Doctoral Dissertation

Input-output analysis for sustainable economic-environmental system management in Vietnam

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Preface

The research work presented in this PhD thesis, titled "Input-output analysis for sustainable economic-environmental system management in Vietnam", was performed at the Division of Sustainable Energy and Environmental Engineering at Osaka University, in Japan, from April 2014 to August 2018 under the supervision of Professor Akihiro Tokai, with collaboration with Professor Kathleen Aviso from De La Salle University.

The overall work completed is included in four manuscripts prepared for scientific journals. The first manuscript, Nguyen et al. (2018a), employs the structural analysis of inter-relationship between environmental pollution and economic activities to aim in identifying the role of sectors as pollution consumers or producers. The second manuscript by Nguyen et al. (2018b) analyzes socio-economic factors responsible for the changes of pollution resulting from economic activities from both production and final demand perspectives. In the third manuscript, Nguyen et al. (2018c) assesses climate policy proposed by Vietnamese government considering the desired economic growth and the improvement of technology state for key polluting sectors. Finally, in the last manuscript, Nguyen et al. (2018d) aims to identify the potential of greenhouse gas reduction in the future in Vietnam through the implementation of low-carbon scenarios for economic sectors.

1. Nguyen HT, Aviso KB, Kojima N, Tokai A (2018a) Structural analysis of interrelationship between economic activities and wastewater emissions in Vietnam in the period of 2000 -2011. Clean Techn. Environ. Policy, 20(3): 621-638. https://doi.org/10.1007/s10098-018-1492-8

2. Nguyen HT, Aviso KB, Dien LQ and Tokai A (2018b) Main drivers of carbon dioxide emissions in Vietnam trajectory 2000-2011: an input-output structural decomposition analysis. Journal of Sustainable Development, 11(4): 129-147

3. Nguyen HT, Kojima N and Tokai A (2018c) An input-output linear programming model for assessing climate policy considering economic growth. Environ. Syst. Decis., 1-15

4. Nguyen HT, Aviso KB, Dien LQ, Kojima N and Tokai A (2018d) An Input-output linear programming model for mapping low-carbon scenarios for Vietnam in 2030. Sustainable Consumption and Production, 16: 134-140

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Abstract

Due to the rapid economic growth accompanied with poor environmental management, Vietnam is now facing severe environmental pollution. It is thus important to develop a framework to evaluate the different aspects associated to economic activities and pollution flows. The developed framework in this thesis relies on a tool used by European Environmental Agency (EEA) namely DPSIR, but modified to be proper for integrated economic-environmental management, thus so called modified DPSIR. The different aspects include the relationship analysis of economic and environmental flows, the identification of priority sectors, the driving force analysis of pollution change, economic restructure, technology state change and risk evaluation. Recent works have demonstrated the effectiveness of the input-output (IO) model in analyzing these different aspects. However, previous researches just focused on an individual aspect, which did not present a comprehensive picture on how the economic growth of various economic sectors affects the environment. Thus, in this research, the proposed method combines the different aspects mentioned in modified DPSIR tool to identify strategies for comprehensively economic-environment system management.

Firstly, chapter 2 focuses on examining the state of water pollution in Vietnam as indicated by water quality parameters, total suspended solids (TSS) and biological oxygen demand (BOD) resulting from various economic sectors during period 2000 - 2011. Environmentally extended input–output (EIO) analysis coupled with vertical integrated coefficient (VIC) method is used to analyze the interindustry linkages of sectors and to classify sector role. The pollution trend reveals the tremendous increase in TSS and BOD. The results of sectoral linkage evaluation highlight that food, beverage and tobacco and agriculture, fishery and forestry sectors were key sectors for both water quality parameters.

In chapter 3, the analysis of the driving forces responsible for the increase in CO2 emissions in Vietnam from both production and final demand perspectives during 2000-2011. The results from the production perspective indicate that the incremental change in CO2 emissions is driven mainly by consumption structure (100.5%) and consumption volume (219.4%), offset by decline in technology (-132.7%) and production structure (-22.5%). Results from the final demand perspective show that household, export and investment are the main drivers responsible for the sharp increase in CO2 emissions, which is offset by decrease in import factor.

In chapter 4, an IO analysis is first used to provide a measure of structural interdependence among economic sectors and identify priority sectors. An IO optimization model is then developed for minimizing the total greenhouse gas (GHG) emissions to identify strategies for GHG intensity reduction in Vietnam by 2020, focusing on the priority sectors. In addition, the effect of GHG emissions on human health using the disability adjusted life years (DALY) is further evaluated. Six scenarios are proposed for this purpose. These scenarios encompass business as usual (BAU), the consideration of different GDP growth rates, economic restructure and the adaptation of lower-pollution technologies for the priority sectors. The optimization solutions present that the best strategy is by taking advantages of identified measures. The best solution obtains 20.3% reduction in GHG intensity compared to baseline.

Finally, in chapter 5, an IO based linear programming model is developed to evaluate the maximum GHG emission reductions which can be achieved given various climate change mitigating strategies. In addition, this work also evaluates the impact of GHG emissions on human health using DALY indicator. Six scenarios are considered to identify the highest GHG emission reduction by the year 2030. These scenarios include BAU, the consideration of economic structure readjustment, the adoption of mixed energy, energy saving, and low-carbon technique uses in the agriculture, transport and waste sectors. Results show that the best strategy is to simultaneously implement all of the identified low-carbon measures, which achieves a 24.6% reduction in overall GHG emissions in comparison to BAU levels.

This work completed in this thesis provides a framework for integrated economic-environmental system management as a valid concept for emerging developing countries such as Vietnam. This is helpful for the government of each country to propose the comprehensive strategies for the development of environmentally friendly economic system.

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Abbreviations

BAU	:	Business As Usual
BOD	:	Biological Oxygen Demand
COP21	:	the 2015 United Nations Climate Change Conference
DALY	:	Disability Adjusted Life Years
DPSIR	:	Driving Forces, Pressures, States, Impacts and Responses
EEA	:	European Environment Agency
EIO	:	Environmentally Extended Input-Output
FDI	:	Foreign Direct Investment
GDO	:	Gross Domestic Output
GDP	:	Gross domestic product
GHG	:	Greenhouse gas
GSO	:	Vietnamese General Statistics Office
GWP	:	Global Warming Potential
IEA	:	International Energy Agency
INDC	:	Intended Nationally Determined Contribution
IO	:	Input-Output
IO-LP	:	Input-Output Linear Programming
IO-SDA	:	Input-Output Structural Decomposition Analysis
IPCC	:	Intergovernmental Panel on Climate Change
IPPS	:	Industrial Pollution Projection System
ISIC 2	:	International Standard Industrial Classification version 2
ISIC 3	:	International Standard Industrial Classification version 3
MNRE	:	Vietnamese Ministry of Natural Resources and Environment
Mt CO_2e	:	Million Tonnes of CO_2 Equivalent
PI	:	Pollution Intensity
LP	:	Linear Programming
SDA	:	Structural Decomposition Analysis
TSS	:	Total Suspended Solid
US	:	United States
VIC	:	Vertical Integration Coefficient
WHO	:	World Health Organization
WTO	:	World Trade Organization

Chapter 1 Introduction

1.1. Background

The world economy is witnessing a new wave of economic globalization, defined as the integration of the world's economies through an increasing array of bilateral and multilateral, regional trade and investment agreements (Gallagher 2009). To correspond this wave, many countries have been made an effort to increase the flows of goods and services across global through enforcing the economic production activities. However, the economic globalization has results in many environmental problems. The environmental pollution by human activities includes the contamination of air, water and soil. In the low - and middle – income countries, the predominant forms of pollution have been indoor air pollution and contaminated drinking water while ambient air pollution, toxic chemicals, pesticides and hazardous wastes are the predominant environmental hazards in richer countries (Landrigan and Fuller 2015). **Fig. 1.1** shows global gross domestic product (GDP), greenhouse gas (GHG) emissions and municipal waste from 1995 to 2012. This figure is a proof that illustrates the increase in environmental impacts (GHG emissions and municipal waste) when world GDP goes up. In other words, global environmental burdens significantly increase as a consequence of economic globalization.

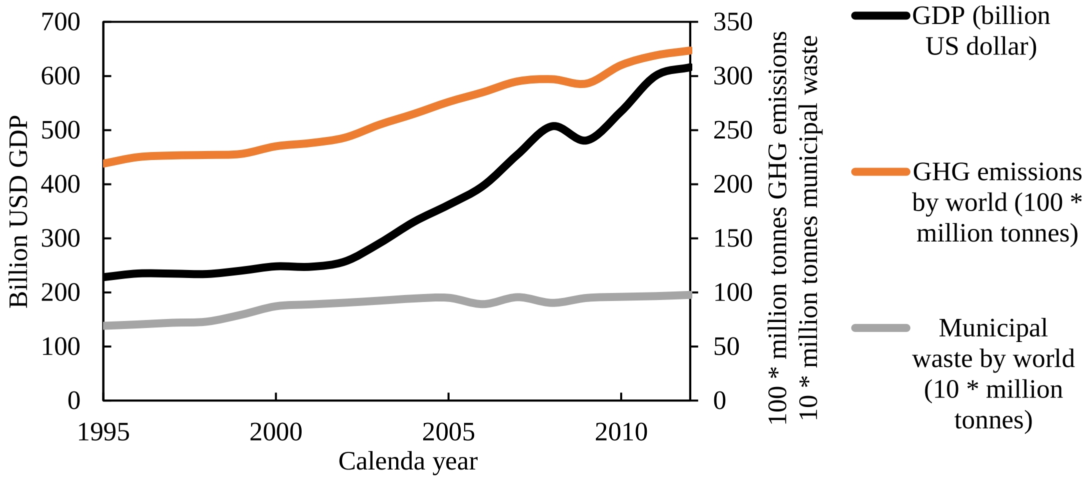


Fig. 1.1 Global GDP, GHG emissions and Municipal waste (Sources: GDP (The World Bank 2018), GHG emissions (WRI 2015) and Municipal waste (OECD 2018))

As a middle-income country located in Southeast Asia, Vietnam has the area of 331,052 square kilometers (FAO 2010) and population of 96 million people, in which 60% of population is in the working age (GSO 2017). Such a golden population structure accompanied with system politic system and abundant resources, Vietnam becomes an attractive destination for foreign investors. These investors strongly have invested and enforced various economic manufacturing activities in Vietnam. This contributes to increase the economic productivity, which needs to meet the demand of country's economic development as well as the demand of trade activities in order to correspond the economic globalization. As a result, since the year 2000, the Vietnamese economy has prospered with annual economic growth rate up to above 5% and forecasted to be the 20th largest in the world by 2050 (PricewaterhouseCoopers 2017). However, this rapid economic development has resulted

Fig. 1.2 Map of Vietnam (Source: Mapcruzin.com)

in the degradation of the living environment for humans as well as the ecosystem (The World Bank et al. 2002). Wastewater discharge, air pollution and urban solid waste are considered as the main important concern for Vietnam (MNRE 2014). **Fig. 1.2** shows the map of Vietnam.

According to Hoang et al. (2017), Vietnam is among of 10 countries with the most polluted environment in the world, and the health of people is affected by the non-guaranteed air and water quality. Under the statistical data of Numbeo (2018), the pollution index in Vietnam ranked 5 in the total of 98 countries involved in the overall environmental assessment. Pollution index measures environmental quality in one region or one country including air, water environmental quality and among others. High pollution index indicates the lower environmental quality. **Fig. 1.3** shows the pollution index of several countries nearby Vietnam. This figure indicates that Vietnam has the highest pollution index in 2017 (Numbeo 2018) comparing to Thailand, Indonesia, Japan and China. The reason for serious environmental problems, especially contamination of air and water in Vietnam, is due to the rapid industrialization and urbanization accompanied with poor waste management in Vietnam (WSSA 2012; Hoang et al. 2017). According to Hoang et al. (2017), the environmental pollution changes the component of environment and induces an imbalance in the environmental status of major cities such as Hanoi and Hochiminh. This results in an adverse effect on lives of things and the ecological environment. This environmental pollution directly affected to people by way of food and drinking water. According to statistics, every day, the people in Hanoi and Hochiminh cities are breathing the dust 10 times higher than that of the World Health Organization (WHO) regulations. Furthermore, rural population still uses groundwater without treatment, which contains many harmful components such as arsenic, nitrates and among others (WSSA 2012), which may cause serious health issues such as cancer or skin problems. According to WHO (2015), there were about 1.6 million people in 2013 suffered from infectious diseases such as diarrhea, malaria and among others which resulted from water drinking and air contamination; resulting in the death of 9,000 people every year. Furthermore, every year there are nearly 200,000 cases diagnosed with cancer due to using unsafe drinking water. Therefore, with such severe environmental pollution and adverse human health impact in Vietnam, the solutions for environmental system management in Vietnam to assure the sustainable economic growth in short and long terms reducing the environmental pollution are ultra-necessary.

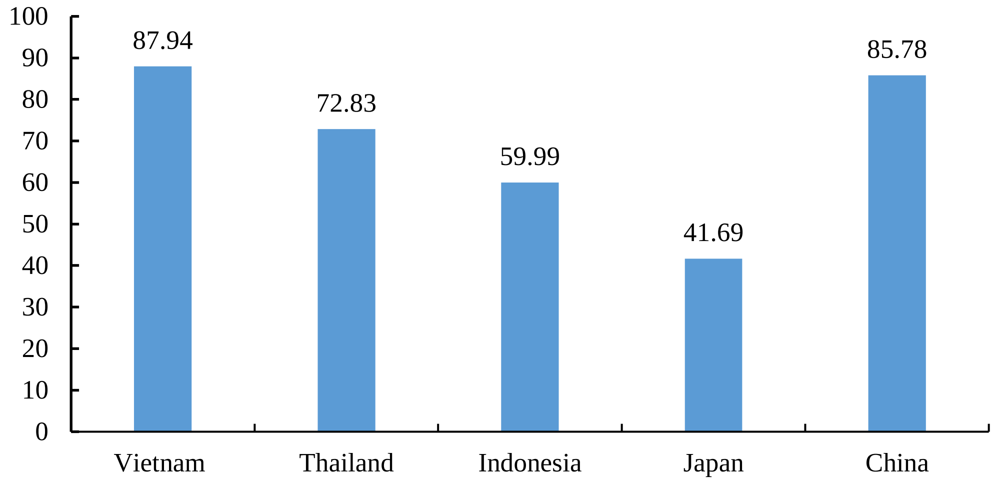


Fig. 1.3 Pollution index in 2017 (Numbeo 2018)

1.2. Environmental pollution management for priority concerns and regulations in Vietnam

1.2.1. Water pollution

Water environmental pollution is considered as the most important concern for Vietnam (Global Environmental Forum 2002). The main reason for water pollution is that a huge amount of wastewater from daily living activities and the operation of factories is directly discharged into water bodies without treatment. The rapid industrialization and urbanization accompanied with poor wastewater management resulted in the drastic degradation of water quality (WEPA 2011; WSSA 2012). For example, for industrial wastewater, only small parts of the total 625,000 enterprises have been equipped with wastewater treatment facility (VNEPAR 2008). Of 82 industrial zones in 2003, only 18 were equipped with wastewater treatment system. As a result, water quality has been influenced seriously with water quality parameters being 1.5 – 3 times higher than the national standard (VEA 2011).

In light of such serious water pollution, Vietnamese government has recognized the importance and urgency in water resources protection to avoid the further pollution of freshwater regions and to ensure clean water supply and sustainable economic growth. To response this, in 2003, Prime minister approved Decision No. 256 which proposed a national strategy for environmental production to 2010 with vision to 2020 (Prime Minister 2003). Under this Decision, there are some objectives related to water quality improvement. The main objective is “to restrict in water pollution, remedy environmental degradation and improve the quality of environment; to fundamentally address environmental degradation in industrial and densely populated areas within main cities and several rural regions; rehabilitate and treat contaminated rivers, ponds, canals and lakes”. Then Decision No. 1216 “the national strategy on environment protection to 2020, with visions to 2030” was approved to continue implementing different methods to reduce water pollution (Prime Minister 2012).

To cope with such water quality degradation, based on the direction of above two strategies, the various countermeasures from regulatory to economic tools have been employed. For example, there are laws, sub-law regulations and technical standards upon protection of water resources and water quality. However, many industrial factories, business and individuals have not complied with these laws and standards because the inspection and enforcement from government side are not strictly implemented. In Vietnam, the complication in management organization among agents and the overlap among various laws, authority and regulation creates an ambiguous responsibility for implementation and enforcement (VEA 2011). Many regulations did not rely on real situation of locals, thus are not feasible. The technical standards are adopted from developed countries so that they are difficult to comply with the country’s conditions and resources (Wasbeek 2007). Furthermore, according to Le et al. (2013), another reason for ineffectiveness of different action deployment is that the interrelationship between the economy and the environment has not been well understood. Understanding this relationship is vital in identifying the key sources of pollution and characterizing wastewater releases which indicate sectors as pollution sellers or/and pollution purchasers. This will be useful in providing and selecting more environmentally friendly production supply chains such as the selection of less pollutive raw materials or inputs and the use of cleaner technologies.

1.2.2. Air pollution

According to VNEPAR (2008), emissions from industrial manufacturing activities, coal combustion and increasing numbers of vehicles using fossil fuels are main reasons of air quality degradation in urban and industrial areas. Overall exposures to particulates, CO, CO_2, SO_2 and NO_x exceed permissible levels at many major urban locations. Thus, one of the priorities in air environmental quality management in Viet Nam is to upgrade and standardize air quality, to monitor, report and handle data in order to propose the necessary regulations and technical standard. In fact, there were several decisions and instruction given by government related to air pollution resolution. For example, Prime minister's instruction No. 24 (Prime Minister 2000) was given to designate the switch from leaded gasoline into unleaded one for the purpose of mitigation of impact from growing vehicular emissions. In addition, the instructions also required to improve the efficiency of energy use, especially in thermal power generation, gradually replacing fossil fuels into clean energy (i.e., wind, biomass energ). Prime Minister (2012) also approved strategies to improve quality of air in urban and residential areas. Under this decision, there is need "to tighten regulations, requirements and solutions for pollution prevention caused by construction sites as well as transportation of wastes and building materials in urban and residential areas"; "to strictly or ban projects which fail to meet environment protection requirements"; "to realize the roadmap of applying advanced standards on exhaust fumes over vehicles and means of transport; to realize emission registration and control and strictly punish all violations; to minimize and gradually reject all means of transport which can cause air and noise pollution; to renew traffic structure towards developing environmentally sustainable transport and reducing local traffic congestions and pollutions; to take measures to minimize noise pollution in urban areas";

Similar to water pollution management, many actions have been implemented, but have not seemingly brought positive effect. In addition to misunderstanding relationship between economic activities and environmental pollution, the monitoring, handling and reporting data on each pollutant have not done statistically and completely. Therefore, it is difficult to inspect, enforce and timely prevent air pollution issues.

Related to air pollution, there is also need to focus on greenhouse gases and climate change because Vietnam is ranked at the top in the list of countries which are the most vulnerable to climate change induced disasters over the world (Dasgupta et al. 2009). The next sub-section will mention about greenhouse gas (GHG) emissions in Vietnam.

1.2.3. Greenhouse gas (GHG) emissions

The impact of economic production activities on the environment has caused serious global concerns such as global warming. Rising atmospheric concentrations GHG emissions from the continued consumption of fossil fuels remains a main contributor for climate change, which is a global threat to human health and ecosystems (de Schryver et al. 2009). In order to mitigate climate change, the 1992 UN Framework Convention on Climate Change (UNFCCC) developed the Kyoto Protocol, which required member countries to reduce GHG emissions including CO_2, CH_4 and N_2O (UNFCCC 1998).

For Vietnamese economy, as a result of rapid economic growth accompanied by increased energy consumption (MNRE 2014), this resulted in corresponding increases in GHG emissions from energy sectors. Nguyen et al. (2009) reported that the GHG generation from combustion is projected to increase tremendously by 14% per year, reaching approximately 400 million tonnes of CO_2 (Mt CO_2) by 2030. Furthermore, besides the energy sectors, the agriculture sectors, industrial sectors and waste treatment activities also contribute to large amounts of GHG emissions (MNRE 2014). As a non-Annex I country under Kyoto Protocol, Vietnam is not required to reduce GHG emissions. It has however ratified the agreement to make efforts to reduce emissions from energy, agriculture and transportation sectors (KEPA and GreenID 2014).

In response to this, the Vietnamese Government explored various strategies to reduce GHG emissions and meet their CO_2 reduction targets. In 2012, Prime Minister approved a Decision No. 1393 which required to reduce GHG intensity by 8-10% lower than the 2010 level during period 2010-2020 (VNGGS 2012). Recently, in the 2015 Paris Climate Conference, known as COP21, Vietnam's intended nationally determined contribution (INDC) commitment indicates that Vietnam will reduce its GHG emissions by 25 % by the year 2030 under the business as usual (BAU) scenario (UNFCCC 2015). There are many measurements as well as action plans given to obtain these targets. However, there have no studies on assessing the economic impacts of implementing climate policies to reduce GHG emissions, both at the macro-economic and sectoral levels. Especially, the policies including readjusting economic structure, applying cleaner technologies such as the use of renewable energy or more energy efficient technologies, have not been done comprehensively for Vietnam.

1.2.4. Solid waste and disposals

In addition to wastewater, air pollution and GHG emissions, solid waste and disposal have been become big problems leading to serious environmental pollution. According to statistics, there were over 15 million tonnes of waste released to environment in 2004 (VNEPAR 2008). Most of this is not safely disposed, thus threating to public health and ecosystem environment seriously. By 2010, municipal waste generation is projected to increase by over 60%, industrial waste by 50% and the volume of hazardous waste is expected to more than triple compared to the year 2004.

Regarding to solid waste and disposal management, there were strategies of the Government approved by Prime Minister. First, Decision No. 199 on the solutions for improving waste management in urban areas and industrial zones were proposed to “(i) eliminate unauthorized disposal of solid waste; (ii) improve waste collection; and (iii) improve the sorting of waste by polluters for reuse, recycling and treatment” (Prime Minister 1997). Then strategy for the management of solid waste in Vietnamese cities and industrial park was given to “outline actions to be taken by local governments until the year 2020 to implement a comprehensive approach to waste management. The focus of the strategy is infrastructure development in urban areas and industrial zones” (Prime Minister 1999). In addition, Prime Minister (2003) and Prime Minister (2012) also mentioned strategies to further treat solid wastes.

1.3. Integrated environmental assessment framework

In recommendation for the development of a strategy for integrated environmental assessment to the European Environment Agency (EEA), a framework, which distinguished driving forces, pressures, states, impacts and responses (DPSIR), is used. This is based on a simple Pressure–Status–Response (PSR) framework, which was firstly developed by the Organization for Economic Cooperation and Development (OECD 1993). This DPSIR framework provides a comprehensive approach to help better understand the causes and effects within environmental problems. Furthermore, this model aims in identifying environmental indicators which required to enable feedback to decision makers on environmental quality and the resulting impact of policy choices made, or to be made in the future. A DPSIR framework has 5 components namely *driving forces* (population, technology, economic sectors), *pressure* (pollutants), *state* (quality), *impact* (human health, ecosystem damage) and *response* (policies and target).

Regarding to Vietnamese environmental assessment, Ngo (2010) used the DPSIR framework as a tool for presenting environmental indicators for urban air quality assessment and management in Hanoi, Vietnam. However, they failed to analyze the relationship between economic sectors and environment. According to Le et al. (2013), analyzing relationship is vital in identifying the key sources of pollution, socio-economic driving forces of the changes of pollutants, and roles of sectors in relation to pollution releases. This will help develop comprehensive strategies for economic-environment system management.

Studies on the effect of production activities on environmental data in Vietnam are limited. There are only a few studies dealing with the interrelationship between economic activities and pollution flows so far. One of the most important reference related to economic-environmental system management in Vietnam is the ICEM (2007) published by World Bank team, which evaluated the national pollution flows by quantifying the different pollutants found in air, land and water media from the manufacturing industries. However, the focus was only on the pollution of manufacturing sectors, while pollution flows from other sectors such as agriculture, mining, services and consumer use were not included. Furthermore, they failed to indicate the interrelationship among economic sectors and the pollution characteristics of each sector. A better understanding of these factors is useful in providing and selecting more environmentally friendly production supply chains such as the selection of less pollutive raw materials or inputs and the use of cleaner technologies.

To supplement research gap from previous studies, this thesis develops a DPSIR framework as comprehensive tool for economic-environmental system management. This model focuses on assessing and managing environmental issues at macroeconomic level and sectoral level. The components of *driving forces*, *pressures*, *states* and *impacts* are analyzed based on economic production activities. After that policy implications are proposed to support policy makers in designing policies for environmental impact mitigation from economic activities. **Fig. 1.4** presents an economic-environmental system management framework based on DPSIR framework.

Since relationship between economic activities and environmental pollution is best described using input-output (IO) model. Therefore, in this study, IO analysis is used to analyze and assess the components of the economic-environmental system management framework. Next section will mention IO analysis and its extension for economic-environmental impact assessment.

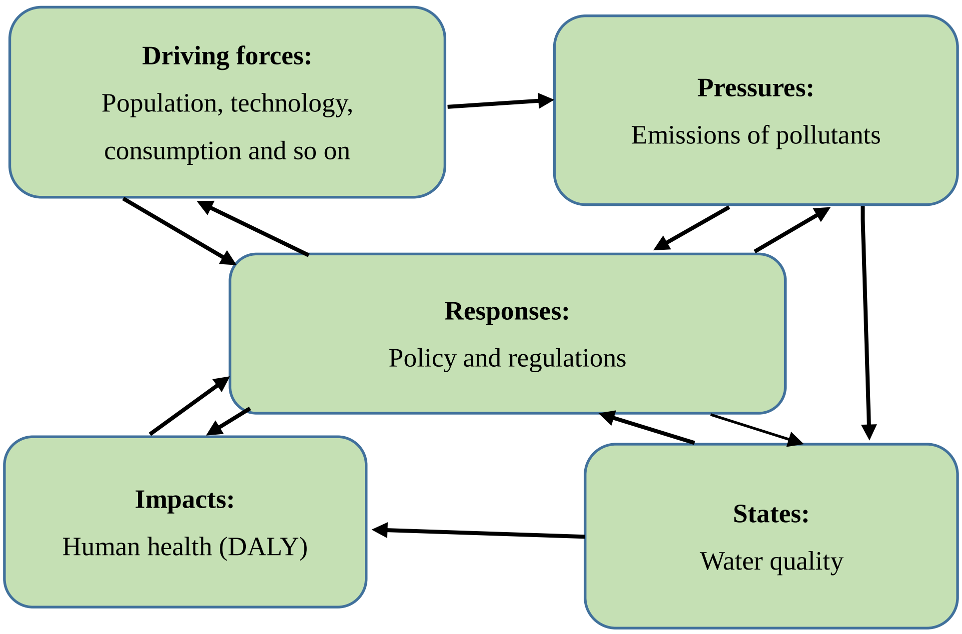


Fig. 1.4 Economic-environmental system management framework

1.4. Input-Output (IO) analysis and its extensions

According to Miller and Blair (2009), the best way to describe the interrelationship among economic sectors is to apply IO analysis. IO analysis is an analytical framework first proposed by Professor Wassily Leontief in the 1930s and provides a quantitative description of how goods and services of an economy are related. In recognition of his work, he achieved the Nobel Prize in Economics in 1973 (Leontief 1936, 1970). The IO analysis shows the interconnectedness of the economy's various sectors by considering the product of each sector both as goods for final demand (i.e., household and government consumption) and as raw materials in the production of commodities in the same sector or in other sectors. The framework captures both direct and indirect effects resulting from an economic shock. The extension of IO model to account for environmental impacts is known as environmentally extended input-output (EIO) analysis and it has been employed in the accounting of carbon emissions in supply chains for sustainability assessment (Suh 2009, Murray and Wood 2010) and in optimizing multi-regional bioethanol supply chains in the presence of multiple objectives (Tan et al. 2008, 2009). Furthermore, IO analysis can be used to study the linkages between economic sectors of an economy and to determine the role of economic sectors (Rasmussen 1956, Yan and Ames 1965).

In Vietnam, the application of IO analysis in environmental-economic impact assessment was performed by Trinh and Nguyen (2013) and Le et al. (2013). However, these researches focused on solving a certain environmental problem. For example, both Trinh and Nguyen (2013) and Le et al. (2013) just gave water pollution load in specific year, while they did not mention to other pollutants. Furthermore, the application of IO model for Vietnamese economic-environmental system management based on DPSIR framework (*driving forces, pressures, states, impacts* and *responses*) has not been done comprehensively. To supplement this research limitation, this manuscript uses the IO model to analyze and assess the different aspects covering five components of DPSIR framework in order to indicate a comprehensive framework for economic-environmental system management for Vietnamese economy system. These different aspects are developed and integrated in study flows shown in **Fig. 1.5**. In these flows, there are four different domains included. First, IO model in economy and sector domain is extended into EIO model in environment domain by adding emissions factors obtained from environmental database. The combination of first and second domains provide models to assess two main problems. First, the integration of EIO and vertical integration coefficient (VIC) methods to analyze the interrelationship between environmental pollution and economic activities to identify the role of sectors. In this model, emissions pollutants (*pressure*) and environmental quality (*state*) are analyzed. Second, EIO analysis is integrated with structural decomposition analysis (SDA) to identify the main socio-economic driving forces of changes of a pollutant (*driving forces*). Next, the environment domain is used to evaluate human health risk (*impacts*) in risk evaluation domain. Finally, based on policy scenarios (*responses*) proposed by Vietnam government, technological options and economic scenarios in economy-technology domain are assessed to identify the pollution mitigation strategies. In third and fourth domains, IO model coupled with linear programming (IO-LP) is used to for these purposes.

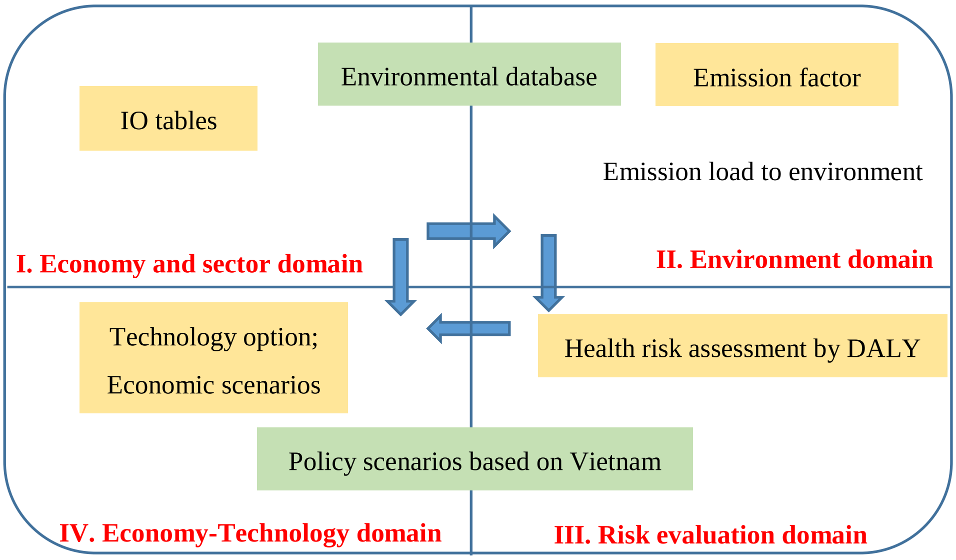


Fig. 1.5 Study flows

1.5. Problem statement

As mentioned above there is a need to develop a framework of economic-environment system management for Vietnam. Specifically, this study aims to answer the following questions:

1. What is relationship between economic sectors and environmental flows resulting from economic activities? What is the role of sector, as a pollution producer or a pollution consumer?
2. What are main socio-economic driving forces, which lead to the changes of pollutants resulting from economic sectors over observed periods?
3. What are priority economic sectors when both economic performance and GHG emissions are considered? How is reduction in greenhouse gas (GHG) intensity when considering different economic growth constraints and applying technology improvement in these priority sectors? How the impact of human health risk is when different policy scenarios are implemented?
4. How the strategies for the maximum GHG emission reductions are when technology factors in economic activities are improved?

1.6. Objectives

In this doctoral thesis, the aim is to develop models for integrated economic-environment system management using IO approach for Vietnamese context. This work is an effort to analyze different aspects based on modified DPSIR framework relating to environmental and economic flows for achieving sustainable economy growth with low pollution. To accomplish this objective, the following specific objectives were considered relevant:

1. To analyze the interrelationship between economic activities and environmental pollution.
2. To identify the main socio-economic driving forces of changes of a pollutant.
3. To assess the climate policy given by government and help identify the potential of GHG intensity reduction through readjusting economic structure, promoting economic growth rate, and applying technology improvement.
4. To assess the climate policy when considering implementation of new technology use policies.

The contribution is aimed at policy and decision-makers with a focus on government and local authorities, but also inclusive to industrial sectors, manufacturers, household and individuals.

1.7. Scope of research

This study uses IO model to quantify the different aspects of causes, effects and linkages related to economic-environmental issues. This will provide a comprehensive tool for economic-environment system management in Vietnam. Other methods such as structural decomposition analysis (SDA), linear programming (LP) and vertical integration coefficient (VIC) are also applied to couple with IO model in order to solve different problems corresponding to specific objectives. To obtain the main objective of research, this thesis will focus on the following contents:

- The economic data for building models will be taken from input-output tables in Vietnam published by Vietnamese General Statistics Office (GSO).
- Due to availability of water pollution (Total suspended solid and Biological oxygen demand) and GHG emissions and due to the serious impacts of these pollutants on Vietnamese environment, this study focuses on these two kinds of pollution as environmental flows in models, whose data are obtained from secondary data such as global database.
- This study will carry out assessing impact of different GHG mitigation policy implementation, thus this study will rely on the different policies and measurements proposed by government.

1.8. Research framework

This research framework is developed based on economic-environmental system management framework given in **Fig. 1.4** and study flows introduced in **Fig. 1.5** in order to identify strategies for sustainable economic-environment system management in a country or region. However, the contents of whole research are distributed in different chapters. There are six chapters, in which the subjects of each chapter are briefly described next. Chapter one presents an introduction to background of research, status of economic growth and environmental pollution in Vietnam –

representative for emerging developing country with many economic-environment concerns. In additions, environmental management strategies and regulations are mentioned, followed by concept of integrated environmental assessment framework, and then discussing the contribution and limitation of previous researches, and explaining modified DPSIR tool for comprehensive economic-environmental system management to overcome such limitations. Next, the importance of IO model in evaluating economic-environmental impacts is given. Finally, objectives and research framework are given. The structural analysis of inter-relationship between environmental pollution and economic activities through using the integration of IO analysis and vertical integration coefficient (VIC) is presented in chapter two. Chapter three, input-output structural decomposition analysis (IO-SDA) is used to identify the socio-economic driving forces inducing to the changes of pollution. In the chapter four, an input-output linear programming (IO-LP) is used to assess climate policy to identify the potential of GHG intensity reduction while considering different economic growth rates. IO-LP is used again in chapter five to identify the strategies for minimizing pollution by improving technology factors in economic activities. Finally, the summary of the main findings, the contribution of this thesis, and proposal for future studies are presented in chapter six. The outline of thesis is presented in **Fig. 1.6**.

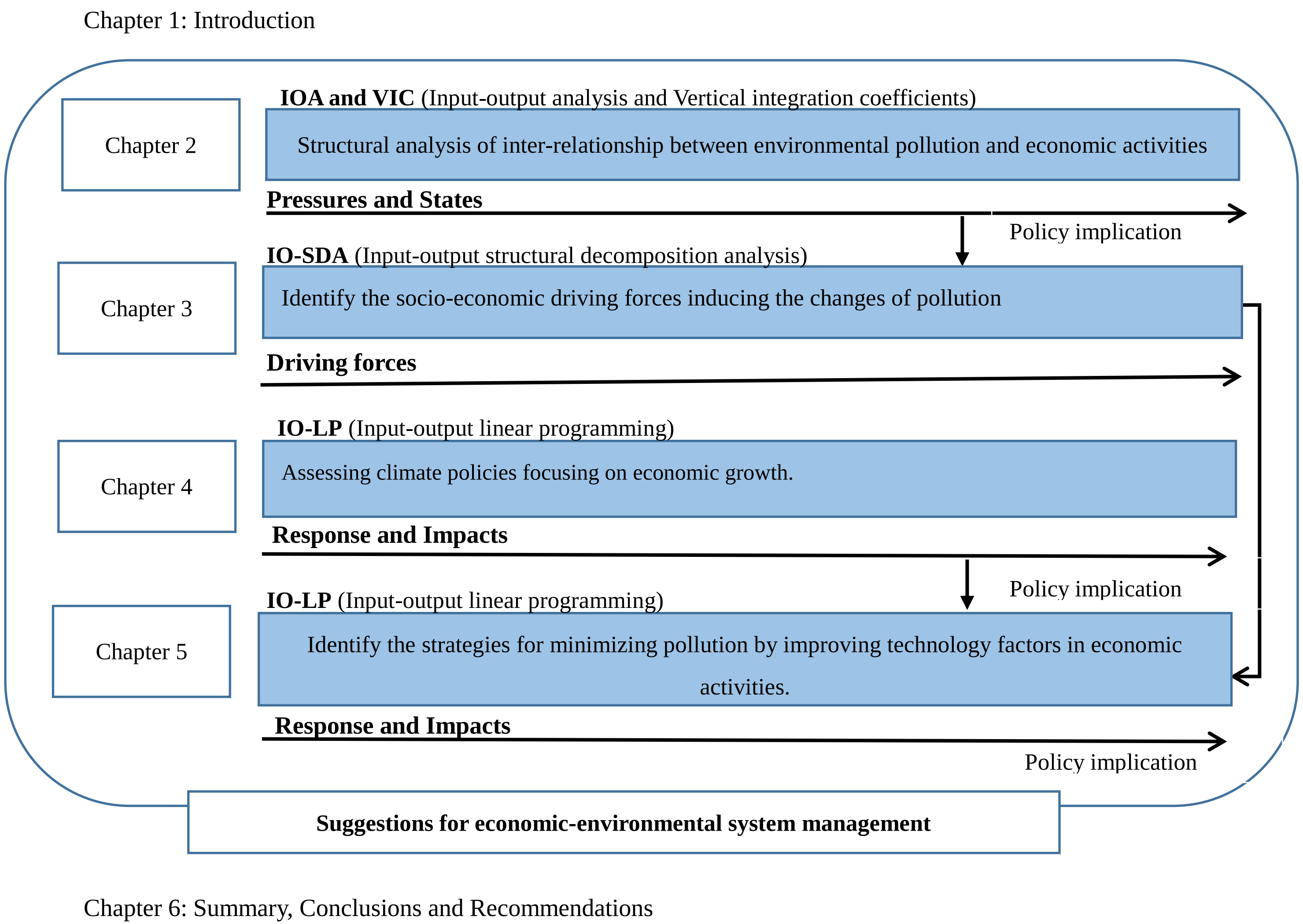


Fig. 1.6 Outline of thesis

References

Dasgupta S, Laplante B, Murray S, Wheeler D (2009) Sea-level Rise and storm surges: a comparative analysis of impacts in developing countries. Washington D.C.: The World Bank.

de Schryver AM, Brakkee KW, Goedkoop MJ, and Huijbregts MAJ (2009) Characterization factors for global warming in life cycle assessment based on damages to humans and ecosystems. Policy Analysis 43(6): 1689–95.

FAO (2010) The profile of Vietnam. Accessed on 20 March 2018. http://www.fao.org/nr/water/aquastat/countries_regions/index.stm

Gallagher KP (2009) Economic globalization and the environment. Annu. Rev. Environ. Resour., 34:279–304.

Global Environmental Forum (2002) Overseas environmental measures of Japanese Companies (Vietnam). Accessed on 12 July 2016. http://www.env.go.jp/earth/coop/oemjc/viet/e/contents.html

GSO (General Statistical Office) (2017) Statistical yearbook of Vietnam 2017. Accessed on 05 May 2018. https://www.gso.gov.vn/default.aspx?tabid=714

Hoang TA, Chu NX, Tran TV (2017) The Environmental pollution in Vietnam: source, impact and remedies. International journal of scientific & technology research, 6 (2).

ICEM (International Center for Environmental Management) (2007) Analysis of pollution from manufacturing sectors in Vietnam. Indooroopilly, Queensland, Australia.

KEPA and GreenID (Service Center for Development Cooperation & Green Innovation and Development Centre) (2014) Assessment of policies on GHG mitigation in Vietnam, 1–31. Accessed on 10 April 2017. https://www.kepa.fi/tiedostot/final_report_vietnam_1marz2014.pdf

Landrigan PJ, Fuller R (2015) Global health and environmental pollution. Int. J. Public Health, DOI 10.1007/s00038-015-0706-7

Le AH, Tokai A, Yamamoto Y (2013) Structural analysis of relationship between economic activities and water pollution in Vietnam.J. Japan Soc. Hydrol. and Water Resour, 25(3):139-151.

Leontief WW (1936) Quantitative input-output relations in the economic system of the United States. Rev. Econ. Stat.,, 18, 105–125.

Leontief WW (1970) Environmental repercussions and the economic structure: an input-output approach. Rev. Econ. Stat., 52(3):262–271.

Miller RE, Blair PD (2009) Input-output analysis: foundation and extensions. Second Ed. Published in the United States of America by Cambridge University Press, New York.

MNRE (Ministry of Natural Resources and Environment) (2014) The initial biennial updated report of Viet Nam to the United Nation Framework Convention on climate change. Viet Nam publishing house of nature resources, environment and cartography. MNRE, Ha Noi, 2014. Accessed on 08 March 2017. http://unfccc.int/resource/docs/natc/vnmbur1.pdf.

Murray J, Wood R (2010) The sustainability practitioners' guide to input-output analysis. Common ground publications Odesanya BO, Ajayi SO, Shittu M, Oshin O (2012) Use of industrial pollution projection system (IPPS) to estimate pollution load by sector in two industrial estates in Ogun State, Western Nigeria. International Journal of Scientific & Engineering Research 3(10).

Ngo HT (2010) Urban air quality modelling and management in Hanoi, Vietnam. National Environmental Research Institute. Aarhus University. PhD thesis.

Nguyen NT, Ha-Duong M, Sandra G (2009) The clean development mechanism in Vietnam: potential and limitations. Paper accepted to present at the fourth GMSARN International Conference 2009 "Energy Security and Climate Change: Problems & Issues in GMS" to be held from 25-27 November 2009 at Ha Long Bay, Vietnam.

Numbeo (2018) Pollution index for country 2018. Accessed on 20 May 2018. https://www.numbeo.com/pollution/rankings_by_country.jsp

OECD (Organization for Economic Cooperation and Development) (1993) OECD core set of indicators for environmental performance reviews.

OECD (2018) Municipal waste, Generation and Treatment. Accessed on 20 March 2018. http://stats.oecd.org/

PricewaterhouseCoopers (2017) The world in 2050. Accessed on 21 August 2017. https://www.pwc.com/gx/en/world-2050/assets/pwc-the-world-in-2050-full-report-feb-2017.pdf

Prime Minister (1997) Decision No. 199/TTg dated April 03, 1997 of the Prime Minister on Urgent measures to manage solid waste in urban areas and industrial zones.

Prime Minister (1999) National strategy of solid waste management, Hanoi.

Prime Minister (2000) Direction No. 24/2000/CT-TTg of November 23, 2000 on the use of non-lead petrol in Vietnam.

Prime Minister (2003) National Strategy for environmental protection until 2010 and vision toward 2020. Hanoi, Vietnam.

Prime Minister (2012) Decision No. 1216 on the national strategy on environment protection to 2020, with visions to 2030.

Rasmussen P (1956) Studies in Intersectoral Relations, Amsterdam, North-Holland.

Suh S (2009) Handbook of input-output economics in industrial ecology. 2nd Printing, ed. Springer.

Tan RR, Culaba AB, Aviso KB (2008) A fuzzy linear programming extension of the general matrix-based life cycle model. Journal of Cleaner Production, 16(13), 1358-1367.

Tan RR, Ballacillo JB, Aviso KB, Culaba AB (2009) A fuzzy multiple objectives approach to the optimization of bioenergy system footprints. Chemical Engineering Research and Design, 87(9), 1162-1170.

The World Bank, the National Environmental Agency, the Danish Agency for international development (2002) Vietnam Environmental Monitor 2002; 20-22. Accessed on 21 May 2016.

http://siteresources.worldbank.org/INTEASTASIAPACIFIC/ Resources/VN-Monitor-02.pdf

The World Bank (2018) World Bank national accounts data, and OECD National Accounts data files. Accessed on 21 March 2018. https://data.worldbank.org/indicator/NY.GDP.MKTP.CD¥

Trinh B, Nguyen PV (2013) Economic-environmental impact analysis based on the changes of economic structures of Hochiminh city and the rest of Vietnam. 2 (3).

UNFCCC (United Nations Framework Convention on Climate Change) (1998) Accessed on 30 September 2017. http://unfccc.int/resource/docs/convkp/kpeng.pdf.

United Nations Framework Convention on Climate Change (UNFCC) (2015) Adoption of the Paris Agreement, 1-32. https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf. Accessed on 08 Feb 2018

VEA (Vietnam Environmental Administration) (2011) National environmental report 2010: general view of Vietnamese Environment. Hanoi, Vietnam.

VNEPAR (Vietnam national environmental performance assessment (EPA) report) (2008) Accessed on 15 March 2018. http://www.gms-eoc.org/resources/viet-nam-epa-report

VNGGS (Vietnam National Green Growth Strategy) 2012. http://2050.nies.go.jp/sympo/120531/presentation/2_E.pdf. Accessed on 8 May 2017

Wasbeek R (2007) Wastewater treatment in Vietnam: what are the opportunities for Dutch companies in the wastewater in Vietnam. Master thesis.

WSSA (Water and Sanitation Sector Assessment report Vietnam 2011) (2012) Accessed on 05 May 2017. http://www.wpro.who.int/vietnam/topics/water_sanitation/watsan_sector_report_vietnam_2011.pdf

WEPA (Water Environment Partnership in Asia) (2011). Accessed on 12 May 2016. http://www.wepa-db.net/policies/state/vietnam/overview.htm

WHO (World Health Organization) (2015) Country statistics and global health estimates by WHO and UN partners. Accessed on 14 June 2018. http://www.who.int/gho/mortality_burden_disease/en/

WRI (World Resources Institute) (2015) Climate analysis indicators tool (CAIT) 2.0: WRI's climate data explore.

Yan C, Ames E (1965) Economic interrelatedness. Review of Economic Studies. Vol. XXIII, no. 4. Accessed on 16 May 2016. http://cje.oxfordjournals.org/

Chapter 2 Structural analysis of the interrelationship between economic activities and water pollution in Vietnam in the period of 2000-2011

This chapter quantifies the water pollution load for period 2000-2010 using two water quality indicators – TSS and BOD. The characterization of economic sectors in relation to water pollution is then indicated based on the computation of pollution components and pollution indices of each sector. This will help in identifying the relationship between economic sectors and water pollution as well as role of sector as key sector or pollution consumer or pollution producer. Results obtained from this study will cover two components of modified DPSIR framework – *pressure* and *state*, which needs to develop strategies for integrated economic-environmental management of an economy.

2.1. Introduction

The comprehensive economic reforms from 1986, which have implemented open door policies and transformed Vietnam from a centrally planned economy into a market economy, has contributed significantly to the country's economic development (Que and Thanh 2001). Since the year 2000, the Vietnamese economy has prospered with annual economic growth rate up to above 5% and forecasted to be the 20th largest in the world by 2050 (PricewaterhouseCoopers 2017). However, this rapid economic development has resulted in the degradation of the living environment for humans as well as the ecosystem (The World Bank et al. 2002). Water environmental pollution is considered as the most important concern for Vietnam (Global Environmental Forum 2002). The main reason for water pollution is that a huge amount of wastewater from daily living activities and the operation of factories is directly discharged into water bodies without treatment. The rapid industrialization and urbanization accompanied with poor wastewater management resulted in the drastic degradation of water quality (WEPA 2011; WSSA 2012). Furthermore, rapid population and economic growth resulted in the increase of freshwater use demand. Tran (2010) reported that the increasing rate of water consumption for industries, domestics and agriculture are 7%, 9% and 3.4% per year, respectively. Meanwhile, the available freshwater resources are insufficient to meet these increasing water use demands (Hoa et al. 2013). Only 70% of the population is likely to have access to safe water and sanitation (Tran 2010). Traditionally, the rural population uses groundwater pumped from private tube wells. However, there is evidence of arsenic contamination in the groundwater in several regions in Vietnam. According to WSSA (2012), there are several causes for arsenic contamination in groundwater; this includes arsenic from geological structures, the use of plant protection drugs containing arsenic and the release of arsenic from chemical factories. This arsenic contamination may cause serious health issues such as cancer or skin problems to people in regions of exposure (Jessen 2009). With such serious issues on water pollution and freshwater resource scarcity, there is thus a need to develop effective strategies to immediately handle this problem in order to avoid the further pollution of freshwater regions and to improve water quality.

To solve these problems, the Vietnamese government has employed various strategies from regulatory to economic tools but these actions have not seemingly brought positive effect. The reason is that the interrelationship between the economy and the environment has not been well understood (Le et al. 2013). Understanding this relationship is vital in identifying the key sources of pollution and characterizing wastewater releases which indicate sectors as pollution sellers or/and pollution purchasers. The environmental performance of an economic sector is linked to all other sectors by virtue of its supply chain (Leontief and Ford 1972). Furthermore, studies on the effect of production activities on water quality and water pollution data in Vietnam are limited. Meanwhile, researches on these aspects are carried carefully in developed countries and many developing countries. For example, Wu et al. (2017) proposed a method for quantifying a water pollution ecological compensation standard for China by using emergy theory. An analysis of virtual water pollution transfer embodied in economic activities was employed for Beijing's economy (Li et al. 2017) while Cazcarro et al. (2016) evaluated the relationship between structural production and environmental impact in consideration of trade among countries. Sanchez-Choliz et al. (2005) analyzed the relationship between processes and water pollution for the Spanish economy to identify the roles of economic sector blocks as either generator or consumer of pollutants. Recently, several researchers made numerous efforts in proposing environmental friendly water pollution treatment methods. For example, Kamyab et al. (2015) looked at the efficiency of microalgae in the removal of pollutants from palm oil mill effluents. The wastewater was then investigated on for its potential as biofuel substrate (Kamyab et al. 2016) and resource for fertilizer production (Kamyab et al. 2017). Microalgae can help significantly reduce water pollutants in wastewater as it utilizes the pollutants as nutrients for growth. Rezania et al. (2016) emphasized that the use of phytoremediation technology is likely to effectively treat heavy metal polluted sites with low treatment cost. In Vietnam, there are only a few studies dealing with the interrelationship between economic activities and pollution flows so far. One of the most important reference is the ICEM (2007) published by World Bank team, which evaluated the national pollution flows by quantifying the different pollutants found in air, land and water media from the manufacturing industries. In addition, Hung et al. (2008) implemented the analysis of industrial pollution, which focused on the effect of trade liberalization on the pollution of sectors and sub-sectors. However, the focus was only on the pollution of manufacturing sectors, while pollution flows from other sectors such as agriculture, mining, services and consumer use were not included. Furthermore, they failed to indicate the interrelationship among economic sectors and the pollution characteristics of each sector. A better understanding of these factors is useful in providing and selecting more environmentally friendly production supply chains such as the selection of less pollutive raw materials or inputs and the use of cleaner technologies.

According to Miller and Blair (2009), the best way to describe the interrelationship among economic sectors is to apply input-output (IO) analysis. IO analysis is an analytical framework first proposed by Professor Wassily Leontief in the 1930s and provides a quantitative description of how goods and services of an economy are related. In recognition of his work, he achieved the Nobel Prize in Economics in 1973 (Leontief 1936, 1970). The IO model shows the interconnectedness of the economy's various sectors by considering the product of each sector both as goods for final demand (i.e., household and government consumption) and as raw materials in the production of commodities in the same sector or in other sectors. The framework captures both direct and indirect effects resulting from an economic shock. The IO model can be extended to capture other characteristics of the economic system. Hoa et al. (2016) for example, utilized the inoperability input-output model (IIM) developed by Haimes and Jiang (2001) and the vulnerability index proposed by Yu et al. (2014) to develop a multi-criteria model for disaster vulnerability due to implications of energy policy. The extension of IO analysis to account for environmental impacts is known as environmentally extended input-output (EIO) analysis and it has been employed in the accounting of carbon emissions in supply chains for sustainability assessment (Suh 2009, Murray and Wood 2010) and in optimizing multi-regional bioethanol supply chains in the presence of multiple objectives (Tan et al. 2008, 2009). Furthermore, IO analysis can be used to study the linkages between economic sectors of an economy and to determine the role of economic sectors (Rasmussen 1956, Yan and Ames 1965). These authors utilized the Leontief inverse or Gosh inverse (Gosh 1958) to categorize sector as either forward linkage sector or backward linkage sector or key sectors (those that act both as forward and backward linkage sectors) or non-significant sectors in relation to purely economic terms. Then Sanchez- Choliz and Duarte (2003, 2005) expanded the scope of these models to include resources and emissions through vertical integration coefficient (VIC) methodology to identify the role of each sector in the economy in consideration of these environmental impacts. The integration of EIO analysis with VIC may thus create a powerful framework for analyzing the interrelationship between sectors from the point of view of pollution.

In Vietnam, the application of EIO in environmental-economic impact assessment was performed by Trinh and Nguyen (2013) and Le et al. (2013). In Trinh‘s study, EIO was employed to present the framework of inter-regional IO model in the year 2000 and 2007. Meanwhile, Le et al. (2013) used the integration of EIO and VIC for the year 2000 to identify and quantify the sources and causes of water pollution, indirect emissions and direct emissions. Although, Le et al. (2013) was successful in quantifying the total pollution load of main sectors, both direct and indirect pollution, they failed to show which sectors are pollution sellers and pollution purchasers. Furthermore, both Trinh and Nguyen (2013) and Le et al. (2013) failed to provide a time series analysis of the total pollution load to establish the total pollution load trend induced by economic sectors.

To supplement this research gap, the main objective of this work focuses on looking at the changes in water quality over the period of year 2000 to 2011. The characterization of economic sectors in relation to water pollution in 2011 is then employed using input-output analysis coupled with VIC to identify the role of each economic sector as a consumer/purchaser or/and a producer/seller of water pollution. Finally, the combination of water quality trend and characterization of sectoral pollution will give a comprehensive picture on main water quality parameters of economic sectors in Vietnam economy. The rest of this chapter is organized as follows. **Section 2.2** formalizes the problem that this research intends to address, the methods are then discussed in **Section 2.3**. **Section 2.4** mentions database used in this work. The results and discussion are then mentioned in **Section 2.5**. Finally, the conclusion and recommendation for future work are discussed.

2.2. Problem statement

In this work, the evaluation of water pollution of different economic sectors in an economy relies on results from both the water quality trend and the characteristics of sectors in relation to water pollution. The water quality trend focuses on the annual total pollution load contributed by the different sectors during the observed period. In contrast, the characteristics of sectors are obtained by taking into account water pollution flows and sectoral linkages during a specific year. The formal problem statement can thus be stated as follows:

- Given an economy with *n* number of economic sectors, an *n* x *n* technical coefficient matrix, **A**, can be obtained for a specific year which describes the interactions between the economic sectors. There is a *1* x *n* vector, **x**, which represents the gross domestic output (GDO) of sectors. This is collected from the statistical databases according to the identified time series range.

- There are environmental flows in the production of goods and services from each sector which are quantified using *k* number of quality indicators. In this context, only two indicators of water quality are considered, biological oxygen demand (BOD) level and total suspended solid (TSS). Thus a *2* x *n* vector of pollution intensity, **PI,** is estimated for each year in the observed period.

The problem then is to evaluate how each economic sector contributes to the yearly change in water quality and to identify whether an economic sector is a purchaser (has inputs from high polluting sectors) or seller (is an input to other economic sectors) of water pollution or both. Suggestions for policy makers and manufacturers on the priority for emission reduction are given.

2.3. Methods

The framework developed for evaluating environmental quality parameters is shown in **Fig. 2.1**:

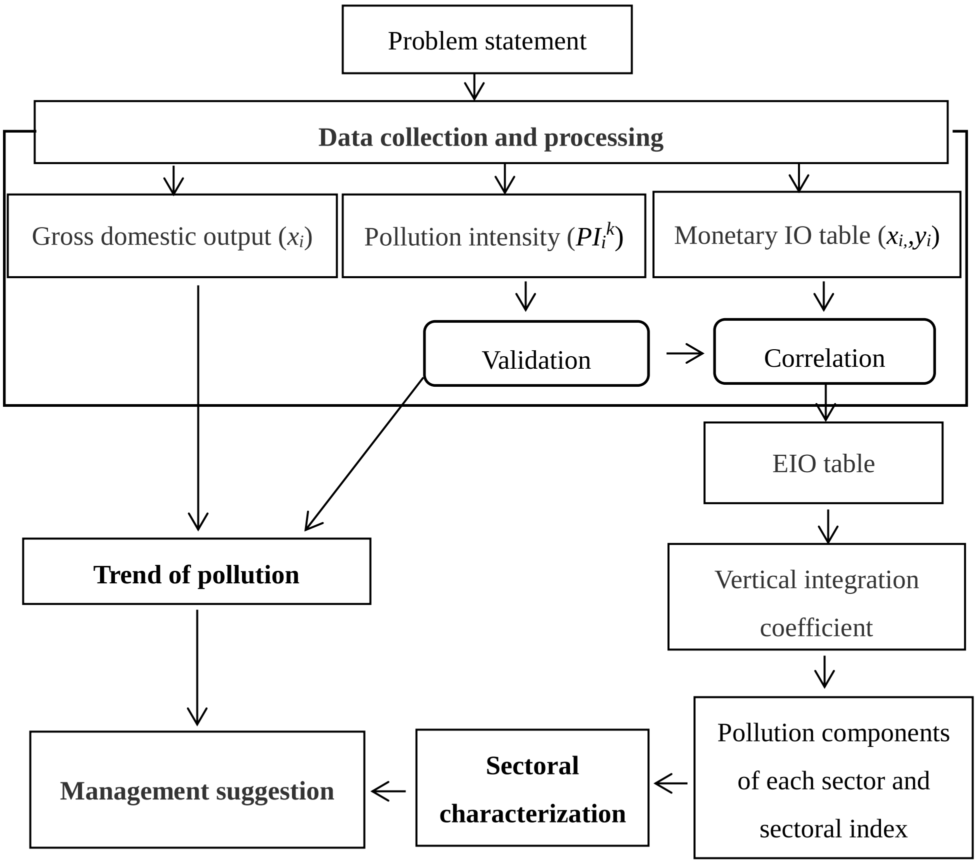


Fig. 2.1 Framework of water quality parameter assessment

2.3.1. Generic input-output (IO) model

The IO framework has been traditionally applied to study the interconnectedness between various economic sectors in an economic system. Its basic formulation includes a system of linear equations in which total output is equal to the amount used internally by the system, as intermediate consumption, plus the amount consumed by final customers (Leontief 1985). For an economy with n sectors, vector **x** denotes the GDO vector, **y** is the final demand vector and **Z** is the n x n input-output transaction matrix which can be obtained from statistical databases. In matrix notion, the IO model can be stated as follows (Miller and Blair 2009):

$$\mathbf{x} = \mathbf{eZ} + \mathbf{y} \tag{2.1}$$

where **e** = [1, 1, …, 1]. Let **A** represent the n x n technical coefficient matrix with elements a_{ij} (a_{ij}= Z_{ij}/ x_j) indicating the amount of product from the i^{th} sector needed to produce one unit of output from the j^{th} sector. Based on this, **Eq. (2.1)** can be rewritten as follows:

$$\mathbf{x} = (\mathbf{I}-\mathbf{A})^{-1}\,\mathbf{y} \tag{2.2}$$

where **I** denote identity matrix and (**I** - **A**)$^{-1}$ is Leontief inverse matrix. Let α_{ij} represent the element of Leontief matrix. Then the element of GDO of sector *i* can be expressed:

$$x_i = \sum_j \alpha_{ij} \; y_j \tag{2.3}$$

The detailed discussion of **Eq. (2.2)** and **Eq. (2.3)** can be found in Miller and Blair (2009).

2.3.2. Environmentally extended input-output (EIO) model, total pollution load and embedded pollution load

The extension of the IO model known as an environmentally extended input-output (EIO) model is considered a useful technique for quantifying resource use and emissions resulting from the production activities of each sector (Butnar and Llop 2007). The amount of resource use or emissions for each sector is assumed to be linearly proportional to the amount of output of that sector. Let **PI** denote pollution intensity which is the amount of pollution load emitted to produce one unit of monetary output for each sector as indicated by water quality parameters. Its elements, PI_i^k, represents pollution intensity corresponding to the k-water quality parameter type for sector *i* in a specific year. The $k \times n$ matrix **PI** is referred to as the pollution intensity matrix. Then the total pollution load (**PL)** can be calculated:

$$\mathbf{PL} = \mathbf{PI\ x} \tag{2.4}$$

And the total pollution load of *k*-parameter for sector *i*, PL_i^k is expressed:

$$PL_i^k = PI_i^k x_i \tag{2.5}$$

Substituting x_i from **Eq. (2.3)** into **Eq. (2.5)**, an equation for calculating the total pollution load of sector *i* is given as follows:

$$PL_i^k = PI_i^k \sum_j \alpha_{ij} \; y_j \tag{2.6}$$

The total pollution load of sector *i* provides the total annual pollution that is released to satisfy whole production of this sector (x_i) including its intermediate ($\sum_j a_{ij} x_j$) and final demands (y_i). The trend of the water quality parameters show how the total pollution load varies in each sector during the observed period. Based on the result of the water quality trend, the policy makers can identify which pollution mitigation methods should be implemented to focus on sectors which contribute greatly towards increasing the BOD or TSS or to manage sectors which have significantly increasing potential of pollution generation in the future.

Beside sectoral total pollution load, there is embedded pollution load which is defined as the pollution load associated with the production of the final demand of given sector, either emitted by itself or by purchasing inputs from other sectors (Sanchez-Choliz and Duarte 2003). It is different from total pollution load of sector, which represents pollution generated to obtain the GDO of that sector. Let DI_i^k denote embedded pollution load of k parameter which represents pollution emitted to obtain the demand y_i of sector i, which is given by:

$$DI_i^k = \sum_j PI_i^k \alpha_{ji} y_i \quad (2.7)$$

The detailed discussion of this formulation was given in Sanchez-Choliz and Duarte (2003). **Eq. (2.7)** shows that when the final demand of sector i increases, there is a need to increase the production of that sector itself. In addition, there is also a need increase the productivity of other sectors which are linked to it either directly (i.e. as a supplier) or indirectly (i.e. across the supply chain). As a result, the environmental burden also increases. The evaluation of water pollution from economic sectors is clearly visualized when the total pollution load and embedded pollution load are decomposed into different components corresponding to product flows. The next section discusses this in more detail.

2.3.3. Vertical integration coefficient (VIC)

The VIC is employed by disaggregating each embedded pollution load from each sector into four components of pollution including true backward linkage (TB_i^k), semi-own pollution (SE_i^k), own pollution (OW_i^k) and final demand pollution (FI_i^k). The total pollution load of sector is also decomposed into four components including true forward linkage (TF_i^k), SE_i^k, OW_i^k and FI_i^k. These components are related to the flows of goods which are produced to provide for the needs of manufacturing processes required for economic activities (**Fig. 2.2**). **Table 2.1** shows the description of pollution components. The detail of VIC methodology introduced by Sanchez-Choliz and Duarte (2003) is mentioned in the **Appendix A**.

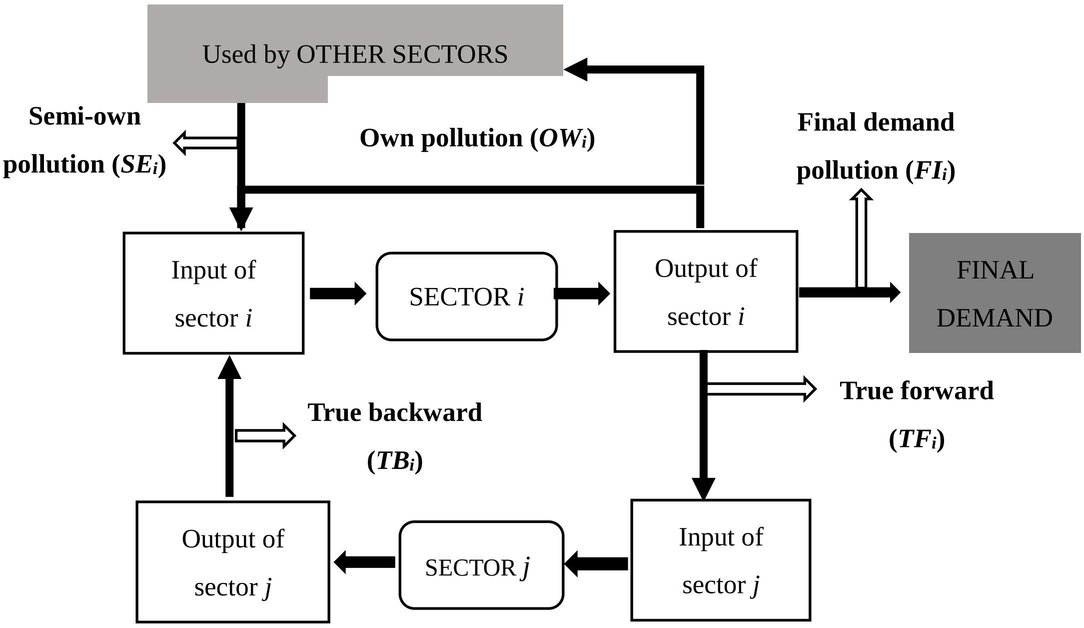


Fig. 2.2 Pollution components in response to flows of products

Table 2.1 Description of pollution components

Components of pollution		Descriptions
Name	Abbreviation	
True backward linkage	TB_i^k	*k*-parameter representing pollution released from other sectors to supply input for sector *i*
Semi-own pollution	SE_i^k	*k*-parameter representing pollution emitted by sector *i* to produce input for other sectors, then this input continuously produces other inputs that sector *i* purchases to produce the final demand
Own pollution	OW_i^k	*k*-parameter expressing pollution released from sector *i* to create input for using by itself
Final demand pollution	FI_i^k	*k*-parameter representing pollution directly emitted by the production of final demand
True forward linkage	TF_i^k	*k*-parameter representing pollution directly generated in the production of intermediate demand to supply inputs for other sectors

After calculating pollution components, the component indices are given to assess sectoral characterization in relation to pollution flows. **Table 2.2** shows indices and their description while details for index computation are shown in the **Appendix A**. Based on these indices, the classification of sectors as either key sectors or forward linkage or backward linkage or non-significant sectors can be obtained using **Table 2.3**. It can be said that the values are low when they are close to 0 and high when they are close to 1. Backward linkage sectors are sectors with high pollution amount by virtue of high inputs (purchases) from other sectors, thus they are called pullers. In contrast, if a sector manufactures goods, then the pollution generated by this sector is virtually sold to other sectors without it finally returning to this sector, this sector is considered as a forward linkage sector and called pusher (Sanchez-Choliz and Duarte 2003, 2005). Key sectors are those that act both as backward and forward linkage sectors. According to Shmelev (2013), key sectors have high propensity to cause pollution across the economy rather than the other sector types. The term "self-polluter by demand" means that pollution is mainly emitted from the production of final demand. In contrast, sectors where most of the pollution is due to own pollution or semi-own pollution are considered as self-polluter by inputs.

Table 2.2 Description of indices of pollution components

Indices	Description
$\varepsilon_{k,i}^{1} = \frac{TB_i^k}{\sum_{j=1}^{n} TB_j^k}$	Vertically integrated backward linkage index
$\varepsilon_{k,i}^{2} = \frac{TF_i^k}{\sum_{j=1}^{n} TF_j^k}$	Vertically integrated forward linkage index
$\varepsilon_{k,i}^{3} = \frac{z_i^k}{\sum_{j=1}^{n} z_j^k}$, with $z_i^k = SE_i^k + OW_i^k$	Vertically integrated self-pollution by input index
$\varepsilon_{k,i}^{4} = \frac{FI_i^k}{\sum_{j=1}^{n} FI_j^k}$	Vertically integrated self-pollution by demand index

Table 2.3 Sectoral characterization in response to water quality parameters (Source: Sanchez-Choliz and Duarte 2003)

Sector indices				Relevant characteristics
$\varepsilon_{k,i}^{1}$	$\varepsilon_{k,i}^{2}$	$\varepsilon_{k,i}^{3}$	$\varepsilon_{k,i}^{4}$	
High	High	High	High	Key sector. Self-polluter by inputs and demand
			Low	Key sector. Self-polluter by inputs
		Low	High	Key sector. Self-polluter by demand
			Low	Key sector. Non self-polluter
	Low and $d_i > 0$	High	High	Backward linkage sector. Self-polluter by inputs and demand
			Low	Backward linkage sector. Self-polluter by inputs
		Low	High	Backward linkage sector. Self-polluter by demand
			Low	Backward linkage sector. None self-polluter
Low	High and $d_i < 0$	High	High	Forward linkage sector. Self-polluter by inputs and demand
			Low	Forward linkage sector. Self-polluter by inputs
		Low	High	Forward linkage sector. Self-polluter by demand
			Low	Forward linkage sector. None self-polluter
	Low	High	High	Self-polluter by inputs and demand
			Low	Self-polluter by inputs
		Low	High	Self-polluter by demand
			Low	Non polluter

2.4. Data collection

2.4.1. Water quality parameters

In terms of harmful effects, there are many substances such as pesticides and fertilizers from agricultural activities, heavy metals from mining activities and chemicals from industries, which are considered as major risks to human health and the ecosystem. However, data on these problems are limited and the monitoring of hazardous substances has not been systematically conducted. Thus, recent researches have focused on main water quality parameters in Vietnam with available data collected from government databases or obtained from secondary data. Trinh and Nguyen (2013) and Nguyen (2015) indicated that total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD) and ammonia-nitrogen (NH4-N) are important parameters for measuring water quality in Vietnam and are used as indicators of water pollution load. These parameters are used to determine the level of suspended solids, organic substances, nutrition, and lubricant. The decomposition processes of these substances may consume dissolved oxygen which needs for growth of spices and organism inside water. As a consequence, when amount of these substances inside water increases, the amount of dissolved oxygen decreases. This may lead the death of fish and other aquatic organism. In other words, at high concentrations, these parameters indicate low water quality. However, the data of these indicators for Vietnamese economic sectors are not available from government statistics. Furthermore, global data allow to calculate only TSS and BOD load, thus these two parameters are chosen for analysis in this chapter. The method presented here can easily be augmented once more information becomes available. Details of data collection and data validation are mentioned in **Subsection 2.4.3**.

2.4.2. Gross domestic output (GDO) and IO table

To calculate the annual total pollution load of sectors in the period 2000-2011 using **Eq. (2.4)**, the data of GDO of different sectors should be known. These data can be obtained from existing IO tables in 2000, 2007 and 2011 (GSO 2003, 2009, 2013). For other years, the GDO of sectors can be achieved from the General Statistics Office (GSO) website (GSO 2006, 2011). To analyze the interrelationship between environmental pollution and economic activities, the integration of EIO and VIC approaches is applied. However, since these methods can be applied for specific years with the condition of IO table availability, the newest IO table of Vietnam in 2011 is employed for this purpose. The 2011 IO table contains 138 columns and rows with 6 final demand columns and 4 value-added rows. The framework of the 2011 IO table is shown in **Table A.1** in **Appendix A** while the complete IO table is available at GSO website (GSO 2013).

Since the Vietnamese IO table was compiled relying on the Provisional Central Product Classification system, whereas the manufacturing industries in industrial pollution projection system

(IPPS) (Hettige et al. 1995) were classified according to International Standard Industrial Classification version 2 (ISIC2) (UN 1990), the manufacturing sectors from the original IO table are reallocated to be consistent with IPPS data. The detailed procedure can be found in Le et al. (2013). After the correlation process, the IO table with 138 sectors is aggregated and classified into 18 main sectors, which is more convenient for environmental pollution computation. The aggregation of sectors applies standard matrix calculations found in Miller and Blair (2009) while this classification is compatible with the classifications found in the IO table from GSO and the classification according to the International Standard Industrial Classification version 3 (ISIC 3) (UN 2002). The description of the 18 sectors and sectoral GDO in 2000 and 2011 are shown in **Table 2.4**.

Table 2.4 Nomenclature of the 18 sectors and GDO in 2000 and 2011

Sector code	Economic sectors	GDO in 2011 (million VND)	GDO in 2000 (Million VND)	% GDO
1	Agriculture, fishery and forestry	1,029,582,812	162,539,580	13.4
2	Mining and quarrying	339,396,098	59,382,594	4.4
3	Food, beverage and tobacco	891,436,918	135,436,416	11.6
4	Textile, wearing apparel and leather industries	479,651,951	76,460,656	6.2
5	Manufacture of wood and wood products	54,681,606	10,373,508	0.7
6	Manufacture of paper and paper products, printing and publishing	98,490,343	11,247,212	1.3
7	Manufacture of industrial chemicals	220,750,863	17,637,509	2.9
8	Manufacture of non-metallic mineral products	199,961,214	25,766,223	2.6
9	Basic metal industries	157,494,854	19,087,004	2.0
10	Manufacturing of fabricated metal products, machinery and equipment	944,851,168	43,058,699	12.3
11	Other manufacturing industries	473,880,422	21,862,409	6.2
12	Electricity, gas and water	175,245,178	20,208,657	2.3
13	Construction	684,211,422	87,649,355	8.9
14	Trade and repairing services	615,591,705	84,381,979	8.0
15	Transportation and communication	542,928,571	28,442,463	7.1
16	Finance, real estate and business services	400,831,479	41,889,501	5.2
17	Government services	145,562,397	22,251,509	1.9
18	Personal, community, and household services	243,780,331	80,621,188	3.2

In this table, the proportion of sectoral GDO, which is calculated using the average GDO of years 2000 and 2011, is also mentioned. Based on **Table 2.4**, it is shown that sectors which contribute the highest amount of GDO to the economy include Sectors 1 (agriculture, fishery and forestry) (13.4%), Sector 10 (manufacturing of fabricated metal products, machinery and equipment) (12.3%) and Sector 3 (food, beverage and tobacco) (11.6%). Sectors which contribute low GDO include Sector 5 (manufacture of wood and wood products) (0.7%), Sector 6 (manufacture of paper and paper products, printing and publishing) (1.3%) and Sector 17 (government services) (1.9%). However, the total pollution load of sectors may have different ranks because they do not only depend on GDO, but also rely on pollution intensity (PI). Sectors with less GDO may have very high total pollution load if they have high PI values. The next part discusses the PI of the different economic sectors.

2.4.3. Pollution intensity of water pollution load (PI) and validation process

To compute the total water pollution load contributed by each sector, there is a need to determine the pollution intensity (PI) which is the amount of pollution load generated in the production of one monetary unit output of each sector (kg/million VND in specific year). The PI data of economic sectors in terms of water quality parameters in Vietnam are not available from government statistics, thus the secondary data are used to estimate the PI. Trinh and Nguyen (2013) were estimated the PI of water quality indicators for the years 2000 and 2007 based on data published by government including survey results in enterprise together with information on wastewater computation employed by National environmental agency and study result of Institute of tropical Technology and Environmental Protection. In Trinh's study, various sectors in 2000 IO table and 2007 IO table were classified into 12 sectors including nine non-manufacturing sectors (Sectors 1, 2, 12, 13, 14, 15, 16, 17 and 18, as listed in **Table 2.4**) and three manufacturing sectors. The classification of nine non-manufacturing sectors in Trinh and Nguyen (2013) is compatible with the classification of nine non-manufacturing sectors in this study, thus PI data of these nine sectors from Trinh and Nguyen (2013) can be applied to calculate the total pollution load in this context. However, the classification of manufacturing sectors in Trinh and Nguyen (2013) was so aggregated and not compatible with the classification in this context. Therefore, PI of nine manufacturing sectors (Sectors 3, 4, 5, 6, 7, 8, 9, 10 and 11 as listed in **Table 2.4**) are obtained from other database - IPPS (Hettige et al. 1995), which was proposed by the Infrastructure and Environment Team of the World Bank. IPPS combines the data of industrial activity with data on pollution release. IPPS relates the PI with respect to value added, GDO and employment (Hettige et al. 1995). In this context, PI with respect to GDO is used because of the availability of GDO data. The PI in the IPPS for the year 1997 (pound per million 1987 US dollars) are adjusted to correlative year in Vietnamese currency (e.g, kg per million 2011 VND) using the deflation factor based on consumer price index (CPI), as outlined by Mani and Jha (2006).

IPPS has been used in many countries such as Nigeria (Oketola 2007, Odesanya et al. 2012), India (Pandey 2005), Lagos (Oketola and Osibanjo 2007), Brazil and Latin American (Aguayo et al. 2001). In Southeast Asia, the estimation of pollution flows for industrial sectors was also applied for Malaysia (Oketola and Osibanjo 2009b), Lao PRD (GMS Environmental Operation Center 2014), Cambodia (San et al. 2018) and Thailand (Benoit and Craig 2001). In Vietnam, ICEM (2007) adapted the database from IPPS to compute the total pollution load of several pollutants for specific regions in the year of 2004. According to this report, many existing industrial operations in Vietnam now make use of technologies which are over 15-20 years old and are similar to technologies operating in the US in the late 1980's. Thus, Vietnamese industrial technologies are well represented by the underlying technologies reflected in IPPS. Furthermore, ICEM (2007) also carried out the validation of IPPS data by comparing with data from CTC Vietnam. Correlation coefficients were calculated using the pollution load of TSS and BOD between CTC data and IPPS data at the provincial level and at the sectoral level; these were then ranked from lowest value to highest value. The purpose of this process was to know whether high values of total pollution load estimated from the IPPS data well corresponded with high values of total pollution load obtained from CTC data. The results of this process are shown in **Table A.2** and **Table A.3** in **Appendix A**.

Table A.2 indicates high positive correlation for both TSS and BOD (0.71 and 0.69) which implies that there is a close match in terms of priority ranking of these two data. **Table A.3** gives the correlation coefficient at the sectoral level which resulted in a relatively low value (TSS: 0.24 and BOD: 0.33). However, ICEM (2007) then performed a statistical test of the level of significance. The results show that differences of total pollution load between sectors of these two data are not statistically significant. This means that PI data from IPPS is suitable to use for the Vietnam scenario. After the PI of sectors is given, the extended IO table is obtained and is also found in the **Table A.4** in **Appendix A**.

2.5. Results and Discussion

2.5.1. Total Pollution load trend

In the manufacture of goods and services, the products of each sector are distributed into intermediate demand (inputs to other sectors) and final demand (i.e., household and government consumption). Each process corresponds to a certain amount of generated pollution load. Thus, the total pollution load of an economic sector is simply the sum of the pollution associated with the production of goods or services in the sector in order to serve all requirements needed by the economy to operate. This is expressed in **Eq. (2.4)**. The trend of the total water pollution load as indicated by the water quality parameters, represents the variations in total pollution load within the period of 2000 – 2011. This trend is given for two main water quality indicators **-** TSS and BOD.

2.5.1.1. Trend of total suspended solids (TSS)

The TSS trend is shown in **Fig. 2.3**. In detail, the line representing the TSS of the entire economy indicates that in the year 2000 TSS was approximately 300,000 tonnes, but this number increased to more than 1,000,000 tonnes by the year 2011. It means the TSS of the whole economy increased 4 times within 11 years. The reason is that the GDO of each sector increased quickly from 2000 to 2011 (except 2002) as a result of rapid economic growth in Vietnam. At the sectoral level, results also indicate the rapid increase in TSS of each sector. The variation of TSS among the top 6 most polluting sectors and rest of sectors in the period is also shown in **Fig. 2.3**. It can be seen that Sector 9 (basic metal industries), despite comprising only a small proportion of GDO (2%, **Table 2.4**), was a main contributor to TSS, accounting for 71% of TSS within the period of consideration. This results from the high PI of this sector (9.88 kg/million VND, as average value within the period) which was 10 times larger than that of the second highest source (Sector 6 with 0.98 kg/million VND). The second source of TSS was Sector 11 (other manufacturing sectors), accounting for 7% of average TSS of the whole period. Following these sectors was Sector 6 (manufacture of paper and paper product, printing and publishing), Sector 7 (manufacturing of industrial chemicals). These sectors had high TSS because many of the processes in these sectors require intensive water. In addition, wastewater treatment was not well employed (ICEM 2007). Sector 3 (food, beverage and tobacco) and Sector 1 (agriculture, fishery and forestry) show mid-level of TSS. These sectors had lower TSS per unit of GDO but they had the highest proportion of GDO compared to other sectors (**Table 2.4**). The rest of the sectors had insignificant TSS because they had low PI and low GDO.

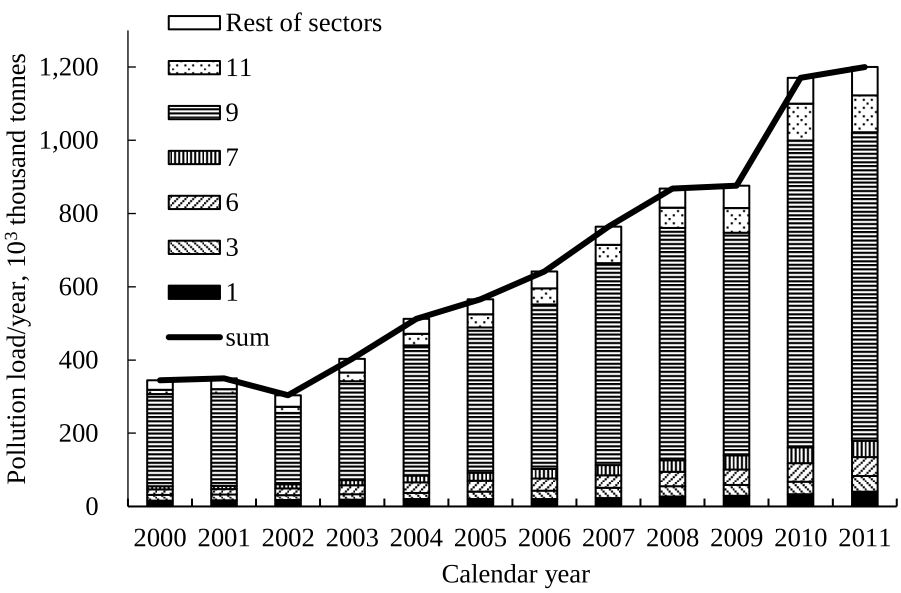


Fig. 2.3 The TSS trend of top 6 most polluting sectors

From this study, the total amount of TSS due to economic activities in the year 2000 was 344,942 tonnes. The results obtained by other researchers in Vietnam such as Trinh and Nguyen (2013) was 71,391 tonnes of TSS. Trinh and Nguyen (2013) made use of a PI factor which was estimated based on data published by government. The results indicate a large difference between the two studies with +0.79 dissimilarity. The difference derives from the large difference in the pollution intensity (PI) of TSS used in these two studies. The average PI of TSS of all manufacturing sectors in this study is 1.7479 kg/million VND. This is almost the same as the result obtained by Le et al. (2013) with 1.8995 kg/million, but it is 28 times higher than in Trinh and Nguyen (2013) (0.06 kg/million VND). If the PI of Sector 9 (basic metal industries) (13.19 kg/million VND) was replaced by PI of Sector 6 (manufacture of paper and paper products, printing and publishing) (1.307 kg/million VND), which had the second highest PI, the total TSS in 2000 became 118,154 tonnes. Hence, the dissimilarity can reduce to only +0.4. Therefore, it can be said that the high value of PI of TSS in Sector 9 (basic metal industries) obtained from IPSS explains the difference in TSS among researches.

2.5.1.2. Trend of biological oxygen demand (BOD)

The results of total BOD pollution load indicate that BOD pollution load was 8 times less than TSS. However, the BOD of entire economy also quickly increased from 42,600 tonnes in 2000 to 121,360 tonnes in 2011 (**Fig. 2.4**). Sector 3 (food, beverage and tobacco) was the main driver of BOD with the average amount of 24,834 tonnes, accounting for 35% of total BOD generation. The next major source of BOD was Sector 1 (agriculture, fishery and forestry) with 19,649 tonnes accounting for 28% of the total average BOD in this period. Two of these sectors show high level of total BOD pollution load because of the high GDO. The mid-level contributor of BOD was Sector 6 (manufacture of paper and paper product, printing and publishing), Sector 9 (basic metal industries), Sector 2 (mining and quarrying) and Sector 7 (manufacturing of industrial chemicals). These sectors were water-intensive industries but their GDO were low. The remaining sectors had low-level BOD because of very low PI values and sectoral GDO; thus, these sectors were considered as insignificant.

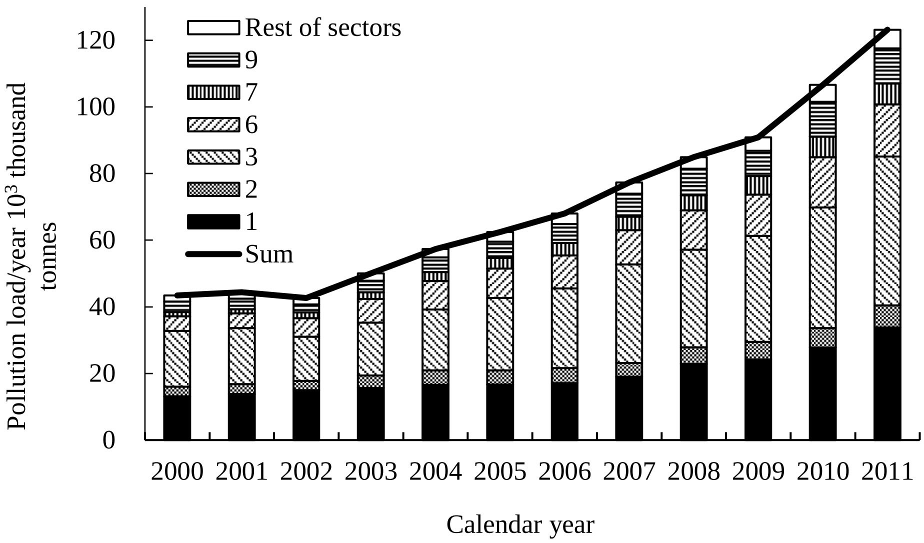


Fig. 2.4 The BOD trend of top 6 most polluting sectors

The total amount of BOD in the year 2000 for the whole economy was 43,419 tonnes which is -0.017 dissimilar to the work of Trinh and Nguyen (2013). This points out that there is a slight difference between estimating the PI of BOD obtained from the IPPS and that obtained from the government database. In other words, the IPPS data can be well applied for BOD calculation in Vietnam. The trends of the water quality indicators highlight the variations in total pollution load generated by economic sectors to satisfy all the demand needed to operate the economy. Meanwhile, these results do not reflect the role of sectors and their sectoral connections in terms of pollution. Thus, there is a need to decompose each water pollutant load and embedded pollution load into different components, then to evaluate these components to establish the characteristics of sectors in relation to water pollution. This helps in identifying the role of each sector (i.e. a consumer/purchaser, a producer/seller of water pollution). The next section explains this in more detail.

2.5.2. Role of sectors in relation to water pollution

This subsection uses formulas, which are discussed in detail in the **Appendix A** to calculate for the components of TSS and BOD parameters in the year 2011. **Table A.5** in the **Appendix A** shows the total pollution load (PL_i^k), the embedded pollution load (DI_i^k) and pollution components in 2011. In **Table A.5**, it can be seen that Sector 9 (basic metal industries) was responsible for majority of TSS. A total of 95% of TSS from Sector 9 was sold to other sectors of the Vietnamese economy. Thus, Sector 9 was considered as a pollution producer or so-called pollution pusher. In contrast, Sector 10 (manufacturing of fabricated metal products, machinery and equipment) and Sector 13 (construction) were of the opposite extreme case and are considered as TSS purchasing sectors, and called pollution consumers/pullers. Sector 10 (manufacturing of fabricated metal products, machinery and equipment) bought more than 47% of the TSS generated by other sectors of the economy by virtue of the required inputs into Sector 10. Similarly, Sector 13 (construction) purchased more than 39%.

The largest purchaser of BOD was Sector 10 (manufacturing of fabricated metal products, machinery and equipment), which purchased 50,500 tonnes (34%) of total BOD from other sectors (**Table A.4** in **Appendix A**). The second highest purchaser of BOD was Sector 13 (construction) purchasing 45,400 tonnes (31%). These sectors were thus pollution pullers again. Meanwhile, Sector 9 (basic metal industries) was again considered as a pollution pusher and was responsible for contributing the highest BOD, with 58% of its total pollution load distributed to other sectors.

From this result, pollution-pushing sectors and pollution-pulling sectors with respect to TSS and BOD can be identified. For prioritization of sectors, the computation of sectoral indices is performed to indicate the characteristics of sectors. These indices are classified as high and low values as mentioned in the **Table 2.3**. The classification of indices is employed by splitting the 18 sectors into 3 groups, namely sectors with high, intermediate and low values of indices. The largest six indices are classified as high, while the smallest six indices are classified to be low. Based on **Table 2.3**, the characteristic of each sector in relation to TSS and BOD for the year of 2011 is given in **Table 2.5**. **Table 2.5** helps visualize the role of sectors more clearly. Sector 1 (agriculture, fishery and forestry) and Sector 3 (food, beverage and tobacco) were thus considered key sectors in terms of both TSS and BOD. These sectors had the highest propensity to cause water pollution across the economy. **Table 2.6** shows the summary of important results, which indicates sectors with high impact on water pollution in terms of both TSS and BOD.

Table 2.5 Sectoral characteristic/role with respect to TSS and BOD in 2011

Sector indices				Relevant characteristics	Water quality parameters	
$\varepsilon_{k,i}^{1}$	$\varepsilon_{k,i}^{2}$	$\varepsilon_{k,i}^{3}$	$\varepsilon_{k,i}^{4}$		**TSS**	**BOD**
High	High	Low	High	Key sector. Self-polluter by demand		Sector 1 and Sector 3
			Low	Key sector. None self-polluter	Sector 1 and Sector 3	
Low	Low and $d_i>0$	Low	High	Backward linkage sector. Self-polluter by demand		Sector 4
			Low	Backward linkage sector. None self-polluter	Sector 2, Sector 10 and Sector 13	Sector 10 and Sector 13
	High and $d_i<0$	High	High	Forward linkage sector. Self-polluter by inputs and demand	Sector 6, Sector 7, Sector 9 and Sector 11	
			Low	Forward linkage sector. Self-polluter by inputs		Sector 6, Sector 7, Sector 9 and Sector 11
	Low	High	High	Self-polluter by inputs and demand	Sector 5 and Sector 8	
			Low	Self-polluter by inputs		Sector 5 and Sector 8

Table 2.6 The role of important sectors in relation to water pollution

Parameters	Key sectors	Highest pushers	Highest pullers
TSS	Sector 1 and Sector 3	Sector 9	Sector 10 and Sector 13
BOD	Sector 1 and Sector 3	Sector 9	Sector 10 and Sector 13

2.5.3. Pollution reduction priority

The analysis of the trend of total pollution load during the year 2000 to 2011 and the assessment of pollution components help identify the management priorities. The reduction priority should focus on:

(i) Sectors with high total pollution load during the period. This includes Sector 9 (basic metal industries) for TSS; Sector 1 (agriculture, fishery and forestry) and Sector 3 (food, beverage and tobacco) for BOD.

(ii) Sectors having high water pollution impact. Sector 1 (agriculture, fishery and forestry) and Sector 3 (food, beverage and tobacco)) have been identified as key sectors in terms of TSS and BOD. Sector 13 (construction) and Sector 10 (manufacturing of fabricated metal products, machinery and equipment) were considered pollution pullers. Sector 9 (basic metal industries) was considered a pollution pusher.

To decrease water pollution, there are several suggestions to help government, policy makers, household sectors and industrial manufactures in the development and effective implementation of strategies. An example strategy for pollution pulling sectors is to improve the efficiency of technologies employed in their processes. This can potentially reduce the required inputs of industries and sectors.

On the side of government and policy makers, there is a need to devise appropriate regulations for wastewater management in manufacturers belonging in sectors with high total pollution load contributions and with high water pollution impact.

On the manufacturer side, the best way to reduce pollution of these sectors is to lower the value of PI. In Sector 9 for example, improvements may look into strategies for reducing the TSS intensity of their processes. This can be obtained by applying cleaner technologies or by improving the wastewater treatment systems. In addition, the manufacturers can reduce pollution by shifting from highly pollutive raw materials into less pollutive inputs or by improving the process efficiency.

For household sectors, there is a need to manage the household consumption by encouraging the use of more environmentally friendly products. Furthermore, the decrease of consumption also helps.

2.6. Conclusions and recommendation

This study can be considered as a preliminary investigation of the total water pollution load as indicated by water quality parameters contributed by economic activities in Vietnam. This can potentially help environmental managers and policy makers in monitoring water pollution in Vietnam by taking into account the water quality trend over the period of 2000-2011.The methods make use of available IO tables in 2000, 2007 and 2011 and other economic data in Vietnam to calculate for two conventional water quality indicators including TSS and BOD. The results show a tremendous increased in TSS, from 345,000 tonnes in 2000 to 1,199,000 tonnes in 2011 while the total BOD increased from 43,400 tonnes in 2000 to 123,000 tonnes in 2011. For TSS, Sector 9 (basic metal industry) was the main contributor, while Sector 3 (food, beverage and tobacco) and Sector 1 (agriculture, fishery and forestry) were the main contributors for BOD.

In taking account of the linkages among economic sectors and the interrelationship between economic sectors and water pollution, the combination of EIO and VIC methods is employed to identify the role of sectors. This is based on an evaluation of a number of pollution component indices proposed by Sanchez-Choliz and Duarte (2003). The advantage of the methodology is that it overcomes the deficiencies of the traditional indices based on simply the Leontief inverse and Gosh inverse. Weighting of environmental impact with final demand or production are considered, thus the assessment of environmental impact completely depends on the structure of the economy. This methodology hence provides a more complete analysis for identifying the role of sectors as producer/seller or consumer/purchaser or both seller and purchaser (key sectors) of water pollution. The IO table of 2011 is used for this purpose and the results highlight that for both TSS and BOD, Sector 1 (agriculture, fishery and forestry) and Sector 3 (food, beverage and tobacco) were considered as key sectors, Sector 9 (basic metal industry) was the highest pollution pusher, while Sector 10 (manufacturing of fabricated metal products, machinery and equipment) and Sector 13 (construction) were the highest pollution pullers. Finally, based on the results of water pollution for long time periods and the role of sectors in relation to water pollution, the suggestions of pollution reduction priority are presented to help government, policy makers, house hold sectors and industrial manufactures in identifying the proper water pollution mitigation strategies.

This research is especially proposed for the Vietnam case, but it can be easily adapted for use in other nations with existing IO tables and environmental data. This chapter is used as another example which applies environmental data from IPPS to calculate environmental pollution. Other developing countries can make use of the methodology presented in this work to track pollution generation in the economy and to analyze the interrelationship between economic activities and environmental pollution. The weak point of this research is that the application of global data such as IPPS may result in some uncertainties. Furthermore, this research just focuses on TSS and BOD, while other water quality indicators such as chemical oxygen demand, ammonia-nitrogen and hazard chemicals are not considered. Therefore, future work can focus on other pollutants or environmental quality indicators in Vietnam in consideration of different environment media such as water, air and land. In addition, tools for handling data uncertainty can be integrated in the model to result in more robust analysis.

References

Aguayo F, Gallagher P, Gohzalez A (2001) Dirt is in the eye of the beholder: the World Bank air pollution intensities for Mexico. Global development and environment institute working paper no. 01–07.

Benoit L, Craig M (2001) Estimating conventional industrial water pollution in Thailand. In Paper presented to the Development Research Group of the World Bank.

Butnar I, Llop M (2007) Composition of Greenhouse Gas Emissions in Spain: An Input–Output Analysis. Ecological Economics, 61(2-3):388–395.

Cazcarro I, Duarte R, and Sanchez-Choliz J (2016) Downscaling the grey water footprints of production and consumption. Journal of Cleaner Production, 132:171–83.

CTC Vietnam. Accessed on 01 May 2016. http://www.ctcgroupe.com/en/locations/ctc_vietnam.php

Global Environmental Forum (2002) Overseas environmental measures of Japanese Companies (Vietnam). Accessed on 12 July 2016. http://www.env.go.jp/earth/coop/oemjc/viet/e/contents.html

Ghosh A (1958) Input-output approach to an allocative system. Economica, 25(1):58-64.

GMS Environmental Operations Center (2014) Estimating industrial pollution in Lao PDR, Bangkok, Thailand. Accessed on 15 November 2017. http://www.gms-eoc.org/uploads/resources/453/attachment/EstimatingIndustrialPollutioninLaoPDR_1.PDF

GSO (General Statistical Office) (2003) Input-Output: IO of Vietnam Year 2000. Statistical Publishing House: Hanoi; 142- 246.

GSO (General Statistical Office) (2006) Statistical Yearbook of Vietnam (2005). Accessed on 05 May 2016. http://www.gso.gov.vn/default_en.aspx?tabid=515&idmid=5&ItemID=5691

GSO (General Statistical Office) (2009) Input-Output: IO of Vietnam Year 2007. Statistical Publishing House: Hanoi.

GSO (General Statistical Office) (2011) Statistical Yearbook of Vietnam 2010. Accessed on 05 May 2016. http://www.gso.gov.vn/default_en.aspx?tabid=515&idmid=5&ItemID=11974

GSO (General Statistical Office) (2013) Input-output: IO of Vietnam year 2011. Statistical Publishing House: Hanoi.

Haimes YY, Jiang P (2001) Leontief-based model of risk in complex interconnected infrastructures. Journal of Infrastructure Systems, 7(1):1–12.

Hettige H, Martin P, Singh M, Wheeler D (1995) The industrial Pollution Projection System. Work Bank Policy Research Working Paper.

Hoa NT, Dien LQ, Promentilla MAB, Yu KDS, Aviso KB (2016) A model for multi-criteria disaster vulnerability assessment of economic systems: implications for Vietnam’s bioethanol policy. Clean Techn. Environ. Policy, 18(6):1917-1929. doi:10.1007/s10098-016-1120-4

Hoa NT, Promentilla MA, Aviso KB (2013) Fuzzy multi-objective optimization of a multi-regional bioethanol supply chain. ASEAN Engineering Journal Part B, 2 (2). Accessed on 05 February 2014. http://www.seed-net.org/wp-content/uploads/2015/12/Invited-Paper_FUZZY-MULTI-OBJECTIVE-OPTIMIZATION-OF-A-MULTI-REGIONAL-BIOETHANOL-SUPPLY-CHAIN.pdf

Hung PT, Tuan BA, Chinh NT (2008) The impact of trade liberalization on industrial pollution: empirical evidence from Vietnam. Accessed on 29 June 2016. http://www.idrc.ca/uploads/users/12483164701Pham_Hung_Thai_2008_RR5.pdf

ICEM (International Center for Environmental Management) (2007) Analysis of pollution from manufacturing sectors in Vietnam. Indooroopilly, Queensland, Australia.

Jessen S (2009) Groundwater arsenic in the Red River delta, Vietnam: Regional distribution, release, mobility and mitigation options. Accessed on 21 August 2017. http://orbit.dtu.dk/fedora/objects/orbit:82605/datastreams/file_5034320/content

Kamyab H, Chelliapan S, Din MFM, Shahbazian-Yassar R, Rezania S, Khademi T, Kumar A, Azimi M (2017) Evaluation of lemna minor and chlamydomonas to treat palm oil mill effluent and fertilizer production. Journal of Water Process Engineering, 17:229–36. Accessed on 15 November 2017. http://dx.doi.org/10.1016/j.jwpe.2017.04.007

Kamyab H, Din MFM, Hosseini SE, Ghoshal SK, Ashokkumar V, Keyvanfar A, Shafaghat A, Lee CT, Bavafa AA, Majid MZA (2016) Optimum lipid production using agro-industrial wastewater treated microalgae as biofuel substrate. Clean Techn. Environ. Policy 18(8):2513–23.

Kamyab H, Din MFM, Keyvanfar A, Majid MZA, Talaiekhozani A, Shafaghat A, Lee CT, Shiun LJ, Ismail HH (2015) Efficiency of microalgae chlamydomonas on the removal of pollutants from palm oil mill effluent (POME). Energy Procedia, 75:2400–2408. Accessed on 15 November 2017. http://dx.doi.org/10.1016/j.egypro.2015.07.190.

Le AH, Tokai A, Yamamoto Y (2013) Structural analysis of relationship between economic activities and water pollution in Vietnam.J. Japan Soc. Hydrol. and Water Resour, 25(3):139-151.

Leontief WW (1936) Quantitative Input-Output Relations in the Economic System of the United States. Review of Economics and Statistics, 18(3):105–125.

Leontief WW (1970) Environmental repercussions and the economic structure: an input-output approach. Rev Econ Stat, 52(3):262–271.

Leontief WW (1985) Input–output analysis. In W. Leontief (Ed.), Input–output economics. NewYork: Oxford University Press, 19–40.

Leontief WW, Ford D (1972) Air pollution and the economic structure: empirical results of input-output computations. In Andrew Brody and Anne P. Carter (eds). Input-output techniques (Amsterdam-London: North-Holland Publishing Company: 9-30.

Li H, Yang Z, Liu G, Casazza M, Yin X (2017) Analyzing virtual water pollution transfer embodied in economic activities based on gray water footprint: A case study. Journal of Cleaner Production, 161:1064–73.

Mani M, Jha S (2006) Trade liberalization and the environment in Vietnam. Policy Research Working Paper WPS3879; 16-17 and 30. Accessed on 15 May 2016. http://go.worldbank.org/J62ASJBSR0.

Miller RE, Blair PD (2009) Input-Output Analysis: Foundation and Extensions. Second Ed. Published in the United States of America by Cambridge University Press, New York.

Murray J, Wood R (2010) The sustainability Practioners' Guide to Input-Output Analysis. Common Ground PublicationsOdesanya BO, Ajayi SO, Shittu M, Oshin O (2012) Use of industrial pollution projection system (IPPS) to estimate pollution load by sector in two industrial estates in Ogun State, Western Nigeria. International Journal of Scientific & Engineering Research 3(10).

Nguyen TH (2015) Overview of Water Environmental Pollution in Vietnam Nguyen Thi Hue .Technology, Environmental, Vietnamese Academy, and Hoang Quoc Viet. Accessed on 15 November 2017. http://www.wepa-db.net/pdf/0712forum/paper04.pdf

Odesanya BO, Ajayi SO, Shittu M, Oshin O (2012) Use of industrial pollution projection system (IPPS) to estimated pollution load by sector in two industrial estates in Ogun State, Western Nigeria. International Journal of Scientific & Engineering Research, 3 (10).

Oketola AA (2007) Industrial pollution assessment in Lagos, Nigeria using Industrial Pollution Projection System and effluent analysis. PhD Thesis, Department of Chemistry, University of Ibadan.

Oketola AA, Osibanjo O (2007). Estimating sectoral pollution load in Lagos by Industrial Pollution Projection System (IPPS). Sci. Total Environ. 377:125–141.

Oketola AA, Osibanjo O (2009b) Industrial pollution load assessment by industrial pollution projection system (IPPS). Toxicol. Environ. Chem. 91:989–997.

Pandey R (2005) Estimating sectoral and geographical industrial pollution Inventories in India: implications for using effluent charge versus regulation. J. Dev. Stud. 41:33–61.

PricewaterhouseCoopers (2017). The world in 2050. Accessed on 21 August 2017. https://www.pwc.com/gx/en/world-2050/assets/pwc-the-world-in-2050-full-report-feb-2017.pdf

Que TT, Thanh VA (2001). Vietnam: Achievements and challenges. Social Watch on Poverty Eradication and Gender Equity Report 2001:172-173.

Rasmussen P (1956) Studies in Intersectoral Relations, Amsterdam, North-Holland.

Rezania S, Taib SM, Din MFM, Dahalan FA, Kamyab H (2016) Comprehensive review on phytotechnology: heavy metals removal by diverse aquatic plants species from wastewater. Journal of Hazardous Materials 318: 587–99. Accessed on 15 May 2017. http://dx.doi.org/10.1016/j.jhazmat.2016.07.053

San V, Vin S, and Johannes S (2018) Science of the Total Environment Industrial Pollution Load Assessment in Phnom Penh , Cambodia Using an Industrial Pollution Projection System.” Science of the Total Environment 615: 990–99. Accessed on 15 November 2017. https://doi.org/10.1016/j.scitotenv.2017.10.006

Sanchez-Choliz J, Duarte R (2003) Analyzing pollution by way of vertically integrated coefficients, with an application to the water sector in Aragon. Cambridge Journal of Economics 27(3):433-448.

Sanchez-Choliz J, Duarte R (2005) Water pollution in the Spanish economy : Analysis of sensitivity to production and environmental constraints. Ecological economics, 53(3):325–38.

Shmelev SE (2010) Environmentally extended input-output analysis of the UK economy: key sector analysis.Published in: QEH Working Paper Series No. Working Paper Number 183. Accessed on 08 June 2016. http://www3.qeh.ox.ac.uk/pdf/qehwp/qehwps183.pdf

Suh S (2009). Handbook of input-output economics in industrial ecology. 2nd Printing, ed. Springer

Tan RR, Culaba AB, Aviso KB (2008) A fuzzy linear programming extension of the general matrix-based life cycle model. Journal of Cleaner Production, 16(13):1358-1367.

Tan RR, Ballacillo JB, Aviso KB, Culaba AB (2009) A fuzzy multiple objectives approach to the optimization of bioenergy system footprints. Chemical Engineering Research and Design, 87(9):1162-1170.

The World Bank, the National Environmental Agency, the Danish Agency for international development (2002) Vietnam Environmental Monitor 2002; 20-22. Accessed on 21 May 2016. http://siteresources.worldbank.org/INTEASTASIAPACIFIC/ Resources/VN-Monitor-02.pdf

Tran HTH (2010) Water utilization and efficiency in Vietnam, the challenges and solutions. Ministry of natural resources and environment. Vietnam environment administration. Accessed on 21 May 2016. http://www2.gec.jp/gec/en/Activities/ietc/fy2010/wf/wf_s5-1.pdf

Trinh B, Nguyen PV (2013) Economic-environmental impact analysis based on the changes of economic structures of Hochiminh city and the rest of Vietnam. 2 (3)

UN (United Nations) (1990) International Standard Industrial Classification of All Economic Activities, Rev.2 (ISIC 2). Accessed on 12 June 2016. https://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=8

UN (United Nations) (2002) International Standard Industrial Classification of All Economic Activities, Rev.3 (ISIC 3). Accessed on 12 June 2016. https://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=2

Water and Sanitation Sector Assessment report Vietnam 2011 (WSSA) (2012) Accessed on 05 May 2017. http://www.wpro.who.int/vietnam/topics/water_sanitation/watsan_sector_report_vietnam_2011.pdf

Water Environment Partnership in Asia (WEPA) (2011). Accessed on 12 May 2016. http://www.wepa-db.net/policies/state/vietnam/overview.htm

Wu Z, Guo X, Lv C, Wang H, Di D (2017) Study on the quantification method of water pollution ecological compensation standard based on emergy theory. Ecological Indicator, 92:189-194. Accessed on 15 November 2017. https://doi.org/10.1016/j.ecolind.2017.09.052

Yan C, Ames E (1965) Economic interrelatedness. Review of Economic Studies. Vol. XXIII, no. 4. Accessed on 16 May 2016. http://cje.oxfordjournals.org/

Yu KDS, Tan RR, Aviso KB, Promentilla MAB, Santos JR (2014) A vulnerability index for post-disaster key sector prioritization. Econ Syst Res 26(1):81–97.

Chapter 3 Main drivers of carbon dioxide emissions in Vietnam trajectory 2000-2011: an input-output structural decomposition analysis

This chapter analyze the different driving forces which induce the changes of CO2 emissions in two observed periods 2000-2007 and 2007-2011. The analysis is based on both production and final demand perspectives. Obtained results from this chapter provide *driving force* component of modified DPSIR framework for designing strategies for integrated economic-environmental management.

3.1. Introduction

The impact of economic production activities on the environment has caused serious global problems such as global warming. Rising greenhouse gas (GHG) emissions, mainly CO_2 generation, from the continued consumption of fossil fuels remains a main contributor to global warming which has induced climate change. The World Bank (2010) reported that if anthropogenic activities continue to operate at usual conditions, this could result in a 5^{o}C increase in global temperature but timely and appropriate intervention may limit it within 2^{o}C. Thus, reducing GHG releases has become an emerging economic development research interest world-wide (Wang et al. 2012).

Currently, Vietnam is in the last process of rapid industrialization and is expected to pass into an innovative stage of development (Maryzin 2013). Since 2000, the Vietnamese economy has positively prospered with annual economic growth rates up to above 5% (PricewaterhouseCoopers 2017). This rapid economic growth was accompanied by increased energy consumption (MNRE 2014) and resulted in corresponding increases in GHG emissions from the energy sector. Nguyen et al. (2009) reported that the projection of GHG generation from energy combustion will increase tremendously by up to 14% per year, reaching nearly 400 million tonnes of CO_2 in 2030. In order to mitigate the impact of climate change, the 1992 UN Framework Convention on Climate Change (UNFCCC) developed the Kyoto Protocol which required member countries to promote environmental policies to reduce GHG emissions (UNFCCC 1998). As a non-annex I country under Kyoto Protocol, Vietnam is not required to abate GHG emissions. It has however ratified the agreement to pursue efforts of reducing emissions in polluting sectors such as the energy, agriculture and transportation sectors (KEPA & GreenID 2014). In light of this, Vietnam submitted an intended nationally determined contribution (INDC) to the 2015 United Nations Climate Change Conference (COP21), which commits to a 25% reduction in GHG emissions by 2030 compared to the business-as-usual (BAU) levels (UNFCCC 2015a, 2015b). Nguyen et al. (2018b) employed a high-level assessment of the potential effectiveness of mitigating GHG emissions by considering low-carbon measures including differentiated growth of sectors, shift to low-carbon energy mix, broad deployment of energy conservation measures for final consumption and use of low-carbon technologies in agriculture, transport and waste sectors. The results indicate that the targets of GHG emissions outlined in INDC are achievable if all the strategies outlined are implemented altogether. However, according to KEPA and GreenID (2014), in addition to technology factor and annual growth, there are many other socio-economic factors which impact the incremental changes in GHG emissions of an economy. In-depth understanding of these drivers may help in developing short-term and long-term sustainable energy emission mitigation strategies. In Vietnam, the main contributor to total GHG emissions is CO_2, which accounts for 48% (Nguyen et al. 2018b, MNRE 2014) of the total. Thus, the effectiveness of GHG mitigation measures can be enhanced and maximized if the main drivers of CO_2 generation can be identified. In other words, uncovering these main drivers could be helpful in reaching reduction targets and projecting future low-emission scenarios (Shahiduzzaman & Layton 2017, Guan et al. 2008).

Cansino et al. (2016) indicated that decomposition analysis facilitates the identification of driving forces which are more crucial for mitigating CO_2 emissions. Liu and Wang (2013) proved that using decomposition method allows for the analysis of how different factors contribute to the changes of SO_2 emissions. Frequently used methods of decomposition analysis include the LMDI method (Shrestha et al. 2009, Cansino et al. 2015, Chen et al. 2018), the IPCC method (IPCC 2006), and the SIRPAT method (Fu et al. 2015, Shuai et al. 2017). Recently, the Kaya Index method was used for identifying the drivers of CO_2 emissions in Vietnam (Nguyen 2012), for linking changes in GHG emissions in Baltic States (Štreimikienė and Balezentis 2016), and for identifying the driving forces of CO_2 emissions from construction (Mavromatidis et al. 2016), to name a few. The advantage of these methods is the ability to examine the various factors, which affect energy-based CO_2 emissions. They are later used to propose the differentiated measures, which should be adopted for each region. However, these previous works have failed to provide a comprehensive analysis of how the connections between the different economic sectors and other economic structure factors affect emissions. To fill this gap, a hybrid input-output structural decomposition analysis (IO-SDA) method using economic input-output tables is applied to provide a more detailed assessment of economic structure changes over time (Xie 2014). Furthermore, IO-SDA can show socio-economic factors from both production and consumption perspectives (Cansino et al. 2016, Wang et al. 2013). With decomposition on a sectoral scale, IO-SDA can analyze the driving factors for pollutants from high-polluting sectors (Cansino et al. 2016, Wang et al. 2016)

Rose and Chen's (1991) seminal work using IO-SDA assessed the changes in the sectoral energy use in the U.S. while Rose and Casler (1996) later gave the basic principles to get equations for structural decomposition. A similar approach was implemented for optimizing supply chain network under water footprint constraints (Aviso et al. 2011). IO-SDA model has been used successfully not only on a national scale (Huang and Wu 2013, Koh et al. 2016), but also on a city scale (Wang and Wang 2015, Wei et al. 2017). IO-SDA was also utilized in analyzing the emissions embodied in trade among countries (Xu and Dietzenbacher 2014, Wang et al. 2017) and in projecting the future emission scenarios (Shahiduzzaman and Layton 2017).

There are few studies which have utilized decomposition analysis for analyzing the Vietnamese economy. Nguyen (2012) applied the Kaya Index to analyze CO_2 emission variability in Vietnam during 1986 - 2008, while Zimmer et al. (2015) used it for the period of 1975-2010. These authors were successful in evaluating the changes in CO_2 emissions using a macro-economic scale, but they failed to identify the changes in CO_2 emissions at the sectoral scale. Nguyen and Ishihara (2006a, 2006b) used IO-SDA to analyze the variation of energy flows in Vietnam from 1989 to 2000. These helped identify the changes in energy flows at the sectoral level, but they focused primarily on energy intensity and lacked analysis of other socio-economic drivers such as production structure, population and consumption structure to name a few.

To supplement this research gap, this chapter used the IO-SDA to analyze the driving forces of CO_2 emissions looking at various perspectives over two categorical periods, 2000 - 2007 and 2007 - 2011. In light of this, more recent data on emissions, gross domestic product (GDP), population and IO tables are used in order to achieve the three fold objectives as follows:

1. Decompose the changes in CO_2 emissions from the production perspective with five socio-economic driving forces including technology, production structure, consumption structure, consumption volume and population growth.

2. Decompose the changes in CO_2 emissions from the consumption (final demand) perspective with different consumption categories including government, household, investment, import and export.

3. Propose policy recommendations for policy makers, manufacturers and relevant partners for reducing CO_2 emissions.

The rest of chapter is organized as follows. The methods is discussed in **Section 3.2**. **Section 3.3** shows the dataset used. Results, discussion and policy implications are then mentioned in **Section 3.4**. Finally, conclusions and recommendations for future work are presented in **Section 3.5**.

3.2. Methods

The framework developed to achieve the objectives of the study is illustrated in **Fig. 3.1**:

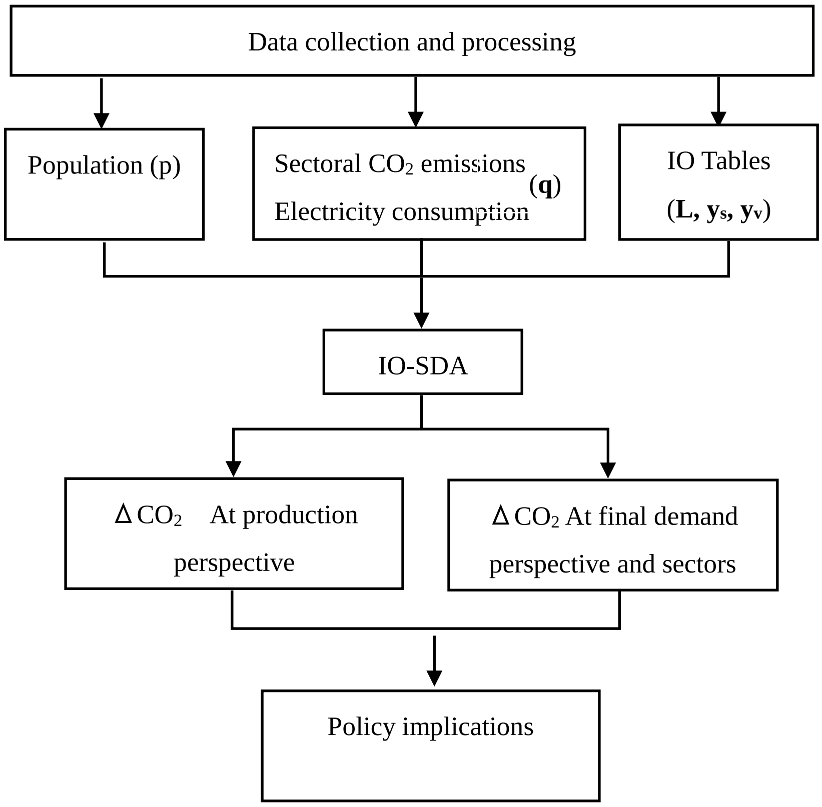


Fig. 3.1 Research framework of IO-SDA

3.2.1. Generic input-output (IO) analysis

The IO framework has been conventionally used to describe the interrelationship between different economic sectors in an economy. Its basic formulation contains a system of linear equations where the total output of the system is equal to the amount consumed internally by the system as intermediate consumption plus the amount used by final customers (or final demand such as household and government consumption) (Leontief 1936, 1986). For an economy with *n* sectors, **x** can denote the *n* x *1* gross domestic output vector, **y** the *n* x *1* final demand vector and **Z** the *n* x *n* input-output matrix. In a matrix notation, the IO model can be written as follows (Miller & Blair 2009):

$$\mathbf{x} = \mathbf{Z}\mathbf{e} + \mathbf{y} \tag{3.1}$$

where $\mathbf{e}$ is column vector with all elements having a value of 1. $\mathbf{A}$ denotes the *n* x *n* technology coefficient matrix with elements a_{ij} ($a_{ij} = Z_{ij}/x_j$) representing the amount of product from the i^{th} sector needed to produce one unit of output from the j^{th} sector. Based on this, **Eq. (3.1)** can be converted as follows:

$$(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \mathbf{x} \tag{3.2}$$

where $\mathbf{I}$ denotes an n x n identity matrix and $(\mathbf{I}-\mathbf{A})^{-1}$ is the n x n Leontief inverse matrix ($\mathbf{L}$) which expresses the requirements for an economy's production.

By adding environmental factors into the economic IO model, Environmentally Extended Input-Output (EIO) analysis may be used to account for environmental interventions of each sector. This method is discussed in detail in Miller and Blair (2009). The EIO model links environmental interventions with sector production and final demand consumption. Suh (2009) employed this model in accounting for CO_2 releases in a supply chain network to conduct sustainability assessment while Tan et al. (2008) and Tan et al. (2009) applied the EIO for optimizing a multi-regional bioethanol supply chain network with the presence of multiple objectives. Wiedmann and Barrett (2011) used EIO to account for GHG generation embodied in goods and services purchased by Central Government. Recently, Nguyen et al. (2018a) applied this model to analyze the inter-relationship between economic sectors and water pollution in Vietnam. In this case, CO_2 emissions contributed by economic sectors in Vietnam are considered the environmental intervention. The amount of CO_2 emission of each sector is assumed to be proportional to the total output of that sector. Let $\mathbf{q}$ represent a *1* x *n* vector which contains the sectoral pollution intensity. The pollution intensity of a sector is equal to the amount of emissions generated by the sector divided by its gross output. Therefore, the quantity of CO_2 emissions can be expressed as follows:

$$\mathbf{Q} = \mathbf{q}\,\mathbf{L}\,\mathbf{y} \tag{3.3}$$

where $\mathbf{Q}$ is the total CO_2 emissions from all sectors.

3.2.2. Input-output structural decomposition analysis (IO-SDA)

IO-SDA is a method frequently applied to quantify the contribution of various factors to the total changes in economic and environmental flows using IO tables (Hoekstra & van den Bergh 2002, Minx et al. 2011, Xu et al. 2011). The IO-SDA framework is utilized in this study to analyze the variations of CO_2 emissions in categorical periods due to 5 factors including production structure ($\mathbf{L}$), pollution intensity ($\mathbf{q}$), population (p), consumption structure ($\mathbf{y_s}$) and consumption volume ($\mathbf{y_v}$).

Production structure is considered as the Leontief inverse matrix ($\mathbf{L}$). The changes in this factor express the changes in input requirement of each sector. Pollution intensity ($\mathbf{q}$) can reflect the improved energy efficiency or technology factor (energy consumption per unit output) when there is less emission per unit of energy output. To differentiate the contributions of various consumption components, final demand, $\mathbf{y}$, is decomposed into three components namely consumption structure, consumption volume and population as follows.

$$\mathbf{y} = \mathbf{y_s}\,\mathbf{y_v}\,\mathrm{p} \tag{3.4}$$

where $\mathbf{y_s}$ is a n x m matrix of consumption structure with m amount of consumption categories (in this study m = 5 (e.g. household, government, investment, export and import)). Assuming that **F** is a n x m matrix of consumption flows, its element, F_{id}, denotes the amount of final demand of category d in the i^{th} sector. Thus, the consumption structure of final demand category d in response to the i^{th} sector is expressed as $y_s^{id} = \frac{F_{id}}{\sum_{i=1}^{n} F_{id}}$; $\mathbf{y_v}$ is a 1 x m vector of consumption volume, its element, $y_v^d = \frac{\sum_{i=1}^{n} F_{id}}{p}$ represents the per capita final demand of category d; and p is a scalar value representing the population. Therefore, **Eq. (3.4)** can be rewritten as:

$$\mathbf{Q} = p\mathbf{q}\ \mathbf{L}\ \mathbf{y_s}\ \mathbf{y_v} \tag{3.5}$$

Over a given time period, any change in CO_2 emissions (ΔQ) in an economy can be indicated by **Eq. (3.6)**, where the five factors including emission intensity, population, production structure, consumption structure and consumption volume completely account for the increase or decrease in CO_2 emissions from the production perspective. Thus, **Eq. (3.5)** can be written as:

$$\Delta Q = \Delta p\mathbf{q}\ \mathbf{L}\ \mathbf{y_s}\ \mathbf{y_v} + p\Delta\mathbf{q}\ \mathbf{L}\ \mathbf{y_s}\ \mathbf{y_v} + p\mathbf{q}\Delta\mathbf{L}\ \mathbf{y_s}\ \mathbf{y_v} + p\mathbf{q}\ \mathbf{L}\ \Delta\mathbf{y_s}\ \mathbf{y_v} + p\mathbf{q}\ \mathbf{L}\ \mathbf{y_s}\ \Delta\mathbf{y_v} \tag{3.6}$$

where $\Delta p, \Delta\mathbf{q}, \Delta\mathbf{L}, \Delta\mathbf{y_s}$ and $\Delta\mathbf{y_v}$ represent the changes of each factor in which each Δ is calculated when all other factors are assumed to be constant. For example, $\Delta\mathbf{y_s}$ is change in consumption structure, and this term ($p\mathbf{q}\mathbf{L}\Delta\mathbf{y_s}\ \mathbf{y_v}$) represents the change of total CO_2 emissions resulting from a change in consumption structure with population, CO_2 emission intensity, production structure and consumption volume staying constant.

In structural decomposition analysis, it is possible to compare various factors related to any point in time within a study period. According to Dietzenbacher and Los (1998), there are plenty of possible solutions of decomposition. If the number of decomposed factors is k, the number of possible decomposition equations is k! (in this case k= 5). Since the number of decision factors are excessively powerful to compute, this problem can be solved using the average of all possible first-order of decompositions for simplification (Koh et al. 2016). This work applies the structural decomposition analysis method proposed by Koh et al. (2016). For further details, see **Appendix B**.

In consideration of IO-SDA for assessing the changes in CO_2 emissions from the final demand perspective, the formulas introduced by Peters (2008) can be applied to allocate the variations in CO_2 emissions to the appropriate final demand category d as follows:

$$\mathbf{Q}_d = \mathbf{q}\ \mathbf{L}\ \mathbf{y_d} \tag{3.7}$$

Based on **Eq. (3.7)**, the changes in CO_2 emissions from the consumption perspective, which includes household consumption, government consumption, investment, export and import, can be achieved. Note that the total changes in CO_2 emissions from consumption (**Eq. 3.7**) is equal to the change from the production perspective (**Eq. 3.6**). It can be understood that the changes from production perspective are obtained by analyzing directly the effect of socio-economic factors on the production of all economic sectors. Meanwhile, final demand perspective allows the analysis of changes in CO_2 emissions based on changes in final consumption. In fact, the impact of these socio-economic factors on the economy will also be reflected in its GDP (total final demand). For example, any change in population, or production structure among others, is reflected in GDP or final demand categories.

3.3. Data collection

The neccesary economic data utilized in this work were obtained from Vietnam IO tables for 2000, 2007 and 2011 which were published in the Vietnamese General Statistical Office (GSO) website (GSO 2003, 2009, 2013). These contained the most recent information available. The 2000 IO table contains 112 sectors while IO tables 2007 and 2011 have 138 sectors. These IO tables were classified and aggregated into 18 main sectors as shown in **Table 3.1**. The classification of sectors was based on the classifications indicated for the IO table from GSO and according to the International Standard Industrial Classification version 3 (UN 2002). Furthermore, these aggregated IO tables of 2007 and 2011 were converted from 2007 and 2011 prices, respectively, into 2000 constant price through the double deflation methods using each sector's producer price index as obtained from the Vietnamese statistical Yearbook (GSO 2007, 2011). The Vietnamese IO data include five categories of final demand – households, government, investment, exports and imports. An example of the structure of the Vietnamese IO tables was shown in Nguyen et al. (2018a).

Table 3.1 Nomenclature of sectors

Sector code	Economic sectors
1	Agriculture, Fishery and Forestry
2	Mining and Quarrying
3	Food, Beverage and Tobacco
4	Textile, Wearing Apparel and Leather Industries
5	Manufacture of Wood and Wood products
6	Manufacture of Paper and Paper Products, Printing and Publishing
7	Manufacture of Industrial Chemicals and petro chemicals
8	Manufacture of Non-metallic Mineral Products
9	Basic Metal Industries
10	Manufacturing of Fabricated Metal Products, Machinery and Equipment
11	Other Manufacturing Industries
12	Electricity, Gas and Water
13	Construction
14	Trade and Repairing Services
15	Transportation and Communication
16	Finance, Real Estate and Business Services
17	Government Services
18	Personal, Community, and Household Services

CO_2 emissions by sector resulting from fuel combustion in Vietnam are obtained from the International Energy Agency (IEA 2016). Since electricity produced by power and heat sectors is mainly used by other sectors, CO_2 generation from electricity should be allocated to all sectors based on their electricity consumption (Hsu and Chou 2000). The data of electricity consumption by sector in Vietnam were obtained from IEA (2017). The sectoral CO_2 emissions for different years are shown in **Fig. 3.2** while the pollution intensity of sectors is given in **Table B.2** in **Appendix B**. The IEA database indicated that Vietnam's energy-related CO_2 emissions resulting from economic activities increased by 108%, from 44,223 thousand tonnes (kt) to 91,969 kt from 2000 to 2007 and increased by 80.8% from 2007 to 2011. In the period 2000 - 2007, Sector 11, Sector 15 and Sector 18 were the highest contributors to total direct CO_2 emissions (**Fig. 3.2**). These sectors are considered as energy-intensive sectors. Meanwhile, other sectors which mainly consist of manufacturing sectors such as Sectors 3-10 contributed insignificantly. In contrast, in 2011, not only energy-intensive sectors (Sector 11, 15 and 18), but also manufacturing sectors such as Sector 8 and Sector 4 have high CO_2 emissions. The considerable increase in emissions in manufacturing sectors in 2011 was due to Vietnam's accession to the World Trade Organization (WTO) since 2007, which has stimulated international trade between Vietnam and other countries (Le 2017). Economic sectors, especially manufacturing sectors, were boosted to strongly develop to meet the demand of international trade.

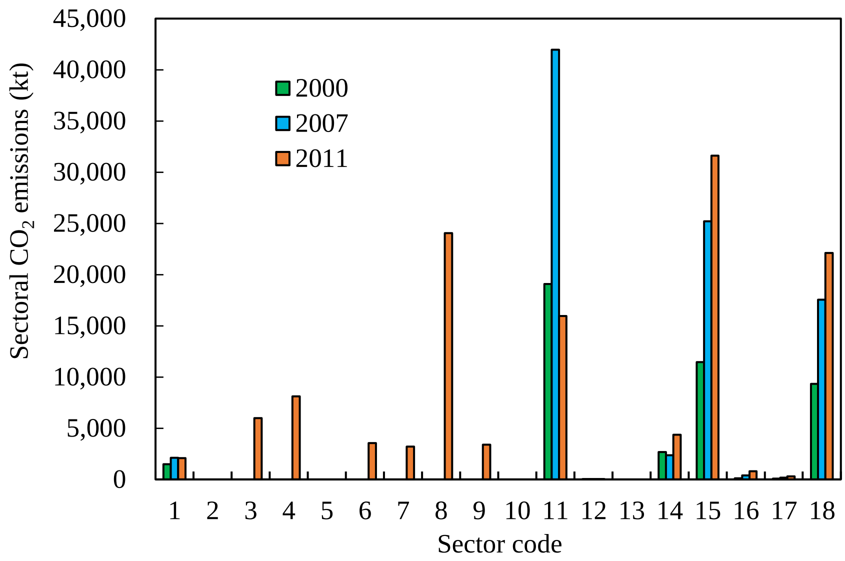


Fig. 3.2 Sectoral CO_2 emissions in 2000, 2007 and 2011 (IEA 2016)

3.4. Results, discussion and policy implications

3.4.1. Analysis from the production perspective

Solving **Eq. (3.6)** using decomposition methods discussed in the **Appendix B** to account for any change in CO_2 emissions from the production perspective, the results indicate that in the 11 years from 2000 to 2011, Vietnam's energy-related CO_2 emissions increased by 188.8% (83,495 kt). The structural decomposition analysis for the year 2000, 2007 and 2011 reveals how different factors contribute to the change in CO_2 emissions (**Fig. 3.3**). In light of this, three factors: (i) steady growth in population (24.1%, 10,660 kt); (ii) consumption structure (100.5%, 44,423 kt); and (iii) consumption volume triggered by per capita consumption (219.4%, 97,029 kt) acted as tremendous accelerators of CO_2 emissions from 2000 until 2011. Meanwhile, the changes in production structure led to a slight decrease in CO_2 emissions (-22.5%, 9,927 kt), and the changes in improved energy efficiency (pollution intensity) resulted in a -132.7% (58,690 kt) decrease. Despite production structure and improved efficiency in production contributing to the decrease in CO_2 emissions, consumption structure, consumption volume and population contributes to the sharp increase of emissions. This led to accelerating tendency of CO_2 emissions in period 2000-2011. These findings are consistent with the analysis of changes in CO_2 emissions and energy consumption from 1986 to 2008 carried out by Nguyen (2012).

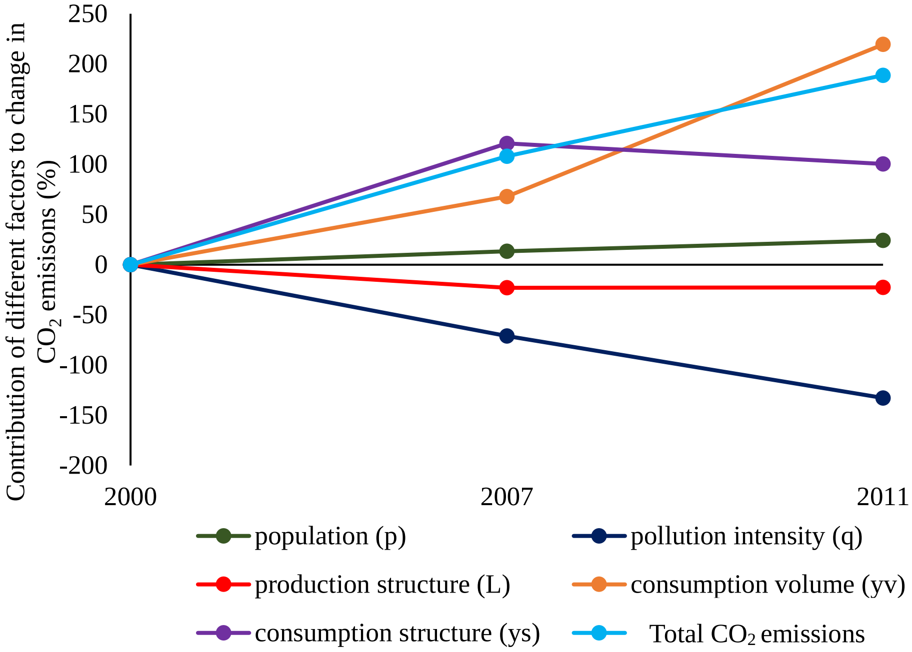


Fig. 3.3 Contributions of driving factors to changes in Vietnamese CO_2 emissions between 2000 and 2011

Fig. 3.4 shows which factors dominated within the shorter periods of 2000 - 2007 and 2007 - 2011. During 2000 - 2007, population growth, increased consumption volume and increased consumption structure increased CO_2 emissions by 202% (89,343 kt) (13.3%, 5,894 kt; 67.8%, 29,982 kt; and 120.9%, 53,467 kt, respectively) (**Fig. 3.4**). However, production structure (-23%, 10,160 kt) and pollution intensity (-71.1%, 31,436 kt) were two factors which offset the incremental change in CO_2 in the same period. Overall, the CO_2 emissions increased significantly by 108% (47,747 kt) between 2000 and 2007. In the period of 2007 - 2011, population (10.8%, 4,766 kt) and consumption volume (151.6%, 67,047 kt) exerted upward influence on CO_2. This was offset by an improvement in efficiency (-61.6%, 27,253 kt) and consumption structure (-20.5%, 9,044 kt), which led to an actual increase in total CO_2 generation of 80.8% (35,748 kt). Meanwhile, changes in production structure remained almost constant.

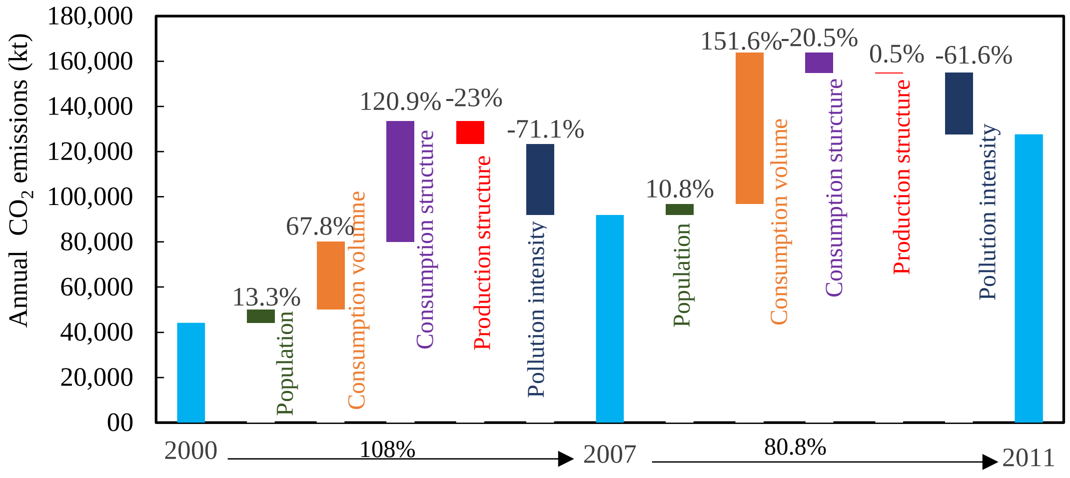


Fig. 3.4 Contributions of different factors to Vietnam's CO_2 emission change based on two periods 2000-2007 and 2007-2011

From these results, it can be stated that notable improvement in efficiency for both periods contributes to offsetting the increment in CO_2. This was reasoned by Dinh and Lin (2014) and Zimmer et al. (2015). First, the production of Vietnam's economic industries mainly depended on imported oil, meanwhile the international oil prices rose significantly in the 21st century. This urged the implementation of advanced energy-saving and/or the improvement of energy-efficient technologies (Andrei 2007). Second, Vietnam shifted from fossil fuel into a fuel mix which increased the consumption of natural gas to partially replace coal. Furthermore, the consumption of biofuel and waste for power generation was also a main contributor to CO_2 emission reduction.

Consumption volume was a main factor contributing to the sharp increase. Meanwhile, the consumption structure varied between two periods. During 2000 - 2007, consumption structure contributes to an increase of 120.9% while this number decreased to -20.5% between 2007 and 2011. The drastic variation as explained by Le (2017) is that Vietnam's accession to WTO since January 2007 strongly affected trade liberalization and improved market access for the new member country's exports and imports (Le 2017). As a result, trade activities, especially import, increased sharply during 2007 - 2011, which significantly contributed to the reduction of CO_2 emissions. Thus, accession to WTO increased emissions in consumption volume due to an increase of production activities and consumptions but they had positive effect on CO2 mitigation in terms of consumption structure due to the sharp decrease of CO_2 in import factor. The next section discusses the allocation of total emissions to different final demand categories.

3.4.2. Analysis from the consumption perspective

Analyzing the changes of CO_2 emissions from the consumption (final demand) perspective could uncover underlying driving factors in the whole supply chain network (Liu et al. 2012, Wang et al.

2013, Peters et al. 2007). In this chapter, **Eq. (3.7)** is used to account for this. The allocation of CO_2 emissions into the different final demand categories is shown in **Table 3.2** and analysis results of economic sectors are given in **Table 3.3** and **Tables B.3** and **B.4** in the **Appendix B**.

Table 3.2 Contribution of different consumption categories to CO_2 emissions (kt)

Categories \ Period	2000-2007	2007-2011
Household	29,756	27,021
Government	3,675	1,069
Investment	-3,033	30,385
Export	23,908	46,665
Import	-8,740	-69,334

Changes in household consumption caused 29,765 kt and 27,021 kt increases in CO_2 emissions during the first and second period, respectively (**Table 3.2**). Changes in household were analyzed by sector during 2000 - 2011 and are shown in **Table 3.3** and **Fig. 3.5**. Meanwhile, the contribution of government to changes in CO_2 was not considerable (**Fig. 3.6**).

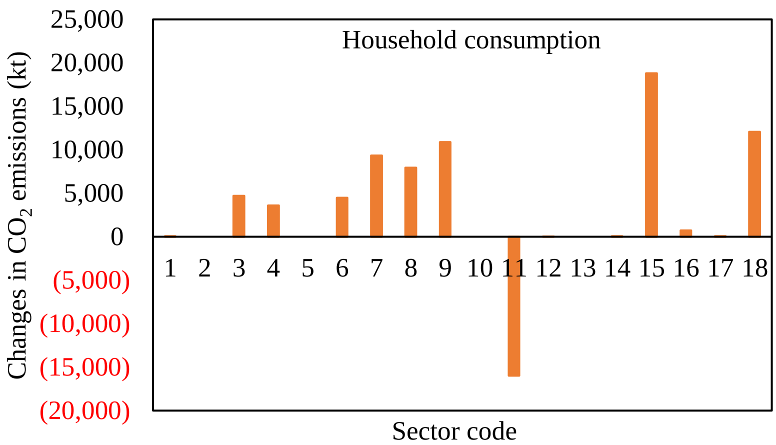


Fig. 3.5 Allocation of CO_2 emission changes (kt) during 2000 - 2011 by household consumption

Table 3.3 Allocation of CO_2 emission changes (kt) during 2000 **-** 2011 by different consumption categories and sectors

Categories / Sector code	**Household**	**Government**	**Investment**	**Export**	**Import**
1	68	6	125	823	-434
2	0	0	0	0	0
3	4,707	34	-2,629	5,614	-1,736
4	3,591	48	-1,503	14,344	-8,373
5	0	0	0	0	0
6	4,474	295	430	4,846	-6,485
7	9,346	340	3,312	12,179	-21,960
8	7,950	325	21,240	13,662	-19,119
9	**10,874**	**257**	**22,115**	**20,440**	**-50,305**
10	0	0	0	0	0
11	**-15,999**	**-1,554**	**-17,529**	**-12,198**	**44,162**
12	11	1	6	13	-17
13	0	0	0	0	0
14	64	-47	-504	1,228	965
15	**18,819**	**704**	**1,920**	**9,796**	**-11,069**
16	729	39	96	265	-442
17	83	145	0	1	-1
18	**12,061**	**4,150**	**273**	**-439**	**-3,260**

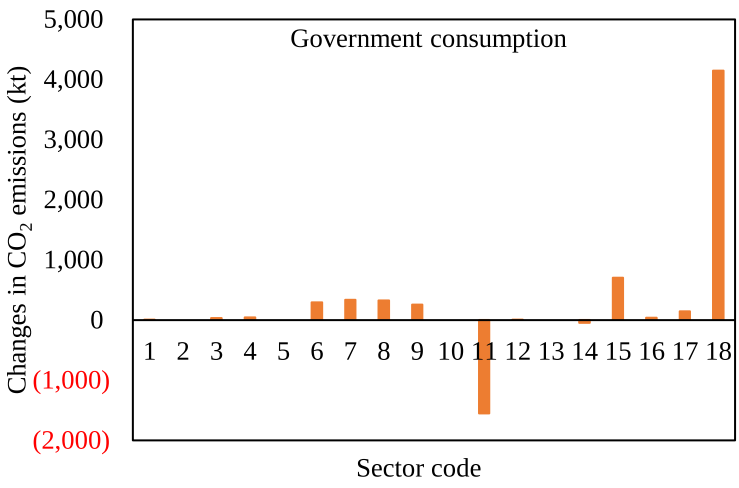


Fig. 3.6 Allocation of CO_2 emission changes (kt) during 2000 - 2011 by government consumption

The changes in investment followed an irregular path for both periods. In the first period, there was a slight decrease in CO_2 emissions from investment, but it sharply increased up to 30,385 kt in the second period. This was explained that there was an increase in foreign direct investment (FDI) during 2006 - 2010 compared to 2001 - 2005 (Ngo et al. 2017) which was mainly used for the expansion of manufacturing production (Dinh and Lin 2014). As a result, CO_2 emissions from manufacturing industries sharply changed during 2006 - 2011 (see **Fig. 3.2**). **Fig. 3.7** indicates the increase and decrease in CO_2 emissions in various sectors resulting from investment. Under which, Sector 8 (manufacture of non-metallic mineral products, 21,240 kt) and Sector 9 (basic metal industry, 22,115 kt) were the main contributors in the increase of CO_2 emissions. In contrast, Sector 11 (Other Manufacturing Industries) was the main sector in the reduction of CO_2 emissions (-17,529 kt). These results are consistent with information mentioned by Dinh and Lin (2014). According to Dinh and Lin (2014), the investment in Sectors 8 and 9 resulted in the increase in emissions because these sectors require intensive-energy for their production. Meanwhile, emissions in Sector 11 reduced because investment was used for both economic growth and environmental protection, (e.g. application of cleaner and more efficient production activities and/or end-of-pipe treatment technologies in factories).

Fig. 3.7 Allocation of CO_2 emission changes (kt) during 2000 - 2011 by investment

Export was also a key driving force of CO_2 emission incremental change during both periods. Changes in export caused a sharp increase from the first period (23,908 kt) to second period (46,665 kt). The analysis by sector is shown in **Fig. 3.8**.

Fig. 3.8 Allocation of CO_2 emission changes (kt) during 2000 - 2011 by export

Import activities were main drivers in CO_2 reduction with -8,740 kt during 2000 - 2007 and -69,334 kt during 2007 - 2011. Since the CO_2 emissions in this chapter was estimated as production-based emissions, the increase in production of domestic products for different purposes such as household, government and export normally causes the increment in pollution for Vietnam, but the increase in the importation of goods and services produced from other countries may help this country avoid emissions. The analysis by sector in terms of import is given in **Fig. 3.9**. From these results, it can be stated that the accession to WTO from 2007 helped improve import and export between Vietnam and other countries. This greatly affected the economic development and environmental pollution in Vietnam from the year of 2007 onwards.

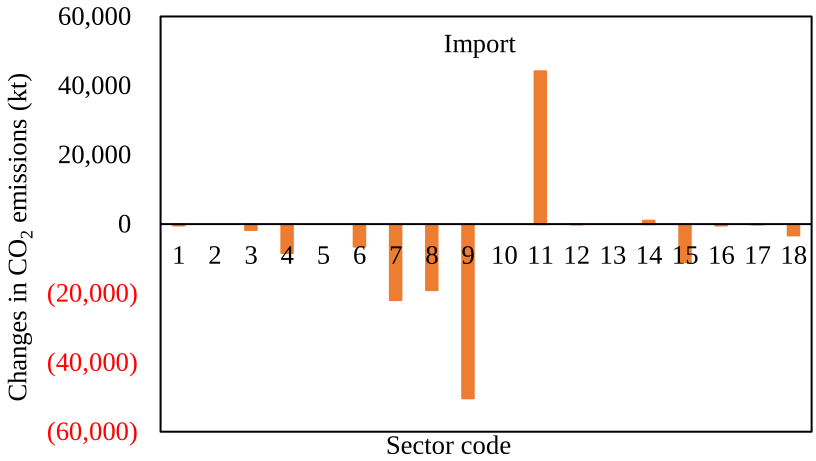


Fig. 3.9 Allocation of CO_2 emission changes (kt) during 2000 - 2011 by import

3.4.3. Policy implications for mitigating CO_2 emissions

As a result of rapid industrialization and modernization, especially after accession to WTO, the Vietnamese economy has positively prospered through the expansion of manufacturing industries and the increase in international trade activities with other countries. These led to increasing energy consumption induced CO_2 emissions. Thus, the appropriate identification of driving factors related to increase in CO_2 emissions is significant in developing policies.

3.4.3.1. From the production perspective

Using the production perspective, the consumption volume, consumption structure and pollution intensity are the main driving forces which influence CO_2 emissions in Vietnam. Meanwhile, population growth, had a small effect on the increase in CO_2 release, but the rapid population growth in the future especially in big cities such as Hanoi and Ho Chi Minh may affect environmental-social-economic development. Thus, implementing the policies to encourage birth rate reduction is of significance for emission reduction. Pollution intensity or technical factor is a strong factor in offsetting CO_2 generation in all other factors considered in this chapter. According to KEPA and GreenID (2014), there is still significant potential for further improving energy use efficiency by varying fuel mix use (i.e., increasing natural gas use and decreasing coal and oil uses), replacement of fossil fuels by clean and renewable energy such as wind energy, solar energy and bio-gas, and carbon capture and sequestration. Furthermore, policies for encouraging continued energy conservation should be given. In addition to technology improvement, strong regulations are required to capture other potentials to mitigate emissions through economic structural adjustment and optimization in both production and consumption sides. In the whole observed time period, Vietnam's CO_2 emissions were 22% lower due to improvement in production structure. These emissions due to production structure can be further lowered through increased resource efficiency such as reducing highly pollutive inputs, recycling products and waste.

3.4.3.2. From the consumption perspective and sectors

From deeply analyzing from the consumption perspective, household, investment, export and import are key driving factors to the changes in CO_2 emissions. The growth of CO_2 emissions relative to household consumption is driven by a combination of increased consumption of urban household and urbanization (DEA, 2017). Therefore, to reduce emissions from household consumption, there is a need to shift structure toward using more environmental friendly products or reducing the use of energy-intensive products (i.e., appliances and electricity).

Investments are important for economic development in Vietnam, but the downside is the increase in emissions from the production of heavy manufacturing such as cement, steel, glass, etc. However, if investments are channeled towards improving the efficiency of technologies or implementing cleaner technologies, Vietnam can further reduce its emissions. These may also stimulate the enterprises toward low-CO_2 production.

International trade including import and export has been an important driving forces for Vietnam's economic development. **Table 3.2** has shown that trade activities may contribute to the decrease in CO_2 emissions by promoting import. However, this may result in high emissions in original countries where products are produced. Thus, to reduce global pollution problem, there is need to import goods from countries that can produce more efficiently. Furthermore, there is a need to optimize trade structures between Vietnam and other countries. Reducing the import of highly-pollutive materials also help reduce emissions for domestic production.

When taking into account CO_2 emissions from various economic sectors, it can be realized that Sector 15 (transportation and communication) and Sector 18 (personal, community, and household services) and the manufacturing sectors (Sector 3-11) are main contributors to CO_2 emissions in Vietnam. To reduce emissions in Sector 18, there is a need to shift economic structure toward using more environmental friendly goods and services or reducing the consumption of energy-intensive products. To decrease emissions in Sector 15 the most logical option for Vietnam is to invest in traffic infrastructure to develop public transportation and reduce private vehicles. Using energy-efficient vehicles to replace traditional ones is also helpful. For manufacturing sectors (Sector 3-11), the best option to reduce pollution is by using cleaner technologies, improving process efficiency and waste treatment systems, and replacing highly pollutive raw materials with less pollutive inputs.

3.5. Conclusions and recommendations

This chapter uses IO-SDA model to analyze underlying driving forces for the changes in energy-based CO_2 emissions in Vietnam during two periods 2000 - 2007 and 2007 - 2011. This model is more useful than traditional SDA methods because it can highlight any change of pollutant resulting from different socio-economic factors at both macro-economic and sectoral levels. This method makes use of available IO tables in 2000, 2007 and 2011 and other socio-economic data to indicate the variation of CO_2 emissions contributed by economic activities for both production perspective (technology, production structure, consumption structure, consumption volume and population growth) and final demand perspective (government, household, investment, import and export). Such analysis is helpful for decision makers, manufacturers and relevant partners to know the structural dynamics of CO_2 generation. These can be used to formulate effective and sustainable emission mitigation strategies and management protocols for short and long-term plans.

The results from the production perspective indicate that the overall energy-related CO_2 emissions in Vietnam from 2000 to 2011 increased by 188.8% (83,495 kt). Consumption structure and consumption volume were the main drivers responsible for this incremental change in CO_2 emissions, while CO_2 pollution intensity and production structure were two main factors which offset this increase. However, population growth had a small effect on the increase in CO_2 generation during this period, but it may have significant effect if population growth rate increased rapidly in the future. From the final demand perspective, household, export and investment are the key drivers responsible for the sharp increase in CO_2 emissions between 2000 and 2011, while import factor contributes to the abatement of CO_2 emissions. Government had inconsiderable effect on the growth in CO_2 emissions. Between these two periods, different factors contributed differently to the increase and decrease in CO_2. Consumption structure has the largest variation with an increase of 120.9% during 2000 - 2007 and a decrease of 20.5% between 2007 and 2011. This was due to the increase in import activities in the second period resulting from the accession to WTO in 2007. In consideration of CO_2 changes by sector, Sector 11 (other manufacturing industries), Sector 15 (transportation and communication) and Sector 18 (personal, community, and household services) were energy-intensive sectors which contributed greatly to the total CO_2 emissions during 2000-2007. In contrast, between 2007 and 2011, besides the energy-intensive sectors mentioned above, manufacturing sectors such as Sector 9 (basic metal industry,), Sector 8 (manufacture of non-metallic mineral products), Sector 7 (manufacture of industrial chemicals) and Sector 4 (textile, wearing apparel and leather industries) also have high CO_2 emissions and strongly impacted the changes in CO_2 emissions in this period. These results suggest that the mitigation of domestic CO_2 emissions in Vietnam can be obtained by CO_2 pollution intensity reduction, structural adjustment and optimization of production and final demand activities. Furthermore, optimizing international trade is greatly significant for the abatement of national and global CO_2 generation.

This research is especially developed for the Vietnam context, but the same methods can be easily adapted for analyzing in other economies using existing IO table and pollution data. Furthermore, these methods can be applied for analyzing the structural changes of any kind of pollutants induced by various economic sectors, once the data are available. The limitation of this study is that it just focuses on CO_2 emissions from energy sectors, while CO_2 emissions from remaining sectors are not considered. Future work can develop a model to evaluate the changes in CO_2 pollution intensity as the industrial and manufacturing sectors apply more advanced treatment and cleaner technology. Furthermore, a model should be developed in the future to see the effect of reduced birth rate in CO_2 emission. In addition, tools for handling data uncertainty can be coupled in this model to result in more robust analysis.

References

Andrei I (Editor) (2007) Reasonability of protocol and kyoto-type targets, climate change policy and economic growth: a way forward to ensure both, Margo Thorning (International Council of Capital Formation) and Andrei Illarionov (Institute of Economics Analysis), 1-30.

Aviso KB, Tan RR, Culaba AB, Cruz JB (2011) Fuzzy input-output model for optimizing eco-industrial supply chains under water footprint constraints. J. Clean. Prod., 19(2-3):187-196.

Cansino JM, Roman R, Ordóñez M (2016) Main drivers of changes in CO2 emissions in the Spanish economy: A structural decomposition analysis. Energy Policy, 89:150-159.

Cansino JM, Sánchez-Braza A, Rodríguez-Arévalo ML (2015) Driving forces of Spain's CO2 emissions: a LMDI decomposition approach. Renew. Sustain. Energy Rev. 48:749–759.

Chen B, Li JS, Zhou SL, Yang Q, Chen GQ (2018) GHG emissions embodied in Macao's internal energy consumption and external trade: Driving forces via decomposition analysis. Renewable and Sustainable Energy Reviews, 82(3):4100-4106. Accessed on 11 November 2017. http://dx.doi.org/10.1016/j.rser.2017.10.063

DEA (Danish Energy Agency) (2017) Vietnam Energy Outlook Report 2017. https://ens.dk/sites/ens.dk/files/Globalcooperation/ Official_docs/Vietnam/vietnam-energy-outlook-report-2017-eng.pdf. Accessed on 10 Jan 2018

Dietzenbacher E, Los B (1998) Structural decomposition techniques: sense and sensitivity. Economic Systems Research, 10(4):307–324.

Dinh and Lin (2014) CO_2 emissions, energy consumption, economic growth and FDI in Vietnam. Managing Global Transitions, 12(3): 219-232.

Fu B, Wu M, Che Y, Wang M, Huang Y, Bai Y (2015) The strategy of a low carbon economy based on the STIRPAT and SD models. Acta Ecol. Sin., 35(4):76-82.

GSO (General Statistical Office) (2003) Input-Output: IO of Vietnam Year 2000. Statistical Publishing House: Hanoi; 142- 246.

GSO (General Statistical Office) (2007) Statistical Yearbook of Vietnam. Statistical Publishing House: Hanoi.

GSO (General Statistical Office) (2009) Input-Output: IO of Vietnam Year 2007. Statistical Publishing House: Hanoi.

GSO (General Statistical Office) (2011) Statistical Yearbook of Vietnam. Statistical Publishing House: Hanoi.

GSO (General Statistical Office) (2013) Input-output: IO of Vietnam year 2011. Statistical Publishing House: Hanoi.

Guan D, Hubacek K, Weber CL, Peters GP, Reiner DM (2008) The drivers of Chinese CO2 emissions from 1980 to 2030. Global Environmental Change, 18(4): 626–634.

Hoekstra R, van den Bergh JCJM (2002) Structural decomposition analysis of physical flows in the economy. Environmental and Resource Economics, 23(3):357–378.

Hsu GJY, Chou FY (2000) Integrated planning for mitigating CO2 emissions in Taiwan: a multiobjective programming approach. Energy Policy, 28(8):519–523.

Huang YH, Wu JH (2013) Analyzing the driving forces behind CO2 emissions and reduction strategies for energy-intensive sectors in Taiwan, 1996–2006. Energy, 57:402–411

IEA (International Energy Agency) (2016) CO2 Emissions from Fuel Combustion, OECD/IEA, Paris. Accessed on 30 May 2017. http://wds.iea.org/wds/pdf/Worldco2_Documentation.pdf

IEA (International Energy Agency) (2017). Accessed on 12 December 2017. http://www.iea.org/Sankey/#?c=VietNam&s=Final consumption

IPCC (Intergovernmental Panel on Climate Change) (2006) IPCC Guidelines for National Greenhouse Gas Inventories.

KEPA and GreenID (Service Center for Development Cooperation & Green Innovation and Development Centre) (2014) Assessment of policies on GHG mitigation in Vietnam, 1–31. Accessed on 10 April 2017. https://www.kepa.fi/tiedostot/final_report_vietnam_1marz2014.pdf

Koh SCL, Ibn-Mohammed T, Acquaye A, Feng K, Reaney IM, Hubacek K, Fujii H, Khatab K (2016) Drivers of U.S. toxicological footprints trajectory 1998–2013. Scientific Report, 6: 39514. DOI: 10.1038/srep39514

Le AT (2017) Effects of WTO accession on Vietnam's trade: The gravity model approach. Publisher: Reprosentralen, University of Oslo. Accessed on 10 January 2018. http://www.duo.uio.no/

Leontief WW (1936) Quantitative input and output relations in the economic systems of the United States. The review of economic and statistics, 18(3):105-125.

Leontief WW (Ed.) (1986) Input-output economics. Oxford University Press.

Liu Z, Geng Y, Lindner S, Zhao H, Fujita T, Guan D (2012) Embodied energy use in China's industrial sectors. Energy Policy, 49:751–758.

Liu Q, Wang Q (2013) Pathways to SO2 emissions reduction in China for 1995–2010: Based on decomposition analysis. Environmental Science & Policy, 33:405-415.

Maryzin VM (2013) Economic modernization in Vietnam from industrialization to innovation stage. Journal of Economics and Business, 29(2): 87-106.

Mavromatidis G, Orehounig K, Richner P, Carmeliet J (2016) A strategy for reducing CO2 emissions from buildings with the Kaya identity e a Swiss energy system analysis and a case study. Energy Policy, 88(C):343-354.

Miller RE, Blair PD (2009) Input-Output Analysis: Foundation and Extensions. Second Ed. Published in the United States of America by Cambridge University Press, New York.

Minx JC, Baiocchi G, Peters GP, Weber CL, Guan D, Hubacek K (2011) A "Carbonizing Dragon": China's fast growing CO2 emissions revisited. Environ. Sci. Technol., 45 (21):9144–9153.

MNRE (Ministry of Natural Resources and Environment) (2014) The initial biennial updated report of Viet Nam to the United Nation Framework Convention on climate change. Viet Nam publishing house of nature resources, environment and cartography. MNRE, Ha Noi, 2014. Accessed on 08 March 2017. http://unfccc.int/resource/docs/natc/vnmbur1.pdf

Ngo HP, Đao HV, Nguyen HT, Dao TTT (2017) Improving quality of foreign direct investment attraction in Vietnam. Int. J. Qual. Innov., 3:7. https://doi.org/10.1186/s40887-017-0016-7

Nguyen ATK (2012) Structural decomposition analysis of CO2 emission variability in Vietnam during the 1986-2008 period. VNU Journal of Science, Economics and Business 28(2):115-123.

Nguyen TTA, Ishihara KN (2006a) Analysis of changing hidden energy flow in Vietnam. Energy Policy, 34:1883–1888.

Nguyen TTA, Ishihara KN (2006b) Energy productivity during the years of Doi Moi. Journal of Applied Input-output Analysis, 11&12.

Nguyen HT, Aviso KB, Kojima N, Tokai A (2018a) Structural analysis of the interrelationship between economic activities and water pollution in Vietnam in the period of 2000 -2011. Clean Techn. Environ. Policy, 20(3):621-638. https://doi.org/10.1007/s10098-018-1492-8

Nguyen HT, Aviso KB, Le DQ, Kojima N, Tokai A (2018b) An Input-output linear programming model for mapping low-carbon scenarios for Vietnam in 2030. Sustainable and Production and Consumption.

Nguyen NT, Ha-Duong M, Sandra G (2009) The clean development mechanism in Vietnam: potential and limitations. Paper accepted to present at the fourth GMSARN International Conference 2009 “Energy Security and Climate Change: Problems & Issues in GMS" to be held from 25-27 November 2009 at Ha Long Bay, Vietnam

Peters GP (2008) From production-based to consumption-based national emission inventories. Ecol. Econ., 65(1):13–23.

Peters GP, Weber CL, Guan D, Hubacek K (2007) China’s growing CO2 emissions: a race between increasing consumption and efficiency gains. Environ. Sci. Technol., 41 (17):5939–5944.

PricewaterhouseCoopers (2017) The world in 2050. Accessed on 21 August 2017. https://www.pwc.com/gx/en/world-2050/assets/pwc-the-world-in-2050-full-report-feb-2017.pdf

Rose A, Chen CY (1991) Source of change in energy use in the US economy, 1972–1982: a structural decomposition analysis. Resour. Energy, 13 (1):1–21.

Rose A, Casler S (1996) Input–output structural decomposition analysis: a critical appraisal. Econ. Syst. Res. 8 (1):33–62.

Shahiduzzaman M, Layton A (2017) Decomposition analysis for assessing the United States 2025 emissions target: How big is the challenge? Renewable and Sustainable Reviews, 67:372-383.

Shrestha RM, Anandarajah G, Liyanage MH (2009) Factors affecting CO2 emission from the power sector of selected countries in Asia and the Pacific. Energy Policy, 37:2375–2384.

Shuai C, Shen L, Jiao L, Wu Y, Tan Y (2017) Identifying key impact factors on carbon emission:

Evidences from panel and time-series data of 125 countries from 1990 to 2011. Applied Energy, 187:310–325.

Štreimikienė D, Balezentis T (2016) Kaya identity for analysis of the main drivers of GHG emissions and feasibility to implement EU “20–20–20” targets in the Baltic States. Renewable and Sustainable Energy Reviews, 58:1108–1113.

Suh S (2009) Handbook of input–output economics in industrial ecology. 2nd Printing, Ecology edn. Springer, Berlin.

The World Bank, 2010 World development report. The World Bank, Washington, DC.

Tan RR, Culaba AB, Aviso KB (2008) A fuzzy linear programming extension of the general matrix-based life cycle model. J. Clean Prod., 16:1358–1367.

Tan RR, Ballacillo JB, Aviso KB, Culaba AB (2009) A fuzzy multi- ple objectives approach to the optimization of bioenergy system footprints. Chem. Eng. Res. Des., 87(9):1162–1170.

UN (United Nations) (2002) International Standard Industrial Classification of All Economic Activities, Rev.3. (ISIC 3). https://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=2. Accessed on 12 June 2016

UNFCCC (United Nations Framework Convention on Climate Change) (1998) Accessed on 30 September 2017. http://unfccc.int/resource/docs/convkp/kpeng.pdf

United Nations Framework Convention on Climate Change (UNFCC) (2015a) Adoption of the Paris Agreement, 1-32. Accessed on 08 Feb 2018. https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

United Nations Framework Convention on Climate Change (UNFCC) (2015b) Intended Nationally Determined Contribution of Vietnam, 1-11. Accessed on 08 Feb 2018. http://www4.unfccc.int/ndcregistry/PublishedDocuments/Viet%20Nam%20First/VIETNAM'S%20INDC.pdf

Wang C, Wang F (2015) Structural decomposition analysis of carbon emissions and policy recommendations for energy sustainability in Xinjiang. Sustainability, 7:7548-7567. doi:10.3390/su7067548

Wang H, Ang BG, Bin Su (2017) A multi-region structural decomposition analysis of global CO2 emission intensity. Ecol. Econ., 142:163-176.

Wang X, Huang K, Yu Y, Hu T, Xu Y (2016) An input–output structural decomposition analysis of changes in sectoral water footprint in China. Ecological Indicators, 69:26–34. Accessed on 11 November 2017. http://dx.doi.org/10.1016/j.ecolind.2016.03.029

Wang Z, Huang K, Yang S, Yu Y (2013) An input–output approach to evaluate the water footprint and virtual water trade of Beijing, China. J. Clean. Prod., 42 (3):172–179.

Wang Z, Yin F, Zhang Y, Zhang X (2012) An empirical research on the influencing factors of regional CO2 emissions: evidence from Beijing city, China. Appl. Energy, 100:277-284.

Wei J, Huang K, Yang S, Li Y, Hu T, Zhang Y (2017) Driving forces analysis of energy-related carbon dioxide (CO_2) emissions in Beijing: an input-output structural decomposition analysis. Journal of Cleaner Production, 163:58-68.

Wiedmann T and Barrett J (2011) A greenhouse gas footprint analysis of UK Central Government, 1990–2008. Environmental Science & Policy, 14(8):1041-1051.

Xie SC (2014) The driving forces of China's energy use from 1992 to 2010: An empirical study of input–output and structural decomposition analysis. Energy Policy, 73:401–415.

Xu Y, Dietzenbacher E (2014) A structural decomposition analysis of the emissions embodied in trade. Ecol. Econ., 101:10–20.

Xu M, Li R, Crittenden JC, Chen Y (2011) CO_2 emissions embodied in China's exports from 2002 to 2008: a structural decomposition analysis. Energy Policy, 39:7381–7388.

Zimmer A, Jakob M, Steckel JC (2015) What motivates Vietnam to strive for a low-carbon economy? — On the drivers of climate policy in a developing country. Energy for Sustainable Development, 24:19–32.

Chapter 4 An input-output linear programming model for assessing climate policy considering economic growth

In this chapter, the EIO model from chapter 2 is developed to identify the relationship between economic sectors and GHG emissions and analyze sector linkages in terms of economic performance and GHG factors. Obtained results will indicate priority sectors, which have high impacts relative to both economy and GHG emissions. IO-LP model is then used to assess climate policy by minimizing the total GHG emissions in consideration of different economic growth rates. Different scenarios including the consideration of different economic growth, adjustment of economic structure and improvement of technical factors for these priority sectors are given to identify the potential of GHG intensity reduction in Vietnam. Furthermore, human health impact is also assessed using DALY indicator. This indicator is used to evaluate the efficiency of climate policy implementation. Results of this chapter contribute to give *impact* (human health) and *response* (assessment of climate policy) components of modified DPSIR model which needs to propose the strategies for comprehensive economic-environmental system management.

4.1. Introduction

The impact of environment resulting from economic production activities has caused serious global problems (i.e., global warming). Increasing atmospheric concentrations of greenhouse gas (GHG) emissions from the continued consumption of fossil fuels remains a main contributor to climate change, which is a global threat to people's health and ecosystems (de Schryver et al. 2009). In order to reduce climate change, the 1992 UN Framework Convention on Climate Change (UNFCCC) developed the Kyoto Protocol, which required member countries to lower GHG emissions including CO_2, CH_4 and N_2O (UNFCCC 1998). However, the deployment of climate policies to meet these targets may have adverse effects on social welfare and economic growth. These effects are different from country to country depending upon the state of economic structure and economic growth (Fan et al. 2010).

Vietnam is now in the last process of rapid industrialization and going to pass an innovation period of growth (Maryzin 2013). PricewaterhouseCoopers (2017) reported that the Vietnam's economy has positively thrived with annual economic growth rates reaching more than 5%. According to MNRE (2014), this rapid economic growth has been accompanied by increased energy consumption and have resulted in corresponding increases through GHG release from energy sectors. Nguyen et al. (2009) reported that the GHG generation from energy combustion is projected to go up tremendously by 14% per year, reaching approximately 400 million tonnes of CO_2 (Mt CO_2) by 2030. Furthermore, in addition to the energy sectors, the agriculture sectors, industrial sectors and waste treatment also contribute to the large amounts of GHG emissions (MNRE 2014). As a non-annex I country under Kyoto Protocol, Vietnam is not commanded to mitigate GHG generation. However, the country has ratified an agreement to make efforts to mitigate GHG amount from agriculture, energy, industry and transportation sectors

(KEPA and GreenID 2014).

In response to this, the Vietnamese Government paid great attention to GHG control with a target which required to reduce GHG intensity by 8-10% lower than the 2010 level by 2020, according to Decision 1393 (VNGGS 2012). There are several measures proposed to reduce GHG intensity including adjustment of economic structure or application of low-carbon technologies (KEPA and GreenID 2014). However, the implementation of measures to reduce GHG emissions may have constraining impacts on Vietnam's economy (KEPA and GreenID, 2014), especially if sectors having the most economic productivity are also the most polluting. Hence, it is particularly relevant for the government, manufactures and decision-makers to assess how the implementation of pollution mitigation policies influence the economic development (Oliveira et al. 2016). The best way to assess the economic and environmental impacts is to apply input-output (IO) analysis proposed by Leontief (1936, 1970). The IO analysis provides a framework for capturing the interrelationship among various sectors of an economy or a region. This is done by considering the product from each economic sector both as commodities for final consumption and as raw material in the production of goods in the same or in other sectors (Miller and Blair 2009, Tan et al. 2017). The IO model can be extended to take into account other aspects of this economic system. For instance, Hoa et al. (2016) used the inoperability IO model (IIM) proposed by Haimes and Jiang (2001) and the vulnerable index given by Yu et al. (2014) to develop a multi-criteria model for disaster vulnerability evaluation due to the implementation of a biofuel policy. The extension of IO framework which captures environmental influences has been used for measuring environmental protection in China's industries (Fan et al. 2016); and in developing a tool for simultaneous management of production activities and waste resulting from the construction industry (Golzarpoor et al. 2017). The environmental IO approach is also considered a useful tool in measuring structural interdependence of an economy and in identifying key sectors in terms of both monetary and environmental performance through forward and backward inter-sectoral linkages (Lenzen et al. 2003; Piaggio et al. 2012). Shmeleve (2013) then used these economic and environmental linkage coefficients to trade-offs between economic growth and environmental protection. Recently, Nguyen et al. (2018) applied the environmental IO model for evaluating the trend and impact of water pollution in Vietnam within a time series. In addition, Nguyen et al. (2018) also measured the inter-sectoral linkages to indicate the role of sectors as either key polluting sectors, polluting pushers/producers, or polluting pullers/consumers, in terms of their contribution to water pollution.

The value of IO model is further strengthened when it is integrated with linear programming (LP), it is called IO-LP (Vogstad 2009). A recent review work of the IO-LP indicates the strong point of this integrated approach comparing to the conventional IO framework (Oliveira et al. 2016). The IO-LP can identify the suitable productivity of sectors to seek optimum solutions for a desired objective function (i.e., maximize gross domestic product, GDP) while satisfying the balance of sectoral activity as defined by the

IO model. Furthermore, IO-LP may provide a more comprehensive assessment of efficient production probabilities and economic impacts of potential regulations, which allows to study trade-offs among conflicting objectives (Oliveira et al. 2016). For example, the IO-LP has been applied for quantifying the macro-economic costs of CO_2 mitigation in China's economy (Fan et al. 2010), and in evaluating the economic, energy and environment (E3) trade-offs in Brazil's economy (de Carvalho et al. 2016). This model was also used to optimize GDO in the Greek economy in consideration of integrated impacts of solid waste and other pollutants (Hristu-Varsakelis et al. 2012). Recently, Cayamanda et al (2017) modified the IO-LP model into a fractional programing IO model indicating the potential CO_2 intensity reductions for the Philippines' economy.

In general, these previous studies (i.e., Oliveira et al. 2016, de Carvalho et al. 2016 and among others) were successful in dealing with multi-objective problems regarding detailed economic-environmental concerns for each country. They, however, failed to highlight the prioritization of sectors in both terms of economic and environmental performance. The assessment of the environmental impact on an economic system, which focuses on priority sectors having higher impacts on both economy and environment, may help avoid the economic losses from low-polluting sectors. It is because once the ranking of sectors in consideration of environmental and economic factors is known, the economic performance will be adjusted in the direction which prioritizes the growth of low-polluting sectors and limits the production of high-polluting sectors to some extents. Therefore, the prioritization of sectors is important for trade-off economic-environmental objectives. However, this has not been figured out in these previous studies of multi-objective optimization model. Another limitation of these previous works is that the impacts of human health and the ecosystem due to climate change resulting from different environmental pollutants have not been involved. According to Foster et al. (2007), pollutant emissions can be translated into environmental endpoint indicators such as Disability Adjusted Life Years (DALY) for measuring impact on human health damage (Hofstetter 1998) and the loss of species diversity for evaluating the damage of the ecosystem (Kollner 1999).

In Vietnam, studies on analyzing the potentials of reducing environmental pollutants in consideration of desired economic growth at the sectoral level, evaluating human health impact, and analyzing inter-sectoral linkages in consideration of pollutant factors have not been done comprehensively. To supplement these research gaps, this context first uses IO analysis to measure the structural interdependence between sectors of Vietnamese economy considering both economic and environmental flows. The priority sectors which have higher impact on economic and GHG emissions are indicated. An IO-LP optimization model is then developed to minimize the total GHG emissions. From the solution of optimization model, maximum reduction of GHG intensity focusing on these priority sectors in the trajectories to 2020 is estimated. This is a new finding of this study. In addition, this study extends the model to account for GHG impact on human health using DALY indicator. Different scenarios based on economic growth targets and given climate policies are considered to compare the business as usual (BAU) scenario. This framework uses 18-sector IO table and GHG emission data in 2011 as necessary data which serve as the baseline to compute for the growth trajectories to 2020. The rest of the chapter is organized as follows. The methods are explained in **Section 4.2**. **Section 4.3** mentions data collection; while, the results and discussions are presented in **Section 4.4**. And, finally, the conclusions and recommendations for future work are discussed.

4.2. Methods

The framework developed to achieve the objectives of study is illustrated in **Fig. 4.1**:

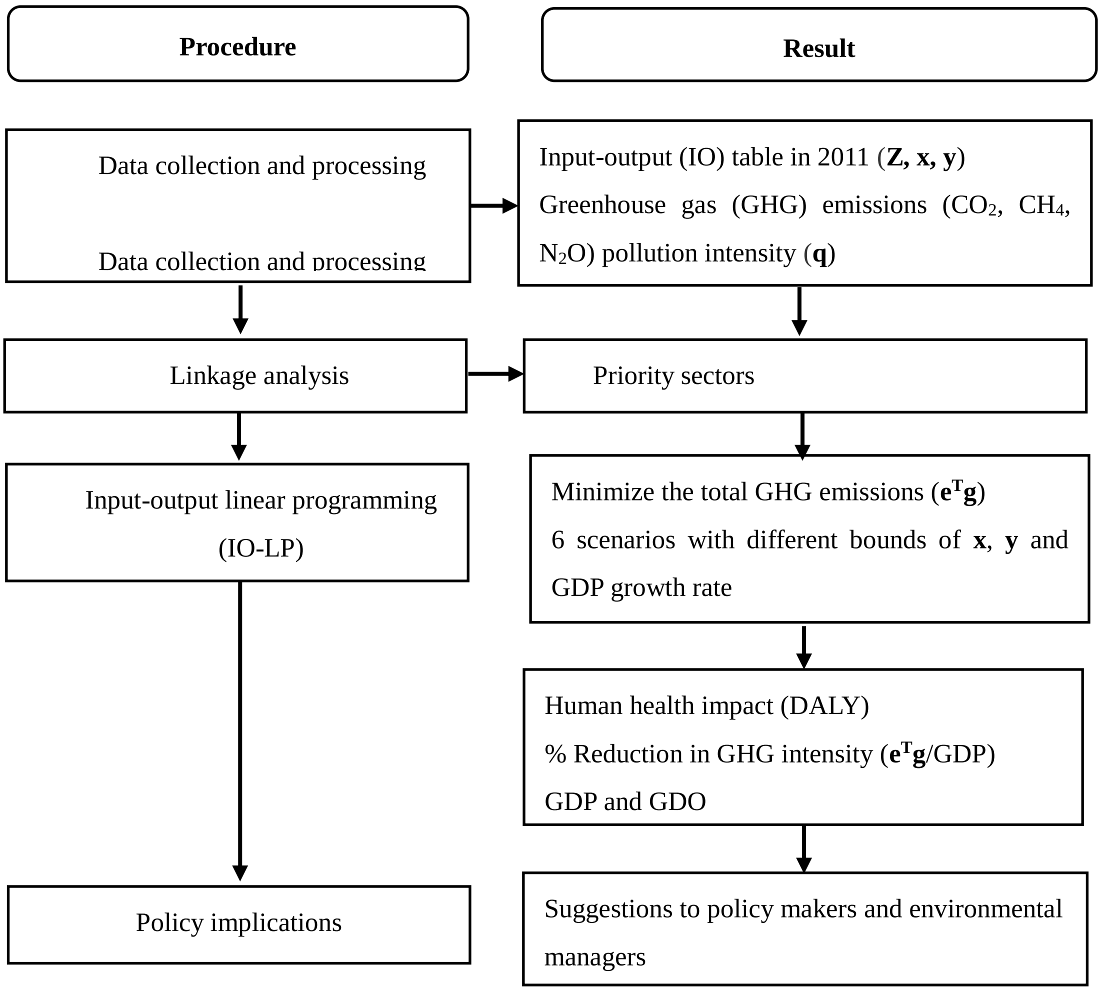


Fig. 4.1 Research framework of IO-LP model

4.2.1. Generic input-output (IO) analysis

The IO framework has been conventionally applied to describe the relationship among various economic sectors in an economy or a region. Basically, it consists of a system of linear equations where total GDO is equal to intermediate demand, which is consumed internally by this system, plus the amount used by final customers (final demand) (Leontief 1985). A more complete discussion of IO analysis can be found in Miller and Blair (2009), while a brief explanation can be obtained from Tan et al. (2017). For an economy with *n* sectors, the parameter **x** represent the *n* x *1* GDO vector, **y** is the *n* x *1* vector for final demand and **Z** is the *n* x *n* matrix for IO transaction. Note that the total final demand is equal to the gross domestic product (GDP) of this economy. In a matrix notion, the IO framework can be stated as (Miller and Blair 2009):

$$\mathbf{x} = \mathbf{Ze} + \mathbf{y} \tag{4.1}$$

where $\mathbf{e} = [1, 1, \ldots, 1]^T$ is the *n* x *1* vector with elements of value 1; **A** denotes the *n* x *n* technology coefficient matrix with elements a_{ij} ($a_{ij} = Z_{ij}/x_j$) representing the amount of product from the i^{th} sector required to make one unit of GDO from the j^{th} sector. Relying on this, **Eq. (4.1)** can be written again as follows:

$$\mathbf{x} = \mathbf{Ax} + \mathbf{y} \tag{4.2a}$$

Consequently, **Eq. (4.2a)** is equivalent to **Eq. (4.2b)**

$$(\mathbf{I} - \mathbf{A})\mathbf{x} = \mathbf{y} \tag{4.2b}$$

where **I** denote the *n* x *n* identity matrix.

4.2.2. Environmental impact

The extension of IO model which accounts for the environmental intervention associated with each sector is mentioned in Miller and Blair (2009). Given that there are *m* pollutants considered (in our case *m* = 3 which includes CO_2, CH_4 and N_2O), the amount of environmental intervention of each pollutant in response to a sector is proportional to the sector size (i.e., GDO). Let **q** represent the *m* x *n* pollution intensity matrix, its elements, q_{kj}, is defined as the amount of pollutant *k* emitted by the j^{th} sector so that the *m* x *1* total intervention vector, **g**, can be expressed as:

$$\mathbf{g} = \mathbf{qx} \tag{4.3}$$

4.2.3. Disability adjusted life years (DALY)

According to McMichael et al. (2003), the GHG emissions which contribute towards climate change, further cause an increase in different diseases (i.e., diarrhea, malaria and heat stress). This decreases peoples' longevity or healthy life years. The assessment of the impact of GHG emissions can be carried out at mid-point and end-point. At mid-point, GHG emissions are evaluated based on infra-red forcing indicator or global warming potential (GWP), while at the end-point, the effects of

GHG emissions are translated into damage indicators. The most common end-point indicator for human damage is put in terms of Disability Adjusted Life Year (DALY). DALY is defined as years of life lost to early death and years of life with disability due to loss of function (Murray and Lopez 1996). The characterization factors of pollutants for quantifying DALY have been estimated for many kinds of diseases, including non-communicable diseases, vector-borne diseases, and various cancer types (Murray and Lopez 1996). There were several methods to obtain these characterization factors including the Eco-indicator 99 methodology (Goedkoop and Spriensma 2001) quantifying human health, Environmental Priority System (EPS) accounting for impacts on both human health and ecosystem damages (Steen 1999), and life cycle assessment (LCA) methods capturing human health damage (Goedkoop et al. 2009). De schryver et al. (2009) developed new characterization factors for 63 GHG pollutants affecting on both human and terrestrial ecosystems. This research used the characterization factors (DALY per ktonne of emissions) obtained from de schryver et al. (2009) to assess the impact of GHG emissions emitted from each economic activity. The total DALY expressed in number of lost years is given by **Eq. (4.4)**:

$$\mathrm{DALY} = \mathbf{cg} \tag{4.4}$$

where **c** is the 1 x m characterization factor vector corresponding to m pollutants.

4.2.4. Forward and backward linkages

The assessment of inter-sectoral linkages and identification of key sectors using IO analysis have been performed by many researchers (Rasmussen 1956; Dietzenbacher et al. 2005). These authors used Gosh inverse (Gosh 1958) or Leontief inverse to measure the linkages between sectoral monetary transactions. The approach was then developed to identify the key sectors and linkages when environmental impacts resulting from economic sectors were taken into account using the IO model (Lenzen et al. 2003; Nguyen et al. 2018). These key sectors may cause high environmental impact to other sectors, since economic sectors are connected to all other economic sectors by virtue of its supply chain network (Leontief and Ford 1972). Shmeles (2013) stated that sectors having a forward linkage coefficient greater than one tend to create a greater than average effect on downstream sectors in the supply chain. Meanwhile, sectors having a backward linkage coefficient greater than one tend to have a higher than average effect on upstream sectors in the supply chain. Key sectors are those having both forward linkage and backward linkage coefficients greater than one.

Lenzen et al. (2003) indicated that priority sectors from linkage analysis in terms of environmental impacts are different from the ranking achieved from purely monetary terms. Evaluating sector linkages, while accounting for both economic and environmental impacts, provides a better perspective for sustainable development. These authors computed forward and backward linkage coefficients for both sides for two scenarios including weighting linkage coefficients with final demand and value added, and vice versa (unweighting). The comparison of unweighted and weighted results was then performed and identified that the later one has more advantage to assess the economic and environmental impacts among sectors. Therefore, this paper uses a generalized framework introduced by Lenzen et al. (2003) to obtain linkage coefficients, then weighting them with final demand and value added to identify key sectors.

4.2.5. Optimization problem

The implementation of climate policies which assists to reduce GHG generation will have an impact in the growth of some economic sectors because of the need to adjust the economic structure or due to limitations of the productivity of carbon-intensive sectors. This can interfere with an economy's macro-economic development. The contradiction between economic growth and GHG emission reduction needs to be balanced by decision makers. In the work, IO-LP is used to study the relationship between the Vietnam's continued economic development and GHG emission reduction resulting from the readjustment of economic structure or the implementation of low-carbon measures.

The optimization problem is set up to seek the minimization of total GHG emissions in consideration of Vietnam's different GDP growth rates, and subject to the bound of sectoral final demand. Furthermore, this model allows economic sectors to obtain different levels of productivity. The following is a notation form of objective function:

$$\text{Min } \mathbf{e^T g} \tag{4.5}$$

where $\mathbf{e^T}$ is the *1* x *m* vector with elements of value 1.

This objective function is subject to economic, environmental constraints and health impact, which are expressed in Eq. **(4.2b)**, **Eq. (4.3)**, and **Eq. (4.4)**, respectively.

$$\text{Production bound: } \mathbf{x_L} \leq \mathbf{x} \leq \mathbf{x_u} \tag{4.6}$$

where $\mathbf{x_L}, \mathbf{x_u}$ are the *n* x *1* column vectors containing the lower and upper limits on GDO. In every sector GDO must be non-negative.

$$\text{Final demand bound: } \mathbf{y_L} \leq \mathbf{y} \leq \mathbf{y_u} \tag{4.7}$$

where $\mathbf{y_L}, \mathbf{y_u}$ are the *n* x *1* column vectors for the lower and upper limits of final demand.

The bounds in sector size (GDO) and in sectoral final demand given in **Eq. (4.6)** and **Eq. (4.7)** is placed to avoid solutions, which push the production of some sectors to unfeasible levels, ensuring the economic growth target.

4.3. Data collection

This section contains the empirical data used to illustrate our model. The data consists of: (i) economic data including the Vietnamese IO table, and (ii) air pollution including CO_2, CH_4 and N_2O.

4.3.1. IO table

The newest IO table for the Vietnamese economy was from the year 2011, which was obtained from the Vietnamese General Statistical Office (GSO) website (GSO 2013). This IO table has 138 rows and columns with four value-added rows and six final consumption columns. The framework of the year of 2011 IO table is detailed in Nguyen et al. (2018). The original IO table is aggregated and categorized into 18 economic sectors using established IO techniques (Miller and Blair 2009). This is more convenient for accounting environmental emissions. This classification of sectors is compatible with that given in the 2011 IO table from GSO (2013) and the classification found in the International Standard Industrial Classification version 3 (ISIC 3) (UN 2002). The nomenclature of the 18 economic sectors, sectoral GDO in million Vietnamese dongs (Million VND) in 2011 and the percentage of GDO contribution from each sector, are shown in **Table 4.1** while the numerical values of **A** matrix are presented in **Table C.1** in **Appendix C**. **Table 4.1** shows that sectors, which contribute to the largest amount of total GDO are Sector 1 (agriculture, fishery and forestry) accounting for 13.4%, Sector 10 (manufacturing of fabricated metal products, machinery and equipment) with 12.3% and Sector 3 (food, beverage and tobacco) with 11.6%. Besides GDO, the aggregated IO provides the IO matrix **Z** and final demand vector **y,** which are needed for the calculation and assessment of environmental-economic impact.

Table 4.1 Nomenclature of sectors, GDO, percentage of GDO and pollution intensity of GHG emissions

Sector number	Economic sector	GDO (x, trillion VND)	% GDO	Pollution intensity of GHG emissions (q, kg CO_2e/million VND)		
				CO_2	CH_4	N_2O
1	Agriculture, Fishery and Forestry	1,029	13.4	2.91813	81.34052	42.76569
2	Mining and Quarrying	339	4.4	5.77364	61.66947	0.01437
3	Food, Beverage and Tobacco	891	11.6	14.88240	1.51200	0.07004
4	Textile, Wearing Apparel and Leather Industries	479	6.2	25.90904	0.02610	0.07004
5	Manufacture of Wood and Wood products	55	0.7	8.37145	0.02610	0.07004
6	Manufacture of Paper and Paper Products, Printing and Publishing	98	1.3	26.80138	10.08224	0.07004
7	Manufacture of Industrial Chemicals	221	2.9	16.96586	0.02955	0.07004
8	Manufacture of Non-metallic Mineral Products	200	2.6	254.66759	0.02610	0.07004
9	Basic Metal Industries	157	2	22.00112	0.04792	0.07004
10	Manufacturing of Fabricated Metal Products, Machinery and Equipment	945	12.3	8.37145	0.02610	0.07004
11	Other Manufacturing Industries	474	6.2	28.79517	0.02723	0.07004
12	Electricity, Gas and Water	175	2.3	9.47642	0.00343	0.02348
13	Construction	684	8.9	0.00000	2.44716	0.04930
14	Trade and Repairing Services	615	8	10.05966	2.44270	0.03019
15	Transportation and Communication	543	7.1	71.16232	2.66868	0.20523
16	Finance, Real Estate and Business Services	401	5.2	3.38932	2.42531	0.00840
17	Government Services	146	1.9	3.38932	2.42531	0.00840
18	Personal, Community, and Household Services	244	3.2	111.99322	37.68895	9.41169

4.3.2. Pollution load and correlation process

The data for annual CO_2 emissions from fuel combustion in Vietnam are achieved from the International Energy Agency (IEA 2016). In this database, the total CO_2 emissions were classified into 50 different sectors and categories based on ISIC 3 (UN 2002) (excluding electricity generation), which is compatible with the classification of sectors in IO table. Thus, sectors from IEA were easily relocated and aggregated to be consistent with 18 sectors in aggregated IO table, which was mentioned above. However, the data of CO_2 emissions resulting from electricity generation were obtained from power and heat sectors, which were mainly used by other sectors. Hence, CO_2 emissions from electricity should be allocated to all other sectors based on their electricity consumption (Hsu and Chou 2000). The data of electricity consumption by sector in Vietnam were obtained from IEA (2017). Based on these data, the data of CO_2 emissions for 18 economic sectors in 2011 are obtained.

The data of other air emissions were reported by the Vietnamese Ministry of Natural Resources and Environment (MNRE 2014) in fulfillment of the UNFCCC obligation. European Environment Agency indicates that there are three main issues on air pollution. These include GHGs, which promote global warming, pollutants, which induce acidification (ACID), and those, which have tropospheric ozone forming potential (TOFP). However, the analysis employed by Hristu-Varsakelis et al. (2010) has highlighted that the effect of the last two impacts were much smaller than that of GHG. For this reason, only GHG emissions particularly CO_2, CH_4 and N_2O, estimated in million tonnes of CO_2 equivalents (Mt CO_2e), is considered in this work. MNRE used intergovernmental panel on climate change (IPCC) methodology for GHG inventory (IPPC 2006). This IPPC methodology includes the QA/QC and verification activities, which contribute to the objectives of good practice in inventory processing, namely to consistency, credibility, applicability and completeness of national greenhouse gas inventories. Furthermore, the classification of sectors in IPCC is also compatible with the classification of IO table because both of these sectoral classifications are based on ISIC 3 (IPCC 2006). Therefore, it is easy to combine sectors from MNRE to be consistent with sectors in aggregated IO table. However, in Vietnam, the data of GHG emission inventory are available for the year of 1994, 2000 and 2010. Therefore, we took data of total pollution load of CH_4 and N_2O emissions of 18 economic sectors in the year 2010 from MNRE (2014) to compute CH_4 and N_2O pollution intensities of sector in 2010 by dividing this pollution load by sectoral GDO data in 2010 (GSO 2011). Assuming that there is no change in technology factor of economic activities between 2010 and 2011, therefore the pollution intensities of 18 sectors in 2010 and 2011 are constant. **Table 4.1** shows the pollution intensity of each GHG pollutant in the year 2011, while the GHG emissions in 2011 are shown in **Fig. 4.2**. The total GHG emissions in 2011 is 357 Mt CO_2e, in which 188 Mt CO_2e is contributed by CO_2 emissions. Three sectors, Sector 8 (manufacturing of non-metallic mineral products), Sector 15 (transport and communication) and Sector 18 (personal, community, and household services) are together responsible for 62.25% of the CO_2 emissions; 27.13% of these emissions comes from Sector 8 (manufacturing of non-metallic mineral products) and 20.58% of CO_2 emissions corresponds to the Sector 15 (transport and communication). Sector 2 (mining and quarrying) is responsible for 17.12% of CH_4 emissions in 2011, while Sector 1 (agriculture, fishery and forestry) is responsible for 68.52% of the CH_4 emissions. The same sector is the main emitter of N_2O emissions accounting for 94.15% of total N_2O emissions.

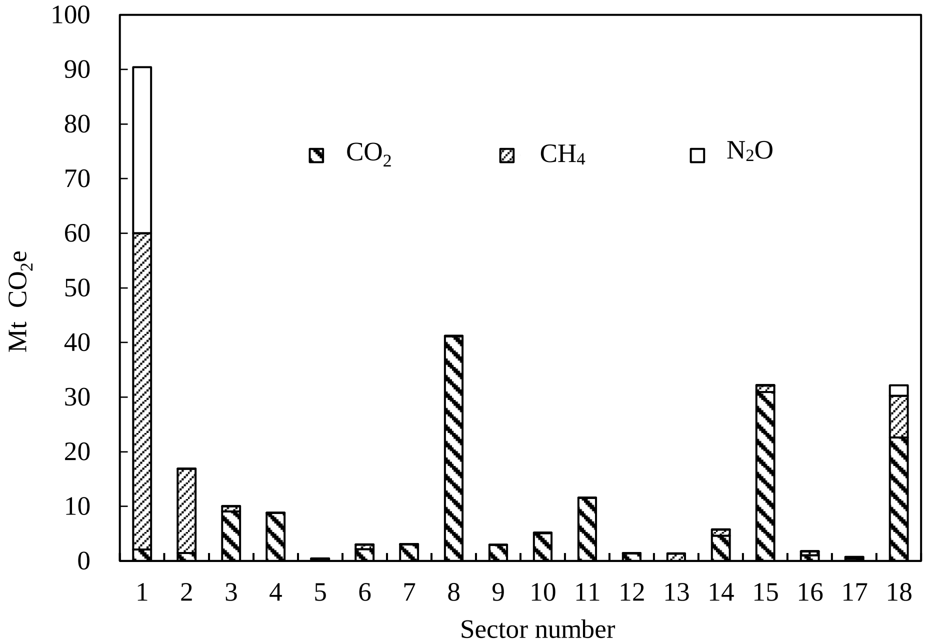


Fig. 4.2 GHG emissions of sectors (Source: IEA 2016, MNRE 2014)

4.3.3. DALY

To quantify the effect of each type of GHG emission on people's health, the characterization factors for DALY should be known. In this paper, the characterization factors for human damage due to climate change corresponding to CO_2, CH_4 and N_2O for hierarchical perspective were obtained from de Schryver et al. (2008) and expressed in DALY/ktonne units (DALY per thousand tonnes of pollutant). The hierarchical perspective coincides with the point of view that effects can be avoided with appropriate management, and that the selection in this model is relied on the level of scientific consensus (Goedkoop and Spriensma 2001). Thus, data based on this perspective are considered as standard to assess people health damage and ecosystem damage. The global warming potentials (GWP) (MNRE 2104) are used to convert the amount of each GHG emitted into CO_2 amount which results in an equivalent effect to that of the actual gas emitted. **Table 4.2** shows the characterization factors of pollutants and GWP. The generation of 1 ktonnes of CH_4 for example, has the same GWP as 21 ktonnes of CO_2e. Based on the data of pollution intensity of each pollutant for each sector mentioned above, the DALY values of each sector corresponding to each pollutant, which were shown in **Fig. 4.3**, are almost ratio with emissions of that pollutant in **Fig. 4.2**. The calculation indicates that the total DALY induced by total GHG emissions in 2011 is 89,768 lost years, in which Sector 1 causes the highest impact on human health with 32,697 lost years. Sector 8 ranks 2 in terms of DALY with 12,991 lost years, followed by Sector 15 with 10,230 lost years and Sector 18 with 9,784 lost years.

Table 4.2 Characterization factors of greenhouse gas emissions (Sources: de Schryver et al. 2008)

Pollutants	(DALY/ktonnes)	GWP
CO_2	0.255	1
CH_4	5.04	21
N_2O	83.3	310

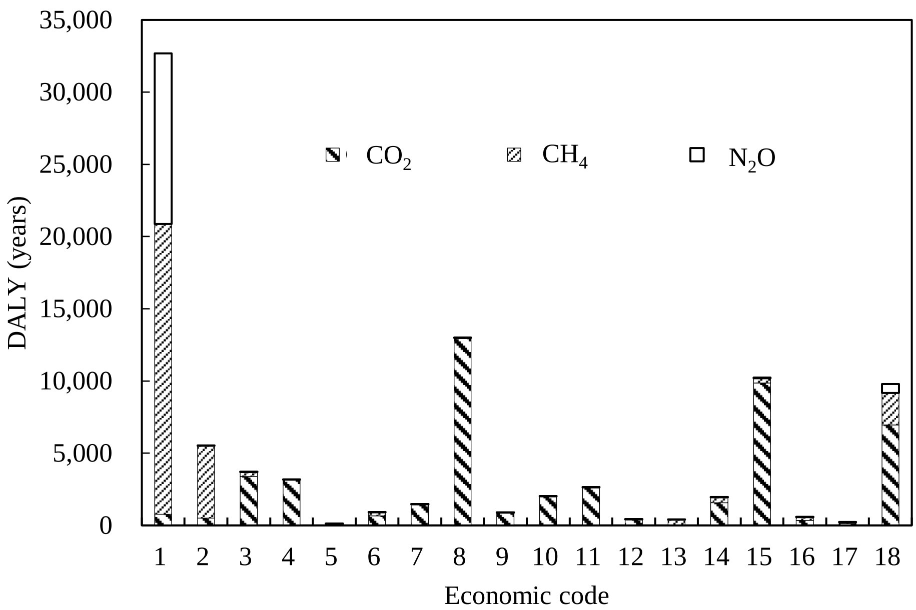


Fig. 4.3 DALY of sectors in 2011

4.4. Results and discussion

4.4.1. Backward and forward linkages

Using formulas introduced by Lenzen et al. (2003), forward and backward linkage coefficients of sectors in monetary terms and in GHG terms in consideration of weighting with final demand and value added are obtained. **Fig. 4.4** shows sectoral linkage coefficients in monetary terms while **Fig. 4.5** illustrates coefficients in terms of GHG. In these diagrams, the forward linkage coefficients are set on the vertical axis while the backward coefficients are on the horizontal axis. Sectors 5 - 9 have negative backward values (regions III and IV) because these sectors have negative values of final demand. This was caused by negative net investment and high imports while values of other final demand categories are low (Nguyen-Huu and Nguyen-Khac 2017). Net investment is equal to gross investment minus depreciation, in which depreciation is value of capital assets lost over their life. A sector, which has productive capacity is decreasing, may have lower gross investment than depreciation. Since computation of coefficients was weighted by final demand, the negative final demand results in negative backward coefficients for these sectors.

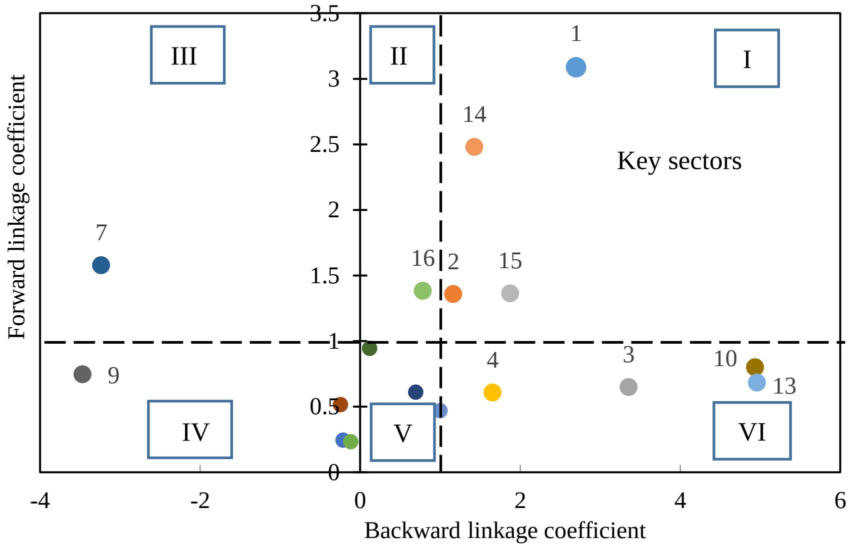


Fig. 4.4 Sectoral linkage coefficient in monetary term

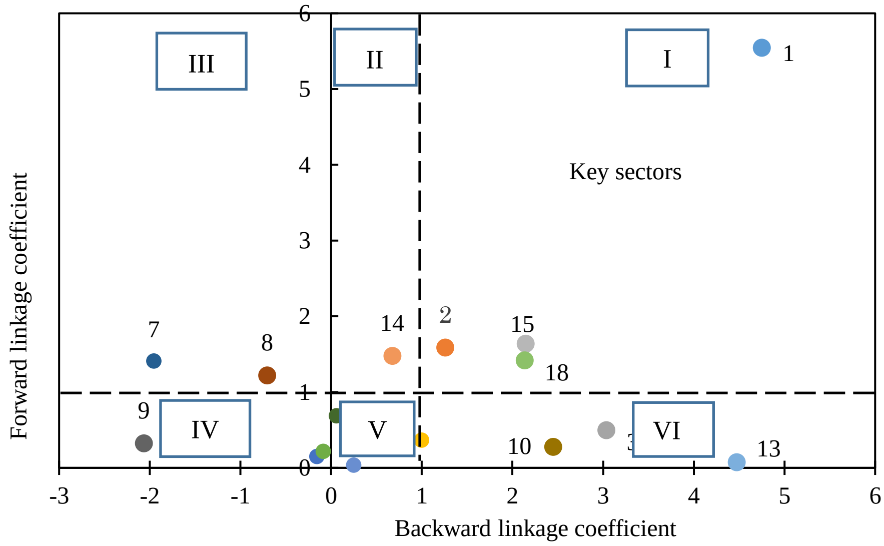


Fig. 4.5 Sectoral linkage coefficients with GHG emission factor

Key sectors are those which are in the upper right corner of figure (region I). In monetary terms, key sectors in 2011 include Sector 1 (agriculture, fishery and forestry), Sector 15 (transport and communication), Sector 14 (trade and repairing services) and Sector 2 (mining and quarrying) (Fig. 4.4). These sectors have the strongest economic connection with the rest of the economy; thus, they are capable of stimulating economic growth. Meanwhile, key sectors, in terms of GHG emissions, are Sector 1 (agriculture, fishery and forestry), Sector 15 (transport and communication), Sector 18 (personal, community, and household services) and Sector 2 (mining and quarrying) (**Fig. 4.5**). These results demonstrate that a translation of key sectors from monetary terms into GHG terms can generate different rankings. Sector 1 has very high linkage coefficients, especially in terms of GHG emissions with 4.7 for backward linkage and 5.4 for forward linkage. Sector 1 is thus considered as the most important sector in the country in terms of GHG emissions followed by Sector 15 then Sector 18 and Sector 2. Besides these four sectors, Sector 8 (manufacture of non-metallic mineral products) as backward linkages, which has the second highest GHG generation after Sector 1, should be considered as priority sector for pollution reduction (**Fig. 4.2**). Thus, great attention should be given to these five priority sectors when implementing GHG abatement strategies. The next section will mention different scenarios for optimization problem, which are considered for analyzing the potential of GHG emission mitigation, in the Vietnamese economic context. Out of scenarios, there are scenarios indicating how the change of technology state from these priority sectors influence the reduction of GHG intensity.

4.4.2. Scenario analysis

Vietnamese government ratified the Kyoto Protocol through approving the National Green

Growth Strategy (Decision No. 1393, 2012) which mandates the reduction of 8-10% GHG intensity (total GHG emissions per GDP) by 2020 relative to 2010 level (VNGGS 2012). Based on this policy, this work considers six scenarios corresponding to the different average economic growth rates from 2011 to 2020 and the change of technology state to indicate how the reduction of GHG intensity in 2020 compared to 2011 level (baseline) is. Furthermore, in this topic, DALY is used as indicator for assessing the efficiency of climate policy implementation. The results from different scenarios also provide the insights of the effect in reduction of GHG intensity on GDO, GDP and human health damage.

- Scenario 1 serves as the business as usual (BAU) scenario which is expected to have the annual GDP and sectoral final demand growth rate as the historical trend. According to the statistical data, the average annual GDP growth rate from 2011 to 2017 is 6% (CEIC 2017). Therefore, this scenario considers that Vietnam has an annual GDP growth of 6% from 2011 level (3,030 trillion VND) to 2020. Furthermore, the growth in the sectoral final demand in this scenario is assumed to vary from 5.5% to 6.5% per year during 9-year modeling horizon. The state of technology factor is assumed to be constant in this scenario (i.e, constant **A** and **q**).

- Scenario 2, Scenario 3 and Scenario 4 are assumed to have the annual GDP growth of 7%, 8% and 5%, respectively. These figures are based on historical trend found in CEIC (2017) and projections of GDP growth rate during period of 2011-2030 (DEA 2017), which indicate that Vietnam GDP growth rate from 2000-2030 is varied from 5% to 8%. These scenarios also consider the adjustment of economic structure at wider ranges, thus the sectoral final demand growth vary at wider ranges. The bounds of sectoral GDO are placed to correspond to accumulated changes, which result from a different sector growth.

- In scenario 5, the annual GDP growth and bounds of sectoral final demand are the same as BAU scenario, but the state of technology is changed to reduce GHG pollution intensity in the priority sectors, which are mentioned in backward and forward linkages. In light of this, the pollution intensities of Sector 1, 8, 15 and 18 are reduced by 12%, 15%, 5% and 4%, respectively. Such reductions of the agriculture and transportation sectors are based on the emissions reduction plans given in a study on management of GHG emissions and management of business of carbon credits (SMGGEMBCC), which approved by government under Decision 1755 in 2011 (KEPA and GreenID 2014). Meanwhile, a reduction in Sector 8 can be obtained by using advanced energy efficiency technologies or reducing energy consumption which were found in nationally appropriate mitigation action (NAMA 2015). The 4% reduction in GHG pollution intensity from Sector 18 can be achieved by improving energy efficiency. This is one of strategies to achieve low carbon development path (LCDP), published by the World Bank (Audinet et al. 2016).

- Scenario 6 combines the measures given in scenario 3 and 5 including high growth rate of GDP, differentiated sector growth and reduction of pollution intensity in the priority sectors. The six scenarios are summarized in **Table 4.3**.

Table 4.3 Scenarios

	Scenario 1 (BAU)	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Annual GDP growth	6%	7%	8%	5%	6%	8%
Variation of sectoral final demand	5.5%～6.5%	4%～10%	5%～12%	3%～7%	5.5%～6.5%	5%～12%
Variation of sector size (GDO)	N/A	-22.6%～28.3%.	-22.4% ～38.7%	-16%～18.5%	N/A	-22.4%～38.7%
State of technology	Constant	Constant	Constant	Constant	Change **q** (Pollution intensities of sector 1, 8, 15 and 18 are reduced by 12%, 15%, 5% and 4%, respectively)	Change **q** (Pollution intensities of sector 1, 8, 15 and 18 are reduced by 12%, 15%, 5% and 4%, respectively)

The IO-LP in this study is solved using a linear solver in Lingo 17. Lingo provides a completely integrated tool, which includes a powerful language for solving optimization models. It is designed to make building and solving linear, nonlinear, integer optimization and among others which are faster, easier and more efficient. Lingo 17 can be found in website https://www.lindo.com and was applied by many researchers and industrial manufacturers. For example, Hoa et al. (2015) used Lingo for solving fuzzy multi-objective optimization problem for finding the optimal multi-regional bioethanol supply chain. Aviso et al. (2013) applied Lingo to design robust water exchange networks for eco-industrial symbiosis.

After applying Lingo 17 to solve for **Eqs. (4.2b) (4.3)** and **(4.5)** to **(4.7)** for each of the six scenarios, the overall results are summarized in **Table 4.4**, while the contributions of the sectoral GDO and sectoral GHG emissions are shown in **Table C.2** and **Table C.3** in the **Appendix C**. The results indicate that solving scenario 1 as BAU scenario for the year 2020 gives a GDP of 5,119 trillion VND (in 2011 currency), a total GDO of 12,977 trillion VND, a DALY of 148,451 years and 590 Mt CO_2e. The corresponding intensity is 115.3 kg CO_2e per million Vietnamese dongs, which expresses 2% reduction compared to baseline (the 2011 level). These results imply that the climate policy of 8-10% reduction in GHG intensity by 2020 cannot be achieved with a BAU scenario.

Table 4.4 Result summary of modelling scenarios

	Baseline (2011)	**Scenario 1 (BAU)**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
Total GDO (trillion VND)	7,698	12,976.6	14,042	14,910	11,860	12,990	14,888
GDP (trillion VND)	3,030	5,118.8	5,572	6,061	4,698	5,119	6,061
CO_2 emissions (Mt CO_2e)	357	590	574	610	505	547	568
GHG intensity (kg CO_2e/million VND)	117.6	115.3	103.0	100.6	107.6	106.8	93.7
Reduction in GHG intensity (%)	n/a	2.0	12.4	14.5	8.5	9.2	20.3
DALY (years)	89,768	148,451	144,311	153,200	127,119	137,527	142,786

With different average annual GDP growth, differentiated growth rates of economic sectors and variation of sector size, scenario 2, 3 and 4 contribute to reduce GHG intensity by 12.4%, 14.5% and 8.5%, respectively, relative to the baseline year. Such these reductions are due to the variation of sector size at wider range, which allows to restructure in sectoral productivity by limiting the growth of high-emission sectors. Results show that the priority sectors, mentioned in backward and forward linkage section (Sector 1, 15, 18 and 8), experiences the reduction in total GDO, resulting in 9%, 5%, 10% and 17% reduction in total GDO compared to BAU, respectively (**Table C.2**). Meanwhile, most of low-polluting sectors (i.e., Sector 17, 16 and 5) achieve the increase in total GDO.. The results from these scenarios indicate that higher growth rate in GDP achieves higher reduction in GHG intensity. However, the economy will suffer from increase in total GHG emissions when GDP growth rate increases. The total GHG emissions in scenario 4 (5% of GDP growth rate), scenario 2 (7%) and scenario 3 (8%) are 505 Mt CO_2e, 574 Mt CO_2e and 610 Mt CO_2e, respectively. Similarly, the corresponding DALY results are 144,311 years for scenario 2, 153,200 years for scenario 3, and 127,119 years for scenario 4. However, scenario 2 and scenario 4 have lower human health damage compared to BAU scenario.

Solving scenario 5, which considers GDP growth rate as BAU, but the pollution intensities of priority sectors are reduced, achieve a 9.2% reduction in GHG intensity relative to the year 2011. While total GDO and GDP remain the same as BAU, total GHG emissions and DALY are reduced to 547 Mt CO2e and 137,527 years. The results highlight that application of low-carbon technology for polluting sectors considerably reduces GHG intensity, total GHG emissions and human health damage, while keeping the economic productivity at a desired level (BAU).

Finally, the solution of scenario 6, which combines scenario 3 and 5, greatly reduce GHG intensity by 20.3% compared to 2011. This scenario allows to reduce total GHG emissions and DALY to 568 Mt CO_2e and 142,786 years compared to BAU. Based on these results, the best measure for mitigating GHG intensity is scenario 6 which reduces up to 20.3% by 2020 relative to 2011, followed by scenario 3 by 14.5%, scenario 2 by 12.4%, scenario 5 by 9.2%, scenario 4 by 8.5% and finally BAU by 2%. It can be concluded that scenario 6 achieves the highest reduction in GHG intensity because it combined the most advantages of all measures.

4.4.3. Policy implications

From the analytical modeling results for the six scenarios theorized, there are significant insights regarding GHG emission mitigation policies in pursuit of continued economic growth. These scenarios analyze the potentials of reduction in GHG intensity for Vietnamese economy. This includes: (i) BAU scenario; (ii) the combination of different GDP growth rates, differentiated sector growth and the variation of economic sector size which allows to readjust economic productivity such as production of high-polluting sectors are constrained to a certain extent while low-polluting sectors are prioritized; and (iii) application of technology to reduce pollution intensity in carbon-intensive sectors (energy efficiency improvement, implementation of energy saving strategies and so on). From the results of these scenarios, there are several suggestions provided for policy makers and manufacturers in proposing the strategies to reduce GHG emissions per GDP:

1. The best way to reduce GHG intensity is to combine the advantages of all measures (scenario 6) including the increase in GDP growth rate as high as possible (i.e., 8% for scenario 3), allowing of economic restructure at wide range (i.e., -22.4% - 38.7% growth/contraction of sectors for scenario 3), and use of low-carbon technology for carbon-intensive sectors (scenario 5). These combinations can achieve up to 20.3% reduction in GHG intensity.

2. If the GDP growth rate can be obtained at only BAU or lower than BAU level, the adjustment of economic structure may be useful to significantly reduce the GHG intensity (i.e., 8.5% for scenario 4).

3. If the GDP growth rate can be achieved at only BAU level and adjustment of economic productivity is difficult to deploy, the application of low-carbon energy technology for polluting sectors is a good suggestion (i.e., 9.2% for scenario 5).

4.5. Conclusion and recommendations

This study examines the potentials of GHG intensity reduction in response to a climate policy given by Vietnamese government considering different economic growth rates and the change of technology state from economic activities. Such a reduction in GHG intensity can potentially contribute towards decreasing negative human health impacts induced by climate change. First, the approach of forward-backward linkages is used to indicate the backward linkage sectors, forward linkage sectors and key sectors in terms of economic and GHG emission performance. The sectors are prioritized as follows: Sector 1 (agriculture, fishery and forestry), Sector 15 (transportation and communication), Sector 18 (personal, community and household services), Sector 8 (manufacture of non-metallic mineral products) and Sector 2 (mining and quarrying), which have high impact in terms of both economy and GHG emissions. These sectors need to focus on pollution mitigation strategies; thus, the consideration of their pollution intensity reduction is proposed in optimization model. Second, an optimization approach based on IO-LP is developed and solved in order to minimize the total GHG emissions (in Mt CO_2e) under the constraints of desired GDP growth rates. The IO table and GHG emission data in 2011 are used as economic and environmental data which serve as the baseline to compute for the growth trajectories to 2020. The reduction of GHG intensity in 2020 relative to the year 2011 is then given to compare to the given policy. The results reveal that the combination of increased GDP growth rate, readjustment of economic structure and application of low-carbon techniques in the priority sectors can achieve the highest reduction potential of GHG intensity (by 20.3%). This figure exceeds the target outlined in Decision No. 1393 which mandates the reduction of GHG intensity by 8-10% during 2010-2020 in comparison to the 2010 level. In addition, these combined measures do not only contribute to the increase in 1,911 trillion VND of total GDO, 943 trillion VND of GDP compared to BAU scenario; but, they also help save 21,150 Mt CO_2e of total GHG emissions and 5,533 years of DALY.

This work will be helpful for policy makers in analyzing the potential effectiveness of applying various measures for reducing different pollutants. This study focuses on the case of Vietnam, but the same methodology can be easily adapted for applying in other economies if IO tables and environmental data are available. The disadvantage of this work is that it just focuses on GHG emissions in domestic production, while emissions from import-export activities between Vietnam and other countries have not yet been considered. Therefore, future work can consider the further potential effectives of GHG reduction by applying the changes of different technology factors such as energy efficiency improvement, widespread deployment of energy conservation strategies or other measures. Furthermore, other types of emissions should be focused on while taking into account trade effects. This will provide a more comprehensive assessment of the impact on environment resulting from Vietnamese economic activities. Besides, tools for dealing with data uncertainty should be integrated in this framework to assess the variation range in collected data for overall performance of an economy system.

References

Audinet P, Singh B, Kexel DT, Suphachalasai S, Makumbe P, Mayer K (2016) Exploring a low-carbon development path for Vietnam. Report published by the World Bank Group. https://doi.org/10.1596/9781464807190

Cayamanda CD, Aviso KB, Biona JBM, Culaba AB, Promentilla MAB, Tan RR, Ubando AT (2017) Mapping a low-carbon future for the Philippines: Scenario results from a fractional programming input-output model. Process Integration and Optimization for Sustainability, 1(4):293-299.

CEIC (2017) https://www.ceicdata.com/en/indicator/vietnam/real-gdp-growth. Accessed on 5 May 2018

de Carvalho AL, Antunes CH, Freire F, Henriques CO (2016) A multi-objective interactive approach to assess economic–energy–environment trade-offs in Brazil. Renewable and Sustainable Energy Reviews, 54:1429–1442.

de Schryver AM, Brakkee KW, Goedkoop MJ, and Huijbregts MAJ (2009) Characterization factors for global warming in life cycle assessment based on damages to humans and ecosystems. Policy Analysis 43(6):1689–95.

Dietzenbacher E (2005) More on multipliers, Journal of Regional Science, 45(2):421 – 426.

Fan Y, Zhang X, & Zhu L (2010) Estimating the macroeconomic costs of CO2 emission reduction in China based on multi-objective programming. Advances in Climate Change Research, 1(1):27–33.

Fan Y, Wu S ,Lu Y , Wang Y , Zhao Y , Xu S , Feng Y (2016) An approach of measuring environmental protection in Chinese industries: a study using input-output model analysis. Journal of Cleaner Production, 137:1479–1490.

Forster P, Ramaswamy V, Artaxo P, Berntsen T, Betts R, Fahey DW, Haywood J, Lean J, Lowe DC, Myhre G, Nganga J, Prinn R, Raga G, Schulz M, Van Dorland R (2007) Changes in Atmospheric Constituents and in Radiative Forcing. In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change; [Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL, Eds.] Intergovernmental Panel on Climate Change: Cambridge, U.K. and New York.

Ghosh A (1958) Input-output approach to an allocative system. Economica, 25(1):58-64.

Goedkoop M, Heijungs R, Huijbregts, MAJ, De Schryver A, Struijs J, van Zelm R (2009) ReCiPe 2008. A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. http://www.lcia-recipe.net. Accessed on 7 July 2017

Goedkoop M, Spriensma R (2001) The Eco-indicator 99. A damage oriented method for life cycle impact assessment. Methodology report and annex. Pré Consultants, Amersfoort, The Netherlands. Third edition. http://www.pre.nl/eco-indicator99/. Accessed on 7 July 2017

Golzarpoor H, Gonzalez V , Shahbazpour M , O'Sullivan M (2017). An input-output simulation model for assessing production and environmental waste in construction. Journal of Cleaner production, 143:1094-1104.

GSO (General Statistical Office) (2011) Statistical Yearbook of Vietnam 2010. Accessed on 05 May 2016. http://www.gso.gov.vn/default_en.aspx?tabid=515&idmid=5&ItemID=11974

GSO (General Statistical Office) (2013) Input-output: IO of Vietnam year 2011. Statistical Publishing House: Hanoi.

Haimes YY, Jiang P (2001) Leontief-based model of risk in complex interconnected infrastructures. Journal of Infrastructure Systems, 7(1):1–12.

Hoa NT, Dien LQ, Promentilla MAB, Yu KDS, Aviso KB (2016) A model for multi-criteria disaster vulnerability assessment of economic systems: implications for Vietnam's bioethanol policy. Clean Techn. Environ. Policy, 18(6):1917-1929. doi:10.1007/s10098-016-1120-4

Hofstetter P (1998) Perspectives in life cycle impact assessment. A structured approach to combine models of the technosphere; ecosphere and valuesphere: London, U.K.

Hristu-Varsakelis D, Karagianni S, Pempetzoglou M, Sfetsos A (2010) Optimizing production with energy and GHG emission constraints in Greece: An input–output analysis. Energy Policy, 38(3):1566–1577.

Hristu-Varsakelis D, Karagianni S, Pempetzoglou M, Sfetsos A (2012) Optimizing production in the Greek economy: Exploring the interaction between greenhouse gas emissions and solid waste via input–output analysis. Economic Systems Research, 24(1):57–75.

Hsu GJY, Chou FY (2000) Integrated planning for mitigating CO2 emissions in Taiwan: A multiobjective programming approach. Energy Policy, 28(8):519–523.

IEA (International Energy Agency) (2016) CO2 Emissions from Fuel Combustion, OECD/IEA, Paris. http://wds.iea.org/wds/pdf/Worldco2_Documentation.pdf. Accessed on 30 May 2017

IEA (International Energy Agency) (2017) https://www.iea.org/Sankey/. Accessed on 30 May 2017

IPCC (Intergovernmental Panel on Climate Change) (2006) IPCC Guidelines for National Greenhouse Gas Inventories.

KEPA and GreenID (Service Center for Development Cooperation & Green Innovation and Development Centre) (2014) Assessment of policies on GHG mitigation in Vietnam, 1–31. https://www.kepa.fi/tiedostot/final_report_vietnam_1marz2014.pdf. Accessed on 10 April 2017

Kollner T (1999) Species-pool effect Potentials (SPEP) as a yardstick to evaluate land-use impacts on biodiversity. J. Cleaner Prod., 8 (4):293–311.

Lenzen M (2003) Environmentally important paths, linkages and key sectors in the Australian economy. Structural Change and Economic Dynamics, 14(1):1–34.

Leontief WW (1936) Quantitative Input-Output Relations in the Economic System of the United States. Rev. Econ. Stat., 18(3):105–125.

Leontief WW (1970) Environmental repercussions and the economic structure: an input-output approach. Rev. Econ. Stat., 52(3):262–271.

Leontief WW (1985) Input–output analysis. In W. Leontief (Ed.), Input–output economics. NewYork: Oxford University Press, 19–40.

Leontief WW, Ford D (1972) Air pollution and the economic structure: empirical results of input-output computations. In Andrew Brody and Anne P. Carter (eds). Input-output techniques (Amsterdam-London: North-Holland Publishing Company: 9-30.

Mazyrin VM (2013) Economic modernization in Vietnam from industrialization to innovation stage. Journal of Economics and Business, 29(2):87-106.

McMichael AJ, Campbell-Lendrum DH, Corvalan CF, Ebi KL, Githeko A, Scheraga JD, Woodward A (2003) Climate change and human health: risk and responses; World Health Organization: Geneva, Switzerland, 322.

Miller RE, Blair PD (2009) Input-Output Analysis: Foundation and Extensions. Second Ed. Published in the United States of America by Cambridge University Press, New York.

MNRE (Ministry of Natural Resources and Environment) (2014) The initial biennial updated report of Viet Nam to the United Nation Framework Convention on climate change. Viet Nam publishing house of nature resources, environment and cartography. NRE, Ha Noi, 2014. http://unfccc.int/resource/docs/natc/vnmbur1.pdf. Accessed on 08 March 2017

Murray CJL, Lopez AD (1996a) The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020. Global Burden of Disease and Injury Series Volume I. Harvard School of Public Health, World Bank, World Health Organisation, USA. 990.

NAMA (Nationally Appropriate Mitigation Action) (2015) Nordic Partnership Initiative: cement sector NAMA Readiness Programme in Vietnam. Nordisk Ministerråd, 6.

Nguyen HT, Aviso KB, Kojima N, Tokai A (2018) Structural analysis of interrelationship between economic activities and wastewater emissions in Vietnam in the period of 2000 -2011. Clean Techn. Environ. Policy, 20(3): 621-638. https://doi.org/10.1007/s10098-018-1492-8

Nguyen-Huu TT, Nguyen-Khac M (2017) Impacts of export-platform FDI on the production of upstream industries. Do third country size, trade agreements and local content requirement matter? Evidence from the Vietnamese supporting industries. Economics: The Open-Access, Open-Assessment E-Journal, 11 (2017-22):1–31. http://dx.doi.org/10.5018/economics-ejournal.ja.2017-22. Accessed on 26 November 2017

Nguyen NT, Ha-Duong M, Sandra G (2009) The clean development mechanism in Vietnam: potential and limitations. Paper accepted to present at the fourth GMSARN International Conference 2009 “Energy Security and Climate Change: Problems & Issues in GMS" to be held from 25-27 November 2009 at Ha Long Bay, Vietnam.

Oliveira C, Coelho D, Antunes CH (2016) Coupling input – output analysis with multiobjective of economy – energy – environment – social (E3S) trade-offs : a review. Annals of Operations Research, 247(2):471–502. http://doi.org/10.1007/s10479-014-1773-5. Accessed on 18 June 2017

Piaggio M, Alcántara V, Padilla E (2012) Economic structure and key sectors analysis of greenhouse gas emissions in Uruguay. 20th International input-output conference, June, Bratislava, Slovakia, 1–30

PricewaterhouseCoopers (2017) The world in 2050. https://www.pwc.com/gx/en/world-2050/assets/pwc-the-world-in-2050-full-report-feb-2017.pdf. Accessed on 07 July 2017

Rasmussen P (1956) Studies in Intersectoral Relations, Amsterdam, North-Holland.

Shmelev SE (2013) Environmentally extended input – output analysis of the UK economy : key sector analysis. Working paper (183):13–17.

Steen BA (1999) Systematic approach to environmental priority Strategies in Product Development (EPS), Version 2000, General System Characteristics, Models and Data; Centre for Environmental Assessment of Products and Material Systems: Chalmers University of Technology.

Tan RR, Yu KDS, Aviso KB, Promentilla MAB (2017) Input–output modeling approach to sustainable systems engineering. In: 500Abraham M (ed) Encyclopedia of sustainable technology. Elsevier, 501 Amsterdam, 519–523. https://doi.org/10.1016/B978-0-12- 409548-9.10243-X

UN (United Nations) (2002) International Standard Industrial Classification of All Economic Activities, Rev.3 (ISIC 3). https://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=2. Accessed on 12 June 2016

UNFCCC (United Nations Framework Convention on Climate Change) (1998) Available online: http://unfccc.int/resource/docs/convkp/kpeng.pdf. Accessed on 30 September 2017

VNGGS (Vietnam National Green Growth Strategy) (2012) http://2050.nies.go.jp/sympo/120531/presentation/2_E.pdf. Accessed on 8 May 2017

Vogstad KO (2009) Input–output analysis and linear programming. In S. Suh (Ed.), Handbook of input–output economics in industrial ecology. Eco-efficiency in industry and science. New York: Springer, 801–818.

Yu KDS, Tan RR, Aviso KB, Promentilla MAB, Santos JR (2014) A vulnerability index for post-disaster key sector prioritization. Econ. Syst. Res., 26(1):81–97.

Chapter 5 A linear programming input-output model for mapping low-carbon scenarios for Vietnam in 2030

This chapter develops a IO-LP model based on model in chapter 4 to identify the potential of maximum GHG emission reduction when low carbon scenarios are given. These scenarios focused on improving technology factors for economic sectors. DALY is also used to assess the improvement of human health impact when low carbon technologies are implemented. Results from this chapter further contribute to indicate *response* (assessment of government policy) and *impact* (human health) components of modified DPSIR tool for proposing methods for comprehensive economic-environmental management.

5.1. Introduction

The impact of economic activities on climate has caused serious global concerns. Rising atmospheric levels of greenhouse gases (GHG), and particularly CO_2, from the continued consumption of fossil fuels are driving climate change, which in turn poses a serious threat to humans and ecosystems (De Schryver et al. 2009). The Kyoto Protocol developed by the 1992 UN Framework Convention on Climate Change (UNFCCC) to reduce GHG emissions including CO_2, CH_4 and N_2O (UNFCCC 1998) urged countries to commit to explore various strategies to reduce GHG emissions. Countries have thus explored various strategies to meet their emissions reduction targets. For example, decarbonized electricity emerged as the dominant strategy in the simulations of Williams et al. (2012) for meeting the GHG reduction targets in California, while Cohen (2017) focused on GHG emissions reduction strategies in solid waste management. Recent work has recognized that too much focus on GHG emissions reduction might result in adverse unintended consequences, such as the increase of other environmental impacts (Kouloumpis et al. 2015) or negative effects on economic growth and social welfare. These effects differ from country to country, depending on the state of economic development and structure (Fan et al. 2010).

Vietnam is currently in the process of rapid industrialization (Maryzin 2013). Since the year 2000, the Vietnamese economy has prospered, with an average annual economic growth rate of more than 5 % (PricewaterhouseCoopers 2017). As a result of this rapid economic development, energy consumption in the country has also grown (MNRE 2014) along with GHG emissions. In addition, the agricultural and industrial sectors (including waste treatment activities) also contribute large amounts of GHG emissions (MNRE 2014). Nguyen and Nguyen (2014) reported that total GHG emissions generated from energy sectors, agriculture, forestry and other land use (AFOLU) and waste sector are projected to quadruple by 2030 relative to the year 2005, reaching 686.5 million tons of CO_2 equivalent ($MtCO_2e$) under the business-as-usual (BAU) scenario. As a non-Annex I country under Kyoto Protocol, Vietnam is not required to reduce GHG emissions. It has, however, ratified the agreement to make an effort to reduce emissions from the energy, agriculture and the transportation sectors (KEPA and GreenID 2014).

In the 2015 Paris Climate Conference (COP21), Vietnam's intended nationally determined contribution (INDC) commitment is to reduce its GHG emissions by 25% by the year 2030. This reduction is evaluated relative to the emissions projections under the BAU scenario (UNFCCC 2015a). However, this commitment is dependent on the availability of international support. Various measures have been proposed to reduce GHG emissions to meet this target (UNFCCC 2015b). The measures focus on either reducing GHG emission intensity from electricity and other energy sectors, or applying energy efficient technologies to promote energy conservation throughout the economy. The former involves increasing renewable and clean energy in the national electricity mix, and the application of low-carbon technologies in transport, waste treatment and agriculture. As mentioned above, these measures to reduce GHG emissions may constrain the growth of Vietnam's economy, especially if the most productive economic sectors are also the most pollutive (KEPA and GreenID 2014). Hence, it is particularly relevant for decision-makers and the government to evaluate how pollution mitigation strategies influence economic growth (Oliveira and Antunes 2004).

Input-output (IO) analysis (Leontief 1936, 1970) provides a framework for linking economic activities with their associated environmental impact. IO analysis captures the interdependencies between various sectors of an economy through aggregated supply chain linkages (Miller and Blair 2009). The basic IO model can be extended to capture other aspects of an economic system. Hoa et al. (2016) for example, applied the inoperability input-output model (IIM) proposed by Haimes and Jiang (2001) and the vulnerability index developed by Yu et al. (2014) to develop a multi-criteria model for disaster vulnerability assessment resulting from the implementation of a biofuel policy in Vietnam. The extension of IO analysis, which takes into account environmental impacts, has been used for fuzzy multi-objective optimization of multi-regional bioethanol supply chains (Tan et al. 2008, 2009); in optimizing supply chains under water footprint constraints (Aviso et al. 2011); and in identifying the role of sectors as pollution contributors (Nguyen et al. 2018).

The value of IO analysis is further enhanced when it is coupled with linear programming (LP) to allow optimization to be performed instead of mere analysis (Vogstad 2009). A recent review of the LP-IO approach outlines the advantages of this hybrid framework in comparison to the traditional IO model (Oliveira et al. 2016). The LP-IO can identify the appropriate level of sectoral activity to optimize a given objective function (e.g., to maximize gross domestic product) while satisfying the balance of sectoral production levels. Furthermore, LP-IO may provide a more complete evaluation of efficient production possibilities and economic effect of potential policies and allow for the study of trade-offs between conflicting objectives (Oliveira et al. 2016). For example, Quaddus and Holzman (1985) used LP-IO for economic planning in Bangladesh, while Hsu et al. (1987) applied it for assessing trade-offs between GDP and energy use to support energy planning in Taiwan. The LP-IO framework has been employed to investigate the effect of mitigating CO_2 generation in Taiwan while maximizing gross domestic product (GDP) (Chen 2001). It has been used for estimating the macroeconomic costs of CO_2 emission reduction in China's economy (Fan et al. 2010), and for assessing the trade-offs between economic, energy and environmental (E3) objectives in Brazil's economy (De Carvalho et al. 2016). This model was also applied to optimize the gross domestic output (GDO) in the Greek economy in consideration of energy, GHG, and final demand constraints (Hristu-Varsakelis et al. 2010); and later extended to integrate the impact brought by solid waste (Hristu-Varsakelis et al. 2012). Recently, Cayamanda et al. (2017) developed a fractional programming (FP) IO model, which aims to minimize the carbon intensity of the Philippines in consideration of economic growth and climate policies outlined in the Philippine INDC. Their work also considered the potential CO_2 emission reductions measures for the Philippines. However, other GHGs such as methane (CH_4) contribute to climate change as well, and a clearer picture of global warming potential can be derived when other GHG emissions are considered in the evaluation. In addition, it has been shown that GHG emissions are also linked with other impacts, such as those which affect human health (West et al. 2013).

There has been limited work on evaluating how GHG emissions eventually impact human health. According to McMichael et al. (2003), the GHG generation, which contributes to climate change, causes an increase in various diseases such as diarrhea, malaria and heat stress. This may decrease peoples' longevity, or may contribute towards reduced levels of health. The evaluation of the effects of GHG generation can be conducted by looking at midpoint and endpoint impact indicators (Forster et al. 2007). At the midpoint, GHG emissions are assessed using the radiative forcing indicator or global warming potential (GWP), while the impact of GHG emissions is converted into damage indicators at the endpoint. The most common endpoint indicator for human health damage is measured in terms of Disability Adjusted Life Years (DALY), which is defined as years of life lost due to premature death and years of life spent with disability (Murray and Lopez 1996). Goedkoop et al. (2009) has found that the application of DALY has been useful for assessing the human health impact from GHG emissions.

Macro-economic and sectoral levels studies on assessing the economic impacts of climate policies in Vietnam have not been done comprehensively. Such policies may include promoting cleaner and more efficient technologies. To address this gap, this paper develops an LP-IO optimization model to determine how to achieve minimal GHG emissions in kg of CO_2 equivalents. In addition, this work extends the evaluation to account for human health using DALY as an indicator. Different scenarios based on given climate policies and economic growth targets are considered against the BAU scenario. The modeling framework is applied for the 18-sector IO model of the Vietnam economy, looking at its growth trajectories to 2030. The rest of paper is organized as follows. The modeling framework is discussed in **Section 5.2**. **Section 5.3** mentions the six different scenarios considered. Results and discussions from these scenarios are then analyzed in **Section 5.4**. **Section 5.5** then discusses some implications of the results with regards to the development of national policies. Finally, the conclusion and recommendation for future work are given.

5.1. Modeling framework

The implementation of climate policies which aim to reduce GHG emissions will have an impact in the development of economic sectors. There may be a need to readjust the economic productivity of certain sectors due to limitations imposed on the growth of sectors with high emissions. This can constrain a country's macroeconomic development. The conflict between economic growth and GHG emission mitigation is something that a decision-maker needs to contend with. In this work, LP-IO is developed to minimize the total GHG emissions in consideration of Vietnam's continued economic growth amidst the implementation of low-carbon measures. To implement optimization, this model allows economic sectors to achieve different levels of productivity.

The LP-IO model parameters and variables are defined as follows:

Model parameters:

$\mathbf{A}$	technical coefficient matrix
$\mathbf{I}$	identity matrix
$\mathbf{x_L}$	column vector for the minimum level of total sector output
$\mathbf{x_U}$	column vector for the maximum level of total sector output
$\mathbf{y_L}$	column vector for the minimum level of the sector final demand
$\mathbf{y_U}$	column vector for the maximum level of the sector final demand
$\mathbf{b^T}$	row vector for the sector GHG emissions intensity in ktonnes CO_2e
$\mathbf{i}^T$	row vector with elements of value 1
$\mathbf{C}^T$	row vector for characterization factor
DALY	disability adjusted life year end-point indicator

Model variables

$\mathbf{x}$	column vector for sector total output
$\mathbf{y}$	column vector for sector final demand
$\mathbf{g}$	column vector for total GHG emissions in ktonne CO_2e

Objective function

$$\text{Min } \mathbf{i}^{T}\mathbf{g} \tag{5.1}$$

Constraints

$$(\mathbf{I} - \mathbf{A})\ \mathbf{x} = \mathbf{y} \tag{5.2}$$

$$\mathbf{b}^{\mathbf{T}}\ \mathbf{x} = \mathbf{g} \tag{5.3}$$

$$\text{DALY} = \mathbf{C}^{T}\mathbf{g} \tag{5.4}$$

$$\mathbf{x_L} \leq \mathbf{x} \leq \mathbf{x_U} \tag{5.5}$$

$$\mathbf{y_L} \leq \mathbf{y} \leq \mathbf{y_U} \tag{5.6}$$

Eq. (5.1) corresponds to the objective function, which is to minimize the total GHG emissions. **Eq. (5.2)** is the basic equation of conventional IO models (Miller and Blair 2009) and defines the balance of goods and services in the economic system. **Eq. (5.3)** on the other hand accounts for the total emissions resulting from economic activities according to the direct emission intensities and gross output of economic sectors. This equation is based on the environmentally-extended IO model (Heijungs and Suh 2013), which is used to account for environmental interventions of an economic system (Miller and Blair 2009). **Eq. (5.4)** accounts for the impact of climate change on human health measured in DALY. This is achieved by multiplying each GHG pollutant with the corresponding characterization factor as explained in de Schryver et al. (2009). **Eq.s (5.5)** and (**5.6)** provide the limits for the total output and the final demand of each sector, respectively. Such bounds are introduced for specific scenarios to ensure that the economy still achieves the target economic growth level. This optimization problem is solved using a linear solver in Lingo 17.0 using an Intel Core i7 – 6500U processor at 2.50 GHz with 8.00 GB RAM.

5.2. Scenarios

In this paper, the optimization model is developed using formulations presented in the previous section. The technical coefficient matrix **A** was obtained from the 2011 IO table of Vietnam which is the most recent available information. The IO table is published by the Vietnam General Statistics Office (GSO 2013). The framework of the 2011 IO table is detailed in Nguyen et al. (2018). The original IO table is aggregated and classified into 18 main sectors using established IO techniques (Miller and Blair 2009). This is more convenient for accounting environmental emissions. This classification is compatible with the classifications found in the IO table from GSO (2013) and the classification according to the International Standard Industrial Classification version 3 (UN 2018). The nomenclature of the 18 sectors and the associated gross output of each sector are shown in

Table 5.1, while the technical coefficient matrix **A** is shown in **Table 5.2**. Vector **b** is calibrated to express the GHG emissions. Due to data limitations of other GHG emissions such as O_3 and Chlorofluorocarbons (CFCs), this paper focuses on the main pollutants which include CO_2, CH_4 and N_2O. Emissions data are collected from different sources, including energy-based CO_2 emission data from the International Energy Agency (IEA 2016) and CO_2, CH_4, and N_2O process emissions (e.g. industrial process, agriculture, waste and so on) from the Vietnamese Ministry of Natural Resources and Environment (MNRE 2014). After collecting data, CO_2, CH_4 and N_2O emission loads in million tons (Mt) are converted into the equivalent CO_2 amount (Mt CO_2 equivalent, MtCO_2e) in order to calculate the total CO_2 emission equivalents. **Table 5.3** shows the characterization factors for global warming potential (GWP) and DALY used for the study. The emission of 1 ktonne of CH_4 for example, has the same GWP as 21 kt of CO_2e. Furthermore, the characterization factors for impact on human health resulting from climate change have been estimated for a wide range of diseases (Murray et al., 1996). The characterization factors corresponding to the impact on human health were obtained from De Schryver et al. (2009) and expressed in DALY/kt of substance. **Table 5.4** shows the direct emission intensity of pollutants in each sector which indicates that Sector 18 has the highest emission intensity of about 739 kg CO_2e/million VND while sectors 2, 5, 10 and 14 have emission intensities equal to 0. Following the work of Cayamanda et al. (2017) six scenarios are considered for analyzing the potential of GHG emission reductions in the Vietnamese economy.

Table 5.1 Nomenclature of sectors and corresponding gross output

Sector code	Sector name	Gross output (x, in trillion VND)
1	Agriculture, Fishery and Forestry	1,030
2	Mining and Quarrying	36
3	Food, Beverage and Tobacco	891
4	Textile, Wearing Apparel and Leather Industries	480
5	Manufacture of Wood and Wood products	55
6	Manufacture of Paper and Paper Products, Printing and Publishing	98
7	Manufacture of Industrial Chemicals and petrochemicals	221
8	Manufacture of Non-metallic Mineral Products	200
9	Basic Metal Industries	157
10	Manufacturing of Fabricated Metal Products, Machinery and Equipment	945
11	Other Manufacturing Industries	359
12	Electricity	162
13	Other energy	418
14	Construction	684
15	Commercial and public services	1,251
16	Transportation	220
17	Resident	478
18	Water supply and waste	13

Table 5. 2 Technical coefficient matrix of the Vietnam economy in 2011 (A) (GSO 2013)

Sector code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	0.1463	0.0001	0.3400	0.0089	0.2024	0.0115	0.0240	0.0034	0.0000	0.0001	0.0220	0.00001	0.00000	0.0008	0.0081	0.0002	0.0750	0.0027
2	0.0005	0.0402	0.0009	0.0001	0.0011	0.0004	0.0072	0.0379	0.0065	0.0013	0.0013	0.00198	0.00119	0.0168	0.0004	0.0007	0.0002	0.0057
3	0.1286	0.0004	0.3232	0.0002	0.0018	0.0015	0.0176	0.0003	0.0000	0.0001	0.0003	0.00017	0.00002	0.0001	0.0068	0.0008	0.0999	0.0004
4	0.0021	0.0009	0.0016	0.5590	0.0106	0.0372	0.0021	0.0045	0.0001	0.0085	0.0216	0.00219	0.00041	0.0025	0.0062	0.0007	0.0029	0.0032
5	0.0008	0.0006	0.0004	0.0005	0.2948	0.0175	0.0014	0.0026	0.0000	0.0018	0.1522	0.00012	0.00100	0.0075	0.0006	0.0004	0.0010	0.0003
6	0.0003	0.0008	0.0181	0.0118	0.0117	0.4505	0.0128	0.0369	0.0003	0.0036	0.0177	0.00144	0.00130	0.0056	0.0074	0.0013	0.0212	0.0025
7	0.0634	0.0300	0.0161	0.0947	0.0512	0.0538	0.4323	0.0260	0.0020	0.0246	0.1952	0.00099	0.02379	0.0082	0.0036	0.0010	0.0411	0.0441
8	0.0010	0.0038	0.0024	0.0007	0.0201	0.0013	0.0203	0.2954	0.0129	0.0125	0.0089	0.00122	0.00071	0.2098	0.0018	0.0007	0.0030	0.0089
9	0.0003	0.0140	0.0036	0.0015	0.0160	0.0015	0.0077	0.0142	0.7657	0.1737	0.0202	0.00050	0.02254	0.1421	0.0012	0.0017	0.0005	0.0122
10	0.0041	0.0299	0.0112	0.0099	0.0112	0.0155	0.0129	0.0220	0.0155	0.4024	0.0430	0.03501	0.00700	0.0465	0.0157	0.0176	0.0123	0.0265
11	0.0032	0.0215	0.0311	0.0258	0.0106	0.0714	0.0539	0.0309	0.0008	0.1011	0.1852	0.03442	0.00553	0.0165	0.0124	0.0296	0.0125	0.0482
12	0.0071	0.0263	0.0105	0.0184	0.0176	0.0365	0.0194	0.0638	0.0178	0.0147	0.0208	0.14810	0.00665	0.0048	0.0185	0.0052	0.0242	0.0584
13	0.0380	0.1503	0.0123	0.0095	0.0165	0.0322	0.0716	0.0842	0.0416	0.0101	0.0202	0.11184	0.30355	0.0437	0.0250	0.2722	0.0144	0.0354
14	0.0008	0.0019	0.0005	0.0009	0.0006	0.0003	0.0003	0.0006	0.0003	0.0012	0.0051	0.00506	0.00401	0.0436	0.0072	0.0054	0.0047	0.0179
15	0.0315	0.0501	0.0624	0.0486	0.0447	0.0525	0.0735	0.0550	0.0229	0.0642	0.0538	0.03984	0.02752	0.0482	0.1552	0.0572	0.0677	0.0324
16	0.0048	0.0911	0.0213	0.0110	0.0146	0.0254	0.0230	0.0148	0.0102	0.0156	0.0132	0.00718	0.02402	0.0117	0.0195	0.1080	0.0146	0.0060
17	0.0027	0.0034	0.0052	0.0023	0.0041	0.0038	0.0215	0.0045	0.0007	0.0036	0.0028	0.03618	0.00687	0.0080	0.0175	0.0126	0.0472	0.0066
18	0.0005	0.0008	0.0013	0.0018	0.0010	0.0012	0.0022	0.0013	0.0017	0.0018	0.0014	0.00169	0.00028	0.0010	0.0012	0.0009	0.0039	0.1082

Table 5.3 Characterization factors of greenhouse gas emissions to DALY (de Schryver et al. 2009) and GWP (MNRE 2014)

Pollutants	**In DALY/ktonnes**	**GWP (in ktonnes CO_2e / ktonnes CO_2)**	**In DALY/ ktonne CO_2e (C^T)**
CO_2	0.255	1	0.255
CH_4	5.04	21	0.240
N_2O	83.30	310	0.269

Table 5.4 Direct emission intensity vector b in kg CO_2e/million VND

		Direct emission intensity (kg CO_2e/million VND)																	
Pollutants	Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
CO_2		2.56	0.00	5.49	14.78	0.00	15.53	7.24	207.53	11.48	0.00	24.64	263.81	3.69	0.00	3.22	149.28	16.62	3.15
CH_4		90.35	0.00	0.00	0.00	0.00	0.00	0.02	0.37	0.00	0.00	0.02	0.10	39.39	0.00	0.01	0.51	0.67	647.20
N_2O		47.50	0.00	0.00	0.00	0.00	0.00	0.10	0.80	0.00	0.00	0.07	0.65	0.01	0.00	0.01	0.43	0.06	88.49

The six scenarios considered are:

- Scenario 1: This scenario serves as the BAU scenario mentioned in Vietnam's NDC. According to the economic growth projection from 2015-2030, as reported in the Vietnam Energy Outlook Report of 2017 (DEA, 2017), Vietnam is expected to have an annual GDP growth of 7% from the 2011 level (3,030 trillion VND) to 2030. This scenario assumes constant state of technology (i.e., constant **A** and **b**). Furthermore, it is assumed that the growth in the final demand of sectors may vary between 6.5% and 7.5% per year during the 19-year modeling horizon.

- Scenario 2: This scenario is similar to scenario 1, but the annual growth of each sector is allowed to vary from 5.7% to 8.0% per annum during the period of 19 years, which provides a wider growth range compared to the BAU as proposed in Vietnam's economic growth strategies (Vu, 2013). Such adjustment of economic structure contributes to reducing GHG emissions by limiting the production of high-polluting sectors while prioritizing the growth of low-polluting sectors. Furthermore, the bounds for gross output of sectors are given to correspond to a cumulative change resulting from a differentiated sector growth. The range is from a relative contraction of -20% to a relative growth of +20%. This scenario thus results in a potential change in each sector's contribution to GDP, gross output, GHG emissions and DALY. This scenario expresses the possibility of economic growth redirection through the implementation of different policies which may focus on identified sectors.

- Scenario 3: This scenario is similar to scenario 2, except that the GHG emission intensity of electricity generation and other energy sectors is reduced by 40% and 30% relative to 2011 level, respectively (i.e., from 0.6244 tCO_2e/kWh to 0.365 tCO_2e/kWh) (KEPA and GreenID, 2014; Tuyen and Michaelowa, 2006). Such reductions can be obtained via the planned actions issued by the government in the National Climate Change Strategy (Vietnam Government Portal, n.d.) as measures to obtain the target of Vietnam's NDC. Under these measures, Vietnam increases the use of low-carbon energy which includes the use of renewables (e.g. biomass, waste, wind) and nuclear energy. This also reduces the consumption of fossil fuels such as coal, oil and natural gas.

- Scenario 4: This scenario is similar to scenario 2, but includes the wide scale deployment of energy efficient strategies for final consumption and other energy conservation measures throughout the economy. This results in a 17% reduction in electricity use and an 8.1% reduction in other energy use with energy being used as intermediate inputs for production activities. Such reductions were indicated in a study focusing on the energy efficiency potential of Vietnam (DEA, 2017). This is also one of the strategies to achieve the GHG mitigation targets of the NDC.

- Scenario 5: This scenario is similar to scenario 2, but assumes the reduction in emission intensity in the agriculture sectors by 25%, in the waste sector by 6.5% and in the transport sector by 10%

by the year 2030 relative to 2011 level. Such reductions are based on the emission mitigation plans of sectors given in a study on management of greenhouse gas emissions; management of business of carbon credits (SMGGEMBCC) as approved by the Prime Minister under Decision 1755 in 2011 (KEPA and GreenID, 2014). Furthermore, such reductions can be obtained by improving the effectiveness of agriculture production, using advanced waste treatment technologies, and using low-energy consuming means of transport (i.e., using electricity vehicles).

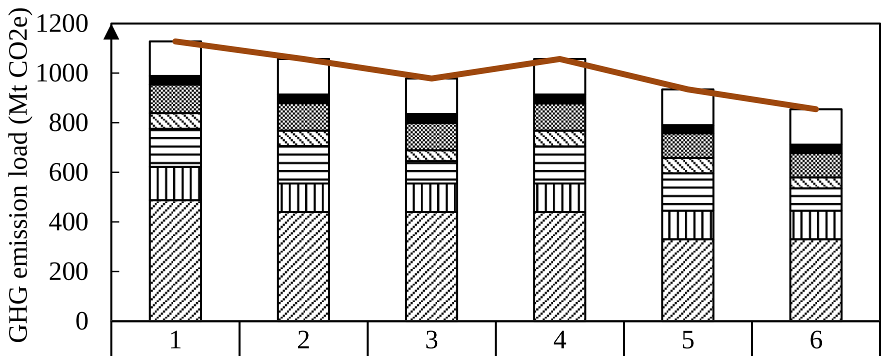
- Scenario 6: This scenario combines all four measures indicated in scenarios 2 to 5, which includes differentiated sector growth, adoption of a low-carbon electricity mix, an extensive use of energy conserving technologies, and reduction of emissions in high polluting sectors.

5.3 Results and discussions

The LP-IO model is solved for each of the six scenarios, and the overall results are summarized in **Table 5.5**, while **Fig. 5.1** shows the variation of GHG emission load by sectors in different scenarios. The contributions of the sector final demand and sector GHG emissions can be found in **Tables D.1** and **D.2** in the **Appendix D**.

Table 5.5 Summary of results of modeling scenarios

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
GHG emission (Mt CO_2e)	1,128	1,058	979	1,057	934	855
% reduction in emissions	n/a	6.2	13.2	6.7	17.2	24.6
DALY (years)	283,909	266,208	246,306	266,030	235,312	215,289



	1	2	3	4	5	6
Rest of sectors	138.87	143.77	143.77	143.57	143.78	143.57
18	35.0	35.3	35.3	35.3	33.0	33.0
16	115.3	110.0	110.0	109.9	98.9	98.9
13	63.6	62.2	43.5	62.6	62.2	43.8
12	152.7	151.0	90.6	150.2	150.8	90.1
8	134.9	115.0	115.0	114.9	115.1	114.9
1	487.6	440.4	440.4	440.4	330.5	330.3
sum	1128.0	1057.6	978.6	1056.9	934.2	854.7

Scenarios

Fig. 5.1 Sector GHG emission of different scenarios

Solving **Eq.s (5.1)** to **(5.6)** using the assumptions of scenario 1 for the year 2030 gives a GDP of 10,959 trillion VND (in 2011 currency), a total gross output of 27,548 trillion VND, a DALY of 283,909 years, and 1,128 million tonnes of CO_2 equivalent ($MtCO_2e$) emissions. The contributions of the 18 sectors to the gross output and the corresponding emissions are shown in **Fig. D.1** in the **Appendix D**.

The GDP obtained from scenario 1 is then used for all other scenarios to determine the potential of the different strategies to reduce GHG emissions given the same level of economic growth. Scenario 2, with the differentiated growth rates of economic sectors, contributes to reduce total GHG emissions to 1,058 $MtCO_2e$, which represents a 6.2% reduction relative to the baseline (i.e. scenario 1). Such a reduction is due to the adjustment in sectoral productivity, which translates to limiting the growth of sectors with high emission intensity. This achieves the desired emission reduction while using the current state of technology without taking into account potential changes brought by technology advancement and changes in energy consumption level. Results show that sector 6 experiences the highest reduction in productivity, resulting in a 27% reduction in final demand output in comparison to BAU, while sector 12 achieves the highest growth which translates to a 12% increase in final demand. It is interesting to note however, that even when sector 12 had the second highest emission intensity as indicated in **Table 5.4**, it still experienced the highest growth. The interdependence between the different sectors clearly contributes significantly to the over-all GHG emission of an economy. In addition, the sector size also plays a vital role since sector 12 was only ranked as the 11th most productive sector among the 18. The analysis of GHG emission reduction in an economy is not so straight forward. **Fig. D.2** in the **Appendix D** shows the contribution of each sector to the gross output and total GHG emissions. The combination of differentiated sector growth with either an adoption of a low-carbon electricity mix (scenario 3), the widespread use of energy saving measures (scenario 4) or low-carbon technology use in agriculture, waste and transport sectors (scenario 5), further reduces GHG emissions levels to 979 $MtCO_2e$, 1,057 $MtCO_2e$ and 934 $MtCO_2e$, respectively. These correspond to 13.2%, 6.7% and 17.2% reductions relative to BAU scenario, respectively. While the corresponding DALY results are 246,306 years for scenario 3, 266,030 years for scenario 4 and 235,312 years for scenario 5. The share of each sector to the gross output and their contribution to the total GHG emissions of the economy in these three scenarios are shown in **Figs. D.3**, **D.4** and **D.5** in the **Appendix D**, respectively. Finally, the solution of scenario 6, which combines all strategies outlined in scenarios 2 to 5, greatly reduces GHG generation to 855 $MtCO_2e$ while the corresponding health impact is 215,289 DALY. This result contributes to a reduction of 24.6% in GHG emissions compared to the results of scenario 1. **Fig. D.6** in the **Appendix D** shows the contribution of each sector to both gross output and total GHG emissions for scenario 6. Based on these results, the best measure for reducing GHG emissions is scenario 6 which has a total GHG emission of 855 $MtCO_2e$, followed by scenario 5 at 934 $MtCO_2e$, scenario 3 at 979 $MtCO_2e$, scenario 4 at 1,057 $MtCO_2e$, and finally scenario 2 at 1,058 $MtCO_2e$. It can be stated that scenario 6 achieves the lowest GHG emissions among all scenarios since it combined all measures indicated in scenarios 2 to 5. However, if only a single strategy is implemented, the most reduction was achieved in Scenario 5 when the emission intensity of agriculture, waste and transport were reduced. DALY values correspond to the impact of climate change to human health as a result of GHG emissions. This indicator shows the gap between the scenario being modelled and an ideal scenario where people live free of diseases. Lower values of DALY imply that the human health damage is less. A reduction of 24.2% in DALY relative to BAU was observed in scenario 6.

5.3. Policy implications

From the modeling results for the six scenarios given, there are important insights regarding policy implications on GHG emission mitigation strategies in Vietnam. These scenarios analyze the potential effectiveness of four measures to mitigate the GHG emission load of the Vietnamese economy. This includes differentiated sector growth to readjust economic structure such that non-carbon-intensive sectors are prioritized while the growth of carbon-intensive sectors are limited to a certain extent; adoption of low-carbon electricity mix through increased consumption of renewable and/or clean energy such as solar energy, wind energy and bio-gas in place of fossil fuels; extensive use of energy saving strategies and techniques; and the application of low-carbon technologies for agriculture, waste and transport sectors. The government can look at developing policies to facilitate economic growth in identified sectors by allocating investments for infrastructure improvement, increasing privatization of industries to boost technological innovations and improve production efficiencies, or increasing interest rates on undesirable activities. Each of the six scenarios was solved with limitations to indicate the general potential for emission cuts within allowed economic growth. Results indicate that allowing for a wider range in differentiated sector growth, contributes to the reduction in GHG emissions by 6.2% relative to BAU (scenario 2). Meanwhile, complementing scenario 2 with the technical interventions of reductions in GHG intensity of the power grid and other energy sectors by 40% and 30%, respectively (scenario 3); or with improved energy efficiency in electricity use and energy use per unit output (scenario 4); or reduction in GHG intensity of agriculture, waste and transport sectors (scenario 5) contribute to the reduction in GHG emissions by 13.2%, 6.7% and 17.2%, respectively.

If implemented all together, these measures result in a 24.6% reduction in overall GHG emissions relative to the baseline (from 1,128 to 855 $MtCO_2e$). This result almost meets the target of Vietnam's INDC of 25%. Furthermore, these combined measures reduce human health damage from the baseline indicator of 283,909 DALY to 215,289 DALY for scenario 6. It can be said that GHG mitigation targets in the Vietnam's INDC are suitable with the economic growth targets and the current resource conditions. However, it will require the simultaneous implementation of different GHG mitigating strategies.

More specific actions, which can be implemented, are given as follows:

- For decision makers and government, to propose proper regulations for managing energy consumption and GHG emissions especially in sectors contributing to high pollution load by implementing disincentives associated to energy consumption.
- For energy sectors, there is a need to further improve technology factors. According to KEPA and GreenID (2014), there is still considerable potential for achieving further energy use efficiency by optimizing the fuel mix consumption (i.e., decreasing oil and coal uses while increasing natural gas use). This can be done by replacing fossil fuels with renewable and clean energy such as wind, solar and bio-gas, and putting in place technology such as carbon capture and sequestration.
- To reduce emissions in household sectors, there is a need to make available more environment friendly goods and services or to decrease the use of energy-intensive commodities.
- To decrease emissions in transportation, the most appropriate option for Vietnam is to develop and invest in infrastructure suitable for efficient public transportation. Increasing the use of

energy-efficient vehicles to replace traditional ones is also helpful.

- For manufacturing sectors, the best option to reduce pollution is by improving the performance of current technologies by applying innovative technologies, enhancing process efficiency and waste treatment systems, and shifting from carbon intensive raw materials into low-carbon intensive inputs.

- For agriculture, forestry and fishery sectors, there is a need to further apply the advanced technologies in agricultural production and waste treatment and to reduce pesticide use. Moreover, the reinforcement of sustainable forest management and conservation of forest carbon stocks are also necessary to contribute to GHG emission mitigation from these sectors.

5.4. Conclusions

An LP-IO model was developed in this work to determine the minimum total GHG emissions achievable in Vietnam by the year 2030 while allowing for economic development. The results indicate that the combination of differentiated sector growth, shift to low-carbon energy, improving energy efficiency in the final consumption throughout the entire economy, and the application of energy efficient technologies in agriculture, waste and transport sectors can achieve a total reduction of 24.6% in GHG emission load by 2030. This figure almost meets the official INDC of Vietnam, which commits to a 25% reduction relative to BAU. In addition, these combined measures can also help save 68,620 years of DALY compared to the baseline.

These results can help policy makers in analyzing the potential effectiveness of applying various specific measures for reducing emissions. The government can look at improving infrastructure to support the development of low-carbon technologies and providing a more encouraging environment for the private sector to improve their efficiency levels through technological innovation. While this work focuses on the case of Vietnam, the same methodology can be easily adapted for use in other nations provided the necessary economic and environmental data are available. The model developed does not account for GHG emissions embedded in trade; future work can focus on an extended model to consider such aspects. A more comprehensive evaluation of the emissions in the Vietnamese economy can be done with such a model to aid in crafting strategies to further reduce emissions. In addition, techniques for handling data uncertainty can be integrated in the model to evaluate how variations in data (e.g., for new technologies) affect the over-all performance of an economy.

References

Aviso KB, Tan RR, Culaba AB, Cruz Jr JB (2011) Fuzzy input-output model for optimizing eco-industrial supply chains under water footprint constraints. J. Clean. Prod., 19(2-3):187-196.

Cayamanda CD, Aviso KB, Biona JBM, Culaba AB, Promentilla MAB, Tan RR, Ubando AT (2017) Mapping a Low-Carbon Future for the Philippines: Scenario Results from a Fractional Programming Input-Output Model. Process Integration and Optimization for Sustainability, 1(4):293-299.

Chen TY (2001) The impact of mitigating CO2 emissions on Taiwan's economy. Energy Economics, 23(2):141-151.

Cohen B (2017) Modelling approaches for greenhouse gas emissions projections from the waste sector. Sustainable Production and Consumption, 10:15-20.

Danish Energy Agency (DEA) (2017) Vietnam Energy Outlook Report 2017. https://ens.dk/sites/ens.dk/files/Globalcooperation/ Official_docs/Vietnam/vietnam-energy-outlook-report-2017-eng.pdf. Accessed on 10 Jan 2018

de Carvalho AL, Antunes CH, Freire F, Henriques CO (2016). A multi-objective interactive approach to assess economic-energy-environment trade-offs in Brazil. Renewable and Sustainable Energy Reviews, 54:1429-1442.

de Schryver AM, Brakkee KW, Goedkoop MJ, Huijbregts MA (2009) Characterization factors for global warming in life cycle assessment based on damages to humans and ecosystems. Policy Analysis, 43(6):1689 – 1695.

Fan Y, Zhang X, Zhu L (2010) Estimating the macroeconomic costs of CO2 emission reduction in China based on multi-objective programming. Advances in Climate Change Research, 1(1):27-33.

Forster P, Ramaswamy V, Artaxo P, Berntsen T, Betts R, Fahey DW, Haywood J, Lean J, Lowe DC, Myhre G, Nganga J, Prinn R, Raga G, Schulz M, Van Dorland R (2007) Changes in atmospheric constituents and in radiative forcing. In Climate Change 2007: The Physical Science Basis. Intergovernmental Panel on Climate Change: Cambridge, U.K. and New York.

General Statistical Office (GSO) (2013) Input-output: IO of Vietnam year 2011. Statistical Publishing House: Hanoi.

Goedkoop M, Heijungs R, Huijbregts MAJ, de Schryver A, Struijs J, van Zelm R (2009) ReCiPe 2008. A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. http://www.lcia-recipe.net. Accessed on 7 July 2017

International Energy Agency (IEA) (2016) CO2 Emissions from Fuel Combustion, OECD/IEA, Paris. http://wds.iea.org/wds/pdf/Worldco2_Documentation.pdf. Accessed on 30 May 2017

Haimes YY, Jiang P (2001) Leontief-based model of risk in complex interconnected infrastructures. Journal of Infrastructure systems, 7(1):1-12.

Heijungs R, Suh S (2013) The computational structure of life cycle assessment (Vol. 11). Springer Science & Business Media, Dordrecht.

Hoa NT, Promentilla MAB, Yu KDS, Aviso KB (2016) A model for multi-criterion disaster vulnerability assessment of economic systems: implications for Vietnam's bioethanol policy. Clean Technologies and Environmental Policy, 18(6):1917-1929.

Hofstetter P (2000) Perspective in life cycle impact assessment: A structured approach to combine of the technosphere, ecosphere and valuesphere. The International Journal of Life Cycle Assessment, 5(1):58-58.

Hristu-Varsakelis D, Karagianni S, Pempetzoglou M, Sfetsos A (2010) Optimizing production with energy and GHG emission constraints in Greece: An input–output analysis. Energy Policy, 38(3):1566-1577.

Hristu-Varsakelis D, Karagianni S, Pempetzoglou M, Sfetsos A (2012) Optimizing production in the Greek economy: Exploring the interaction between greenhouse gas emissions and solid waste via input–output analysis. Economic Systems Research, 24(1):57-75.

Hsu GJY, Leung P, Ching CTK (1987) A multiobjective programming and interindustry model for energy-economic planning in Taiwan. Energy Systems and Policy, 11(3):185 – 204.

KEPA and GreenID (Service Center for Development Cooperation & Green Innovation and Development Centre) (2014). Assessment of policies on GHG mitigation in Vietnam, 1–31. https://www.kepa.fi/tiedostot/final_report_vietnam_1marz2014.pdf. Accessed on 10 April 2017

Köllner T (2000) Species-pool effect potentials (SPEP) as a yardstick to evaluate land-use impacts on biodiversity. Journal of cleaner production, 8(4):293-311.

Kouloumpis V, Stamford L, Azapagic A (2015) Decarbonising electricity supply: Is climate change mitigation going to be carried out at the expense of other environmental impacts?. Sustainable Production and Consumption, 1:1-21.

Leontief WW (1936) Quantitative Input and Output Relations in the Economic System of United States. Review of Economics and Statistics, 18(3):105-125.

Leontief WW (1970) Environmental repercussions and the economic structure: an input-output approach. The review of economics and statistics, 52 (3):262-271.

Mazyrin VM (2013) Economic modernization in Vietnam from industrialization to innovation stage. Journal of Economics and Business, 29(2):87-106.

McMichael AJ, Campbell-Lendrum DH, Corvalan CF, Ebi KL, Githeko A, Scheraga JD, Woodward A (2003) Climate change and human health: risk and responses; World Health Organization: Geneva, Switzerland, 322.

Miller RE, Blair PD (2009) Input-output analysis: foundations and extensions. New York, United States of America: Cambridge University Press.

Ministry of Natural Resources and Environment (MNRE) (2014) The initial biennial updated report of

Viet Nam to the United Nation Framework Convention on climate change. Viet Nam publishing house of nature resources, environment and cartography. MNRE, Ha Noi, 2014. http://unfccc.int/resource/docs/natc/vnmbur1.pdf. Accessed on 08 March 2017

Murray CJ, Lopez AD, World Health Organization (1996) The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020. Global Burden and Injury Series Volume I. Harvard School of Public Health, World Bank, World Health Organisation, USA.

Nguyen HT, Aviso KB, Kojima N, Tokai A (2018) Structural analysis of interrelationship between economic activities and wastewater emissions in Vietnam in the period of 2000 -2011. Clean Techn. Environ. Policy, 20(3):621-638. https://doi.org/10.1007/s10098-018-1492-8

Nguyen HT, Nguyen LT (2014) Low carbon society scenarios Vietnam 2030. Research conducted in collaboration between the Institute of Strategy and Policy on National Resources and Environment (ISPONER) from Vietnam, and Kyoto University (KU), National Institute for Environmental Studies (NIES), Institute for Global Environmental Strategies (IGES), E-Konzal and Mizuho Information and Research Institute (MHIR) from Japan. http://2050.nies.go.jp/LCS/eng/list.html. Accessed on 02 July 2018

Oliveira C, Antunes CH (2004) A multiple objective model to deal with economy–energy–environment interactions. European Journal of Operational Research, 153(2):370-385.

Oliveira C, Coelho D, Antunes CH (2016) Coupling input–output analysis with multiobjective linear programming models for the study of economy–energy–environment–social (E3S) trade-offs: a review. Annals of Operations Research, 247(2): 471-502

PricewaterhouseCoopers (2017) The world in 2050. https://www.pwc.com/gx/en/world-2050/assets/pwc-the-world-in-2050-full-report-feb-2017.pdf. Accessed on 07 July 2017

Quaddus MA, Holzman AG (1985) Interactive approach to macroeconomic planning with multiple objectives: Results of an experiment. In N. K. Jaiswal (Ed.), OR for developing countries. New Delhi: The Operational Research Society of India, 89–100.

Tan RR, Culaba AB, Aviso KB (2008) A fuzzy linear programming extension of the general matrix-based life cycle model. Journal of Cleaner Production, 16(13):1358-1367.

Tan RR, Ballacillo JAB, Aviso KB, Culaba AB (2009) A fuzzy multiple-objective approach to the optimization of bioenergy system footprints. Chemical Engineering Research and Design, 87(9):1162-1170.

Tuyen TM, Michaelowa A (2006) UNFCCC Kyoto protocol clean development mechanism baseline construction for Vietnam national electricity grid. Mitigation and Adaptation Strategies for Global Change, 11(3):723-740.

United Nations (2002) International Standard Industrial Classification of All Economic Activities, Rev.3. (ISIC 3). https://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=2. Accessed on 12 June 2016

United Nations Framework Convention on Climate Change (UNFCC) (1998) Available online: http://unfccc.int/resource/docs/convkp/kpeng.pdf. Accessed on 30 September 2017

United Nations Framework Convention on Climate Change (UNFCC) (2015a) Adoption of the Paris Agreement, 1-32. https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf. Accessed on 08 Feb 2018

United Nations Framework Convention on Climate Change (UNFCC) (2015b) Intended Nationally Determined Contribution of Vietnam, 1-11. http://www4.unfccc.int/ndcregistry/PublishedDocuments/Viet%20Nam%20First/VIETNAM'S%20INDC.pdf. Accessed on 08 Feb 2018

Vietnam Government Portal, n.d. National Strategy on Climate Change (2011). http://www.chinhphu.vn/portal/page/portal/English/strategies/strategiesdetails?categoryId=30&articleId=10051283. Accessed on 10 Nov 2017

Vogstad KO (2009) Input-output analysis and linear programming. In S. Suh (ed.), Handbook of input-output economics in industrial ecology. Eco-efficiency in industry and science (pp. 801-818). Springer, Dordrecht.

Vu CH (2013) Economic restructure and reform of growth model in Vietnam. Wies I Rolnictwo, NR 3 (160).

West JJ, Smith SJ, Silva RA, Naik V, Zhang Y, Adelman Z, Fry MM, Anenberg S, Horowitz LW, Lamarque JF (2013) Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. Nature climate change, 3(10):885.

Williams JH, Debenedictis A, Ghanadan R, Mahone A, Moore J, Iii WRM, Price S, Torn MS (2012) Greenhouse Gas Emissions Cuts by 2050 : The Pivotal Role of Electricity. Science (80-.). 335:53–59.

Yu KDS, Tan RR, Aviso KB, Promentilla MAB, Santos JR (2014) A vulnerability index for post-disaster key sector prioritization. Economic Systems Research, 26(1):81-97.

Chapter 6 Conclusions

6.1. Summary

The rapid economic growth and poor environmental management have left many countries such as Vietnam with severe environmental pollution. Although many regulations and strategies were proposed to treat and manage environment, but they have not brought positive effect. It is thus important to develop models to evaluate the different aspects in relation to economic activities and pollution flows in order to identify strategies for comprehensively economic-environment system management within the context of economic development. The different aspects which need implementing to obtain this objective include the analysis of relationship between economic sectors and environmental flows, the identification of role of economic sector, the analysis of driving forces of pollutant change, the readjustment of economic structure, the improvement of technical factors and evaluation of human health risk. Recent works have demonstrated the effectiveness of the IO model in analyzing these different aspects for economic-environmental system management. However, previous researches just focused on individual aspect, which do not present a comprehensive picture on how the economic growth of various economic sectors affects the environmental problems. The consolidation of various aspects associated to behaviors of economic-environmental flows is needed to propose comprehensive strategies for promoting sustainable economic-environmental growth. However, this has been limited in previous studies. For Vietnamese economy, the analysis and consolidation of different aspects also have not been fully addressed in previous studies.

Hence, this PhD thesis analyzes the different aspects based on integrated economic-environmental management framework, which involves five components of modified DPSIR model including *driving forces*, *pressures*, *states*, *impacts* and *responses*, to identify strategies for economic-environment system management using the IO approach for Vietnam economy. The different aspects are analyzed in different chapters. The content of each chapter is summarized as following:

In chapter 2, a preliminary investigation of the total water pollution load (*pressures*) as indicated by water quality parameters (*states*) contributed by economic activities in Vietnam is carried out. The methods take advantage of available IO tables in 2000, 2007 and 2011 and other economic data in Vietnam to calculate for two conventional water quality indicators namely TSS and BOD. The results show a tremendous increase in TSS, from 345,000 tonnes in 2000 to 1,199,000 tonnes in 2011 while the total BOD increased from 43,400 tonnes in 2000 to 123,000 tonnes in 2011. For TSS, Sector 9 (basic metal industry) was the main contributor, while Sector 3 (food, beverage and tobacco) and Sector 1 (agriculture, fishery and forestry) were the main contributors for BOD.

In taking into account of the linkages among economic sectors and the interrelationship between economic sectors and water pollution, the combination of EIO and VIC methods is employed to identify the role of sectors as producer/seller or consumer/purchaser or both seller and purchaser (key sectors) of water pollution. The IO table of 2011 is used for this purpose and the results highlight that for both TSS and BOD, Sector 1 (agriculture, fishery and forestry) and Sector 3 (food, beverage and tobacco) were considered as key sectors, Sector 9 (basic metal industry) was the highest pollution pusher, while Sector 10 (manufacturing of fabricated metal products, machinery and equipment) and Sector 13 (construction) were the highest pollution pullers. Finally, based on the analysis of time cost change of water pollution and the role of sectors in relation to water pollution, the suggestions of pollution reduction priority are presented to help government, policy makers, household sectors and industrial manufactures in identifying the proper water pollution mitigation strategies.

In chapter 3, the IO-SDA model is used to analyze underlying driving forces (*driving force* component) for the changes in energy-based CO_2 emissions in Vietnam during two periods 2000 - 2007 and 2007 - 2011. These method makes use of available IO tables in 2000, 2007 and 2011 and other socio-economic data to indicate the variation of CO_2 emissions contributed by economic activities for both production perspective (technology, production structure, consumption structure, consumption volume and population growth) and final demand perspective (government, household, investment, import and export).

The results from the production perspective indicate that the overall of Vietnam's energy-related CO_2 emissions from 2000 to 2011 increased by 188.8% (83,495 kt). In light of this, consumption structure and consumption volume were the main drivers responsible for this incremental change in CO_2 emissions, while CO_2 pollution intensity and production structure were two main factors, which offset this increase. Population growth, however, had a small effect on the increase in CO_2 emissions but it may have significant effect if population growth rate increased rapidly in the future. From the final demand perspective, household, export and investment are the main drivers responsible for the sharp increase in CO_2 emissions, while import factor contributes to the abatement of CO_2 emissions. Government had inconsiderable effect on the increase in CO_2 emissions. Between these two periods, different factors contributed differently to the increase and decrease in CO_2. Consumption structure has the largest variation with an increase of 120.9% during 2000 - 2007 and a decrease of 20.5% between 2007 and 2011. This was due to increase in import activities in the second period resulting from the accession to WTO in 2007. In consideration of CO_2 changes by sector, Sector 11 (other manufacturing industries), Sector 15 (transportation and communication) and Sector 18 (personal, community, and household services) were energy-intensive sectors, which contributed greatly to the total CO_2 emissions during 2000-2007. In contrast, between 2007 and 2011, besides the energy-intensive sectors mentioned above, manufacturing sectors such as Sector 9 (basic metal industry,), Sector 8 (manufacture of non-metallic mineral products), Sector 7 (manufacture of industrial chemicals) and Sector 4 (textile, wearing apparel and leather industries) also have high CO_2 emissions and strongly impacted the changes in CO_2 emissions in this period. These results suggest that the mitigation of domestic CO_2 emissions in Vietnam can be obtained by CO_2 pollution intensity reduction, structural adjustment and optimization of production and final demand activities. Furthermore, optimizing international trade is significant for reduction of national and global CO_2 emissions.

Chapter 4 examines the potentials of GHG intensity reduction in response to a climate policy (*responses*) given by Vietnamese government considering different economic growth rates and the change of technology state from economic activities. First, the approach of forward-backward linkages is used to indicate the backward linkage sectors, forward linkage sectors and key sectors in terms of economic and GHG emission performance. The sectors are prioritized as follows: Sector 1 (agriculture, fishery and forestry), Sector 15 (transportation and communication), Sector 18 (personal, community and household services), Sector 8 (manufacture of non-metallic mineral products) and Sector 2 (mining and quarrying), which have high impact in terms of both economy and GHG emissions. These sectors need to focus on pollution mitigation strategies; thus, the consideration of their pollution intensity reduction is proposed in optimization model. Second, an optimization approach based on IO-LP is developed and solved in order to minimize the total GHG emissions (in Mt CO_2e) focusing on different GDP growth rates and readjustment of economic structure at different ranges. The IO table and GHG emission data in 2011 are used as economic and environmental data, which serve as the baseline to compute for the growth trajectories to 2020. The reduction of GHG intensity in 2020 relative to the year 2011 is then given to compare to the given policy. The results reveal that the combination of increased GDP growth rate, readjustment of economic structure and application of low-carbon techniques in the priority sectors can achieve the highest reduction potential of GHG intensity (by 20.3%). This figure exceeds the target outlined in Decision No. 1393 which mandates the reduction of GHG intensity by 8-10% during 2010-2020 in comparison to the 2010 level. In addition, these combined measures do not only contribute to the increase in 1,911 trillion VND of total GDO, 943 trillion VND of GDP compared to BAU scenario; but, they also help save 21,150 Mt CO_2e of total GHG emissions and 5,533 years of DALY (*impact*).

Chapter 5 develops an IO-LP model to seek the minimum total GHG emissions (in CO_2e) achievable in Vietnam even when economic growth is still desired. The IO table of 2011 as economic data is used to develop this model. The results indicate that the combination of differentiated sector growth, shift to a low-carbon energy, improving energy efficiency in the final consumption throughout the entire economy, and the application of low-carbon techniques in agriculture, waste and transport sectors can achieve the total reduction of 24.6 % in GHG emission load by 2030. This figure almost meets the targets outlined in the INDC of Vietnam (*responses*) which committed 25% reduction relative to BAU. In addition, these combined measures can help save 68,620 years of DALY (*impacts*) compared to baseline.

6.2. Policy implications

Based on the analysis and assessment results of the different aspects based on modified DRSIR framework including 5 components - *driving forces*, *pressures*, *states*, *impacts* and *responses*, there are some policy implications proposed to help government, policy makers, household sectors, industrial manufacturers and relevant partners in Vietnam in developing strategies for effectively economic-environmental system management:

For manufacturing sectors, the best way to reduce pollution of economic sectors is to lower the value of pollution intensity (PI). As analysis results of driving forces in chapter 3, PI representing for technology factor is a strong driver in offsetting pollution (especially for GHG emissions). Thus, there is a need to further improve energy use efficiency through fuel mix use (i.e., increasing natural gas use and decreasing coal and oil uses), replacement of fossil fuels by renewable and clean energy such as solar energy, wind energy and bio-gas, and carbon capture and sequestration. Furthermore, production structure should be improved through increasing resource efficiency such as reducing highly pollutive inputs, recycling products and waste.

For policy makers and government, there is a need to propose policies for encouraging continued energy conservation. In addition, strong policies are required to capture other potentials to reduce emissions through economic structural adjustment and optimization in production and consumption. Furthermore, according to chapter 3, the rapid population growth in big cities may affect environmental-social-economic development. Thus, policy makers and government should give polices to encourage birth rate reduction. This will be of significance for emission reduction.

To reduce emissions from household sectors, there is a need to shift structure toward using more environmental friendly products or reducing the consumption of energy-intensive products such as electricity and appliances.

To reduce emissions due to impact of trade and investment, there is a need to use investment sources towards improving the efficiency of technologies or using cleaner technologies. Investment can be used to stimulate the enterprises toward low-CO_2 production development. To reduce pollution from trade activities, there is a need to import goods from more efficient production countries. Furthermore, the optimization of trade structures between Vietnam and other countries is also useful to reduce emissions. Finally, reducing the import of highly-pollutive materials also help reduce emissions for domestic production.

6.3. Contribution of this study

Current mathematical models are developed based on the foundation of IO and integrated economic-environmental framework (modified DPSIR) to analyze different aspects related to economic-environmental system management for Vietnam. First, these models analyze the inter-relationship between environmental flows and economic activities. Its extension shows the linkages among sectors through integration of IO model and VIC approach. This method is useful to identify the role of sectors in terms of both economic and environmental sides. Furthermore, application of IO-SDA for analysis of socio-economic driving forces is helpful to identify the role of various factors in increase or decrease of pollution resulting from economic activities. Solving optimization problem using IO-LP is needed to assess climate policy considering different economic growth rates, economic restructure and technical status improvement for high-polluting economic sectors. Furthermore, IO-LP is extended to seek the maximum the reduction in pollution when scenarios are considered for analyzing the potential of pollution reductions. These scenarios focus on improving technology factors in economic production activities such as clean energy use, energy conservation, energy efficiency enhance and treatment system improvement. In addition, these model are also successful in assessing human health impact which is induced by climate change due to pollution releasing from economic sectors and indicate how to reduce people health damage when the regulations of pollution mitigation are implemented. Finally, based on the analysis results of different economic-environmental aspects, policy implications for economic-environmental system management are presented to help government, policy makers, household sectors and industrial manufactures in designing regulations and policies for sustainable economic-environmental management.

This research is successfully applied for the Vietnam case, but it can be easily adapted for use in other nations with existing IO tables and other economic - environmental data. Furthermore, these methods can be applied for assessing the effect of any kind of pollutants induced by various economic sectors, once the data are available.

6.4. Limitation and future work

Although this thesis is successful to develop a framework for economic-environmental system management for Vietnam, there are still several limitations. First, environmental data such water pollution data used in chapter 2 is not available for Vietnam, thus the global data obtained from IPPS is used to calculate. This may result in some uncertainties. Furthermore, the other environmental data for Vietnam are not available even in secondary database, thus this thesis just focuses on water pollution and GHG emissions. Meanwhile, other pollutants such as solid waste, hazard chemicals and other kinds of water pollution and air pollution are not considered. In addition, only the effect of emissions on domestic production has been considered while the effects from trade activities among countries still need to be investigated on. Using pure IO analysis also has some limitations that input requirement and relative prices are assumed constant. This will make some uncertainty when applying several economies such as modern economic system. Furthermore, the application of pure IO model cannot deal with detailed issues in processing models or a supply chain, which use physic units.

Therefore, future work can focus on other pollutants in Vietnam in consideration of different environment media such as water, air and land. Furthermore, trade effects should be taken into account to provide a more comprehensive evaluation of the impact of emissions on the Vietnamese economy. In addition, tools for handling data uncertainty can be integrated in the model to result in more robust analysis. Finally, the combination of EIO model with other approaches such as life cycle assessment so called EIO-LCA or dynamic input – output model will help to overcome the limitation of pure IO analysis.

Appendices

Appendix A

The method of vertically integrated coefficient

The method of VCI is developed by Sanchez-Choliz and Duarte (2003) which is based on the Leontief equation:

$$\hat{x}_i = A\,\hat{x}_i + \hat{y}_i \tag{A1.1}$$

Eq. (A1.1) can be modified to be new equation:

$$\hat{x}_i = \left(\text{I-A}\right)^{-1} \hat{y}_i \tag{A1.2}$$

where $\hat{y}_i$ vector of final demand

$\hat{}$ symbol for diagonal matrix

$A = (a_{ij})$ technical coefficient matrix with n x n dimension

I identity matrix

From **Eq. (A1.1)** and **Eq. (A1.2)**, it can be rewritten as:

$$\hat{x}_i = A\left(\text{I-A}\right)^{-1} \hat{y}_i + \hat{y}_i = M\,\hat{y}_i + \hat{y}_i \tag{A1.3}$$

where $$M = A\left(\text{I-A}\right)^{-1} = (m_{ij}) \tag{A1.4}$$

$$(\alpha_{ij}) = (\text{I-A})^{-1} \quad \text{(Leontief inverse)} \tag{A1.5}$$

Then if we multiply pollution intensity PI_j^k , which is the amount of pollution load of an activity j for k-type environmental quality parameter emitted to produce one unit of monetary output for that activity, with final demand y_i we obtain the total value of k-parameter:

$$\hat{DI}_i^k = \sum_{j=1}^{n} PI_j^k \alpha_{ji} \hat{y}_i \tag{A1.6}$$

is the k-parameter that is associated with the production of the final demand y_i of sector i.

Furthermore, pre-multiplying **Eq. (A1.3)** by vector $\hat{PI}_j^k$, we obtain:

$$PI_j^k \hat{x}_i = PI_j^k \hat{M} \hat{y}_i + PI_j^k \hat{y}_i \qquad \text{(A1.7)}$$

It can be seen that **Eq. (A1.7)** can be broken down into:

$$PI_j^k \alpha_{ji} y_i = PI_j^k m_{ji} y_i \quad \text{if } i \# j \qquad \text{(A1.8)}$$

And $PI_i^k \alpha_{ii} y_i = PI_i^k m_{ii} y_i + PI_i^k y_i$ if $i = j$ (A1.9)

From the combination of three Equations (**Eq. A1.6**, **A1.8** and **A1.9**), it can be written as follows:

$$DI_i^k = \sum_{j=1, j\#i}^{n} PI_j^k \alpha_{ji} y_i + PI_i^k \alpha_{ii} \hat{y}_i = \sum_{j=1, j\#i}^{n} PI_j^k \alpha_{ji} y_i + PI_i^k m_{ii} y_i + PI_i^k y_i$$
$$= \sum_{j=1, j\#i}^{n} PI_j^k \alpha_{ji} y_i + PI_i^k \left(\sum_{j=1, j\#i}^{n} a_{ij} \alpha_{ij} \right) y_i + PI_i^k a_{ii} \alpha_{ii} y_i + PI_i^k y_i \qquad \text{(A1.10)}$$

Each term of **Eq. (A1.10)** is defined as follows:

$$TB_i^k = \sum_{j=1, j\#i}^{n} PI_j^k \alpha_{ji} y_i$$ True backward linkage (A1.11)

$$SE_i^k = PI_i^k \left(\sum_{j=1, j\#i}^{n} a_{ij} \alpha_{ij} \right) y_i$$ Semi-own pollution (A1.12)

$$OW_i^k = PI_i^k a_{ii} \alpha_{ii} y_i$$ Own pollution (A1.13)

$$FI_i^k = PI_i^k y_i$$ Final demand pollution (A1.14)

<u>Forward linkage:</u>

$PI_i^k x_i$ is total pollution load of sector *i* which consists of TB_i^k, SE_i^k, OW_i^k, FI_i^k and the one emitted to produce inputs for other sectors without returning which is considered as true forward linkage:

$$TF_i^k = PI_i^k x_i - FI_i^k - OW_i^k - SE_i^k \qquad \text{(A1.15)}$$

The difference between true backward linkage and true forward linkage is following:

$$d_i = TB_i^k - TF_i^k \qquad \text{(A1.16)}$$

d_i tells us whether true backward linkage (buying of pollution from other sectors) or true forward linkage (selling of production to other sectors) is the larger. If $d_i > 0$, then sector *i* is an overall polluting pullers and other sectors pollute for it. if $d_i < 0$, then sector *i* is an overall polluting pusher and pollutes for other sectors to obtain their final demands.

Table A.1 Framework of IO table 2011

Billion VND	Sector Code	Name	Intermediate demand				Final demand (**y**)					**x**
							Final consumption			Ex	Im	
			1	2	…	18	HH	G	C			
Intermediate input	1	Agriculture	150,641	6		722	160,099	0	213,201	178,657	53,106	1,029,583
	2	Mining, quarrying	815	14,410	…	118	5,392	0	26,270	235,050	17,971	339,396
	…	…	…	…	…	…	…	…	…	…	…	…
	18	Personal, Community…	376	575	…	16,456	196,235	45,329	0	9,354	38,428	243,780
Pollution intensity		TSS	0.039	0.045	…	0.001	(Kg/million VND)					
		BOD	0.033	0.020	…	0.002						

Table A.2 Spearman rank correlation between estimated BOD and TSS at the provincial level

(Source: ICEM 2007)

	IPPS BOD	CTC BOD	IPPS TSS	CTC TSS
IPPS BOD	1			
CTC BOD	0.69	1		
IPPS TSS	0.77	0.66	1	
CTC TSS	0.71	0.96	0.71	1

Table A.3 Spearman rank correlation between estimated BOD and TSS at the sectoral level

(Source: ICEM 2007)

	IPPS BOD	CTC BOD	IPPS TSS	CTC TSS
IPPS BOD	1			
CTC BOD	0.33	1		
IPPS TSS	0.74	0.2	1	
CTC TSS	0.37	0.95	0.24	1

Table A.4 Water quality parameter-extended IO table in 2011

	i \ j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	y
Economic sector (Billion VND)	1	150,642	6	303,083	4,273	11,065	1,130	5,290	673	1	61	7,918	36	521	9,117	35,178	872	142	723	498,852
	2	816	14,411	2,629	364	91	963	2,963	16,426	4,292	1,969	18,198	13,268	11,876	579	1,236	456	1	119	248,742
	3	132,430	21	288,153	81	100	144	3,892	58	5	111	110	32	54	7,987	47,153	241	208	815	409,842
	4	2,148	173	1,398	268,130	581	3,662	455	896	22	8,004	7,784	398	1,711	6,137	947	1,243	318	606	175,040
	5	809	55	315	255	16,119	1,721	319	527	5	1,694	55,039	24	5,104	307	345	269	148	244	-28,616
	6	297	64	16,093	5,671	639	44,367	2,827	7,380	51	3,434	6,872	266	3,807	2,371	7,455	2,899	3,360	3,560	-12,923
	7	65,264	10,224	14,349	45,432	2,800	5,295	95,428	5,190	317	23,205	70,890	738	5,635	1,574	960	2,353	525	18,914	-148,341
	8	1,077	416	2,168	313	1,098	124	4,473	59,073	2,028	11,832	3,208	313	143,531	1,429	991	619	184	601	-33,516
	9	308	9,888	3,232	721	877	150	1,710	2,839	120,586	164,154	7,291	241	97,213	625	448	864	55	154	-253,859
	10	4,173	3,340	9,941	4,741	613	1,527	2,849	4,408	2,438	380,223	16,117	6,024	31,847	8,241	9,725	3,692	3,311	4,431	447,211
	11	42,113	33,725	36,793	16,618	1,454	9,273	26,320	14,163	3,405	104,370	145,229	11,938	40,854	30,714	71,559	8,226	5,740	8,218	-136,833
	12	7,764	3,066	10,521	9,679	1,013	3,714	4,786	13,014	3,063	15,611	8,791	26,473	3,949	12,379	11,971	7,445	2,539	5,075	24,393
	13	791	1,733	414	413	31	30	61	115	44	1,143	1,837	1,055	29,857	1,830	5,080	967	2,937	1,638	634,237
	14	28,308	5,852	45,229	17,767	1,779	4,413	11,346	8,348	2,465	46,821	16,450	2,971	20,533	10,152	18,021	2,162	2,272	3,375	367,326
	15	8,889	15,681	24,149	7,105	1,142	2,986	9,864	3,857	1,760	19,189	7,033	2,140	15,783	27,561	44,683	18,310	8,585	7,692	316,520
	16	2,551	2,997	8,991	4,518	469	566	4,576	2,305	1,065	12,106	5,862	3,609	9,540	16,623	17,830	119,507	5,773	12,434	169,510
	17	26	27	13	23	10	2	9	6	4	32	29	11	21	4	76	42	4,556	162	140,511
	18	376	575	784	295	66	79	252	335	46	616	230	5,347	671	984	965	814	2,399	16,456	212,491
PI	TSS	0.03945	0.04458	0.04738	0.00851	0.00540	0.53005	0.19988	0.02480	5.34863	0.00243	0.21248	0.01147	0.03610	0.03792	0.00001	0.00062	0.00092	0.00123	Kg/million
	BOD	0.03288	0.01950	0.05010	0.00423	0.00118	0.15847	0.02850	0.00064	0.06701	0.00019	0.00287	0.00008	0.00000	0.00004	0.00000	0.00228	0.00226	0.00227	VND

Table A.5 Values of pollution components in 2011

Sector Code / Parameters	Components	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
TSS (kt)	TB_i^k	208.5	282.5	320.8	160.5	-32.7	-13.1	-175.9	-45.1	-29.5	3364.6	-222.3	17.1	2813.6	125.6	221.1	61.1	71.0	107.6
	TF_i^k	15.1	3.3	10.6	0.7	0.5	64.9	101.5	6.2	6872.0	0.4	148.8	1.7	0.7	8.9	0.0	0.1	0.0	0.0
	SE_i^k	2.1	0.2	2.0	0.0	0.0	-0.1	-2.9	0.0	-55.2	0.1	-4.3	0.0	0.1	0.3	0.0	0.0	0.0	0.0
	OW_i^k	3.7	0.5	10.2	1.9	-0.1	-5.7	-24.8	-0.4	-4616.5	0.8	-14.7	0.1	1.0	0.2	0.0	0.0	0.0	0.0
	FI_i^k	19.7	11.1	19.4	1.5	-0.2	-6.8	-29.7	-0.8	-1357.8	1.1	-29.1	0.3	22.9	13.9	0.0	0.1	0.1	0.3
	DI_i^k	234.0	294.3	352.4	163.9	-32.9	-25.8	-233.2	-46.3	-6059.1	3366.5	-270.5	17.4	2837.6	140.1	221.1	61.2	71.1	107.9
	PL_i^k	40.6	15.1	42.2	4.1	0.3	52.2	44.1	5.0	842.4	2.3	100.7	2.0	24.7	23.3	0.0	0.2	0.1	0.3
	d_i	193.4	279.1	310.2	159.9	-33.2	-78.0	-277.4	-51.3	-6901.5	3364.2	-371.1	15.4	2812.9	116.7	221.1	61.0	71.0	107.6
BOD (kt)	TB_i^k	13.7	5.5	20.2	7.3	-1.4	-0.4	-5.5	-1.5	-3.8	50.5	-7.6	0.4	45.4	4.6	11.4	2.1	2.7	4.6
	TF_i^k	12.6	1.5	11.3	0.3	0.1	19.4	14.5	0.2	86.1	0.0	2.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
	SE_i^k	1.7	0.1	2.1	0.0	0.0	0.0	-0.4	0.0	-0.7	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	OW_i^k	3.1	0.2	10.8	0.9	0.0	-1.7	-3.5	0.0	-57.8	0.1	-0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0
	FI_i^k	16.4	4.9	20.5	0.7	0.0	-2.0	-4.2	0.0	-17.0	0.1	-0.4	0.0	0.0	0.0	0.0	0.4	0.3	0.5
	DI_i^k	34.9	10.7	53.6	9.0	-1.4	-4.2	-13.7	-1.6	-79.3	50.7	-8.2	0.4	45.4	4.6	11.4	2.6	3.0	5.1
	PL_i^k	33.9	6.6	44.7	2.0	0.1	15.6	6.3	0.1	10.6	0.2	1.4	0.0	0.0	0.0	0.0	0.9	0.3	0.6
	d_i	1.1	4.1	8.9	7.0	-1.5	-19.8	-20.0	-1.7	-89.9	50.5	-9.6	0.4	45.4	4.6	11.4	1.7	2.7	4.5

Appendix B

Structural decomposition method

As presented in Methods, the changes of CO_2 emissions are decomposed into five terms and each term expresses the contribution of the changing factor to total CO_2 emissions. According to Koh et al. (2016), **Eq. (3.6)** is rewritten as follows:

$$\Delta Q = w^p \Delta p + w^q \Delta q + w^L \Delta L + w^{y_s} \Delta y_s + w^{y_v} \Delta y_v \qquad \text{(B.1)}$$

where $w^p, w^q,\ w^L,\ w^{y_s}$ and w^{y_v} are called weight or coefficient for each the change of factor (Δfactor) population, pollution intensity, production structure, consumption structure and consumption volume, respectively. Due to no unique solution for the decomposition, Dietzenbacher and Los (1998) and Haan (2001) suggested to use the average of all the k! (5! = 120) decomposition equations. The calculation of Δfactor and weight or coefficient were given in detail in Koh et al. 2016. In light with this, assuming that in each given period, the changing factor is calculated from base year (t-1) to the target year (t). Therefore, each "w" attached to the Δfactor in **Eq. (B.1)** can be expressed, for example:

$$w^p \Delta p = \frac{1}{120}[\big(24\,.\,\Delta p\,.\,q_{(t-1)}\,.\,L_{(t-1)}\,.\,y_{s(t-1)}\,.\,y_{v(t-1)}\big) +$$

$$(6\,.\,\Delta p\,.\;q\,.\,L_{(t-1)}\,.\,y_{s(t-1)}\,.\,y_{v(t-1)}) +$$

$$\big(6\,.\,\Delta p\,.\;q_{(t-1)}\,.\,L_{(t)}\,.\,y_{s(t-1)}\,.\,y_{v(t-1)}\big) +$$

$$\big(6\,.\,\Delta p\,.\;q_{(t-1)}\,.\,L_{(t-1)}\,.\,y_{s(t)}\,.\,y_{v(t-1)}\big) +$$

$$\big(6\,.\,\Delta p\,.\;q_{(t-1)}\,.\,L_{(t-1)}\,.\,y_{s(t-1)}\,.\,y_{v(t)}\big) +$$

$$\big(4\,.\,\Delta p\,.\;q_{(t)}\,.\,L_{(t)}\,.\,y_{s(t-1)}\,.\,y_{v(t-1)}\big) +$$

$$\big(4\,.\,\Delta p\,.\;q_{(t)}\,.\,L_{(t-1)}\,.\,y_{s(t)}\,.\,y_{v(t-1)}\big) +$$

$$\big(4\,.\,\Delta p\,.\;q_{(t)}\,.\,L_{(t-1)}\,.\,y_{s(t-1)}\,.\,y_{v(t)}\big) +$$

$$\big(4\,.\,\Delta p\,.\;q_{(t-1)}\,.\,L_{(t)}\,.\,y_{s(t)}\,.\,y_{v(t-1)}\big) +$$

$$\big(4\,.\,\Delta p\,.\;q_{(t-1)}\,.\,L_{(t)}\,.\,y_{s(t-1)}\,.\,y_{v(t)}\big) +$$

$$\big(4\,.\,\Delta p\,.\;q_{(t-1)}\,.\,L_{(t)}\,.\,y_{s(t)}\,.\,y_{v(t)}\big) +$$

$$\big(6\,.\,\Delta p\,.\;q_{(t-1)}\,.\,L_{(t)}\,.\,y_{s(t)}\,.\,y_{v(t)}\big) +$$

$$\left(6\,.\,\Delta p\,.\;q_{(t)}\,.\,L_{(t-1)}\,.\,y_{s(t)}\,.\,y_{v(t)}\right)+$$

$$\left(6\,.\,\Delta p\,.\;q_{(t)}\,.\,L_{(t)}\,.\,y_{s(t-1)}\,.\,y_{v(t)}\right)+$$

$$\left(6\,.\,\Delta p\,.\;q_{(t)}\,.\,L_{(t)}\,.\,y_{s(t)}\,.\,y_{v(t-1)}\right)+$$

$$\left(24\,.\,\Delta p\,.\;q_{(t)}\,.\,L_{(t)}\,.\,y_{s(t)}\,.\,y_{v(t)}\right)]$$

Similarly, the other terms can be obtained using **Table B.1**

Table B.1 Subscripts for the components of Δfactors and their weights.

Subscript for the components in the of Δfactors				**weight**
Order of factors				
first	second	third	fourth	
t-1	t-1	t-1	t-1	**24**
t	t-1	t-1	t-1	**6**
t-1	t	t-1	t-1	
t-1	t-1	t	t-1	
t-1	t-1	t-1	t	
t	t	t-1	t-1	**4**
t	t-1	t	t-1	
t	t-1	t-1	t	
t-1	t	t	t-1	
t-1	t	t-1	t	
t-1	t-1	t	t	
t-1	t	t	t	**6**
t	t-1	t	t	
t	t	t-1	t	
t	t	t	t-1	
t	t	t	t	**24**

Table B.2 Sectoral pollution intensity (IEA 2016)

Sector code	**q** (kgCO_2/million VND)		
	2000	2007	2011
1	9.196	9.064	6.443
2	0.000	0.000	0.000
3	0.000	0.000	13.256
4	0.000	0.000	32.043
5	0.000	0.000	0.000
6	0.000	0.000	107.767
7	0.000	0.000	23.804
8	0.000	0.000	283.077
9	0.000	0.000	58.349
10	0.000	0.000	0.000
11	917.003	512.650	102.207
12	0.202	0.180	0.181
13	0.000	0.000	0.000
14	31.664	17.696	16.974
15	402.866	151.956	98.525
16	2.990	4.122	3.350
17	2.990	5.038	4.375
18	115.645	254.782	217.159

Table B.3 Contribution of different final demand categories to CO_2 emissions (kt) during 2000-2007

Categories / Sector code	Household	Government	Investment	Export	Import
1	352	12	133	838	-702
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0
10	0	0	0	0	0
11	6505	-516	-7891	20537	4250
12	10	0	2	5	-10
13	0	0	0	0	0
14	-732	-34	-57	-467	968
15	15196	755	4594	4364	-11175
16	317	21	56	55	-170
17	24	91	0	0	-1
18	8083	3346	130	-1423	-1900
Sum	29,756	3,675	-3,033	23,908	-8,740

Table B.4 Contribution of different final demand categories to CO_2 emissions (kt) during 2007-2011

Categories / Sector code	Household	Government	Investment	Export	Import
1	-284	-5	-8	-15	268
2	0	0	0	0	0
3	4707	34	-2629	5614	-1736
4	3591	48	-1503	14344	-8373
5	0	0	0	0	0
6	4474	295	430	4846	-6485
7	9346	340	3312	12179	-21960
8	7950	325	21240	13662	-19119
9	10874	257	22115	20440	-50305
10	0	0	0	0	0
11	-22505	-1037	-9638	-32735	39912
12	1	0	4	8	-8
13	0	0	0	0	0
14	795	-13	-447	1695	-3
15	3623	-51	-2674	5432	106
16	412	18	40	210	-272
17	59	54	0	0	0
18	3978	804	143	985	-1359
Sum	27,021	1,069	30,385	46,665	-69,334

Appendix C

Table C.1 Technical coefficient matrix of the Vietnamese economy in 2011 (**A**)

Sector code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	0.1463	0.0000	0.3400	0.0089	0.2024	0.0115	0.0158	0.0034	0.0000	0.0001	0.0220	0.0002	0.0008	0.0148	0.0648	0.0022	0.0010	0.0030
2	0.0008	0.0425	0.0029	0.0008	0.0017	0.0098	0.0576	0.0821	0.0272	0.0021	0.0131	0.0757	0.0174	0.0009	0.0023	0.0011	0.0000	0.0005
3	0.1286	0.0001	0.3232	0.0002	0.0018	0.0015	0.0116	0.0003	0.0000	0.0001	0.0003	0.0002	0.0001	0.0130	0.0868	0.0006	0.0014	0.0033
4	0.0021	0.0005	0.0016	0.5590	0.0106	0.0372	0.0014	0.0045	0.0001	0.0085	0.0216	0.0023	0.0025	0.0100	0.0017	0.0031	0.0022	0.0025
5	0.0008	0.0002	0.0004	0.0005	0.2948	0.0175	0.0021	0.0026	0.0000	0.0018	0.1524	0.0001	0.0075	0.0005	0.0006	0.0007	0.0010	0.0010
6	0.0003	0.0002	0.0181	0.0118	0.0117	0.4505	0.0099	0.0369	0.0003	0.0036	0.0180	0.0015	0.0056	0.0039	0.0137	0.0072	0.0231	0.0146
7	0.1011	0.1233	0.0263	0.1036	0.0672	0.0765	0.5440	0.0658	0.0228	0.0339	0.2472	0.0369	0.0514	0.0349	0.1176	0.0214	0.0285	0.0933
8	0.0010	0.0012	0.0024	0.0007	0.0201	0.0013	0.0134	0.2954	0.0129	0.0125	0.0089	0.0018	0.2098	0.0023	0.0018	0.0015	0.0013	0.0025
9	0.0003	0.0291	0.0036	0.0015	0.0160	0.0015	0.0052	0.0142	0.7657	0.1737	0.0202	0.0014	0.1421	0.0010	0.0008	0.0022	0.0004	0.0006
10	0.0041	0.0098	0.0112	0.0099	0.0112	0.0155	0.0105	0.0220	0.0155	0.4024	0.0433	0.0344	0.0465	0.0134	0.0179	0.0092	0.0227	0.0182
11	0.0032	0.0062	0.0311	0.0258	0.0106	0.0714	0.0384	0.0309	0.0008	0.1011	0.1857	0.0354	0.0165	0.0176	0.0160	0.0050	0.0145	0.0180
12	0.0075	0.0090	0.0118	0.0202	0.0185	0.0377	0.0167	0.0651	0.0194	0.0165	0.0226	0.1511	0.0058	0.0201	0.0220	0.0186	0.0174	0.0208
13	0.0008	0.0051	0.0005	0.0009	0.0006	0.0003	0.0002	0.0006	0.0003	0.0012	0.0051	0.0060	0.0436	0.0030	0.0094	0.0024	0.0202	0.0067
14	0.0275	0.0172	0.0507	0.0370	0.0325	0.0448	0.0375	0.0417	0.0157	0.0496	0.0429	0.0170	0.0300	0.0165	0.0332	0.0054	0.0156	0.0138
15	0.0086	0.0462	0.0271	0.0148	0.0209	0.0303	0.0311	0.0193	0.0112	0.0203	0.0183	0.0122	0.0231	0.0448	0.0823	0.0457	0.0590	0.0316
16	0.0025	0.0088	0.0101	0.0094	0.0086	0.0057	0.0217	0.0115	0.0068	0.0128	0.0101	0.0206	0.0139	0.0270	0.0328	0.2981	0.0397	0.0510
17	0.0000	0.0001	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0000	0.0000	0.0001	0.0001	0.0313	0.0007
18	0.0004	0.0017	0.0009	0.0006	0.0012	0.0008	0.0008	0.0017	0.0003	0.0007	0.0006	0.0305	0.0010	0.0016	0.0018	0.0020	0.0165	0.0675

Table C.2 Sectoral gross domestic output (GDO, trillion VNDs) and % change compared to BAU scenario

	Scenario 1 (BAU)	**Scenario 2**		**Scenario 3**		**Scenario 4**		**Scenario 5**		**Scenario 6**	
Sector code	GDO (**x**)	GDO (**x**)	% change GDO	GDO (**x**)	% change GDO	GDO (**x**)	% change GDO	GDO (**x**)	% change GDO	GDO (**x**)	% change GDO
1	1681	1524	-9	1639.2	-2.5	1380	-18	1681	0	1650	-2
2	591	756	28	865.8	46.5	599	1	591	0	862	46
3	1454	1308	-10	1421.1	-2.3	1187	-18	1454	0	1422	-2
4	840	1097	31	788.8	-6.1	866	3	840	0	790	-6
5	98	125	28	75.7	-22.6	106	8	98	0	124	27
6	168	163	-3	161.2	-3.8	156	-7	168	0	161	-4
7	618	899	46	851.4	37.7	703	14	618	0	782	26
8	322	268	-17	281	-12.7	251	-22	322	0	281	-13
9	202	16	-92	15.8	-92.2	32	-84	202	0	16	-92
10	1646	2104	28	2430	47.7	1669	1	1646	0	2429	48
11	620	704	14	720.7	16.2	611	-1	620	0	718	16
12	298	337	13	362.1	21.6	280	-6	298	0	362	21
13	1110	982	-12	1072.6	-3.4	896	-19	1110	0	1073	-3
14	1066	1320	24	1494.9	40.3	1060	-1	1066	0	1494	40
15	916	874	-5	951.3	3.9	781	-15	916	0	950	4
16	695	867	25	988.2	42.1	694	0	695	0	987	42
17	256	343	34	402.9	57.3	268	4	256	0	403	57
18	396	355	-10	387.6	-2.2	322	-19	396	0	388	-2

Table C.3 Sectoral GHG emissions (Mt CO_2e) and % change compared to BAU scenario

	Scenario 1 (BAU)	**Scenario 2**		**Scenario 3**		**Scenario 4**		**Scenario 5**		**Scenario 6**	
Sector code	GHG emissions **(e^Tg)**	GHG emissions **(e^Tg)**	% change **e^Tg**	GHG emissions **(e^Tg)**	% change **e^Tg**	GHG emissions **(e^Tg)**	% change **e^Tg**	GHG emissions **(e^Tg)**	% change **e^Tg**	GHG emissions **(e^Tg)**	% change **e^Tg**
1	214	194	-9	208	-2.5	175	-18	188	-12	184	-14
2	40	51	28	58	46.5	40	1	40	0	58	45
3	23	21	-10	23	-2.3	19	-18	24	2	23	0
4	22	29	31	21	-6.1	23	3	22	1	21	-6
5	1	1	28	1	-22.6	1	8	1	-3	1	33
6	6	6	-3	6	-3.8	6	-7	6	-3	6	-5
7	11	15	45	15	37.7	12	14	11	0	13	26
8	82	68	-17	72	-12.7	64	-22	71	-13	61	-26
9	4	0	-92	0	-92.2	1	-84	5	7	0	-93
10	14	18	28	21	47.7	14	1	14	0	21	47
11	18	20	14	21	16.2	18	-1	18	0	21	16
12	3	3	13	3	21.6	3	-6	3	-1	3	20
13	3	2	-12	3	-3.4	2	-19	3	8	3	-3
14	13	17	24	19	40.3	13	-1	13	0	19	40
15	68	65	-4	70	3.9	58	-15	63	-7	67	-1
16	4	5	25	6	42.1	4	0	4	-1	6	41
17	1	2	34	2	57.2	2	4	2	1	2	54
18	63	56	-10	62	-2.2	51	-19	61	-4	59	-6

Appendix D

Table D.1 Sector final demand (trillion VND) and % change compared to BAU scenario

	Scenario 1 (BAU)	**Scenario 2**		**Scenario 3**		**Scenario 4**		**Scenario 5**		**Scenario 6**	
Sector code	Final demand (**y**)	Final demand (**y**)	% change **y**	Final demand (**y**)	% change **y**	Final demand (**y**)	% change **y**	Final demand (**y**)	% change **y**	Final demand (**y**)	% change **y**
1	1646	1432	-13	Similar to scenario 2		1431	-13	Similar to scenario 2		330321	-32
2	33	36	9			37	10			0	0
3	1353	1176	-13			1176	-13			14904	-10
4	691	756	9			756	9			30003	8
5	-98	-82	-16			-83	-15			0	0
6	-51	-37	-27			-37	-27			5848	8
7	-490	-426	-13			-426	-13			7483	15
8	-132	-145	9			-145	10			114886	-15
9	-1002	-1064	6			-1064	6			26	-99
10	1766	1932	9			1933	9			0	0
11	262	293	12			287	10			33515	5
12	77	67	-13			77	0			90124	-41
13	96	105	9			142	48			43820	-31
14	2093	1820	-13			1820	-13			0	0
15	2878	3148	9			3151	9			16557	7
16	266	232	-13			233	-13			98944	-14
17	1569	1715	9			1720	10			35229	9
18	4	3	-13			3	-11			33002	-6

Table D.2 Sector GHG emission load (Mt CO_2e) and % change compared to BAU scenario

	Scenario 1 (BAU)	**Scenario 2**		**Scenario 3**		**Scenario 4**		**Scenario 5**		**Scenario 6**	
Sector code	Emission load ($\mathbf{i^Tg}$)	Emission load ($\mathbf{i^Tg}$)	% change $\mathbf{i^Tg}$	Emission load ($\mathbf{i^Tg}$)	% change $\mathbf{i^Tg}$	Emission load ($\mathbf{i^Tg}$)	% change $\mathbf{i^Tg}$	Emission load ($\mathbf{i^Tg}$)	% change $\mathbf{i^Tg}$	Emission load ($\mathbf{i^Tg}$)	% change $\mathbf{i^Tg}$
1	487.6	440.4	-9.7	440.4	-9.7	440.4	-9.7	330.5	-32.2	330.3	-32.3
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	16.5	14.9	-9.8	14.9	-9.8	14.9	-9.8	14.9	-9.8	14.9	-9.8
4	27.7	30.0	8.5	30.0	8.5	30.0	8.5	30.0	8.4	30.0	8.5
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	5.4	5.8	7.9	5.8	7.9	5.8	7.9	5.3	-1.6	5.8	7.9
7	6.5	7.5	15.5	7.5	15.5	7.5	15.4	7.5	16.0	7.5	15.4
8	134.9	115.0	-14.8	115.0	-14.8	114.9	-14.8	115.1	-14.7	114.9	-14.8
9	2.8	0.0	-99.1	0.0	-99.1	0.0	-99.1	0.0	-99.1	0.0	-99.1
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	32.0	33.7	5.4	33.7	5.4	33.5	4.8	34.2	7.1	33.5	4.8
12	152.7	151.0	-1.2	90.6	-40.7	150.2	-1.6	150.8	-1.3	90.1	-41.0
13	63.6	62.2	-2.2	43.5	-31.5	62.6	-1.5	62.2	-2.2	43.8	-31.1
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	15.5	16.6	6.5	16.6	6.5	16.6	6.5	16.6	6.5	16.6	6.5
16	115.3	110.0	-4.6	110.0	-4.6	109.9	-4.6	98.9	-14.2	98.9	-14.2
17	32.5	35.2	8.5	35.2	8.5	35.2	8.5	35.2	8.5	35.2	8.5
18	35.0	35.3	0.8	35.3	0.8	35.3	0.8	33.0	-5.8	33.0	-5.8

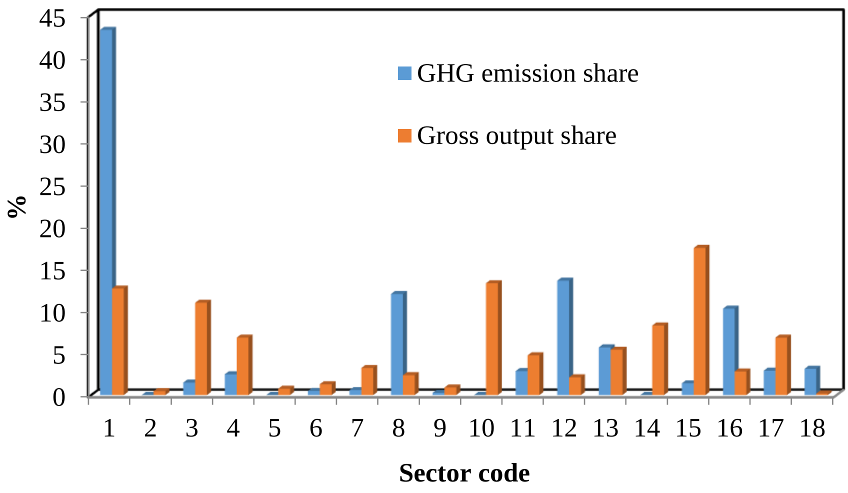


Fig. D.1 Results for scenario 1

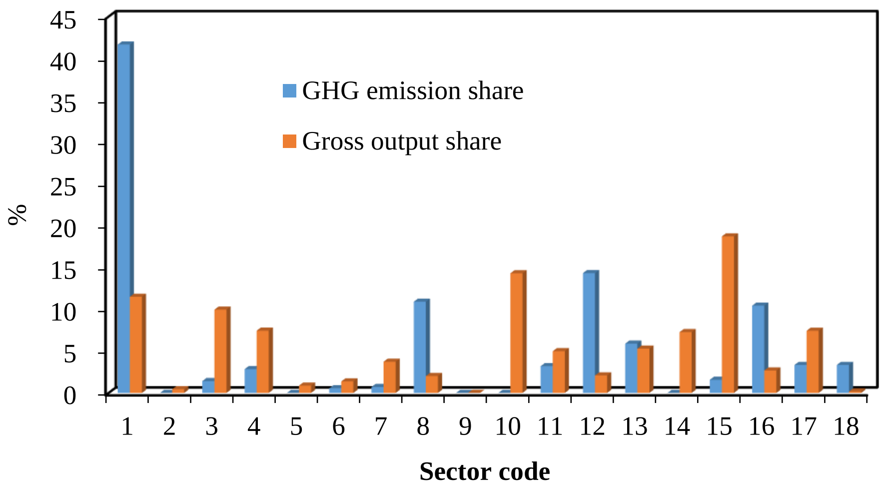


Fig. D.2 Results for Scenario 2

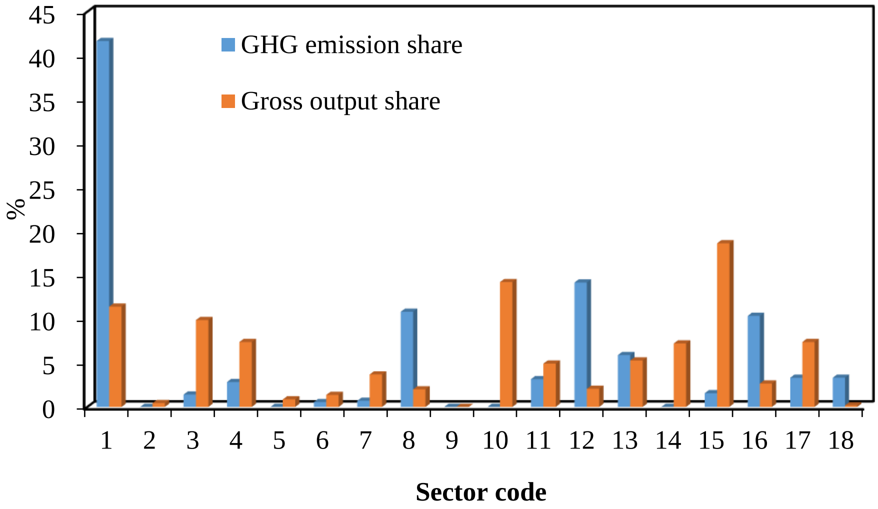


Fig. D.3 Results for scenario 3

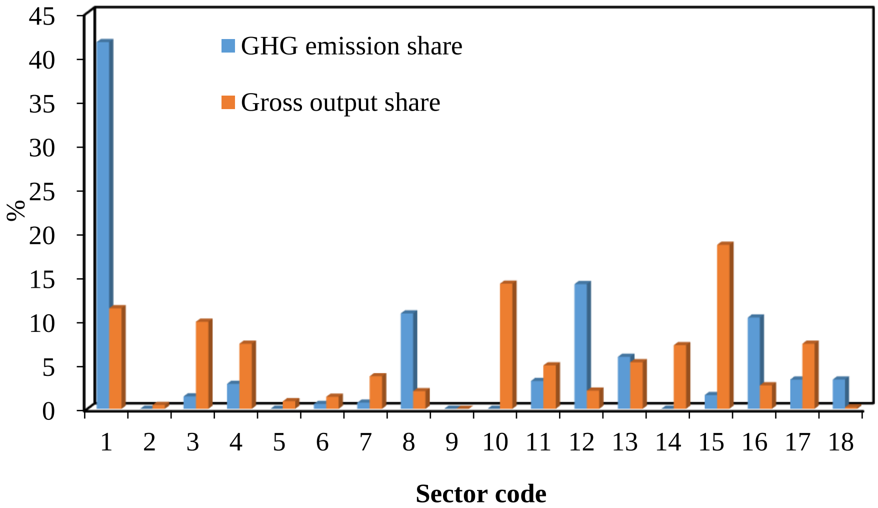


Fig. D.4 Results for scenario 4

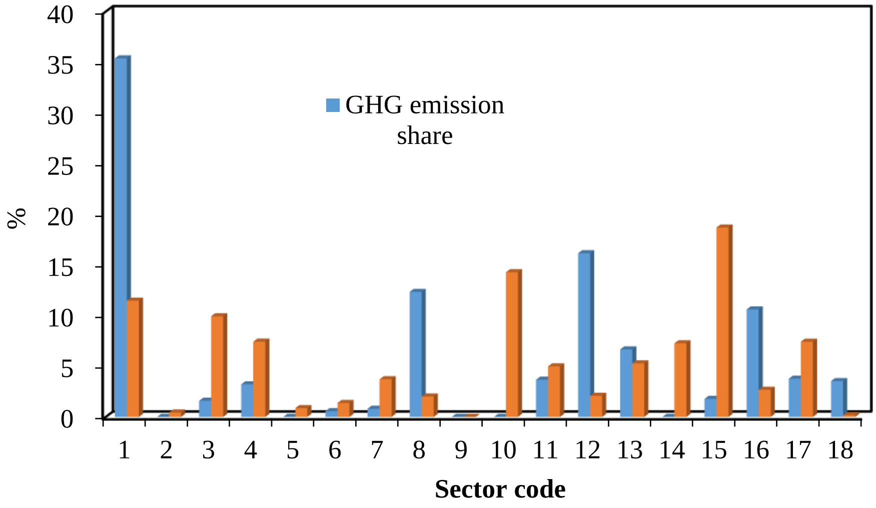


Fig. D.5 Results for scenario 5

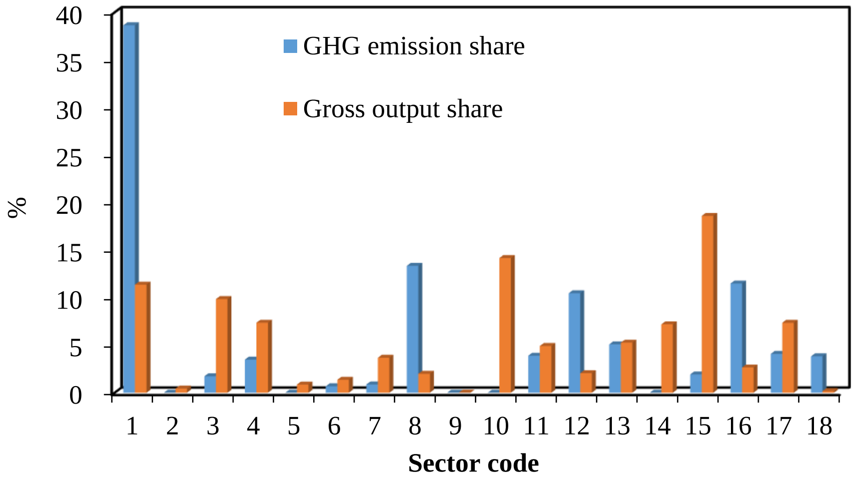


Fig. D.6 Results for scenario 6