr} = TRS\_ENE_{r,tr}$$

$$\cdot \frac{\beta^{trsen}_{r,c,tr} \cdot \left\{ PQD_{r,c} \cdot \left(1+tqd_{r,c,"TRS"}\right) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,c,"trs"} \cdot efffc_{r,c,"trs",g} \right\}^{el^{trsen}_{r,c,tr}}}{\sum_{cp \in ENE} \beta^{trsen}_{r,cp,tr} \cdot \left\{ PQD_{r,cp} \cdot \left(1+tqd_{r,cp,"TRS"}\right) + PGHG_r \cdot \sum_{g \in G} gwp_g \cdot enur_{r,cp,"trs"} \cdot efffc_{r,cp,"trs",g} \right\}^{el^{trsen}_{r,cp,tr}}}$$

$$, \forall r \in R, c \in ENE, tr \in TR$$

Transport total energy consumption:

$$QENE_{r,a} = \sum_{tr \in TR} TRS\_ENE_{r,tr} \qquad , \forall r \in R, a \in A\_TRS$$

Transport total energy consumption by fuel:

$$QINT_{r,c,a} = \sum_{tr \in TR} TRS\_ENE\_FL_{r,c,tr} \qquad , \forall r \in R, c \in ENE, a \in A\_TRS$$

Commodity production and allocation:

$$QXAC_{r,a,c} = \theta_{r,a,c} \cdot QA_{r,a} \qquad , \forall r \in R, a \in A, c \in CX$$

Commodity production and allocation (Non-energy commodities):

$$QX_{r,c} = \alpha^{ac}_{r,c} \cdot \left(\sum_{a \in A} \delta^{ac}_{r,a,c} \cdot QXAC_{r,a,c}{}^{-\rho^{ac}_{r,c}} \right)^{-\frac{1}{\rho^{ac}_{r,c}}} \qquad , \forall r \in R, c \in (CX - ENE)$$

First-order condition for output aggregation function (Non-energy commodities):

$$PXAC_{r,a,c} = PX_{r,c} \cdot QX_{r,c} \cdot \left(\sum_{ap \in A} \delta^{ac}_{r,ap,c} \cdot QXAC_{r,ap,c}{}^{-\rho^{ac}_{r,ap}} \right)^{-1} \cdot \delta^{ac}_{r,a,c} \cdot QXAC_{r,a,c}{}^{-\rho^{ac}_{r,a}-1}$$

$$, \forall r \in R, a \in A, c \in (CX - ENE)$$

Share of commodity production and allocation (Energy commodities):

$$SHAC_{r,a,c} = \frac{\psi^{ac}_{r,a,c} PXAC_{r,a,c}{}^{\eta^{ac}_{r,a,c}}}{\sum_{ap \in A} \psi^{ac}_{r,ap,c} PXAC_{r,ap,c}{}^{\eta^{ac}_{r,ap,c}}} \qquad , \forall r \in R, c \in (CX \cap ENE)$$

Commodity production and allocation (Energy commodities):

$$QXAC_{r,a,c} = QX_{r,c} SHAC_{r,a,c} \qquad , \forall r \in R, a \in A, c \in (CX \cap ENE)$$

Balance of the output and commodity aggregate (Energy commodities)

$$\sum_{a \in A} QXAC_{r,a,c} \cdot PXAC_{r,a,c} = QX_{r,c} PX_{r,c} \qquad , \forall r \in R, c \in (CX \cap ENE)$$

Output transformation (CET) function (Non-energy commodities):

$$QX2_{r,c} = \alpha^{t}_{r,c} \cdot \left(\delta^{t}_{r,c} \cdot QE_{r,c}{}^{\rho^{t}_{r,c}} + (1 - \delta^{t}_{r,c}) \cdot QD_{r,c}{}^{\rho^{t}_{r,c}} \right)^{\frac{1}{\rho^{t}_{r,c}}} \quad , \forall r \in R, c \in (CE \cap CD - ENE)$$

Export-Domestic supply ratio (Non-energy commodities):

$$\frac{QE_{r,c}}{QD_{r,c}} = \left(\frac{PE_{r,c}}{PDS_{r,c}} \cdot \frac{1 - \delta^{t}_{r,c}}{\delta^{t}_{r,c}} \right)^{\frac{1}{\rho^{t}_{r,c} - 1}} \qquad , \forall r \in R, c \in (CE \cap CD - ENE)$$

Output transformation for domestically sold outputs without exports and for exports without domestic sales:

$$QX2_{r,c} = QD_{r,c} + QE_{r,c} \qquad , \forall r \in R, c \in (CE \cap CEN) \cup (CD \cap CDN)$$

Share of the domestically sold and export (Energy commodities):

$$SHQE_{r,c} = \frac{\psi^{t}_{r,c} \cdot \left(\frac{PE_{r,c}}{pe^{pre}_{r,c}} \right)^{\eta^{t}_{r,c}}}{\psi^{t}_{r,c} \cdot \left(\frac{PE_{r,c}}{pe^{pre}_{r,c}} \right)^{\eta^{t}_{r,c}} + \left(1-\psi^{t}_{r,c}\right) \cdot \left(\frac{PDS_{r,c}}{pds^{pre}_{r,c}} \right)^{\eta^{t}_{r,c}}} \quad , \forall r \in R, c \in \left(CE \cap CD \cap ENE \right)$$

Exported energy commodities:

$$QE_{r,c} = QX2_{r,c} \cdot SHQE_{r,c} \quad , \forall r \in R, c \in \left(CE \cap CD \cap ENE \right)$$

Domestically sold energy commodities:

$$QD_{r,c} = QX2_{r,c} \cdot \left(1 - SHQE_{r,c} \right) \quad , \forall r \in R, c \in \left(CE \cap CD \cap ENE \right)$$

Composite supply (Armington) function (Non-energy commodities):

$$QQ_{r,c} = \alpha^{q}_{r,c} \cdot \left(\delta^{q}_{r,c} \cdot QM_{r,c}^{-\rho^{q}_{r,c}} + \left(1-\delta^{q}_{r,c}\right) \cdot QD_{r,c}^{-\rho^{q}_{r,c}} \right)^{-\frac{1}{\rho^{q}_{r,c}}} \quad , \forall r \in R, c \in \left(CM \cap CD - ENE \right)$$

Import-Domestic demand ratio (Non-energy commodities):

$$\frac{QM_{r,c}}{QD_{r,c}} = \left(\frac{PDD_{r,c}}{PM_{r,c}} \cdot \frac{1-\delta^{q}_{r,c}}{\delta^{q}_{r,c}} \right)^{\frac{1}{\rho^{q}_{r,c}+1}} \quad , \forall r \in R, c \in \left(CM \cap CD - ENE \right)$$

Composite supply for non-imported outputs and non-produced imports:

$$QQ_{r,c} = QD_{r,c} + QM_{r,c} \quad , \forall r \in R, c \in \left(CD \cap CMN \right) \cup \left(CM \cap CDN \right)$$

Share of the domestically sold and imported (Energy commodities):

$$SHQM_{r,c} = \frac{\psi^{m}_{r,c} \cdot \left(\frac{PM_{r,c}}{pm^{pre}_{r,c}} \right)^{\eta^{m}_{r,c}}}{\psi^{m}_{r,c} \cdot \left(\frac{PM_{r,c}}{pm^{pre}_{r,c}} \right)^{\eta^{m}_{r,c}} + \left(1-\psi^{m}_{r,c}\right) \cdot \left(\frac{PDD_{r,c}}{pdd^{pre}_{r,c}} \right)^{\eta^{m}_{r,c}}} \quad , \forall r \in R, c \in \left(CM \cap CD \cap ENE \right)$$

Imported energy commodities:

$$QM_{r,c} = QQ_{r,c} \cdot SHQM_{r,c} \quad , \forall r \in R, c \in \left(CM \cap CD \cap ENE \right)$$

Domestically sold energy commodities:

$$QD_{r,c} = QQ_{r,c} \cdot \left(1 - SHQM_{r,c} \right) \quad , \forall r \in R, c \in \left(CM \cap CD \cap ENE \right)$$

Factor income:

$$YF_{r,f} = \sum_{a \in A} WF_{r,f} \cdot WFDIST_{r,f,a} \cdot QF_{r,f,a} + transfr\_f_{r,f} \cdot \overline{EXR_{r}} \quad , \forall r \in R, f \in F$$

Institutional factor incomes:

$$YIF_{r,i,f} = shif_{r,i,f} \cdot \left(\left(1 - tf_{r,f}\right) \cdot YF_{r,f} - transfr_{r,f} \cdot \overline{EXR_{r}} \right) \quad , \forall r \in R, i \in INSD, f \in F$$

Income of non-governmental domestic institution:

$$
\begin{aligned}
YI_{r,i} = & \sum_{f\in F} YIF_{r,i,f} + TRII\_Resource_{r,i} \\
& + shincome_{r,i} \cdot GHGTCOST_r + VRENCAPTOT_{r,i} \\
& - \left(PGHG\_G + PGHG\_IMP\_QUO_r - PGHG\_EXP\_QUO_r\right) \cdot GHG\_IMP_r \cdot \overline{EXR_r} \cdot shincome_{r,i} \\
& + shres_{r,i} \cdot \sum_{a\in A} PRES_{r,a} \cdot QRES_{r,a} + shincome_{r,i} \cdot \sum_{a\in A} QENE_{r,a} \cdot PENE_{r,a} \cdot \left(\frac{1}{1-ADEEI_{r,a}} - 1 \right) \\
& + shincome_{r,i} \cdot \sum_{a\in A} \sum_{emcm\in EMCM} QRED_{r,emcm,a} + shincome_{r,i} \cdot \sum_{a\in A} RQUOQA_{r,a} \cdot QA_{r,a} \cdot PA_{r,a} \\
& + shincome_{r,i} \cdot \sum_{e\in E} \sum_{a\in A} QBIOF_{r,e,a} \cdot PBIOF_{r,e,a} \cdot (1 + RPBIOF_{r,e,a}) \qquad , \forall r \in R, i \in INSDNG
\end{aligned}
$$

Total rent of electricity capacity:

$$VRENCAPTOT_{r,"ent"} = \sum_{a\in A} VRENCAP_{r,a} \qquad , \forall r \in R$$

Household consumption expenditures:

$$EH_{r,h} = \left(1 - shii\_use_{r,h}\right) \cdot \left(1 - MPS_{r,h}\right) \cdot \left(1 - TINS_{r,h}\right) \cdot YI_{r,h} \text{-} GHGCH_{r,h} \qquad , \forall r \in R, h \in H$$

Passenger transport demand by household:

$$QCARU_{r,h} = pcaru_{r,h} \cdot \left(\frac{EH_{r,h} / CPI_r}{EH\_base_{r,h} / CPI\_base_r} \right)^{pasch_{r,h}} \qquad , \forall r \in R, h \in H$$

Energy consumption caused by passenger transport in household:

$$QCARUENET_{r,h} = QCARU_{r,h} \cdot careneeff_{r,h} \qquad , \forall r \in R, h \in H$$

Energy fuel consumption caused by passenger transport in household:

$$QCARUENE_{r,h,c} = QCARUENET_{r,h} \cdot \frac{\beta^{carh}_{r,c,h} \cdot \left\{ PQD_{r,c} \cdot \left(1 + tqd_{r,c,h}\right) + PGHG_r \cdot \sum_{g\in G} gwp_g \cdot enur_{r,c,h} \cdot efffc_{r,c,h,g} \right\}^{el^{carh}_{r,c,h}}}{\sum_{cp} \beta^{carh}_{r,cp,h} \cdot \left\{ PQD_{r,cp} \cdot \left(1 + tqd_{r,cp,h}\right) + + PGHG_r \cdot \sum_{g\in G} gwp_g \cdot enur_{r,cp,h} \cdot efffc_{r,cp,h,g} \right\}^{el^{carh}_{r,cp,h}}}$$

$$, \forall r \in R, h \in H, c \in ENE$$

Energy service demand in household (excluding for transportation):

$$QHENE_{r,h} = HEHE\_base_{r,h} \cdot \left(\frac{EH_{r,h} / CPI_r}{EH\_base_{r,h} / CPI\_base_r} \right)^{el^{eneincome}_{r,h}} \cdot \left(\frac{PENE\_H_{r,h}}{PENE\_H\_base_{r,h}} \right)^{el^{eneagpr}_{r,h}}$$

$$, \forall r \in R, h \in H$$

Energy price of household:

$$PENE\_H_{r,h} = \frac{\sum_{c\in ENE} \left(PQD_{r,c} \cdot dfpq_{r,c,h} \cdot \left(1 + tqd_{r,c,h}\right) + \sum_{g\in G} PGHG_r \cdot gwp_g \cdot efffc_{r,c,h,g} \right) \cdot QH_{r,c,h}}{\sum_{c\in ENE} QH_{r,c,h}}$$

$$, \forall r \in R, \ \forall h \in H$$

Household consumption spending:

$$\begin{aligned}&PQD_{r,c}\cdot dfpq_{r,c,h}\cdot\left(1+tqd_{r,c,h}\right)\cdot QH_{r,c,h}\\&=PQD_{r,c}\cdot dfpq_{r,c,h}\cdot\left(1+tqd_{r,c,h}\right)\cdot\gamma^{m}_{r,c,h} \qquad ,\ \forall r\in R,\, c\in C,\, \forall h\in H\\&+\beta^{m}_{r,c,h}\cdot\begin{pmatrix}EH_{r,h}-\sum_{c'\in C\_ENE}\left(PQD_{r,c'}\cdot dfpq_{r,c',h}\cdot\left(1+tqd_{r,c',h}\right)+\sum_{g\in G}PGHG_{r}\cdot gwp_{g}\cdot efffc_{r,c',h,g}\right)\cdot QINT^{m}_{r,c',h}\\-\sum_{c'\in C}PQD_{r,c'}\cdot dfpq_{r,c',h}\cdot\left(1+tqd_{r,c',h}\right)\cdot\gamma^{m}_{r,c',h}\end{pmatrix}\end{aligned}$$

Investment demand:

$$QINV_{r,c}=IADJ_{r}\cdot\overline{qinv_{r,c}} \qquad ,\ \forall r\in R,\, c\in C$$

Government consumption demand:

$$QG_{r,c}=\overline{GADJ_{r}}\cdot\overline{qg_{r,c}} \qquad ,\ \forall r\in R,\, c\in C$$

Government revenue:

$$\begin{aligned}YG_{r}=&\sum_{i\in INSDNG}TINS_{r,i}\cdot YI_{r,i}+\sum_{f\in F}tf_{r,f}\cdot YF_{r,f}+\sum_{a\in A}ta_{r,a}\cdot PA_{r,a}\cdot QA_{r,a}+\sum_{a\in A}tva_{r,a}\cdot PVA_{r,a}\cdot QVA_{r,a}\\&+\sum_{c\in CM}tm_{r,c}\cdot PWM_{c}\cdot dis\_imp_{r,c}\cdot QM_{r,c}\cdot\overline{EXR_{r}}+\sum_{c\in CE}te_{r,c}\cdot PWE_{c}\cdot dis\_exp_{r,c}\cdot QE_{r,c}\cdot\overline{EXR_{r}}\\&+\sum_{c\in C}\sum_{a\in A}tqd_{r,c,a}\cdot dfpq_{r,c,a}\cdot PQD_{r,c}\cdot QINT_{r,c,a}+\sum_{c\in C}\sum_{h\in H}tqd_{r,c,h}\cdot dfpq_{r,c,h}\cdot PQD_{r,c}\cdot QH_{r,c,h}\\&+\sum_{c\in C}tqd_{r,c,"gov"}\cdot dfpq_{r,c,"gov"}\cdot PQD_{r,c}\cdot QG_{r,c}+\sum_{c\in C}tqd_{r,c,"S-I"}\cdot dfpq_{r,c,"S-I"}\cdot PQD_{r,c}\cdot QINV_{r,c}\\&+\sum_{f\in F}YIF_{r,"gov",f}+TRII\_Resource_{r,"gov"}-TRII\_Use_{r,"gov"}+GHGTCOST_{r}\cdot shincome_{r,"gov"}\\&+GHG\_IMP_{r}\cdot\overline{EXR_{r}}\cdot\left(PGHG\_IMP\_QUO_{r}-PGHG\_EXP\_QUO_{r}\right)\\&+shres_{r,"gov"}\cdot\sum_{a\in A}PRES_{r,a}\cdot QRES_{r,a} \qquad ,\ \forall r\in R\end{aligned}$$

Government expenditure:

$$EG_{r}=\sum_{c\in C}PQD_{r,c}\cdot dfpq_{r,c,"gov"}\cdot\left(1+tqd_{r,c,"gov"}\right)\cdot QG_{r,c}+TRII\_Use_{r,"gov"} \qquad ,\ \forall r\in R$$

Transfer use:

$$TRII\_Use_{r,i}=shii\_use_{r,i}\cdot\left(1-MPS_{r,i}\right)\cdot\left(1-TINS_{r,i}\right)\cdot YI_{r,i} \qquad ,\forall r\in R,\, i\in INSDNG$$

Government transfer use:

$$TRII\_Use_{r,"gov"}=\overline{trnsfr\_CRT_{r,"gov"}}\cdot CPI_{r} \qquad ,\ \forall r\in R$$

Transfer resource:

$$TRII\_Resource_{r,i}=shii\_resource_{r,i}\cdot\left(crt\_in_{r}\cdot\overline{EXR_{r}}-crt\_out_{r}\cdot\overline{EXR_{r}}+\sum_{i'}TRII\_Use_{r,i'}\right)$$

$$,\ \forall r\in R,\, i\in INSD$$

Imported commodity:

$$QWM_{r,c} = QM_{r,c} \qquad , \ \forall r \in R, c \in CM$$

Exported commodity:

$$QWE_{r,c} = QE_{r,c} \qquad , \ \forall r \in R, c \in CE$$

World trade nominal balance:

$$\sum_{r \in R} \left(1 - tw_{r,c}\right) \cdot PWM_c \cdot QWM_{r,c} \cdot dis\_imp_{r,c} = \sum_{r \in R} PWE_c \cdot QWE_{r,c} \cdot dis\_exp_{r,c} + PTRS_c \cdot QTRS_c \qquad , \forall c \in \left(CM \cap CE\right)$$

World trade volume balance:

$$\sum_{r \in R} QWM_{r,c} = \left(1 - \lambda_c^w\right) \cdot \sum_{r \in R} \left(QWE_{r,c} - QTRS_c\right) \qquad , \ \forall c \in \left(CM \cap CE\right)$$

Transport service demand:

$$QTRS_c = tsh_c \cdot \sum_{r} QWE_{r,c} \qquad , \forall \ c \in C\_TRS$$

C.I.F and F.O.B relationship:

$$PTRS_c \cdot QTRS_c = \sum_{r'} tw_{r',c} \cdot PWM_c \cdot QWM_{r',c} \cdot dis\_imp_{r',c} \qquad , \forall \ c \in C\_TRS$$

Biomass consumption (Household):

$$TBH_{r,h} = \frac{EH_{r,h}}{CPI_r} \cdot bioc_{r,h} \cdot biod_{r,h} \qquad , \forall r \in R, h \in H$$

Biomass consumption (Industry):

$$TBI_{r,a} = QA_{r,a} \cdot bioc_{r,a} \cdot biod_{r,a} \qquad , \forall r \in R, a \in A$$

Emissions related to activity level (Industrial activity):

$$EMALI_{r,a,g} = QA_{r,a} \cdot efacl_{r,a,g} \cdot \left(1 - NERED_{r,a,g}\right) \cdot \left(1 + \chi_{r,a,g}\right) - \sum_{emcm \in EMCM} \left(QRED_{r,emcm,a} \Big/ \eta_{emcm,a} \right) \qquad , \forall r \in R, a \in A, g \in G$$

Additional emission reductions related to activity level (Industrial activity):

$$NERED_{r,a,g} = 1 - \left(PGHG_r + 1\right)^{-\sigma_{r,a,g}^{ghg}} \qquad , \forall r \in R, a \in A, g \in G$$

Emissions related to activity level (Household):

$$EMALH_{r,h,g} = \frac{EH_{r,h}}{CPI_r} \cdot efacl_{r,h,g} \qquad , \forall r \in R, h \in H, g \in G$$

Emissions related to fossil fuel combustion (Industrial activity):

$$EMFFI_{r,c,a,g} = QINT_{r,c,a} \cdot enur_{r,c,a} \cdot efffc_{r,c,a,g} \qquad , \forall r \in R, c \in ENE, a \in A, g \in G$$

Emissions related to fossil fuel combustion (Household):

$$EMFFH_{r,c,h,g} = QH_{r,c,h} \cdot efffc_{r,c,h,g} \qquad , \forall r \in R, c \in ENE, h \in H, g \in G$$

Emissions related to biomass combustion (Industrial activity):

$$EMBII_{r,a,g} = TBI_{r,a} \cdot efbio_{r,a,g} \qquad , \forall r \in R, a \in A, g \in G$$

Emissions related to biomass combustion (Household):

$$EMBIH_{r,h,g} = TBH_{r,h} \cdot efbio_{r,h,g} \qquad , \forall r \in R, h \in H, g \in G$$

GHG emissions total in a region:

$$GHGT_r = \sum_{g \in G} gwp_g \cdot \left\{ \begin{array}{l} \left(\sum_{h \in H} \sum_{c \in C} EMFFH_{r,c,h,g} + \sum_{a \in A} \sum_{c \in C} EMFFI_{r,c,a,g} \right) \\ + \left(\sum_{h \in H} EMALH_{r,h,g} + \sum_{a \in A} EMALI_{r,a,g} \right) \\ + \left(\sum_{h \in H} EMBIH_{r,h,g} + \sum_{a \in A} EMBII_{r,a,g} \right) \end{array} \right\} \qquad \forall r \in R$$

GHG emissions including emission trading:

$$GHGT\_CT_r = GHGT_r - GHGT\_IMP_r \qquad , \forall r \in R$$

GHG emissions importing trading upper limit:

$$\overline{ghgt\_imp\_cap_r} - GHGT\_IMP_r \geq 0 \ \perp \ PGHG\_IMP\_QUO_r \geq 0 \qquad , \forall r \in R$$

GHG emissions exporting trading upper limit:

$$GHGT\_IMP_r - \overline{ghgt\_exp\_cap_r} \geq 0 \ \perp \ PGHG\_EXP\_QUO_r \geq 0 \qquad , \forall r \in R$$

GHG emissions price and international price:

$$PGHG_r = EXR_r \cdot \left(PGHG\_G + PGHG\_IMP\_QUO_r - PGHG\_EXP\_QUO_r \right) \qquad , \forall r \in R$$

GHG emissions constraint:

$$\overline{ghgc_r} - GHGT\_CT_r \geq 0 \ \perp \ PGHG_r \geq 0 \qquad , \forall r \in R$$

GHG emissions cost of energy (Industry):

$$GHGCA\_ENE_{r,c,a} = PGHG_r \cdot \sum_{g \in G} gwp_g \cdot EMFFI_{r,c,a,g} \qquad , \forall r \in R, a \in A$$

GHG emissions cost of non-energy (Industry):

$$GHGCA\_NENE_{r,a} = PGHG_r \cdot \sum_{g \in G} gwp_g \cdot \left(EMBII_{r,a,g} + EMALI_{r,a,g} \right) \quad , \forall r \in R, a \in A$$

GHG emissions cost of household:

$$GHGCH_{r,h} = PGHG_r \cdot \sum_{g \in G} gwp_g \cdot \left(\sum_{c \in C} EMFFH_{r,c,h,g} + EMALH_{r,h,g} + EMBIH_{r,h,g} \right) \quad , \forall r \in R, h \in H$$

GHG total cost:

$$GHGTCOST_r = \sum_{a \in A} GHGCA_{r,a} + \sum_{h \in H} GHGCH_{r,h} \quad , \forall r \in R$$

Global GHG emissions constraint:

$$\overline{ghgtot\_c} - \sum_{r \in R} GHGT\_CT_r \geq 0 \ \perp PGHG\_G \geq 0$$

Global GHG emissions constraint price:

$$PGHG\_G = PGHG_r \quad , \forall r \in R$$

Global GHG emissions trading total:

$$\sum_{r \in R} GHG\_IMP_r = 0$$

GHG emissions related to the international bankers:

$$EMFFINT = \sum_{r \in R} \sum_{c \in C} \lambda_c \cdot QWE_{r,c} \cdot efit_c$$

Factor markets:

$$\sum_{a \in A} QF_{r,f,a} = \overline{QFS}_{r,f} \quad , \forall r \in R, \ f \in F$$

Composite commodity markets:

$$QQ_{r,c} + \left(QX2_{r,c} + QM_{r,c} \right) \cdot loss_{r,c} + stch2_{r,c} = \sum_{a \in A} QINT_{r,c,a} + \sum_{h \in H} QH_{r,c,h} + QG_{r,c} + QINV_{r,c} \quad , \forall r \in R, c \in C$$

Current-Account balance for the Rest of the World (in Foreign Currency):

$$\sum_{c \in CM} PM_{r,c} \cdot QM_{r,c} + transfr\_crt\_out_r + GHG\_IMP_r \cdot PGHG_r = \sum_{c \in CE} PE_{r,c} \cdot QE_{r,c} + transfr\_crt\_in_r + \overline{FSAV_r} \quad , \forall r \in R$$

Government balance:

$$YG_r = EG_r + GSAV_r \quad , \forall r \in R$$

Direct tax rate:

$$TINS_{r,i} = \overline{tins_{r,i}} \cdot \left(1 + \overline{TINSADJ_r} \cdot tins01_{r,i}\right) + \overline{DTINS_{r,i}} \cdot tins01_{r,i} \qquad , \forall r \in R, i \in INSDNG$$

Institutional savings rates:

$$MPS_{r,i} = \overline{mps_{r,i}} \cdot \left(1 + \overline{MPSADJ_r} \cdot mps01_{r,i}\right) + DMPS_r \cdot mps01_{r,i} \qquad , \forall r \in R, i \in INSDNG$$

Savings - Investment balance:

$$\sum_{i \in INSDNG} MPS_{r,i} \cdot \left(1 - TINS_{r,i}\right) \cdot YI_{r,i} + GSAV_r + \overline{FSAV_r} \cdot \overline{EXR_r}$$
$$= \sum_{c \in C} PQ_{r,c} \cdot \left(1 + tq_{r,c,"I-S"}\right) \cdot QINV_{r,i} \qquad , \forall r \in R$$

Global investment balance:

$$\sum_{r \in R} FSAV_r = 0$$

Activity constraint (Upper boundary):

$$renew\_up_{r,a} - QA_{r,a} \geq 0\ ,\ VRENCAP_{r,a} \geq 0 \qquad , \forall r \in R, a \in A = \{renew\_up_{r,a} > 0\}$$

Activity constraint (QUOTA):

$$quotaqa_{ragg,aagg} = \sum_{r \in Map\_Ragg(r,ragg)} \sum_{a \in Map\_aagg(a,aagg)} \sum_{c \in C} QA_{r,a} \cdot \theta_{r,a,c} \geq 0 \perp RQUOQA\_agg_{ragg,aagg} \geq 0$$
$$, \forall ragg \in Ragg, aagg \in Aagg$$

Reduction measures (for non-energy related GHG emissions):

$$QRED_{r,emcm,a} = \xi^{\max}_{emcm,a} \cdot \eta_{emcm,a} \cdot \sum_{g \in G} gwp_g \cdot EMALI_{r,a,g} \cdot \left(\frac{PGHG_r}{\eta_{emcm,a} \cdot \left(1 + SURGHG_{r,emcm,a}\right)}\right)^2$$
$$, \forall r \in R, a \in A, emcm \in EMCM0$$

Reduction measures upper boundary (for non-energy related GHG emissions):

$$\xi^{\max}_{emcm,a} \cdot \eta_{emcm,a} \cdot \sum_{g \in G} gwp_g \cdot EMALI_{r,a,g} \geq QRED_{r,emcm,a} \quad \perp \quad SURGHG_{r,emcm,a} \geq 0$$
$$, \forall r \in R, a \in A, emcm \in EMCM0$$

Reduction measures (for energy-related GHG emissions):

$$QRED_{r,emcm,a} = \xi^{\max}_{emcm,a} \cdot \eta_{emcm,a} \cdot \sum_{c \in ENE} \sum_{g \in G} gwp_g \cdot EMFFI_{r,a,c,g} \cdot \left(\frac{PGHG_r}{\eta_{emcm,a} \cdot \left(1 + SURGHG_{r,emcm,a}\right)}\right)^2$$
$$, \forall r \in R, a \in A, emcm \in EMCM1$$

Reduction measures (for biomass power plant GHG absorption):

$$QRED_{r,emcm,a} = \xi^{\max}_{emcm,a} \cdot \eta_{emcm,a} \cdot \sum_{g \in G} gwp_g \cdot EMBII_{r,a,g} \cdot \left(\frac{PGHG_r}{\eta_{emcm,a} \cdot \left(1 + SURGHG_{r,emcm,a}\right)}\right)^2$$
$$, \forall r \in R, a \in A, emcm \in EMCM2$$

Reduction measures upper boundary (for energy-related GHG emissions):

$$\xi_{emcm,a}^{\max} \cdot \eta_{emcm,a} \cdot \sum_{c \in ENE} \sum_{g \in G} gwp_g \cdot EFFII_{r,a,c,g} \geq QRED_{r,emcm,a} \quad \perp \quad SURGHG_{r,emcm,a} \geq 0$$

$$, \forall r \in R,\ a \in A,\ emcm \in EMCM1$$

Reduction measures upper boundary (for biomass power plant GHG absorption):

$$\xi_{emcm,a}^{\max} \cdot \eta_{emcm,a} \cdot \sum_{g \in G} gwp_g \cdot EMBII_{r,a,g} \geq QRED_{r,emcm,a} \quad \perp \quad SURGHG_{r,emcm,a} \geq 0$$

$$, \forall r \in R,\ a \in A,\ emcm \in EMCM2$$

Capital dynamic:

$$QF_{r,"cap",a}^{t} = QF_{r,"cap",a}^{t-1} \cdot \left(1 - dep_r^{t-1}\right) \qquad , \forall r \in R,\ t \in T$$

$$\overline{QFS_{r,"NCAP"}^{t}} = \sum_{c} QINV_{r,c}^{t-1} \qquad , \forall r \in R,\ t \in T$$

Labor dynamic:

$$labor\_stock_r^t = labor\_stock_r^{t-1} \cdot lab\_gr_r^t \qquad , \forall r \in R,\ t \in T$$

$$QFS_{r,f}^{t} = labor\_stock_r^t \qquad , \forall r \in R, t \in T,\ f \in F_{lab}$$

Total Factor Productivity (TFP):

$$\alpha_{r,a}^{va*} = \frac{QVA_{r,a}^{t-1} \cdot \left(1 + gdp\_gr_r^{t*}\right)}{\left(\sum_{f \in F} \delta_{r,a}^{va} \cdot \left(QF_{r,f,a}^{t-1} \cdot \left(1 + fac\_gr_{r,f}^{t}\right)\right)^{-\rho_{r,a}^{va}}\right)^{-\frac{1}{\rho_{r,a}^{va}}}} \qquad , \forall r \in R, a \in A$$

Autonomous Energy Efficiency Improvement (AEEI):

$$iene_{r,c,a}^{t} = iene_{r,c,a}^{"base\_year"} \cdot aeei_{r,c,a}^{t} \qquad , \forall r \in R, c \in ENE, a \in A$$

$$iena_{r,ca}^{t} = iene_{r,c,a}^{"base\_year"} \cdot \sum_{c \in ENE} iene_{r,c,a}^{"base\_year"} \cdot aeei_{r,c,a}^{t} \qquad , \forall r \in R, a \in ACES\_ENE$$

$$\gamma_{r,c,h}^{mt} = \gamma_{r,c,h}^{mt-1} \cdot aeei_{r,c,h}^{t} \qquad , \forall r \in R, c \in ENE, h \in H$$

Sector classification in AIM/CGE model (21)

AIM/CGE aggregation	Original SAM Code	Original SAM Description	GTAP (GSC2) code	ISIC3 code (International Standard Industry Classification ver3)	CPC code (Central Product Classfication)
AGR	AGH	Agriculture	PDR, WHT, GRO, V_F, OSD, C_B, PFB, OCR, CTL, OAP, RMK, WOL		0113, 0114; 0111; 0112, 0115, 0116, 0119; 012, 013; 014; 018; 0192; 015, 016, 017, 0191, 0193, 0194, 0199; 0211, 0299; 0212, 0292, 0293, 0294, 0295, 2097; 2091; 0296
	FSH	Fishery	FSH	015, 05	
FRS	FRS	Forestry	FRS		03
COA	COA	Coal mining	COA	101, 102	
OIL	OIL	Oil mining	OIL	111, 112 (related to oil extraction), 103	
GAS	GAS	Gas mining	GAS	111, 112 (related to gas extraction)	
OMN	OMN	Mineral mining and Other quarrying	OMN	12, 13, 14	
FPR	OMT	Meat products	CMT, OMT		21111, 21112,21115, 21116, 21117, 21118, 21119, 2161; 21113, 21114, 2112, 2113, 2114, 2162
	VOL	Vegetable oils and fats	VOL		2163, 2164, 2165, 2166, 2167; 2168, 2169, 217, 218
	MIL	Dairy products	MIL		22
	SGR	Sugar	SGR		235
	OFD	Food products nec	PCR, OFD		2316; 212, 213, 214, 215, 2311, 2312, 2313, 2314, 2315, 2317, 2318, 232, 233, 234, 236, 237, 239
	B_T	Beverages and Tobacco	B_T		24, 25
LIN	TEX	Textiles and Apparel and Leather	TEX, WAP, LEA	17, 243; 18; 19	
	LUM	Wood products	LUM	20	
PPP	PPP	Paper, Paper products and Pulp	PPP	21, 2211, 2212, 2213, 2219, 222, 223	
CRP	CRP	Chemical, Plastic and Rubber products	CRP	241, 242, 25	
CTF	P_C	Coal refinery	P_C	231, 232, 233	
PRF	P_C	Petroleum refinery	P_C	231, 232, 233	
NMM	NMM	Mineral products nec	NMM	26	
I_S	I_S	Iron and Steel	I_S	271, 2731	
NFM	NFM	Non Ferrous products	NFM	272, 2732	
OMF	FMP	Metal products	FMP	28	
	OME	Machinery	OME	29, 31, 33	
	ELE	Electric equipment	ELE	30, 32	
	MVH	Motor Vehicles	MVH	34	
	OTN	Other Transport nes	OTN	35	
	OMF	Other Manufacturing	OMF	36, 37	
E_COL	E_COL	Coal-fired generation without CCS			
E_OIL	E_OIL	Oil-fired generation without CCS			
E_GAS	E_GAS	Gas-fired generation without CCS			
E_NUC	E_NUC	nuclear electric power generation			
E_HYD	E_HYD	hydroelectric power generation			
E_GEO	E_GEO	geothermal power generation			
E_SPV	E_SPV	photovoltaic power generation			
E_ORN	E_TID	wave-activated power generation			
E_WIN	E_WIN	wind-power generation			
E_BIO	E_BIO	biomass-power generation			
E_BIN	E_BIN	agricultural biomass-power generation			
E_ORN	E_ORN	other renewable energy power generation			
E_COL	C_COL	Coal-fired CHP plant			
E_OIL	C_OIL	Oil-fired CHP plant			
E_GAS	C_GAS	Gas-fired CHP plant			
E_NUC	C_NUC	nuclear CHP power generation plant	ELY	part of 401	
E_GEO	C_GEO	geothermatl CHP power generation plant			
E_BIO	C_BIO	Biomass CHP power generation plant			
E_ORN	C_ORN	Other renewable energy source CHP power generation plant			
E_COL	H_COL	Coal heat supply plant			
E_OIL	H_OIL	Oil heat supply plant			
E_GAS	H_GAS	Gas heat supply plant			
E_GEO	H_GEO	Geothermal heat supply plant			
E_BIO	H_BIO	Biomass heat supply plant			
E_BIN	H_BIN	Agricultural biomass heat supply plant			
E_ORN	H_ORN	Other renewable energy heat supply plant			
EC_COL		Coal-fired generation with CCS			
EC_OIL		Oil-fired generation with CCS			
EC_GAS		Gas-fired generation with CCS			
EC_BIO		biomass-fired generation with CCS			
GDT	GDT	Gas manufacture distribution	GDT	402, 403	
CNS	CNS	Construction	CNS	45	
TRS	TRS	Transport and communications	OTP, WTP, ATP, CMN	60,63; 61; 62; 64	
CSS	WTR	Water	WTR	41	
	TRD	Trade and wholesale and retail	TRD	50, 51, 521, 522, 523, 524, 525, 526, 55	
	FIR	Finance, Insurance, Real estate etc	OFI, ISR, OBS, DWE	65, 67; 66; 70, 711, 712, 713, 72, 73, 74; dwellings	
	CSS	Community, Social Services nes	ROS, OSG	92, 93, 95; 75, 80, 85, 90, 91, 99	

Appendix D - Mathematical summary statements in AIDADS consumption function

- **Sets**

i: a set of HLSS commodities

c: a set of GMID commodities

c_a: a set of aggregated CGE commodities

h: a set of households

y: a set of years

- **Exogenous parameters**

✓ **Available data**

$\overline{EH\_HLSS_h^y}$	Total household expenditure per capita per month from HLSS (thous.VND/capita/month)
$\overline{CE\_HLSS_{h,i}^y}$	Commodity *i* expenditure per capita per month from HLSS (thous.VND/capita/month)
$\overline{POP_h^y}$	Total population from HLSS (thous. pers.)
$\overline{EH_{"TOT"}^y}$	Total household expenditure per year from GMID (for TOT group) (mil.2009USD/year)
$\overline{CE_{"TOT",c}^y}$	Commodity *c* expenditure per year from GMID (for TOT group) (mil.2009USD/year)
$\overline{POP_{"TOT"}^y}$	Total population from GMID (for TOT group) (thous. pers.)
$\overline{CPI\_org_c^y}$	Consumer Price Index of commodity *c* from GMID (1990=100)
$\overline{def}^y$	GDP Deflator ($\overline{def}^{2005}$ =213.523; $\overline{def}^{2009}$ =321.041)

✓ **Pre-calibrated parameters**

$\overline{EH\_share_h^y}$	Household expenditure ratio (share)
$\overline{CE\_share\_all_{h,c\_a}^y}$	Share of commodity *c_a* expenditure
$\overline{EH_h^y}$	Total household expenditure per capita per year (2005USD/capita/year)
$\overline{CE\_agg_{h,c\_a}^y}$	Expenditure per capita per year of commodity *c_a*

	(2005USD/capita/year)
$\overline{CPI\_agg_{c\_a}^{y}}$	CPI of aggregated commodity *c_a* (2005=100)
$\overline{QH\_obs\_agg_{h,c\_a}^{y}}$	Observed consumption per capita per month of commodity *c_a* (unit/capita/year)

- **Endogenous parameters**

α_{h,c_a}	Budget share coefficient
β_{h,c_a}	Budget share coefficient
θ_{h,c_a}	Subsistence minima of commodity *c_a*

- **Variables**

QH_{h,c_a}^{y}	Household consumption demand of commodity *c_a*
A	Constant value
u_{h}^{y}	Utility level
μ_{h,c_a}^{y}	Budget share parameter of commodity *c_a*

Commodity classification in AIDADS function estimation (16)

AIDADS code	Detail classification from GMID for Vietnam	Classification from U.S. I-O sectors	Aggregation to GTAP sectors
COM_AGR	Bread and Cereals	141402, 20201	OFD, GRO
	Meat	10301	CLT
	Fish and Seafood	10302	OAP
	Milk, Cheese and Eggs	140600, 140300, 10200	MIL, OAP
	Oils and Fats	142700	CMT
	Fruit	20401	V_F
	Vegetables	20501	V_F
	Sugar and Confectionery	142005	OFD
	Other Food	143202	OFD
COM_FPR	Coffee, Tea and Cocoa	142800, 142002	OFD
	Mineral Waters, Soft Drinks, Fruit and Vegetable Juices	141301	OFD
	Spirits, Wine, Beer	142103	B_T
	Tobacco	150101	B_T
COM_LIN	Clothing Materials	16	TEX
	Garments	17	TEX
	Other Articles of Clothing and Clothing Accessories	18	TEX
	Cleaning, Repair and Hire of Clothing	19	TEX
	Footwear	33, 34	LEA
	Household Textiles	190100	TEX
	Furniture and Furnishings, Carpets and Other Floor Coverings	220102	LUM
COM_ELY	Electricity	680100	ELY
	Heat Energy	680100	ELY
COM_GAS	Gas (natural gas)	80001	GAS
COM_P_P	Liquid Fuels (LPG, kerosene, gasoline, lubricants)	31	P_C
COM_COP	Liquid Fuels (LPG, kerosene, gasoline, lubricants)	31	P_C
COM_COA	Solid Fuels (coal/charcoal, firewood, biomass)	70000	COA
COM_OMF	Household Appliances	54	OME
	Purchase of Cars, Motorcycles and Other Vehicles	590301	MVH
	Operation of Personal Transport Equipment	61	OTN
	Jewellery, Silverware, Watches and Clocks, Travel Goods	640101, 640104	OMF
COM_NMM	Glassware, Tableware and Household Utensils	350100, 362200	NMM
COM_I_S	Hardware and DIY Goods	420300	FMP
COM_PPP	Newspapers, Magazines, Books and Stationery	240705, 240800	PPP
COM_CRP	Other Major Durables For Recreation and Culture	32	CRP
COM_CNS	Maintenance and Repair of Dwellings	120300	CNS
COM_TRS	Rail Travel	650100	OTP
	Buses, Coaches and Taxis	650200	OTP
	Air Travel	650500	ATP
	Other Travel	650200	OTP
	Telecommunications Equipment	660100	CMN
	Telecommunications Services	660200	CMN
COM_CSS	Household and Domestic Services	720201	TRD
	Water and Miscellaneous Domestic Services	68C	WTR
	Actual Rentals For Housing	730102	DWE
	Imputed Rentals For Housing	710100	DWE
	Postal Services	780100	OSG
	Audio-Visual, Photographic and Information Processing Equipment	730104	OBS
	Other Recreational Items and Equipment, Gardens and Pets	76	ROS
	Recreational and Cultural Services	76	ROS
	Package Holidays	760206	ROS
	Education	770401, 770402	OSG
	Catering	740000	ROS
	Accommodation	72A	TRD
	Pharmaceutical Products, Medical Appliances and Equipment	770301	OSG
	Hospital Services	770200	OSG
	Personal Care	770800	OSG
	Social Protection	770900	OSG
	Insurance	70B	OSG
	Financial Services	70A	OFI
	Other Goods and Services		

Appendix E - Mathematical summary statements in Reconciliation System

➢ Sets

$j \in J$	a set of indicator
J_{trs}	a set of *J* which has upper boundary
$l \in L$	a set of accounting constraints
$m \in M$	a set of multiple constraints
$s \in S$	a set of statistics
$t \in T$	a set of time-series

➢ Parameters

✓ Latin letters

$X_{j,r}^{t}$	unknown variable in year *t*, region *r* and indicator *j*
$\overline{A_{l,j,r}^{t}}$	mapping parameter for accounting constraints
$\overline{B_{m,j,r}^{t}}$	mapping parameter for multiple constraintstas
$\overline{C_{jj,j,r}^{t}}$	map parameter of *jj* and *j*
$\overline{Z_{s,j,r}^{t}}$	observation of year *t*, region *r* and indicator *j* taken by statistics *s*
$e1_{j,r,s}^{t}$	error of observation of year *t*, region *r* and indicator *j* by statistics *s*
$e2_{j,r}^{t}$	error of reference parameter of the ratio in year *t*, region *r* and indicator *j*
$w1_{j,r,s}^{t}$	weight of statistical information of year *t* and region *r* indicator *j*
$w2_{j,r}^{t}$	weight of reference parameter of year *t* and region *r* indicator *j*

✓ Greek letters

$\alpha_{jj,j,r}^{t}$	Ratio of $X_{j,r}^{t}$ to $X_{jj,r}^{t}$ in region *r* and year *t*
$\overline{\rho_{j,r}^{t}}$	upper boundary for ratio $\alpha_{j,r}^{t}$
$\overline{\zeta_{j,r}^{t}}$	reference parameter of the ratio of $X_{j,r}^{t}$ to $X_{jj,r}^{t}$ in region r and year t

Appendix F - List of units

Code	Unit
1000P	1000 people
1000H	1000 household
R	Rate
N_100H	Number of possession per 100 household
DD	Degree Day
1000N	Number
1000GRT	1000 gross registered ton
1000PS	1000 passenger
MPK	million passenger-km
1000T	1000 tonne
MTK	million tonne-km
MVK	million vehicle-km
KM	km
BL_HA	Bales per HA
HA	HA
HEAD	HEAD
LC	Local Currency
M3	CUBIC METERS
M3_T	M3/TON
MT	MT
MT_AN	MT/head
MT_HA	MT/HA
N	Number
NON	Dec. Fraction
USD	US million Dollars
US2000D	US million Dollars (2000 price)
US2005D	US million Dollars (2005 price)
KTOE	kton oil equivalent
usd_ktoe	million US dollars per ktoe
Mm2	million square meter
100Y2000	100 in the year 2000