ESSAYS ON THE ECONOMICS OF ENERGY IN VIETNAM

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Declaration

I declare that this thesis does not include materials which has been accepted for the award of any other degree in any university. It is my own work, unless otherwise indicated.

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Abstract

The past few decades have experienced a remarkable expansion of energy consumption and power generation all over the world. Given the critical role of energy in economic development and its impacts on the environment, energy-related topics have attracted a longstanding interest among academics and researchers. However, the debate on energy in relation to the economy, household welfare, power supply, and international trade remains unsettled in the literature. My thesis aims to revisit this on-going debate with a case study of Vietnam.

Outside of the introduction and conclusion, this thesis contains four core chapters that focus on the following themes: (i) the energy-GDP relationship from a macroeconomic perspective, (ii) the household welfare impact of environmental protection taxes, (iii) the economics of coal-fired power plants, and (iv) the impact of international trade on firms' energy efficiency. This thesis, thus, provides a comprehensive picture of the energy sector in Vietnam from different aspects. These topics deal with important issues for the world at large and particularly for Vietnam and other developing countries increasingly affected by pollution and climate change.

Chapter 2 examines the energy-GDP relationship by constructing a multiplier analysis model using the 2018 social accounting matrix of Vietnam. This model controls for linkages across sectors and the level of inter-dependence between the energy sector and other sectors in the economy. Results show that the impact of changes in sectoral GDP on energy consumption varies across sectors. The elasticity of energy consumption with respect to GDP is, on average, 0.95, which is relatively higher than the world average. The results suggest that there are significant opportunities for innovation activities and a transformation into green energies, and cross-sectoral linkages must be taken into account in development policies.

Chapter 3 investigates the impacts of energy taxes on household welfare in Vietnam by fitting household survey data to a multi-good partial equilibrium model. The study finds that a tax on energy goods (coal, gasoline, electricity, and other fuels) reduces consumer welfare, and that the size of the effect varies across households and household groups depending on their elasticity of substitution between energy and non-energy goods. Households with one of the following features are worse off than their counterparts: those with a male household head, married household head, those in the ethnic majority group, those with household members in

the Communist Party, non-farm households, and those without electricity support from the government. The study finds that energy taxes are neither strictly regressive nor progressive and also discusses the importance of complementary programs, including the use of tax revenue to support poor households.

In Chapter 4, I explore the economics of coal-based power generation with a focus on environmental taxes. Despite the growing prominence of other cleaner energies, coal has been the dominant source of power supply in Vietnam. This study conducts a cost-benefit analysis and indicates that coal-fired power projects are not profitable if carbon taxes are introduced to replace the existing energy taxes. Given the current tax rates, the government has sacrificed environmental quality for economic development. In addition, the economics of coal-fired power plants are very sensitive to changes in coal price and electricity price, while they are less sensitive to variations in operating and maintenance costs. The relative importance of parameters in the sensitivity analysis provides policy implications for the government to control and manage the electricity market more efficiently.

Finally, Chapter 5 examines the impact of Vietnamese firms' participation in international supply chains on their energy efficiency as proxied by energy intensity. I employ endogenous switching regression models to control for heterogeneity and self-selection bias. The empirical results confirm that self-selection does exist, i.e., firms with below average energy intensity self-select into exporting, and participating in international supply chains could improve the energy efficiency of both exporters and non-exporters, though with different magnitudes across the two groups. In particular, non-exporters would be able to reduce their energy intensity by 58.6 per cent if they were to export, and the participation in international supply chains reduced the energy intensity of exporters by 40.2 per cent. The findings provide important policy implications in relation to Vietnam's international trade activities and trade agreements.

Table of Contents

Declaration ..... **i**
Acknowledgement ..... **ii**
Abstract ..... **iv**
Table of Contents ..... **vi**
List of Tables ..... **ix**
List of Figures ..... **x**
List of Abbreviations ..... **xi**
Chapter 1: Introduction **1**
1.1 Definition and classification of energy 1
1.2 Context and stage of debate 2
1.3 The case of Vietnam 6
1.4 Key research questions, methodological approaches, and contribution 7
1.5 Organisation of the thesis 10
Chapter 2: Energy-GDP nexus: A social accounting matrix modelling analysis **11**
2.1 Introduction 11
2.2 Literature review 13
2.2.1 Economy-wide energy efficiency indicators 13
2.2.2 Causality between energy consumption and economic growth 14
2.2.3 Economy-wide impacts of the energy sector 15
2.3 Overview of Vietnam's economy 18
2.4 Methodology and data source 24
2.4.1 Methodology 24
2.4.2 Data 30
2.5 Results 31
2.5.1 Economy-wide linkages 31
2.5.2 Energy-GDP relationship 35
2.5.3 Sensitivity analysis 38
2.6 Discussion 39
2.7 Conclusion 41
Appendix 42
A2.1 Description of economic sectors in the SAM 2018 42
A2.2 The 2018 social accounting matrix of Vietnam 43

A2.3 Detail of a SAM multiplier analysis ... 49
A2.4 Simulation results ... 55
A2.5 Sensitivity tests for changes in sectoral weights ... 57
Chapter 3: Energy tax policy and household welfare: A partial equilibrium analysis ... 58
3.1 Introduction ... 58
3.2 Literature review ... 60
3.3 Background ... 63
3.3.1 Some prominent energy-related policies ... 63
3.3.2 Household energy consumption patterns ... 66
3.4 Methodology and materials ... 70
3.4.1 Methods for distributional impact evaluation ... 70
3.4.2 Methodology ... 72
3.4.3 Data source ... 76
3.4.4 Calibration ... 77
3.5 Results ... 79
3.5.1 Welfare impact per household ... 79
3.5.2 Distributional impacts ... 81
3.5.3 Sensitivity tests ... 84
3.6 Discussion ... 87
3.7 Conclusions ... 90
Appendix ... 91
A3.1 Solutions for utility maximisation problem ... 91
A3.2 Solutions for expenditure minimisation problem ... 93
A3.3 Solution for own-price elasticity ... 95
A3.4 Sensitivity test in the long term ... 96
Chapter 4: The economics of coal-fired power generation ... 97
4.1 Introduction ... 97
4.2 Literature review ... 99
4.3 Background ... 102
4.3.1 Vietnam's electricity sector ... 103
4.3.2 Role of coal-fired power generation ... 105
4.4 Methodology and materials ... 107
4.4.1 Procedure to perform a CBA ... 107
4.4.2 Evaluation techniques in CBA ... 109
4.4.3 Data source ... 112

4.5 Results ... 113
4.5.1 The future of electricity in Vietnam ... 114
4.5.2 Cost-benefit analysis of a coal-fired power plant ... 116
4.5.3 Sensitivity analysis ... 121
4.6 Discussion ... 124
4.7 Conclusion ... 127
Appendix ... 128
A4.1 Methodology for electricity demand forecasting ... 128
A4.2 Cost-benefit analysis of a gas-fired power plant ... 129
Chapter 5: The impact of international trade on energy efficiency ... 130
5.1 Introduction ... 130
5.2 Literature review ... 132
5.2.1 The impact of environmental performance on exports ... 132
5.2.2 The impact of exports on environmental performance ... 134
5.3 Energy performance in Vietnam ... 136
5.4 Conceptual framework ... 138
5.4.1 Addressing the endogeneity problem in export status ... 138
5.4.2 Theoretical basis and empirical specification of an ESR model ... 140
5.4.3 Average treatment effects ... 142
5.5 Data and descriptive statistics ... 143
5.5.1 Data ... 144
5.5.2 Descriptive statistics ... 145
5.6 Empirical results ... 150
5.6.1 Determinants of exporting and its impacts on energy intensity ... 150
5.6.2 Effects of export status on firms' energy performance ... 154
5.6.3 Robustness checks ... 155
5.7 Discussion ... 157
5.8 Conclusion ... 158
Appendix ... 160
A5 Sensitivity analysis with a different measure of energy intensity ... 160
Chapter 6: Conclusion ... 161
6.1 Key findings ... 161
6.2 Policy implications ... 162
6.3 Suggestions for future research ... 164
References ... 165

List of Tables

Table 2.1 Sectoral share in gross output and GDP (%).. 19
Table 2.2 Share of production factors in value added of each sector (%)............................... 20
Table 2.3 Export and import structure (%) 21
Table 2.4 Production and commodity taxes rates (%) 22
Table 2.5 Structure of household income by source 23
Table 2.6 Structure of government expenditure... 23
Table 2.7 Self- and cross-sector multiplier impacts on demand 33
Table 2.8 Response of macroeconomic-real indicators to sectoral final demand.................... 35
Table 2.9 Response of the energy consumption to sectoral final demand 36
Table 2.10 Energy elasticity and energy-related carbon emissions 37
Table 3.1 Tariff schedule of the EPT applied in 2012 64
Table 3.2 Energy usage rate by region (%).. 68
Table 3.3 Summary statistics of variables.. 77
Table 3.4 Welfare impact per household in one year... 80
Table 3.5 Welfare impact by household demographic and region in the short term 82
Table 3.6 Welfare impact by household demographic and region in the long term 83
Table 3.7 Sensitivity tests for welfare impacts in the short term 86
Table 4.1 Parameters in CBA of a coal-fired power plant 113
Table 4.2 Cost-benefit analysis of a coal-fired power plant 120
Table 4.3 Scenarios for sensitivity analysis 121
Table 5.1 Average treatment effects of export status... 143
Table 5.2 Summary statistics of variables in the sample 146
Table 5.3 Characteristics of exporters and non-exporters... 149
Table 5.4 Parameters estimates of export status and energy intensity (Energy cost/Variable costs)... 151
Table 5.5 Impacts of export status on energy intensity (Energy cost/Variable costs) 155
Table 5.6 Impacts of export status on energy intensity (Energy cost/Output)....................... 155
Table 5.7 Sensitivity analysis using different models.. 156

List of Figures

Figure 2.1 A simplistic SAM framework 25
Figure 2.2 General structure of practical SAMs 27
Figure 2.3 Energy-GDP elasticity with variations of 20% in sectoral weights 38
Figure 3.1 CO_2 emissions from fuel combustion by category 1986-2014 65
Figure 3.2 Household expenditure patterns by region 67
Figure 3.3 Energy expenditure patterns by region 69
Figure 3.4 Energy expenditure patterns by expenditure decile 70
Figure 3.5 Relationship between CV, EV, and ΔCS of energy good 75
Figure 3.6 Welfare impact by decile of expenditure 84
Figure 3.7 Sensitivity test for welfare impacts by decile in the short term 87
Figure 4.1 Electricity consumption per capita, 1990-2014 (kWh) 104
Figure 4.2 Electricity intensity, 2010-2017 (kWh/constant USD PPP 2016) 105
Figure 4.3 Electricity generation by sources 1990-2017 (%) 106
Figure 4.4 Electricity demand projections in different scenarios, 2020 – 2050 115
Figure 4.5 Histogram for NPV and BCR 123
Figure 4.6 Tornado graph for BCR 124
Figure 4.7 Tornado graph for LCOE 124
Figure 5.1 Energy intensity (MJ/ USD 2011 PPP) 136

List of Abbreviations

BCR	Benefit-cost ratio
CBA	Cost-benefit analysis
CCS	Carbon capture and storage
CGE	Computational general equilibrium
CO_2	Carbon dioxide
CS	Consumer surplus
CV	Compensation variation
EPT	Environmental Protection Tax
ESAM	Environmentally extended social accounting matrix
ESR	Endogenous switching regression
EUR	Euro
EV	Equivalent variation
FE	Fixed effects
FTAs	Free trade agreements
GHG	Greenhouse gas
GW	Gigawatt
GWh	Gigawatt-hours
HCFC	Hydrogen chlorofluorocarbon liquid
IGCC	Integrated gasification combined cycle
IO	Input-output
IRR	Internal rate of return
IV	Instrumental variables
Ktoe	Kilotonnes of oil equivalent
kWh	Kilowatt-hour
LCOE	Levelized cost of electricity
LHS	Left hand side
LPG	Liquefied petroleum gas
MJ	Megajoule
Mtoe	Million tonnes of oil equivalent
MW	Megawatt
NPV	Net present value

O&M	Operating and maintenance
OLS	Ordinary least squares
PDP	Power Development Plan
RHS	Right hand side
RoW	Rest of the world
SAM	Social accounting matrix
SME	Small and Medium Enterprise
TFEC	Total final energy consumption
TWh	Terawatt-hour
USC	Ultra-supercritical
USD	US Dollar
VAR	Vector autoregression
VHLSS	Vietnam Household Living Standard Survey
VND	Vietnam Dong

Chapter 1: Introduction

1.1 Definition and classification of energy

Energy is defined as the ability to do work or to produce heat (Bhattacharyya, 2011). The ability to do work could reflect the potential of energy (e.g., water stored in a dam) and conversion to motive force (e.g., wind and tidal waves). Also, heat may be produced from fuel combustion (Bhattacharyya, 2011). In terms of physical science, energy flows are characterised by the two laws of thermodynamics. The first law governs the total quantity of energy. It states that energy cannot be created or destroyed, but it can transform from one type to another, which always ensures a balance of energy. The second law (the entropy law) focuses on the quality of energy, i.e., conversion leads to low-grade energy type, which then can be used for less work, though the overall energy is conserved (Prins et al., 2003, Bhattacharyya, 2011).

There are several alternative ways to classify energy. The first classification divides energy into primary and secondary energy. According to the United Nations (1982), primary energy includes those forms of energy that are only involved in extraction or capture processes, and have not gone through any transformation into other types other than separation and cleaning. Some examples of primary energy are crude oil, coal, and natural gas. By contrast, secondary energy refers to forms of energy such as electricity and oil products that have been converted from primary energy sources. In the second type of classification, energy can be classified as renewable and non-renewable energies based on whether the primary energy comes from either a constantly available or finite stock of resources (Bhattacharyya, 2011). Examples for the former group include solar and wind energies, while the latter consists of fossil fuels and nuclear energy. In the third type of classification, energy can also be divided into commercial and non-commercial groups, in which commercial energies are those that are traded in the market and have a definite market price (e.g., kerosene, liquefied natural gas, and oil). Non-commercial energies refer to those that are unavailable in the market and do not have a price (e.g., firewood and farm-by-products) (Bhattacharyya, 2011). These different classifications of energy will be used alternatively throughout this thesis depending on the purpose of analysis.

1.2 Context and stage of debate

The evolution of energy is described by three primary energy eras, namely wood, coal, and petroleum fuels (Griffin and Steele, 1986). The history of wood as the first energy source used for manufacturing and industrial activities can be traced back to less than 50,000 years ago. During this period, workers in Asia Minor and northern Europe used wood for heating to make weapons and ornaments (Griffin and Steele, 1986). After the decline of forest cover, coal began to be used on a large scale in the British Isles since the 1550s and then gradually across Europe, Asia, and Southern Hemisphere (Griffin and Steele, 1986).

In the second era, the role of coal in economic development became prominent during the Industrial Revolution in the 18th and 19th centuries in Europe. Although coal had been employed before for various purposes such as heating and for other industrial activities, the Industrial Revolution in the early 18th century is characterised by the use of coal in the iron and steel industry and the invention of the steam engine (Wrigley, 2013). The application of the steam engine began in metallurgical industries and then spread to textiles and other sectors, while its geographical diffusion saw it spread from Britain to various other countries such as France, Belgium, and Germany by the middle of the 19th century (Fernihough and O'Rourke, 2014). The substitution of the steam engine for human labour led to remarkable growth in output per worker (Griffin and Steele, 1986).

The third era is characterised by the emergence of petroleum fuels in industrial activities. This period started in the 1860s with a new large-scale market for crude oil. Lubricants, kerosene, and eventually oil had many advantages and could compete effectively with coal. At the beginning of the 20th century, the improvement in the internal combustion engine allowed crude oil to displace coal. Natural gas then emerged as a source of energy supply and competed with crude oil after the development of long-distance low-cost gas pipelines in the 1930s. The market for natural gas saw a rapid expansion because of its clean, convenient, and economical features (Griffin and Steele, 1986). Today, natural gas accounts for a substantial part of total energy consumption in many countries such as the US and China (Ishwaran et al., 2017).

The energy sector in the 20th century can also be described by the two major oil crises. In both cases, the world experienced a sudden and unprecedented increase in the oil price, coupled with political turbulence in the Middle East (Venn, 2016). By 1973, 36 per cent of total global oil supply was sourced from countries in this region due to the relative abundance and lower cost of their oil resources (Schumacher, 1985). After Egypt and Syria's attack on Israel in October 1973 which started the Yom Kippur War, many economies in the industrialised world were faced with declining oil supplies, which led to a fourfold increase in oil prices (Schumacher, 1985). The second oil crisis occurred in 1979 on account of anticipated oil shortages throughout the winter of 1979-1980 and the domestic revolution in Iran, which was the major oil exporting country at the time (Venn, 2016). As a result, the price of crude oil rose approximately twelvefold by mid-1980 (Schumacher, 1985). Both oil price shocks are believed to cause wide-reaching and unexpected consequences to the world economy.

Subsequent to these oil shocks, the energy sector has expanded considerably over the last decades. Total final energy consumption (TFEC) in the world increased by about 60 per cent in the 1990-2018 period, from 6,267.2 million tonnes of oil equivalent (Mtoe) to 9,937.7 Mtoe. Oil products took the lead in the TFEC at 40 per cent in 2018, followed by electricity (19 per cent) and natural gas (16 per cent) (IEA, 2020a). In particular, electricity was the only energy type that experienced a consistent and continuous increase in the TFEC, suggesting the growing role of electricity in the world economy. Coal on average was the dominant source of electricity generation with a share of 38 per cent in 2018, followed by natural gas (23 per cent) and hydropower (16 per cent). While some economies such as the US and Europe have gradually moved away from coal, Southeast Asian countries have remained dependent on coal-fired power (IEA, 2019d, Clark et al., 2020). Renewable energies, for example, solar and wind power, have shown more promise in the power generation mix (IEA, 2020a).

The excessive use of energy, however, raises concerns regarding environmental quality and climate change. The energy sector was the largest source of greenhouse gas (GHG) emissions, of which carbon dioxide (CO_2) was the main contributor. Global energy-related CO_2 emissions in 2018 grew by 1.7 per cent compared with the previous year and about 65 per cent since 1990 (IEA, 2019b, 2020a). Coal accounted for over 44 per cent of all energy-related carbon emissions, of which coal-fired power generation was the single largest emitter with a proportion of 30 per cent (IEA, 2019b, 2020a). The concentration of GHG emissions leads to climate change, which is characterised by conditions such as increased temperature and extreme weather events that in turn affect wildlife habitats and people's livelihoods (Inkley et al., 2004, Olsson et al., 2014).

These three energy eras (wood, coal, and petroleum fuels), together with the recent remarkable expansion of the energy sector and its impacts on the environment, have demonstrated the critical role of energy in socio-economic development. Energy is always an important factor in all production processes, which require continuous energy supplies to sustain the economic activity, growth, and development of an economy (Stern, 1997). It is used in production to transform materials into products and transport raw materials, commodities, and people to desired destinations (Stern, 2020). According to ecological economics, energy consumption mainly causes economic growth, and the use of energy directed by capital and labour factors creates value (Stern, 2020).

Nonetheless, empirical evidence does not provide a straightforward conclusion in regard to the role of energy in the economy. Despite having an extensive literature, previous studies demonstrate several directions of causality between energy consumption and economic growth, including unidirectional, bidirectional causality, or even no relationship (see, e.g., Ozturk (2010), Payne (2010a, 2010b), Omri (2014), and Ucan et al. (2014)). The heterogeneous findings are due to many factors such as modelling techniques, time period, levels of economic development, and the selection of independent variables (Belke et al., 2011, Omri, 2014). Some focus on the economy-wide impacts of energy-related issues using multi-sectoral models. The use of different models can lead to diverse results, and each approach has several drawbacks that limit its application (Borges, 1986, Burfisher et al., 2003, Allan et al., 2011, Allan et al., 2014, Gilmartin and Allan, 2015, Van Wyk et al., 2015, Feng et al., 2018).

Furthermore, the harmful impacts of energy consumption, mostly fossil fuels, have attracted attention in terms of environmental protection and climate change mitigation (Klein et al., 2005, Omer, 2008). In order to achieve environmental protection objectives, in particular emissions abatement, three main groups of instruments have been implemented in many countries and regions (Bizer and Julich, 1999, Requate, 2005, Arimura et al., 2008, Bergquist et al., 2013, Kostka, 2016). The first group of instruments use approaches that encourage voluntary activities and social responsibilities of people such as media campaigns to educate residents about energy conservation or environmental labelling. A more commonly used method to reduce pollution in many countries includes command-and-control instruments that set mandatory requirements or restrictions for firms and individuals (e.g., technology-based standards and emissions licences). The third group of instruments consist of market-based approaches that encourage behavioural changes through market signals (e.g., environmental taxes and tradable permits). Instruments are assessed and chosen based on many criteria, for example, cost-effectiveness, long-run effects, equity, and dependency (Perman et al., 2014).

Environmental or energy taxes are widely used in many developed and developing countries due to their cost efficiency (Stavins, 2003, Perman et al., 2014). This approach creates incentives for consumers to switch away from ‘dirty’ goods and provides revenue for the government. The implementation of energy taxes affects various aspects of the economy, of which the distributional effect on household welfare has received much attention as it reflects the equity impact of environmental taxation. Nonetheless, empirical research provides mixed and conflicting evidence on the distributive effects (see, e.g., Labandeira and Labeaga (1999), Symons et al. (2002), Creedy and Sleeman (2006), and Dissou and Siddiqui (2014)). Additionally, the increase in energy prices as a result of these taxes will affect energy-intensive industries, especially power generation (Shrestha and Marpaung, 1999, Liang et al., 2007, Locatelli and Mancini, 2010, Zhao, 2011, Wesseh and Lin, 2018, Lee et al., 2019). Previous studies report diverse impacts depending on the context and characteristics of a country’s energy-intensive sectors. Therefore, pressure has emerged for policymakers to balance the environmental and economic objectives, i.e., cutting down GHG emissions and improving social welfare.

Moreover, enhancing energy efficiency is another approach that alleviates the detrimental impact of energy consumption on the environment (Worrell et al., 2001, Akram et al., 2020). Academics and researchers have directed their attention to the determinants of energy efficiency such as productivity, capital intensity, human capital, and environmental regulations, of which, international trade is a variable of interest due to its increasing importance in global economy (WTO, 2018). The energy-trade nexus, however, is theoretically ambiguous (Frankel and Rose, 2005) and empirically unsettled (Kaiser and Schulze, 2003, Cole et al., 2006, Holladay, 2008, Albornoz et al., 2009, Managi et al., 2009, Zheng et al., 2011, Batrakova and Davies, 2012, Dardati and Saygili, 2012, Roy and Yasar, 2015, Richter and Schiersch, 2017, Zhao and Lin, 2020). The effect of export on energy efficiency differs between countries, sectors, energy types, and the energy-intensity level of firms.

Given such on-going debate and conflicting empirical evidence, the relations between energy and different aspects of the economy are worth examining with updated data and appropriate approaches.

1.3 The case of Vietnam

In recent decades, Vietnam has developed rapidly and has enjoyed several economic achievements. GDP growth rates after the Doi Moi reform process were higher than those in previous periods. The economy experienced an impressive annual GDP growth of 8.2 per cent in the period 1991-1995, which doubled that in the preceding five years. Despite the regional financial crisis, there were continuous increases in GDP at an average of 7.6 per cent per annum in 1995-2000 and 7.34 per cent in 2001-2005. In the following ten years, due to the global economic recession, Vietnam's GDP growth rate slowed but still recorded a high level of around 6 per cent per year (Vuong, 2016). GDP in 2019 was estimated to grow by 7.02 per cent compared with that in 2018 (GSO, 2020). Additionally, the country attained lower-middle income status in 2010 with a GDP per capita of over USD 2,700 in 2018 (World Bank, 2020).

Along with the fast growth, Vietnam's energy market has expanded and is a vital driver of economic development. The country ranked fifth in Southeast Asia in terms of oil and gas production and oil reserves. The total oil and gas reserves for exploitation are estimated to be about 3.8-4.2 billion tonnes of oil equivalent, of which 60 per cent has been located (Nguyen, 2014). The annual growth of domestic energy exploitation in the 2006-2015 period was 1.3 per cent on average. The total primary energy supply increased substantially from 29.2 million tonnes of oil equivalent (Mtoe) in 2000 to 70.6 Mtoe in 2015. Among them, commercial energy has gradually replaced non-commercial energy and contributed 75.5 per cent to total energy supply (Ministry of Industry and Trade, 2017).

The final energy consumption of Vietnam is relatively large when compared with other countries in the region and the world. Total final energy consumption increased from 37.7 Mtoe in 2006 to 54.1 Mtoe in 2015, of which, industrial activities surpassed residential use to become the largest contributor at 43.3 per cent. The residential sector was the runner up at 26.7 per cent, followed by transportation (22.8 per cent), service and commerce activities (3 per cent), and agriculture (1 per cent). Regarding commercial energy consumption, oil took the lead at 40.7 per cent, followed by electricity (29.6 per cent) and coal (27.3 per cent). Natural gas accounted for only a small share of 2.4 per cent (Ministry of Industry and Trade, 2017).

Despite being endowed with various primary energy sources, since 2015 Vietnam has become a net energy importer. The volume of energy exports in 2015 declined by 60 per cent compared with that in 2009, while energy imports have shown a recent upward trend (Ministry of Industry and Trade, 2017). Imports, especially in coal and oil, are expected to be higher than exports in the coming years. In particular, the demand for coal will rise rapidly, mainly from increased power generation in domestic market. This will create more pressure on the domestic coal mining sector. A substantial amount of imported coal will lead to unstable development of the power generation sector (Nong et al., 2020b)

Being one of the most energy-intensive economies in the world (Le, 2019), emissions levels in Vietnam have increased significantly over the past 30 years. This is mainly due to the expansion of industry and construction sectors. The excessive use of fossil fuels for power generation causes about two-thirds of GHG emissions (Ali et al., 2020). These emissions grew by 57 per cent over 1990–2010 and 99 per cent over 2000–2012 (Nong, 2018), thus, the country recorded one of the highest GHG emissions growth rates among ASEAN countries (Ministry of Industry and Trade, 2017). CO_2 accounted for 65 per cent of GHG emissions in 2014, of which the energy sector released 96 per cent of carbon emissions (Tran, 2019). Thus, Vietnam is one of the most affected countries by air pollution in the world (Ali et al., 2020).

1.4 Key research questions, methodological approaches, and contribution

This thesis consists of four core chapters, with each chapter addressing a specific research issue and applying a different technique appropriate to the research questions and context. Chapter 2 examines the energy-GDP nexus in Vietnam by constructing a multiplier analysis model based on the 2018 social accounting matrix (SAM) of Vietnam. SAM is a comprehensive macroeconomic data framework that provides a snapshot of the socio-economic structure and relationship between different agents in an economy within a certain accounting period (Hartono and Resosudarmo, 2008). The use of the SAM modelling approach overcomes the drawbacks of econometric techniques previously used in investigating energy-GDP relationship that only capture partial equilibrium and cannot point out specific channels leading to the correlation. The SAM model is a simple version of general equilibrium models that can control for interactions between production systems, institutions, and other accounts and describes all circular flows in the economy (Fathurrahman et al., 2017, Li et al., 2018). A SAM-based multiplier analysis is used in which a system of equations is set up, and substitution method in algebra is applied to eliminate redundant equations in modelling an economic equilibrium. The system, including 13 equations for 11 sectors, household and enterprises incomes, then solves a new equilibrium for the economy when there are any changes in sectoral GDP.

Chapter 2 is important in three ways. First, the general equilibrium model constructed can estimate the economy-wide impacts on energy while controlling for interdependencies between sectors in the economy. As far as I know, this model uses the most up-to-date data for the analysis. Second, in addition to the impact of a shock to the energy sector on other sectors, this chapter shows that multiplier impacts on energy vary across sectoral changes depending on how close the connections the energy sector and other sectors have. The results demonstrate the role of the energy sector in the economy. Third, to the best of my knowledge, this is the first use of a general equilibrium model to quantify the energy-GDP relationship that takes into account simultaneous linkages across sectors. This provides recommendations for the government to balance economic and environmental objectives in development policies.

Chapter 3 examines the distributional effects of a hypothetical increase in energy taxes on household welfare. This chapter employs a multi-good partial equilibrium model in a household survey, which allows for heterogeneity between agents (e.g., individuals, households, or firms) and is appropriate when available macro data is limited. Goods in the market are classified into energy and non-energy goods, and each type is then further divided into purchased and non-purchased parts. A utility maximisation and an expenditure minimisation problem for the two goods in the market are set up with consumer's utility following a constant elasticity of substitution (CES) function (Arrow et al., 1961). The model derives Marshallian demand functions, Hicksian demand functions, and relative budget shares of energy and non-energy goods for each household. In the model, the elasticity of substitution between the two goods differs across households to reflect the heterogeneity of their preferences. Given that energy prices change, the policy impacts on household welfare are evaluated using three measures, namely compensation variation, equivalent variation, and change in consumer surplus (Varian, 1992). All measures are calculated in monetary units to demonstrate how much households are worse off by.

This chapter makes two key contributions to the existing literature. This is the first study that applies a partial equilibrium approach to analyse the impact of changes in energy taxes in household welfare in Vietnam. The approach controls for differences in consumption patterns by allowing each household to have a distinct elasticity of substitution between energy and non-energy goods. Additionally, this chapter provides a comparison of three measures of change in household welfare that are normally used separately in the literature. Results from the approach can be used for comparison with previous studies that apply different models and serve as an indicative prediction for policy makers about the possible impacts of the energy tax reform.

Chapter 4 directs its attention to the energy sector under the aspect of power generation. This chapter uses of a cost-benefit analysis (CBA) technique to examine the economics of coal-fired power plants in Vietnam. The CBA is an analytical instrument that estimates the welfare change from a project by calculating its associated benefits and costs in monetary units. I apply three conventional methods in CBA, namely net present value, benefit-cost ratio, and internal rate of return (Remer and Nieto, 1995a, 1995b). Results from the CBA provide indicative information for decision makers or investors regarding whether a coal-fired power project is worth proceeding with. In the sensitivity analysis, parameters in the CBA are allowed to vary to show their relative importance in the economic feasibility of coal-based power generation.

This chapter is important in two ways. First, Chapter 4 contributes to the existing literature on the economics of power generation with evidence from a developing country while taking into account an environmental factor, which is proxied by energy taxes or carbon taxes. With the substitution of a hypothetical carbon tax for the current environmental tax, the comparisons between different scenarios demonstrate how stricter tax rates affect the profitability of energy projects. Second, this is the first study that evaluates the impacts of techno-economic parameters on economic feasibility of power projects in Vietnam. The comparison of different environmental taxes combined with variations in the parameters provide a comprehensive economic assessment of coal-based power generation for the country.

Finically, Chapter 5 examining the impact of export status on energy efficiency at the firm level data in Vietnam. This chapter employs the endogenous switching regression (ESR) model proposed by Lee (1982) to address heterogeneity and selection bias. In particular, sample selectivity bias is treated as a missing-variables problem (Fuglie and Bosch, 1995). This model generates better results than the propensity score matching and instrumental variables methods since it controls for both observed and unobserved characteristics potentially affect export status and energy intensity, a proxy of energy efficiency, as well as structural differences between exporting and non-exporting firms. The ESR model uses a probit regression to estimate the determinants of export status and two regression equations to model separately impacts on energy intensity of the two groups. The average treatments effects calculated from the model can distinguish the impacts of export status on energy efficiency from unobservable factors. The estimation of the model can proceed by using the full information maximum likelihood approach proposed by Lokshin and Sajaia (2004), in which equations are estimated simultaneously to avoid heteroskedastic residuals and cumbersome adjustments to obtain consistent standard errors.

This chapter provides two main contributions to the literature on the trade-environment nexus. First, as far as I know, this is the first study that explores the impacts of participation in international supply chains on the energy efficiency of Vietnamese firms. This topic is especially necessary and relevant, given the country's growing position in global trade but also its low level of energy efficiency when compared with other ASEAN countries with similar economic development (World Bank, 2020). Second, aside from controlling for sample selectivity, the use of the ESR model emphasizes the systematic differences between exporting and non-exporting firms that affect their energy efficiency. Thus, the model reports the impacts of international trade on energy intensity of both groups.

1.5 Organisation of the thesis

This thesis consists of six chapters. The four substantive chapters are connected to each other under the broad topic of the economics of energy, but each chapter examines a specific research issue to fill a gap in the literature. Following the introduction in Chapter 1, Chapter 2 revisits the energy-GDP nexus from a macroeconomic perspective. Chapter 3 examines the distributional effect of environmental taxes on household welfare. Next, Chapter 4 takes into account the role of environmental taxes in the economic feasibility of coal-fired power plants. Chapter 5 investigates the impact of participation in international supply chains on energy efficiency at the firm level. Chapters 2 to 5 also provide discussions and policy implications from the results. Chapter 6 concludes the thesis with key findings, main policy implications, and suggestions for future research.

Chapter 2: Energy-GDP nexus: A social accounting matrix modelling analysis

2.1 Introduction

Energy plays an essential role in long-term economic development and growth but is also significantly responsible for environmental problems. Indeed, energy created by fossil fuels has been a vital driver of economic growth in many countries (Pastén et al., 2015, Gozgor et al., 2018, Azam, 2020) since many production activities use energy as a primary input (Asghar, 2008). From a physical viewpoint, energy contributes at least 50 per cent to industrial growth while accounting for less than 10 per cent of production costs (Foran and Poldy, 2002). Global total final energy consumption has increased by nearly 60 per cent from 1990 to 2018 (IEA, 2019a), of which, 78.4 per cent of the total energy use comes from fossil fuels (REN21, 2017). Fossil fuels release greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2), into the atmosphere, which contributes largely to climate change.

Given the vital role of energy in the economy and environmental quality, the energy-economic growth nexus has attracted longstanding interest. The nexus has been examined under different aspects such as energy efficiency indicators (Burke and Csereklyei, 2016, Csereklyei et al., 2016) and the causality between energy consumption and economic growth (Ozturk, 2010, Payne, 2010a, 2010b, Omri, 2014, Ucan et al., 2014, Isa et al., 2015, Tang et al., 2016). These studies, however, have reported mixed and conflicting results. Additionally, econometric techniques used in previous papers can only capture partial equilibrium and ignore cross-sectional linkages in the economy, which cannot show specific channels leading to the correlation between the two variables.

Another strand of literature examines the energy-economic growth nexus by evaluating the economy-wide impacts of energy-related issues. These studies apply multisectoral models such as input-output (IO) and general equilibrium models (see, e.g., Coxhead et al. (2013), Hartono and Resosudarmo (2008), and Xu et al. (2011)) and report the effects on various aspects of the economy, including gross domestic product (GDP), output, employment, investment, and imports-exports. Compared with the econometric approaches, these models seem to be a better option to track the correlation channels and control for cross-sector interdependencies.

The energy-economic growth nexus has also received much attention in developing countries such as Vietnam. The substantial use of energy, especially fossil fuels, to meet the requirements of economic development raises concerns about the country's energy efficiency. Energy intensity, measured as the ratio of energy consumption to GDP, of Vietnam has been higher than that of many ASEAN countries with similar levels of economic development such as Malaysia, Indonesia, and the Philippines (Le, 2019). This poses significant pressure on sustainable development strategies with low-carbon emissions of the country. However, there is a lack of studies using multisectoral models to assess the position of the energy sector in the overall economy with an emphasis on the energy-GDP relationship for Vietnam.

This chapter will fill the gap by examining the energy-GDP relationship from a different perspective. To control for interdependencies within and between sectors and different parts of the economy, a social accounting matrix (SAM)-based multiplier model using a SAM 2018 of Vietnam is constructed. The model employs a system of equations to find a new equilibrium when any changes occur in exogenous demand of one or several sectors. Multiplier impacts on gross output, GDP, enterprise income, and household income are calculated. The study then quantifies the energy multiplier with respect to GDP and the energy-GDP elasticity to describe the energy efficiency situation of Vietnam. A sensitivity analysis is conducted by simulating scenarios with variations in sectoral weights of final demand and comparing them to our main findings.

The study makes a threefold contribution to the literature. Firstly, the SAM-based model uses the latest available data and estimates the economy-wide impacts on energy by controlling for interdependencies between sectors in the economy. Secondly, the chapter shows not only the impacts of a change to the energy sector on other sectors but also how a shock to different sectors has heterogeneous impacts on the energy sector. The estimated multiplier impacts demonstrate the relatively close linkages between the energy sector and others. Thirdly, unlike previous studies, this chapter applies a bottom-up approach to quantify the relationship between energy demand and GDP while considering simultaneous linkages across sectors. These results provide recommendations for the Vietnamese government to balance economic objectives (i.e., increase GDP) and environmental objectives (i.e., reduce energy dependence).

The remainder of the paper is organized as follows. Section 2.2 provides background on Vietnam's economy. Section 2.3 reviews literature on the energy-GDP relationship, particularly methods to estimate economy-wide impacts of energy policy. Section 2.4 presents the methodology with a focus on a SAM-based multiplier analysis and describes data source for the study. Section 2.5 reports the main results of 11 scenarios and sensitivity analysis. A discussion and policy implications are given in Section 2.6, and Section 2.7 concludes the chapter.

2.2 Literature review

This section reviews literature on the energy-GDP nexus. There is a vast literature on the energy-GDP nexus, so I classify previous papers into three groups. First, I review economy-wide energy efficiency indicators constructed from energy consumption and GDP variables. Second, I summarize research on the causality between energy consumption and economic growth based on directions of the causation and econometric techniques. The final subsection focuses on previous studies that assess the economy-wide effects of energy-related issues by different multi-sectoral models.

2.2.1 Economy-wide energy efficiency indicators

Energy consumption and GDP can be used to construct indicators to evaluate energy efficiency at the economy-wide level. Some commonly used monetary-based indicators since the 1970s are energy intensity and energy elasticity (Ang, 2006). Firstly, energy intensity, defined as the total primary energy consumption divided by GDP (or GNP) (Ang, 2006), measures the energy requirement to create a unit of national output. High energy intensity means a low energy efficiency level. The ratio can be computed for many years to show the trends of national energy efficiency and to compare between different countries (Ang, 1987a, 1991, Nilsson, 1993). Previous papers have employed different decomposition methods, particularly Divisa index approach to analyse changes in energy intensity at national and regional levels (see, e.g., Cornillie and Fankhauser (2004), Ma and Stern (2008), and Wu (2012)).

Energy elasticity, also known as energy-GDP elasticity, is another energy efficiency indicator used in energy studies. Energy elasticity is defined as the percentage change in energy consumption associated with 1 percentage change in GDP (Adams and Miovic, 1968, Burke and Csereklyei, 2016). Estimates of the elasticity have often been conducted using different regression models (e.g., between estimator, within estimator, and OLS) on cross-sectional data (Ang, 1987b, Burke and Csereklyei, 2016, Csereklyei et al., 2016). In particular, Csereklyei et al. (2016) use data from 99 countries during the 1971-2010 period to examine the relationship between energy and economic growth and show a consistent long-run elasticity of 0.7. Moreover, Burke and Csereklyei (2016) use GDP per capita data from 132 countries in 1960-2010 to estimate energy elasticities at sectoral levels by decomposing aggregate energy elasticity. The authors report that residential energy use-GDP is inelastic if primary solid biofuels are taken into account.

2.2.2 Causality between energy consumption and economic growth

The causality between energy consumption and economic growth can be tested using four main hypotheses (Apergis and Payne, 2009b, 2009a). Growth hypothesis suggests the important role of energy consumption in economic growth both directly as an input in production activities and indirectly as a complement to labour and capital factors. An increase in energy use is expected to boost GDP whereby the economy is dependent on energy (Stern, 1993, Wolde-Rufael, 2004, Ang, 2007, Chandran et al., 2010, Tan and Tan, 2018). Secondly, the conservation hypothesis indicates that a rise in real GDP increases energy consumption (Kraft and Kraft, 1978, Yoo and Kim, 2006, Lise and Van Montfort, 2007, Balcilar et al., 2019, Rahman and Velayutham, 2020). An energy conservation policy can be implemented without undesirable effect on growth. While the former suggests unidirectional causality running from energy consumption, the latter implies the reverse direction.

The last two testable hypotheses attempt to find the correlation between two variables in both directions. The neutrality hypothesis argues that energy consumption is a small component of national output; thus, it has little or no effect on real GDP (Yu and Jin, 1992, Payne, 2009, Menegaki, 2011, Tamba et al., 2017). This hypothesis implies the absence of a causal relationship between energy consumption and economic growth. Therefore, measures for both the conservation and expansion of energy would not have a detrimental impact on real GDP. Finally, the feedback hypothesis supports the bidirectional causal association between the two variables (Kumar Mandal and Madheswaran, 2010, Dagher and Yacoubian, 2012, Salim et al., 2014, Eren et al., 2019, Sultan and Alkhateeb, 2019), suggesting that energy consumption and economic growth are intercorrelated. This hypothesis has the same policy recommendations as the growth hypothesis, i.e., an energy conservation policy decreases real GDP (Menegaki, 2014).

Previous studies often use time series econometric techniques to assert causality between energy use and economic growth. These studies have reported mixed and conflicting results, which is due to many factors such as differences in modelling techniques, time periods, economic development, trends of energy use, and selected variables (Belke et al., 2011, Omri, 2014). According to Belke et al. (2011), econometric methods applied to estimate the energy-economic growth relationship can be synthesised into four generations: (i) the vector autoregression (VAR) model with the assumption of stationarity in the data, (ii) the Engle and Granger (1987) two-step procedure, which takes into account non-stationarity of the underlying variables, with a cointegration test to check for their long-run relationship, (iii), the Johansen (1991)'s multivariate approach to accommodate for more than two variables in the cointegration relations, and (iv) the panel-estimation techniques to test for stationarity and the cointegration relationship.

Nevertheless, the application of these econometrics techniques has some disadvantages. It is argued that econometric models such as VAR or cointegration approach only capture the partial equilibrium while ignoring the interdependencies between sectors in the economy (Liu et al., 2019). These techniques are used to test the causality of the relationship but cannot point out specific channels leading to the correlation. However, the energy production process requires both the direct and indirect uses of inputs from various sectors (Sánchez-Chóliz et al., 2007). Therefore, multisectoral models seem to be a better option to track the correlation channels and estimate the economy-wide impacts of energy consumption and other related issues.

2.2.3 Economy-wide impacts of the energy sector

Many studies have employed multisectoral models such as IO and general equilibrium models to assert the economy-wide impacts of energy issues (see, e.g., Allan et al. (2011), Lin and Jiang (2011), Xu et al. (2011), Xie (2000)). Firstly, IO is a widely used approach in the energy-economy nexus to capture cross-sectoral linkages. The model is preferred due to its simplicity and transparency, in which data required for the model can be taken easily from statistics offices. Some studies use this method to assert the benefits to employment (among other things) of energy development, for example, coal (Winarno and Drebenstedt, 2016), petroleum (Tang et al., 2013), bioenergy (Madlener and Koller, 2007), and renewable energies (Henriques et al., 2016, Garrett-Peltier, 2017). In particular, Garrett-Peltier (2017) finds that each USD 1 million of spending on clean energy will generate five more jobs than the same amount of spending on fossil fuels. Additionally, Xu et al. (2011) compare the direct, indirect, and induced impacts of the petroleum sector on output and GDP in China. They conclude that while the extraction of petroleum has a larger direct effect on GDP, petroleum processing creates a more significant impact on total output.

However, IO models have some limitations in their application. These drawbacks arise from the models' assumptions, which are linearity, fixed coefficients over time, sector homogeneity, and unconstrained capacity (Karkacier and Gokalp Goktolga, 2005). When evaluating the impact of marine energy, Allan et al. (2014) show that the IO approach overstates the employment and value-added effects compared with computational general equilibrium (CGE) models. Similarly, Gilmartin and Allan (2015) report that an IO model is likely to overstate the employment impacts in the short term and understate the impacts in the long term, which is due to the absence of assumption about capacity constraints. Results from IO models, hence, are used as an upper bound for the short-term effect of a shock (Feng et al., 2018).

A general equilibrium framework is another approach used to estimate the economy-wide impacts of the energy sector. Unlike IO models, the CGE method can capture nonlinear substitution possibilities and supply-side constraints. The prices of factors of production in the models are set to be endogenous (Robinson and Roland-Holst, 1988, Bautista et al., 1999). Many researchers apply CGE models to investigate the impacts of oil price shocks on real GDP, output, investment, final consumption, and other economic indicators (see, e.g., Doroodian and Boyd (2003), Fan et al. (2007), Carbone and McKenzie (2016), Aydin and Esen (2018), and Zhao et al. (2021)). For instance, Fan et al. (2007) simulate the effect of a crude oil price shock on the Chinese economy and report a negative effect on different economic aspects such as GDP, investment, and imports-exports. The shock leads to more disadvantages for the welfare of rural households. Also, CGE models are employed to evaluate the economy-wide impact of other shocks such as those caused by energy subsidy reforms (Lin and Jiang, 2011, Liu and Li, 2011, Solaymani and Kari, 2014) or the power shortage (Ou et al., 2016). Although the absolute effects vary across industries, removing subsidies generally reduce energy demand and emissions.

There are several drawbacks of the CGE method that should be considered. The application of CGE models depends heavily on their underlying assumptions. The required input data is massive and sometimes unavailable (Van Wyk et al., 2015), which needs to be borrowed from other countries. These models have been criticised for their lack of empirical validation, i.e., there is no measure by which the model can track the historical facts (Borges, 1986). The complexity of these models may lead to intransparency of the main factors driving the outcomes (Burfisher et al., 2003), which raises scepticism about their results.

Meanwhile, the SAM approach can balance the advantages and disadvantages of IO and CGE models. A SAM model is an advanced version of an IO model since it can capture interactions between production systems, institutions, and other accounts and describe whole circular flows of the economy (Fathurrahman et al., 2017, Li et al., 2018). For instance, some studies evaluate the economic impacts of an energy project using both IO and SAM models (Swenson and Eathington, 2006, Allan et al., 2011) and conclude that SAM is a more appropriate approach since it captures the income flows in addition to the direct linkage effect (Allan et al., 2011). Furthermore, it is a simple version of general equilibrium models. Although SAM models have some drawbacks such as assumptions about fixed prices and unlimited factors of production, the method is advantageous in terms of simplicity, ability to assess policy impact related to many aspects like income distribution and employment, as well as a comprehensive, compact, and consistent data system (Fathurrahman et al., 2017). Unlike CGE, SAM models do not use assumptions that are difficult to verify, for example constant elasticity of substitution.

SAM models have been applied in various studies to assert the economic impacts of an energy policy. Hartono and Resosudarmo (2008) employ a SAM model with detailed energy sectors (fuel oil, gas fuel, and electricity) to examine the impact of controlling energy consumption on incomes of different household groups in Indonesia. By using various multiplier analyses, the authors conclude (i) the superiority of a policy that improves energy use efficiency compared with one that restricts energy consumption and (ii) a combination of policies that reduce energy subsidy and improve energy use efficiency gives the best outcome. In addition, Liu et al. (2019) use structural path analysis on a SAM model to investigate the importance of renewable energy in China. They report a more vital role of renewable energy in promoting the national economy and upgrading industrial structure than coal energy, suggesting further investment in renewable energy-related industries.

In addition, some researchers construct environmentally extended social accounting matrix (ESAM) models for a country or a region (Xie, 2000, Lenzen and Schaeffer, 2004, Morilla et al., 2007, Gallardo and Mardones, 2013, Rao et al., 2018, Hawkins and Hunt, 2019). Basically, an ESAM combines accounts of economic transaction in monetary unit with environmental data in physical unit. Xie (2000) claims that the integration describes the linkages between economic activities, pollution abatement activities, and emissions. This model can be a useful tool for environmental impact evaluation of pollution-related economic policies.

In the case of Vietnam, the topic of energy-GDP nexus has also received much attention. Most studies for Vietnam focus on the causal relationship between energy consumption and economic growth using various cointegration techniques over different periods from 1970 to 2017 (Binh, 2011, Tang et al., 2016, Morelli and Mele, 2020, Nguyen and Bui, 2020a, 2020b, Phrakhruopatnontakitti et al., 2020). However, their results support different hypotheses, such as conservation, growth, and feedback hypothesis. Additionally, some authors use general equilibrium models to investigate effects of several environmental taxes, including energy taxes and carbon taxes, on the economy (Nguyen and Coxhead, 2011, Willenbockel, 2011, Coxhead et al., 2013, Nong, 2018, Nong et al., 2019, Nong et al., 2020a). Although the impacts on the economy vary depending on tax rates on different energy types, these policies generally lead to reductions in real GDP and emission level. Nonetheless, there has been a lack of studies that use multisectoral models to assess the energy-GDP relationship. This study, hence, will fill the gap by using the SAM modelling approach to revisit the nexus for Vietnam.

2.3 Overview of Vietnam's economy

This section provides a general picture of Vietnam's economy from the SAM 2018. The economic structure is presented with an emphasis on the contribution of different sectors to production and output. I also describe the relative importance of labour, capital, and land in the production process of each sector as well as the trade balance in 2018. Finally, I demonstrate the composition of income and expenditure of households, enterprises, and the government. These statistics demonstrate the close linkages between sectors and suggest possible impacts when the aggregate demand changes. Description of economic sectors and the SAM 2018 are presented in Appendix A2.1 and A2.2.

The service sector has emerged as the largest sector in Vietnam's economy. Table 2.1 presents critical information on sectoral structure of gross output and GDP. The total gross output in 2018 was USD 540,576.9 million, of which the service sector contributed 52.7 per cent, followed by the industry and construction sector (36.8 per cent) and the agriculture sector (10.5

per cent). When the sectors were further disaggregated, out of 52.7 per cent of the service sector, transportation, wholesale and retail trade had the highest proportion with 32.9 per cent. Regarding the industry sector, the manufacturing sector accounted for 22.8 per cent of the gross output. However, the contribution of each sector in GDP was different. The GDP of Vietnam in 2018 was reported at around USD 254,833.6 million. The manufacturing sector contributed the largest part with 26.7 per cent, followed by the transportation, wholesale and retail trade sector (16.8 per cent), and agriculture (13.0 per cent). The energy sector is a small sector in the economy with shares of less than 3 per cent to gross output and GDP.

Table 2.1 **Sectoral share in gross output and GDP (%)**

Sector	Gross output	GDP
Agriculture	10.50	13.02
Mining	4.04	4.73
Manufacturing	22.77	26.72
Energy	1.38	2.81
Water	0.33	0.59
Construction	8.26	6.40
Transportation, wholesale, and retail trade	32.93	16.77
Finance, banking, insurance, and real estates	4.39	9.81
Health care, education, and research	3.90	7.31
Administration and communication	3.98	7.52
Accommodation, tourism, and other services	7.51	4.32

Source: Author's calculation from the SAM 2018

In the production process, the composition of intermediate input demands presents the linkages between different sectors in the economy. Total intermediate inputs in 2018 were USD 309,741 million, of which the manufacturing sector contributed significantly to the production activities. Products from the manufacturing sector provided the main raw materials for production of most sectors such as mining (85.9 per cent), construction (83.0 per cent), agriculture (79.5 per cent), water (53.5 per cent), manufacturing (49.5 per cent), administration and communication (42.4 per cent), and health care, education, and research (34.4 per. cent). Meanwhile, finance, banking, insurance, and real estate activities accounted for the largest part in the intermediate inputs of the accommodation, tourism, and other services sector at 84.4 per cent. The contribution of the energy sector to gross output of the water sector was higher than its contribution to that of other sectors.

Economic development in Vietnam has been mostly dominated by labour-intensive industries. Table 2.2 summarises the contributions of value-added from three production factors (labour, capital, and land) in the production processes of 11 sectors. Labour is generally the main contributor to value added of all sectors. In particular, the added value from labour in the construction sector was the highest at 84.0 per cent, followed by health care, education, and research sector (77.2 per cent), administration and communication (69.7 per cent) and agriculture (69.3 per cent). Land and natural resources contributed to the added value of the agricultural sector at 19.6 per cent. By contrast, the energy sector was the only capital-intensive sector in which the capital factor accounted for three-fourths of the added value. The mining and finance, banking, insurance, and real estate sectors have similar contributions from capital and labour in their added values.

Table 2.2 **Share of production factors in value added of each sector (%)**

Sector	Labour	Capital	Land
Agriculture	69.33	11.05	19.62
Mining	51.15	48.85	-
Manufacturing	66.14	33.86	-
Energy	25.10	74.90	-
Water	64.50	35.50	-
Construction	83.98	16.02	-
Transportation, wholesale, and retail trade	66.75	33.25	-
Finance, banking, insurance, and real estates	53.73	46.27	-
Health care, education, and research	77.20	22.80	-
Administration and communication	69.67	30.33	-
Accommodation, tourism, and other services	68.60	31.40	-

Source: Author’s calculation from the SAM 2018

The outputs of all sectors are then moved to the market for sales. The total output of one sector was sold not only in that commodity market but also in other markets. For example, agricultural products mainly supplied to the agricultural market (99.4 per cent) and partly to manufacturing one (0.6 per cent). The contribution of different sectors in domestic sales can vary, but the total domestic supply of commodities was always equal to the sum of gross output across all sectors at producer prices.

In relations with the rest of the world (RoW), Vietnam recorded a trade surplus in 2018. The total exports were USD 259,491.7 million compared with imports of USD 251,260.7 million.

Table 2.3 shows the trade structure of 11 sectors in 2018. While agriculture and mining sectors had high trade surpluses, the manufacturing sector reported a significantly higher import value. The import value in the manufacturing sector was almost 1.7 times higher than domestic sales. Vietnam was a net energy importer with a trade deficit of USD 252.02 million. The manufacturing sector contributed the largest part to total exports and imports (68.4 per cent and 82.1 per cent, respectively), followed by the agriculture sector (15.4 per cent and 8.3 per cent), and the mining sector (9.1 per cent and 3.1 per cent). The remaining accounted for only less than 10 per cent.

Table 2.3 **Export and import structure (%)**

Sector	**Export**	**Import**
Agriculture	15.42	8.34
Mining	9.14	3.13
Manufacturing	68.41	82.06
Energy	0.02	0.12
Water	0	0
Construction	0	0
Transportation, wholesale, and retail trade	1.91	0.71
Finance, banking, insurance, and real estates	0.59	2.54
Health care, education, and research	0.62	1.64
Administration and communication	0.29	0.57
Accommodation, tourism, and other services	3.60	0.89

Source: Author's calculation from the SAM 2018

Taxes and fees account also provide important information about the economic situation in Vietnam. Taxes include production taxes, commodity taxes (i.e., sales taxes and import tariff), factor taxes and direct taxes (i.e., personal income taxes and corporate income taxes). The total government taxes and fees collected in 2018 were USD 47,345.6 million. Table 2.4 summarises rates of production and commodity taxes by sector, in which production taxes and commodity taxes are calculated as proportions of gross output and total sales (domestic supply and imports), respectively. The largest production tax rate was often found in the service sector. In particular, the financial, banking, insurance and real estate sector recorded the highest rates in both taxes, at 7.5 per cent and 17.1 per cent, respectively.

Table 2.4 **Production and commodity taxes rates (%)**

Sector	Production taxes	Commodity taxes
Agriculture	0.32	2.06
Mining	1.00	4.11
Manufacturing	0.76	3.33
Energy	0.87	5.75
Water	0.86	6.44
Construction	0.05	1.07
Transportation, wholesale, and retail trade	0.26	0.21
Finance, banking, insurance, and real estates	7.52	17.07
Health care, education, and research	0.28	2.29
Administration and communication	0.76	8.58
Accommodation, tourism, and other services	0.86	2.53

Source: Author's calculation from the SAM 2018

Distributions of the income and expenditure of enterprises, households, and government also depict flows and relationships in the economy. Regarding enterprises, they earned income from production factors (i.e., capital) and transfers (subsidies) from the government. Enterprises allocated their expenditure on corporate income taxes (18.2 per cent), other non-tax payments to the government (20.0 per cent), savings or retained profits (11.3 per cent), dividends to households (41.0 per cent), and transfers to the abroad (9.5 per cent). The dividends were also the income that households indirectly receive from the capital factor.

Furthermore, household income and expenditure statistics may provide a basic description and analysis of their socio-economic characteristics. This structure affects the way that households respond to a change in exogenous demand. Table 2.5 summarises household income from different sources. Production factors (labour, capital, and land) were the main source of household income, contributing 74.2 per cent of total income, followed by dividends from enterprises (15.1 per cent), foreign remittances (7.4 per cent) and social transfers from the government (3.3 per cent). In terms of expenditure, final consumption accounted for the largest part of the total household expenditure at 77.4 per cent, followed by savings (20.8 per cent) and personal income tax payment (1.8 per cent). In particular, a representative household spent the largest share on manufacturing products (39.2%), followed by accommodation, tourism, and other services (19.6 per cent), and agricultural products (15.6 per cent).

Table 2.5 **Structure of household income by source**

	Value (USD million)	Share (%)
Factor payments	158,742.22	74.15
Dividend	32,384.25	15.13
Social transfers from government	7,066.17	3.30
Foreign remittances	15,900.00	7.43
Total	214,092.64	100

Source: Author's calculation from the SAM 2018

Structures of government revenue and expenditure are also important information in analysing their fiscal balance. The total government income in 2018 was recorded at USD 63,336.7 million. Additionally, taxes and other fees were the main revenue source, accounting for 74.8 per cent of government revenue, while the contribution of non-tax payments from enterprises was 25.0 per cent. Government expenditure on consumption of goods and services, typically health care, education, and research sector as well as administration and communication services accounts for a total proportion of about 95 per cent. Additionally, the government also used its revenue to subsidise enterprises and households with shares of 36.3 per cent and 11.2 per cent, respectively. The remainder after allocation of revenues and expenditures was government savings, in which the positive value indicates that in 2018 the government had a budget surplus. The government saving rate was recorded at 27.5 per cent. Detail of government spending is presented in Table 2.6.

Table 2.6 **Structure of government expenditure**

	Value (USD million)	Share (%)
Final consumption	15,864.09	25.05
Transfers to enterprises	23,006.69	36.32
Transfers to households	7,066.17	11.16
Saving	17,399.71	27.47
Total	63,336.67	100

Source: Author's calculation from the SAM 2018

Finally, the relationship between savings and investments demonstrates another macroeconomic situation of the economy. Gross domestic savings included savings from enterprises, households, and government. In terms of investment in 11 sectors, the construction sector accounted for the biggest share at 58.7 per cent, followed by the manufacturing (33.8 per cent), agriculture (5.8 per cent), and mining (1.6 per cent) sectors. The difference between gross domestic savings and total investment was the current account balance. This value indicates that Vietnam had a current account surplus, i.e., domestic savings exceeded investment, which shows an improvement in its net lending position as the country reported a current account deficit in 2017 (State Bank of Vietnam, 2019).

2.4 Methodology and data source

This section describes the methodology and data source for the study. First, I present a basic framework of a SAM model and explain how a multiplier analysis works. Second, the disaggregation of a practical SAM used in the analysis is described. I also discuss the approach to derive a multiplier matrix, in which the substitution method in algebra is applied, and redundant equations are cancelled out to model an economic equilibrium. The third subsection presents the specification of a simplified system of equations in matrix format, which computes all sectors' new gross output and expenditures of enterprises and households when a change in exogenous demand happens. Finally, the last section describes the data source for the SAM model.

2.4.1 Methodology

2.4.1.1 A simplistic SAM framework and multiplier analysis

SAM is a comprehensive macroeconomic data framework which records transactions occurring in an economy during a particular accounting period, normally one year. It provides a snapshot of socio-economic structure and relationship between different agents, particularly among sectors in production blocks, institution blocks, and factors of production (Hartono and Resosudarmo, 2008). SAM is considered to be an efficient way to represent a fundamental law of economics at which each income has a corresponding outlay or expenditure (Pyatt, 1988).

The simplified structure of a SAM is a 4×4 matrix as presented in Figure 2.1. Accounts in SAM are divided into endogenous and exogenous accounts. The former includes three blocks, namely production activity, production factor and institutional blocks. The row represents receipts or income while the column shows expenditures or outlays. A SAM is square since each account has both incomes and expenditures, in which the row sum must equal its column sum (Pyatt and Round, 1979, Round, 2003). The ordering of the rows and columns in a SAM is not important, but it usually begins with production block as in an IO table.

Each submatrix generally represents income or expenditure for one account. In Figure 2.1, submatrices T_{ij} and Z_{ij} show the income of account i from account j. In particular, T_{11} is intermediate input requirement, T_{13} presents expenditure pattern of each institution, T_{21} gives value added generated by production factors in various production activities, T_{32} reflects factor income of institutions, and T_{33} presents income transfers within and between institutions. Vectors y_i and z present total income, while vectors y_i' and z' capture total expenditure of each account. Vectors y_i' and z' are the transposes of vector y_i and z.

			EXPENDITURE				
			Endogenous Accounts			Exogenous account	TOTAL
			Production activities	Production factors	Institutions		
INCOME	Endogenous accounts	Production activities	T_{11}	0	T_{13}	Z_1	y_1
		Production factors	T_{21}	0	0	Z_2	y_2
		Institutions	0	T_{32}	T_{33}	Z_3	y_3
	Exogenous account		T_{41}	T_{42}	T_{43}	Z_4	z
	TOTAL		y'_1	y'_2	y'_3	z'	

Figure 2.1 **A simplistic SAM framework**

Source: Hartono and Resosudarmo (2008)

In the multiplier analysis of a basic SAM framework, the coefficient matrix A needs to be derived. Elements in matrix A are obtained by dividing each element in endogenous accounts by the column sum that the element is located. In particular, $a_{mn} = {t_{mn}}/{y_n}$ is the multiplier coefficient where $t_{mn} \in T_{ij}$ and $y_n \in y_j'$. Thus, the sum of each column in matrix A is 1. The relationship between the endogenous and exogenous accounts can be written as

$$y = Ay + x$$

where y is the vector of total income, x is the vector of final demand.

A multiplier matrix is a useful tool in the SAM framework. The matrix captures overall impacts of changes in one sector on other sectors as well as impacts of shocks in exogenous accounts on endogenous accounts within the economy (Hartono and Resosudarmo, 2008). The accounting multiplier matrix can be specified as

$$y = Ay + x \Rightarrow y = (I - A)^{-1}x \Rightarrow y = M_a x$$

in which I is an identity matrix and $M_a = (I - A)^{-1}$ is the multiplier matrix.

2.4.1.2 Modelling economic equilibria in SAM

This study uses a more detailed SAM framework to describe linkages within the economy. Figure 2.2 describes a general structure of practical SAMs with briefing notes on the meanings of blocks. In terms of economic activity, the SAM captures several basic forms, which are production (accounts 1, 2, 3, 4), consumption (accounts 5, 6, 7), taxes (account 8), accumulation (account 9), and transactions with the rest of the world (RoW) (account 10). In particular, the accumulation account includes stock changes in the economy.

Similar to Figure 2.1, I divide ten accounts in the SAM into endogenous and exogenous accounts. Traditionally, accounts of government, taxes, investment-saving, and export-import (i.e., the RoW) are considered exogenous, while the remaining accounts are set as endogenous (Pyatt and Round, 1979, 1985, Thorbecke, 1994). Regarding endogenous accounts, production block is now partitioned into activity and commodity accounts, in which each account is then disaggregated further into 11 sectors (1 agricultural sector, 5 industrial sectors, and 5 service sectors). The second block, factors of production, is divided into three subgroups: labour, capital, and land (natural resources). Institutions, which are the third block in the endogenous account, include enterprises and households. Given available data, the SAM in this study also has one more block to capture the transaction costs in the market. Thus, the SAM consists of 32 rows and columns.

			Endogenous accounts						**Exogenous account**				
			Activities	Commodities	Transaction cost	Factors	Enterprises	Households	Government	Taxes	Investment	Rest of World	Total
			1 (11)[1]	2 (11)	3(1)	4 (3)	5 (1)	6 (1)	7 (1)	8 (1)	9 (1)	10 (1)	
Endogenous accounts	Activities	1		Domestic sales									Activity income
	Commodities	2	Intermediate inputs		Transaction costs			Household consumption	Government consumption		Investment	Exports	Total demand
	Transaction cost	3		Transaction costs									
	Factors	4	Gross value-added										Factor income
	Enterprises	5				Factor income to enterprises			Transfers to enterprises				Enterprise income
	Households	6				Factor income to households	Dividend		Transfers to households			Foreign remittances to households	Household income
Exogenous account	Government	7					Revenue from non-taxes			Tax revenue		Net foreign transfers to the government	Government income
	Taxes	8	Activity taxes	Commodity taxes		Factor taxes	Corporate income taxes	Personal income taxes					Tax revenue
	Savings	9					Enterprises savings	Household savings	Government savings[2]			Foreign savings[3]	Savings
	Rest of World	10		Imports		Payments to imported factors	Net foreign enterprises expenditure						Foreign exchange outflow
	Total		Gross output	Total supply		Factor spending	Enterprise expenditure	Household expenditure	Government expenditure	Tax revenue	Investment spending	Foreign exchange inflow	

Figure 2.2 **General structure of practical SAMs**

[1] Number in parentheses report the disaggregation level of that column and its corresponding row in the SAM 2018.
[2] Fiscal balance
[3] Current account balance

There is one adjustment in constructing an accounting multiplier matrix. To describe the real relationship between different accounts or blocks better, not all multiplier elements are obtained by dividing elements in endogenous accounts by their total column sums. Thus, the column sums of the matrix cannot equal 1, which are different to those of matrix A in the previous subsection. However, the principle of equality between column sum and its corresponding row sum must be satisfied since all income is always accounted for by an expenditure of other types. Given the disaggregation in production and commodity accounts, there are 32 equations in the system to solve the balance of the SAM. If there are any changes in exogenous accounts, the model will find a new equilibrium for the economy.

Firstly, the linkages between activity and commodity accounts are constructed as follows. In the first account (production activities), the multiplier elements are calculated by dividing the cell's value by its column sum, i.e., the gross output. All outputs are then transferred to the market for sales. In the activities-commodities block, the gross output of one sector is sold in several commodity markets. Multiplier elements in each row (row 1-row 11) are calculated as the ratio of domestic supply in one market to gross output of that production activity. Thus, the gross output of each production activity equals its activity income or total value of sales (domestic supply at producer prices), which guarantees the balance of the first 11 equations.

Multiplier elements in the commodity account are derived differently when compared with the conventional way. I assume that imports in each sector are proportional to their domestic supply. Thus, multiplier elements in the RoW-commodities block are the ratios of imports value to the total domestic sales in that sector. Additionally, the transaction costs and commodity taxes are assumed to be proportional to the total value of. Multiplier elements in transaction cost-commodities and taxes-commodities are obtained by dividing the transaction costs and taxes in each sector by the sum of its domestic supply and imports.

Next, equations for transaction costs and production factors are substituted to simplify the system and cancel out redundant equations. Firstly, since transaction costs only come from sector 7 (transportation, wholesale, and retail trade), this cell in transaction cost column is set equal to the sum of transaction costs in all commodities (transaction costs-commodities). Hence, its multiplier element is certainly unity. Secondly, to make column sum equal row sum of production factor block, I calculate multiplier elements by dividing factor incomes, taxes of production factors, and net payments to foreign to its corresponding row sum instead of column sum. It ensures the equality between the total expenditure of each factor (labour, capital, and land/natural resources) and its income. Therefore, four redundant equations, including one equation of transaction costs and three equations of production factors, are removed.

Furthermore, the standard multiplier analysis is applied to the two accounts of institutions (enterprises and households). Each element in the two columns is divided by its total income to obtain the multiplier effects. Thus, the column sums of the two multiplier vectors equal 1 as in coefficient matrix A in previous subsection. Enterprise and household accounts are not expressed by relations with other accounts.

Regarding the exogenous accounts, all of the last four equations will be cancelled out by the substitution method in algebra. Calculation of multiplier effects for these accounts is not required. The balance of taxes account is maintained by substituting tax revenues of the government with the sum of activity taxes, commodity taxes, factor of production taxes, and income taxes from households and enterprises. In addition, to keep the government account balance, this study sets the government-RoW cell as the difference between the column sum of the government account and other remaining cells in the same row.[4] The similar assumption is applied for the saving-RoW block to show the variation in the balance of the current account. The value in this block indicates the net lending position of the economy vis-à-vis the RoW. If all other column sums and row sums equal, the balance of the last account, RoW, will be maintained. Hence, the last four redundant equations in the system can be cancelled out.

2.4.1.3 SAM-based multiplier analysis

In the multiplier analysis, I set up a system of equations to find a new equilibrium for the economy when there are changes in exogenous demand. After removing redundant equations, the simplified system has 13 equations, including 11 equations for the activity blocks and two equations for enterprises and households' accounts. The multiplier analysis is set up in which all endogenous accounts are on the left-hand side (LHS) and exogenous accounts are on the right-hand side (RHS). The system of 13 equations can be written in the matrix format as

[4] I assume that the government budget balance is fixed and depends on its political target. In contrast, the government-RoW cell can vary to reflect the ability to borrow from abroad if the government needs more money as a result of an exogenous demand shock.

$$\boldsymbol{M} \times \boldsymbol{X} = \boldsymbol{E} \Longrightarrow \boldsymbol{X} = \boldsymbol{M}^{-\mathbf{1}} \times \boldsymbol{E}$$

where

$$M_{13\times13} = \begin{bmatrix} m_1^1 & \cdots & m_1^{13} \\ \vdots & \ddots & \vdots \\ m_{13}^1 & \cdots & m_{13}^{13} \end{bmatrix}; \qquad X_{13\times1} = \begin{bmatrix} X_1 \\ \vdots \\ X_{11} \\ X_{ent} \\ X_{hh} \end{bmatrix}; \qquad E_{13\times1} = \begin{bmatrix} E_1 \\ \vdots \\ E_{11} \\ E_{ent} \\ E_{hh} \end{bmatrix}$$

In this model, M is the multiplier matrix which captures impacts of exogenous demand changes on other sectors. m is the multiplier coefficient with subscript and superscript representing its position in the matrix M. X is the vector of gross output of 11 sectors, i.e., production activities $(X_1, X_2, \ldots, X_{11})$ as well as expenditures of enterprises (X_{ent}) and (X_{hh}), E is the vector of exogenous accounts of 11 sectors $(E_1, E_2, \ldots, E_{11})$, enterprises (E_{ent}), and households (E_{hh}). When a change in exogenous demand of one sector occurs, for example, an increase in exports of agricultural commodity (i.e., E_1 rises), the model will find new values for gross output of 11 sectors, enterprises expenditure, and household expenditure such that the economy is at a new equilibrium. In this case, the column sum of each account equals its corresponding row sum. Detail of the model is provided in Appendix A2.3.

2.4.2 Data

This chapter uses the SAM 2018 for the analysis. The SAM 2018 is adopted from the project 'A new model for Vietnam's economic growth in 2021-2030 and vision to 2050: Quantitative assessment'. The project was funded by the Australian Centre for International Agricultural Research in collaboration with the Australian National University. The SAM 2018 was built based on information from the SAM 2012, which was developed by the Central Institute for Economic Management under the supervision of the United Nations University-World Institute for Development Economics Research. The SAM 2018 adopted some proportions in production part from SAM 2012 and updated with data from the General Statistics Office of Vietnam as well as aggregated data from provincial statistics provided by the Ministry of Planning and Investment. Moreover, other blocks in the SAM 2018 were constructed using the information in reports on state budget revenue and expenditure in 2018 provided by the Ministry of Finance, the State Bank of Vietnam (2019), and household's information extracted from the Vietnam Household Living Standard Survey 2018. The SAM 2018 provides a general picture of the economic structure and relationship between different accounts in Vietnam. The production activity and commodity accounts are disaggregated into 11 sectors. Monetary values in the SAM 2018 are converted into USD at the exchange rate VND 22,604/USD.[5]

2.5 Results

This section presents main results and sensitivity analysis for Chapter 2. I quantify impacts of a change in exogenous demand of one sector on other sectors. I calculate how an increase in each of the 11 sectors will change its total demand and other sectors' demand. The next subsection focuses on the energy-GDP relationship, particularly energy multiplier and energy elasticity with respect to GDP. The carbon emission level is then computed to show the effect of variation in exogenous demand on the environment. I conduct a sensitivity analysis to show how shares of sectors in exogenous demand affect the energy-GDP relationship.

2.5.1 Economy-wide linkages

In the main analysis, this subsection presents the economy-wide impacts of a change in exogenous demand. The baseline scenario is defined as the economy at the original equilibrium, in which column sums of all accounts equal their corresponding row sums. I simulate an increase in one sector and assume that other sectors remain unchanged. There are 11 scenarios (S1-S11) corresponding to changes in 11 sectors that come from final consumption of the government, investment, and exports (i.e., RoW). For instance, S1 is the scenario when there is an increase in exogenous demand for agriculture goods. The SAM-based multiplier model will find new values for gross output of 11 sectors, expenditure of enterprises and households such that the economy is at a new equilibrium. Detail of my simulation is provided in Appendix A2.4.

A change in one sector increases the total demand of all sectors. Table 2.7 presents the self- and cross-sector multiplier impacts on demand of 11 scenarios. It is measured by the impact on total demand of one sector per unit of a change in exogenous demand (ΔD_i). Each row presents results for one scenario, while columns represent impacts on different sectors. The impacts on total demand vary within and between scenarios. Firstly, within each scenario, the highest impact is found in the sector that the change occurs. Secondly, among different scenarios, the impact on the sector's total demand itself is highest when there is a shock to the transportation,

[5] The exchange rate is calculated as the 12-month average of rates on the interbank foreign currency market (State Bank of Vietnam, 2019)

wholesale and retail trade sector (S7). The impacts are also relatively high when a change happens in the manufacturing (S3) and the agriculture sector (S1). Nonetheless, a change in the energy sector (S4) and the construction sector (S6) creates the lowest impacts on its total demand.

Changes in other sectors' demand in scenario 4 (S4) and changes in energy demand across different scenarios indicate the relations of the energy sector with others in the economy. First, an increase in exogenous energy demand leads to the most significant growth in total demand of the energy sector, followed by an increase in transportation, wholesale and retail trade sector, and manufacturing sector. The impacts are relatively moderate in comparison with other scenarios. Second, the effects on energy demand across scenarios reflect how close linkages between the energy sector and other sectors. It can be observed from column ΔD_4 that the second highest figure can be found in S5 when there is a change in the water sector. This can be explained by the higher contribution of the energy sector in production of the water sector compared with that in the production of other remaining sectors. The results suggest a relatively close connection between the energy sector and the water sector.

Table 2.7 **Self- and cross-sector multiplier impacts on demand**

Scenario	ΔD_1	ΔD_2	ΔD_3	ΔD_4	ΔD_5	ΔD_6	ΔD_7	ΔD_8	ΔD_9	ΔD_{10}	ΔD_{11}
S1	1.161	0.016	0.576	0.028	0.006	0.020	0.579	0.085	0.061	0.036	0.109
S2	0.085	1.043	0.555	0.022	0.004	0.015	0.433	0.067	0.047	0.027	0.080
S3	0.089	0.018	1.269	0.018	0.004	0.010	0.459	0.044	0.031	0.023	0.054
S4	0.102	0.045	0.348	1.038	0.006	0.020	0.533	0.083	0.060	0.034	0.108
S5	0.139	0.021	0.531	0.063	1.046	0.028	0.480	0.118	0.083	0.041	0.146
S6	0.127	0.029	0.924	0.029	0.007	1.039	0.402	0.109	0.066	0.084	0.115
S7	0.147	0.019	0.519	0.039	0.008	0.030	3.524	0.133	0.090	0.126	0.158
S8	0.087	0.011	0.280	0.023	0.005	0.027	0.175	1.133	0.056	0.027	0.095
S9	0.141	0.018	0.453	0.033	0.008	0.029	0.277	0.121	1.092	0.075	0.152
S10	0.135	0.018	0.477	0.036	0.007	0.028	0.289	0.121	0.086	1.091	0.151
S11	0.112	0.015	0.387	0.028	0.006	0.025	0.223	0.706	0.060	0.030	1.108

Note: ΔD_i is multiplier impact on demand of sector *i* (i=1, 2, …, 11), S_i is scenario in which a change occurs in sector *i*,
1-Agriculture, 2-Mining, 3-Manufacturing, 4-Energy, 5-Water, 6-Construction, 7-Transportation, wholesale and retail trade, 8-Finance, banking, insurance, and real estates, 9-Health care, education, and research, 10-Administration and communication, 11-Accommodation, tourism, and other services

Moreover, various multipliers are calculated to evaluate the impacts of a change in one sector on different aspects of the economy, including gross output, GDP, and income of enterprises and households. All multipliers are estimated per unit of change in demand. In particular, an output multiplier for one sector is defined as the final increase in gross output of all sectors in the economy required to satisfy a dollar growth of final demand for its sector output (Miller and Blair, 2009). Similarly, household income multiplier in the study is defined as the change in household income due to one unit change in sectoral exogenous demand. The multipliers are dimensionless values.

Table 2.8 presents multiplier impacts on some macroeconomic-real indicators. Each row presents multiplier impacts for one scenario. For instance, one unit rise in demand for the agricultural sector (S1) leads to 1.82 unit increase in gross output, vis-à-vis 1.59 unit increase when the shock occurs in the mining sector (S2). The top three sectors that create the highest output multiplier are the transportation, wholesale and retail trade sector (S7), the construction (S6) and the water sector (S5). S7 also reports the highest GDP multiplier and household income multiplier at 1.34 and 0.99, respectively. Nonetheless, a change in the manufacturing sector (S3) generates the smallest multiplier impacts compared with other scenarios. Regarding energy sector (S4), a change in this sector leads to the most considerable impact on enterprise income with a multiplier of 0.55, while the effects on other indicators are moderate.

The values of these multipliers once again describe the characteristics of Vietnam’s economy. The highest effects are generally found in S7, which is reasonable since this is an important sector in the economy. The sector accounted for about 32.9 per cent of gross output and 16.8 per cent of GDP in 2018. The lowest effects are reported in S3, though production in the manufacturing sector contributed significantly to the economy at 22.8 per cent of gross output and 26.7 per cent of GDP. This is due to a large import-leakage in the manufacturing sector (Breisinger et al., 2009) since its import share is notably higher than those of the remaining sectors.

Table 2.8 **Response of macroeconomic-real indicators to sectoral final demand**

Scenario	Gross output multiplier	GDP multiplier	Enterprise income multiplier	Household income multiplier
S1	1.82	0.89	0.15	0.69
S2	1.59	0.77	0.22	0.51
S3	1.11	0.49	0.11	0.34
S4	1.85	1.23	0.55	0.69
S5	2.09	1.32	0.34	0.93
S6	2.18	0.95	0.18	0.72
S7	4.25	1.34	0.33	0.99
S8	1.30	1.05	0.27	0.59
S9	1.77	1.22	0.24	0.94
S10	1.84	1.28	0.28	0.91
S11	2.06	1.05	0.26	0.65

Note: S_i is scenario in which a change occurs in sector *i* (*i*=1, 2, …, 11)
1-Agriculture, 2-Mining, 3-Manufacturing, 4-Energy, 5-Water, 6-Construction, 7-Transportation, wholesale and retail trade, 8-Finance, banking, insurance, and real estates, 9-Health care, education, and research, 10-Administration and communication, 11-Accommodation, tourism, and other services

2.5.2 Energy-GDP relationship

This subsection focuses on energy-GDP relationship. Although both energy demand and GDP increase, this does not indicate the direction of change in aggregate energy intensity. Energy intensity is defined as the ratio of energy use to GDP. I calculate changes in energy intensity by comparing energy intensity in each scenario with the baseline. Out of 11 scenarios, S4 reports a rise in energy intensity, implying declines in economy-wide energy efficiency if a change happens in the energy sector. Other remaining scenarios see reductions in aggregate energy intensity, which indicates that energy use grows slower than GDP. In particular, S8 has the most significant improvement in the aggregate energy efficiency.

Table 2.9 shows the energy multiplier with respect to GDP and its ranking to compare the effects between different scenarios. The energy multiplier for each scenario is provided in the second column of the table, which is defined as the change in energy demand associated with a unit variation in GDP from an exogenous demand shock ($\Delta E/\Delta GDP$). This ratio is also a dimensionless value. The last column presents the rankings of the results to demonstrate which scenario has the most considerable impact on the energy-GDP relationship. Each row reports the result for one scenario.

Table 2.9 **Response of the energy consumption to sectoral final demand**

Scenario	ΔE/ΔGDP	Rank
S1	0.0312	4
S2	0.0288	7
S3	0.0367	3
S4	**0.8440**	**1**
S5	0.0474	2
S6	0.0302	5
S7	0.0291	6
S8	0.0217	11
S9	0.0271	9
S10	0.0277	8
S11	0.0261	10

Note: $\Delta E/\Delta GDP$ is energy multiplier impact with respect to GDP
S_i is scenario in which a change occurs in sector *i* (*i*=1, 2, …, 11).
1-Agriculture, 2-Mining, 3-Manufacturing, 4-Energy, 5-Water, 6-Construction, 7-Transportation, wholesale and retail trade, 8-Finance, banking, insurance, and real estates, 9-Health care, education, and research, 10-Administration and communication, 11-Accommodation, tourism, and other services

A change in one sector leads to changes in supply and demand of the energy sector with respect to GDP. The highest energy multiplier is reported in S4, and the second-highest figure is shown in S5. If the change occurs in non-energy sectors, the energy multipliers are much smaller, of which the lowest figure is found in S8 with a change in the finance, banking, insurance and real estate sector. Services sectors generally have low energy multipliers. The average multiplier impact is 0.10, but this number does not take into account weights of sectors in exogenous demand. The weighted average energy multiplier is 0.03, meaning that one unit growth in GDP is associated with an average increase of 0.03 unit in energy demand.

I also calculate another energy efficiency indicator, i.e., energy-GDP elasticity, energy-related carbon emissions and their corresponding rankings for 11 scenarios (Table 2.10). The second column presents the energy-GDP elasticity (ε_{GDP}^{E}), and the third column shows changes in energy-related carbon emissions per 1 percentage increase in GDP. The last column then shows the ranking for each scenario. In general, rankings of both energy elasticity and change in CO_2 level of different scenarios are the same as the rankings of energy multipliers as in Table 2.9.

There are substantial differences between energy elasticity across scenarios. Energy-GDP elasticity is measured as percentage change in energy consumption associated a percentage in GDP. Energy elasticity in S4 is 23.6, meaning that a one per cent increase in GDP is associated with a 23.6 per cent increase in energy consumption. The second and third highest figures are found in scenarios with changes in the water and manufacturing sectors. The weighted average energy-GDP elasticity is 0.95.

Table 2.10 **Energy elasticity and energy-related carbon emissions**

	ε_{GDP}^{E}	ΔCO_2 (million tonnes)	Rank
S1	0.87	1.98	4
S2	0.80	1.82	7
S3	1.03	2.33	3
S4	**23.58**	**53.42**	**1**
S5	1.33	3.00	2
S6	0.84	1.91	5
S7	0.81	1.84	6
S8	0.61	1.37	11
S9	0.76	1.72	9
S10	0.78	1.76	8
S11	0.73	1.65	10

Note: ε_{GDP}^{E} is energy elasticity, ΔCO_2 is change in carbon emissions level
S_i is scenario in which a change occurs in sector i (i=1, 2, …, 11).
1-Agriculture, 2-Mining, 3-Manufacturing, 4-Energy, 5-Water, 6-Construction, 7-Transportation, wholesale and retail trade, 8-Finance, banking, insurance, and real estates, 9-Health care, education, and research, 10-Administration and communication, 11-Accommodation, tourism, and other services

The amount of CO_2 emissions also differs significantly among scenarios. In order to calculate the corresponding emissions to each scenario, I assume that the composition of different energy types in the energy use mix in Vietnam remains the same; thus, CO_2 emissions vary proportionally to change in energy use. According to IEA (2019a), the total CO_2 emissions from fuel combustion in 2018 were 226.5 million tonnes. S4 reports a rise of 53.4 million tonnes in the CO_2 emissions level as a result of 1 per cent increase in GDP. Since the amount of non-energy-related CO_2 in production processes of other sectors such as agriculture is negligible in Vietnam, the energy-related CO_2 can represent the total CO_2 emissions level for the country (Tran, 2019). Service sectors generate less than 2 million tonnes of carbon emissions for each per cent growth in GDP.

The results in Table 2.9 and Table 2.10 demonstrate the relatively close linkages between the energy sector and other sectors of the economy. In detail, excepting S4, the energy multiplier and elasticity have the highest values in S5, the one with the largest contribution of energy in production process compared with that in other sectors. Hence, sectors with closer linkages with the energy sector will create more impacts on the energy-related indicators.

2.5.3 Sensitivity analysis

In the sensitivity analysis, I assess how the energy-GDP relationship responds to changes in weights of sectors' final demand. Unlike the main analysis, sectoral weights are assumed to vary by 20 per cent. Another sensitivity analysis with a variation of 30 per cent in sectoral weights is provided in Appendix A2.5. In total, there are 3^{10} combinations of weights from 10 sectors (59049 cases) since the water sector does not contribute to the total exogenous demand, as reported in the SAM 2018. In general, the weighted average energy-GDP elasticities in the sensitivity analysis change slightly.

Figure 2.3 shows the histogram of energy-GDP elasticity in different combinations of sectoral weights. The horizontal axis presents values of energy elasticity, and the vertical axis shows the frequency of these values. The vertical dashed line is the mean value. The average energy-GDP elasticity in reported at nearly 0.95, which is consistent with the main analysis. Higher values in the histograms generally come from cases with shares of the manufacturing sector increasing by 20 per cent. The manufacturing sector affects the energy elasticity considerably since this sector contributes the largest part to the total exogenous demand. Although a change in the energy sector creates the highest elasticity, its impacts on the weighted average value is trivial due to its insignificant proportion in the total exogenous demand.

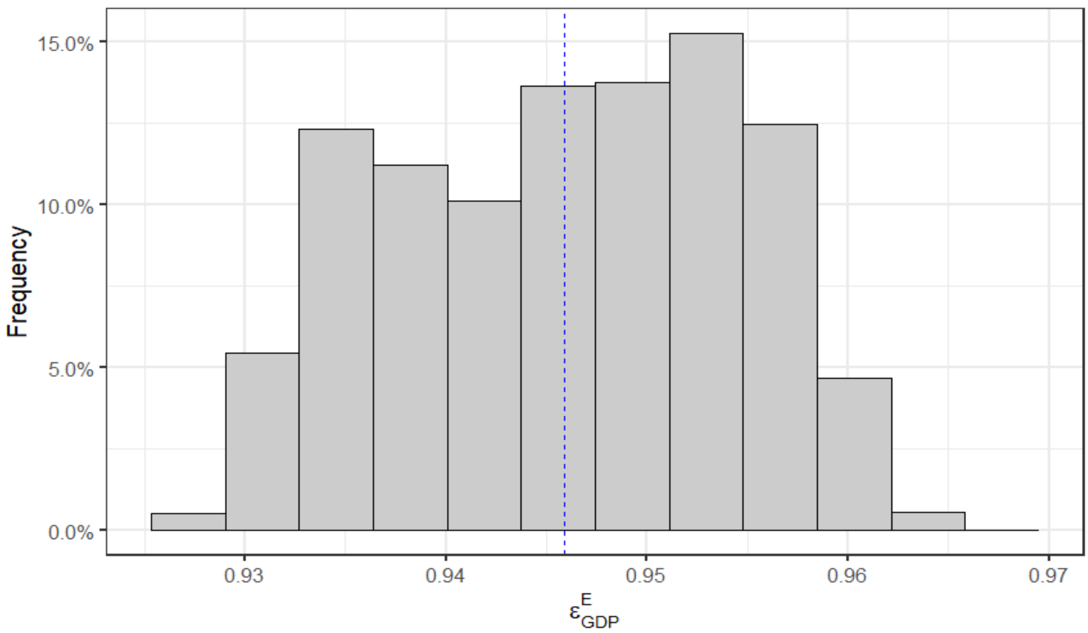

Figure 2.3 **Energy-GDP elasticity with variations of 20% in sectoral weights**

2.6 Discussion

To the best of my knowledge, this is the first study of Vietnam that analyses the energy-GDP relationship while controlling for cross-sectoral linkages in the economy. Compared with econometric techniques, the SAM modelling approach can evaluate simultaneous connections across sectors as well as between production sectors and other institutions (enterprises and households). It shows that any change in the exogenous demand, even a small one, has economy-wide impacts. Hence, the study provides a more comprehensive picture of the energy sector in the country's economic development.

The energy-GDP elasticity of Vietnam is a relatively higher than the world average. Previous studies report an average elasticity of less than unity (Burke and Csereklyei, 2016, Csereklyei et al., 2016). The average energy elasticity in this study is 0.95 in both the main and sensitivity analyses. The higher energy elasticity is understandable since developing countries like Vietnam consume much more energy in the development process. This number is also similar to the prediction of energy elasticity for the period 2010-2035 in Nguyen (2013) and JICA (2008). This study, thus, reaffirms the energy-GDP elasticity of Vietnam by using the bottom-up approach.

The results demonstrate the relatively close linkages between the energy sector and other sectors and parts of the economy. Differences in the energy multiplier and elasticity with respect to GDP across scenarios reflect the strength of their connections. For instance, excepting for S4 when there is a positive change in the energy sector, high figures are found in sectors in which contribution of the energy sector to production activities of these sectors is larger than its contribution to the remaining sectors. Hence, sectors with closer linkages with the energy sector will create more impacts on the energy-related indicators.

My results provide some policy recommendations for the government. To balance economic and environment objective (e.g., increasing GDP while pursuing energy conservation policy), the government needs to take into account the close linkages between sectors. Depending on the contribution of the energy input in the production process, the interdependences between the energy and other sectors are heterogeneous. One policy in different sectors can create distinct impacts on GDP and energy demand. For example, a policy which increases demand in the manufacturing sector leads to a smaller growth in GDP but higher energy consumption compared with the transportation, wholesale and retail trade sector Therefore, the government should choose a policy control that minimises the negative impacts on the environment.

The relatively high energy-GDP elasticity suggests that there are opportunities to improve energy efficiency in Vietnam. The government should encourage or subsidise innovation activities to improve energy efficiency and environmental performance in energy-intensive sectors. Innovation activities help to lower energy intensity in many countries and regions (Subrahmanya and Kumar, 2011, Sohag et al., 2015, Chen et al., 2016, Saudi et al., 2019) and are particularly crucial in reducing energy dependence in highly energy-intensive sectors. For example, conducting research and development activities in the water sector, which uses energy quite extensively compared with other sectors, would decrease its energy use efficiently and the overall emissions of the country. The impact, however, would be trivial if innovation is conducted in sectors that already use less energy.

Moreover, to achieve green growth and sustainable development, the government needs to encourage the green transformation in Vietnam's energy sector. The current energy profile releases a lot of GHG emissions, especially CO_2. The country should reduce consumption of fossil fuels in energy-intensive sectors like electricity generation and promote renewable energy such as wind, solar and modern biomass. Appropriate energy mix policies will help Vietnam to reduce the energy-related CO_2 emissions even when energy demand continues to increase as a result of economic growth and development. The implementation of the Renewable Energy Development Strategy, thus, is very crucial to improve the energy efficiency of the country (Tran, 2019).

However, there are several limitations in the application of a SAM model that should be taken into account when interpreting the results. The model assumes fixed prices, which means that changes in demand affect physical outputs only. Besides, another assumption of the model is the unlimited factors of production, i.e., an increase in demand is accompanied by a growth in supply (Hartono and Resosudarmo, 2008). Another drawback comes from the sectoral aggregation in the SAM 2018 in which different types of energies are not explicitly identified as separate sectors such as fossil fuels and non-fossil fuels. Hence, comparison between their multiplier impacts cannot be conducted (Garrett-Peltier, 2017).

2.7 Conclusion

This chapter has examined the energy-GDP relationship in Vietnam using a SAM modelling approach. I constructed a SAM-based multiplier model to control for interdependencies between sectors in the economy. Various multiplier impacts on gross output, GDP, enterprise income, and household income were calculated and compared to describe the relatively close linkages between the energy and other sectors in the economy. This study then computed the energy multiplier and energy elasticity with respect to GDP to represent aggregate energy efficiency of Vietnam.

Overall, the study demonstrates the role of the energy sector in the economy, particularly in climate change policies. A change in exogenous demand of the energy sector creates the highest impacts on the energy sector itself: a one unit increase in GDP is associated with a 0.84 unit rise in energy demand. Results from the multiplier impacts and energy efficiency indicators suggest that there is a close linkage between the energy sector and the water sector. The linkages are also confirmed by histograms in the sensitivity analysis. Additionally, the study reports the weighted average energy-GDP elasticity of about 0.95 in both the main and sensitivity analyses. The elasticity is slightly higher than the world average, and it is consistent with results reported in the literature for Vietnam.

Results in this chapter provide some policy implications. Given the economy-wide impacts of demand shocks, the government should take into account the relatively close connections between the energy sector and other sectors in the economy in development policies. Investment in innovative technologies in energy-intensive sectors should be encouraged since it improves energy efficiency significantly. In addition, the energy sector in Vietnam should be transformed to a greener fuel mix structure with a higher contribution made by low carbon energies such as renewables. Further research, which disaggregates the energy sector into different energies such as fossil fuels and non-fossil fuels, is essential to provide a more detailed SAM-based multiplier analysis for Vietnam.

Appendix

A2.1 Description of economic sectors in the SAM 2018

Sector	Categories	Description
1	Agriculture	Agricultural, fisheries and forestry
2	Mining	Mining and quarrying
3	Manufacturing	Manufacturing
4	Energy	Electricity, gas, steam and air conditioning supply
5	Water	Water supply, sewerage, waste management and remediation activities
6	Construction	Construction
7	Transportation, wholesale and retail trade	Transportation and storage
		Wholesale and retail trade; repair of motor vehicles and motorcycles
8	Finance, banking, insurance, and real estates	Financial, banking and insurance activities
		Real estate activities
9	Health care, education, and research	Human health and social work activities
		Education and training
		Professional, scientific and technical activities
10	Administration and communication	Administrative and support service activities
		Information and communication
		Activities of Communist Party, socio-political organisations; Public administration and defence; compulsory security
11	Accommodation, tourism, and other services	Accommodation and food service activities
		Arts, entertainment and recreation
		Activities of households as employers; undifferentiated goods and services producing activities of households for own use
		Other service activities

A2.2 The 2018 social accounting matrix of Vietnam

			1	2	3	4	5	6	7	8	9	10	11
Production sectors (activities)	Agricultural, fisheries and forestry	**1**	0	0	0	0	0	0	0	0	0	0	0
	Mining	**2**	0	0	0	0	0	0	0	0	0	0	0
	Manufacturing	**3**	0	0	0	0	0	0	0	0	0	0	0
	Energy	**4**	0	0	0	0	0	0	0	0	0	0	0
	Water	**5**	0	0	0	0	0	0	0	0	0	0	0
	Construction	**6**	0	0	0	0	0	0	0	0	0	0	0
	Transportation, wholesale and retail trade	**7**	0	0	0	0	0	0	0	0	0	0	0
	Finance, banking, insurance, and real estates	**8**	0	0	0	0	0	0	0	0	0	0	0
	Health care, education, and research	**9**	0	0	0	0	0	0	0	0	0	0	0
	Administration and communication	**10**	0	0	0	0	0	0	0	0	0	0	0
	Accommodation, tourism, and other services	**11**	0	0	0	0	0	0	0	0	0	0	0
Commodities	Agricultural, fisheries and forestry	**12**	4,202	4	12,072	0	1	50	47	10	62	13	581
	Mining	**13**	37	946	3,643	275	4	391	31	12	7	2	77
	Manufacturing	**14**	20,046	9,422	32,681	275	223	23,915	4,454	653	1,050	1,842	3,476
	Energy	**15**	275	114	2,020	132	62	65	367	130	72	147	166
	Water	**16**	31	9	634	6	78	29	47	23	27	21	43
	Construction	**17**	60	27	86	10	5	851	168	361	74	85	32
	Transportation, wholesale and retail trade	**18**	83	111	13,165	9	8	111	124,320	101	86	183	54
	Finance, banking, insurance, and real estates	**19**	224	190	778	16	18	941	919	2,092	241	252	25,898
	Health care, education, and research	**20**	72	91	477	6	6	133	306	169	276	191	57
	Administration and communication	**21**	83	32	246	7	6	2,229	4,797	184	1,023	1,362	89
	Accommodation, tourism, and other services	**22**	91	28	179	9	6	90	216	130	136	241	211
Transaction costs		**23**	0	0	0	0	0	0	0	0	0	0	0

			1	2	3	4	5	6	7	8	9	10	11
Production factors	Labour	**24**	21,771	5,434	37,142	1,668	887	13,284	27,965	9,709	13,893	11,855	6,572
	Capital	**25**	3,468	5,189	19,017	4,979	488	2,535	13,930	8,360	4,103	5,162	3,008
	Land	**26**	6,161	0	0	0	0	0	0	0	0	0	0
Enterprises		**27**	0	0	0	0	0	0	0	0	0	0	0
Households		**28**	0	0	0	0	0	0	0	0	0	0	0
Government		**29**	0	0	0	0	0	0	0	0	0	0	0
Taxes		**30**	180	218	940	65	16	21	458	1,785	60	164	347
Saving		**31**	0	0	0	0	0	0	0	0	0	0	0
ROW		**32**	0	0	0	0	0	0	0	0	0	0	0
Total		**33**	56,784	21,815	123,081	7,458	1,809	44,645	178,026	23,718	21,109	21,521	40,611

			12	13	14	15	16	17	18	19	20	21	22
Production sectors (activities)	Agricultural, fisheries and forestry	**1**	56,453	0	329	1	0	0	0	0	0	0	0
	Mining	**2**	0	21,815	1	0	0	0	0	0	0	0	0
	Manufacturing	**3**	5	3	122,958	2	0	9	1	0	5	97	0
	Energy	**4**	0	0	0	7,458	0	0	0	0	0	0	0
	Water	**5**	0	0	1	0	1,807	0	0	0	0	0	0
	Construction	**6**	0	0	8	0	20	44,486	27	90	10	4	0
	Transportation, wholesale and retail trade	**7**	1	8	8	0	0	85	177,924	0	0	0	0
	Finance, banking, insurance, and real estates	**8**	0	0	0	0	0	73	0	23,645	0	0	0
	Health care, education, and research	**9**	0	0	0	0	0	6	0	1	21,060	38	4
	Administration and communication	**10**	0	3	9	0	0	0	61	1	6	21,440	0
	Accommodation, tourism, and other services	**11**	0	0	11	0	0	0	1	0	0	3	40,595
Commodities	Agricultural, fisheries and forestry	**12**	0	0	0	0	0	0	0	0	0	0	0
	Mining	**13**	0	0	0	0	0	0	0	0	0	0	0
	Manufacturing	**14**	0	0	0	0	0	0	0	0	0	0	0
	Energy	**15**	0	0	0	0	0	0	0	0	0	0	0
	Water	**16**	0	0	0	0	0	0	0	0	0	0	0
	Construction	**17**	0	0	0	0	0	0	0	0	0	0	0
	Transportation, wholesale and retail trade	**18**	0	0	0	0	0	0	0	0	0	0	0
	Finance, banking, insurance, and real estates	**19**	0	0	0	0	0	0	0	0	0	0	0
	Health care, education, and research	**20**	0	0	0	0	0	0	0	0	0	0	0
	Administration and communication	**21**	0	0	0	0	0	0	0	0	0	0	0
	Accommodation, tourism, and other services	**22**	0	0	0	0	0	0	0	0	0	0	0
Transaction costs		**23**	0	7,741	1,729	22,079	906	102	0	0	0	0	0
Production factors	Labour	**24**	0	0	0	0	0	0	0	0	0	0	0
	Capital	**25**	0	0	0	0	0	0	0	0	0	0	0
	Land	**26**	0	0	0	0	0	0	0	0	0	0	0

		12	13	14	15	16	17	18	19	20	21	22
Enterprises	**27**	0	0	0	0	0	0	0	0	0	0	0
Households	**28**	0	0	0	0	0	0	0	0	0	0	0
Government	**29**	0	0	0	0	0	0	0	0	0	0	0
Taxes	**30**	180	1,598	1,219	10,981	447	118	476	382	5,143	576	1,975
Saving	**31**	0	0	0	0	0	0	0	0	0	0	0
ROW	**32**	0	20,959	7,862	206,175	306	0	0	1,784	6,390	4,111	1,444
Total	**33**	86,758	32,639	362,561	9,120	2,048	45,135	180,179	35,270	25,768	25,002	43,913

			23	24	25	26	27	28	29	30	31	32	33
Production sectors (activities)	Agricultural, fisheries and forestry	**1**	0	0	0	0	0	0	0	0	0	0	56,784
	Mining	**2**	0	0	0	0	0	0	0	0	0	0	21,815
	Manufacturing	**3**	0	0	0	0	0	0	0	0	0	0	123,081
	Energy	**4**	0	0	0	0	0	0	0	0	0	0	7,458
	Water	**5**	0	0	0	0	0	0	0	0	0	0	1,809
	Construction	**6**	0	0	0	0	0	0	0	0	0	0	44,645
	Transportation, wholesale and retail trade	**7**	0	0	0	0	0	0	0	0	0	0	178,026
	Finance, banking, insurance, and real estates	**8**	0	0	0	0	0	0	0	0	0	0	23,718
	Health care, education, and research	**9**	0	0	0	0	0	0	0	0	0	0	21,109
	Administration and communication	**10**	0	0	0	0	0	0	0	0	0	0	21,521
	Accommodation, tourism, and other services	**11**	0	0	0	0	0	0	0	0	0	0	40,611
Commodities	Agricultural, fisheries and forestry	**12**	0	0	0	0	0	25,904	0	0	3,791	40,020	86,758
	Mining	**13**	0	0	0	0	0	2,442	0	0	1,054	23,721	32,639
	Manufacturing	**14**	0	0	0	0	0	65,021	0	0	21,995	177,509	362,561
	Energy	**15**	0	0	0	0	0	5,516	0	0	0	54	9,120
	Water	**16**	0	0	0	0	0	1,099	0	0	0	0	2,048
	Construction	**17**	0	0	0	0	0	5,158	0	0	38,217	0	45,135
	Transportation, wholesale and retail trade	**18**	32,558	0	0	0	0	4,432	0	0	0	4,957	180,179
	Finance, banking, insurance, and real estates	**19**	0	0	0	0	0	2,181	0	0	0	1,521	35,270
	Health care, education, and research	**20**	0	0	0	0	0	17,470	4,892	0	0	1,619	25,768
	Administration and communication	**21**	0	0	0	0	0	3,987	10,209	0	0	749	25,002
	Accommodation, tourism, and other services	**22**	0	0	0	0	0	32,472	762	0	0	9,342	43,913
Transaction costs		**23**	0	0	0	0	0	0	0	0	0	0	0
Production factors	Labour	**24**	0	0	0	0	0	0	0	0	0	0	150,180
	Capital	**25**	0	0	0	0	0	0	0	0	0	0	70,242
	Land	**26**	0	0	0	0	0	0	0	0	0	0	6,161

		23	24	25	26	27	28	29	30	31	32	33
Enterprises	**27**	0	0	0	56,015	0	0	0	23,007	0	0	0
Households	**28**	0	0	150,180	2,405	6,157	32,384	0	7,066	0	0	15,900
Government	**29**	0	0	0	0	0	15,824	0	0	47,346	0	167
Taxes	**30**	180	0	0	922	5	14,372	3,797	0	0	0	0
Saving	**31**	0	0	0	0	0	8,943	44,614	17,400	0	0	-5,900
ROW	**32**	0	0	0	10,900	0	7,498	0	0	0	0	0
Total	**33**	86,758	32,558	150,180	70,242	6,161	79,022	214,093	63,337	47,346	65,057	269,659

Source: Project 'A new model for Vietnam's economic growth in 2021-2030 and vision to 2050: Quantitative assessment'

A2.3 Detail of a SAM multiplier analysis

In this study, the SAM-based multiplier model has 13 equations with 13 unknowns. The first 11 equations are for 11 sectors, and the last two equations are for enterprise and household expenditures. The system needs to find new values for gross output of 11 sectors, i.e., production activities ($X_1, X_2, \ldots, X_{11}$) and expenditures of enterprises (X_{ent}) and households (X_{hh}) when there is a change in exogenous demand.

Regarding the first equation for agricultural commodity account, the LHS of this equation is the total agriculture demand, which is specified as:

LHS$= A_1 + D_1^{hh} + D_1^{gov} + D_1^{inv} + D_1^{RoW}$

$= A_1^1 + A_1^2 + \cdots + A_1^{11} + D_1^{hh} + D_1^{gov} + D_1^{inv} + D_1^{RoW}$

$= a_1^1 X_1 + a_1^2 X_2 + \cdots + a_1^{11} X_{11} + h_1 X_{hh} + D_1^{gov} + D_1^{inv} + D_1^{RoW}$

It means that agriculture demand includes total intermediate demand for agricultural commodity (A_1), final demand from household (D_1^{hh}), government (D_1^{gov}), investment (D_1^{inv}), and exports (D_1^{RoW}). In particular, A_1 is the sum of intermediate demand for agricultural commodity of all production activities, i.e., $A_1 = A_1^1 + A_1^2 + \cdots + A_1^{11}$. A_1^1 is the intermediate demand for the agricultural commodity of agricultural activity. Then, I substitute A_1^1 as $a_1^1 X_1$, in which a_1^1 is the share of intermediate demand for the agricultural commodity in the total gross output of agricultural activity (X_1). Similar steps can be applied for $A_1^2, \ldots A_1^{11}$. $D_1^{hh} = h_1 X_{hh}$, in which h_1 is the share of household spending (X_{hh}) on agricultural commodity.

Total value of agricultural supply equals total sales of domestic (C^1) and imported goods (M^1), transaction costs (TRC^1) and taxes (T^1). In particular, C^1 is the total domestic supply in the market of agricultural commodity, i.e., $C^1 = C_1^1 + C_2^1 + \cdots + C_{11}^1$. I substitute C_1^1 as $c_1^1 X_1$, in which c_1^1 is the share of domestic supply from agricultural activity sold in agricultural market in the total gross output of that activity (X_1). Similar steps can be applied for $C_2^1, \ldots C_{11}^1$. I assume that imports are proportional to domestic supply, while transaction cost and commodity taxes are proportional to the total value of sales (domestic supply and imported goods). Let denote *m*, *r* and *t* as the proportions of imports, transaction costs, and taxes, I have $m^1 = M^1/C^1$, $r^1 = TRC^1/(C^1+M^1)$, $t^1 = T^1/(C^1+M^1)$. The RHS of the equation for agricultural commodity can be written as:

RHS = $C^1 + TRC^1 + T^1 + M^1$

$= C^1 + r^1(C^1 + M^1) + t^1(C^1 + M^1) + M^1$

$= (1 + r^1 + t^1)(C^1 + M^1)$

$= (1 + r^1 + t^1)(C^1 + m^1C^1)$

$= C^1(1 + r^1 + t^1)(1 + m^1)$

$= (C_1^1 + C_2^1 + \cdots + C_{11}^1)(1 + r^1 + t^1)(1 + m^1)$

$= (c_1^1X_1 + c_2^1X_2 + \cdots + c_{11}^1X_{11})(1 + r^1 + t^1)(1 + m^1)$

If LHS = RHS then:

$-A_1 + C^1(1 + r^1 + t^1)(1 + m^1) - h_1X_{hh} = D_1^{gov} + D_1^{inv} + D_1^{RoW}$

Excepting equation for the transportation, wholesale and retail sector (sector 7), equations for all remaining sectors are similar to that for agricultural sector.

In the transportation, wholesale and retail sector, there exists a transaction cost in its total demand (TRC_7). This equals the sum of all transaction costs supplied for other sectors ($TRC^1, TRC^2, \ldots, TRC^{11}$) that have been discussed above. Then the LHS of the equation is specified as follows:

LHS = $A_7 + TRC_7 + h_7X_{hh} + D_7^{gov} + D_7^{inv} + D_7^{RoW}$

where

$TRC_7 = TRC^1 + TRC^2 + \cdots + TRC^{11}$

$= r^1(C^1 + M^1) + r^2(C^2 + M^2) + \cdots + r^{11}(C^{11} + M^{11})$

$= r^1(C^1 + m^1C^1) + r^2(C^2 + m^2C^2) + \cdots + r^{11}(C^{11} + m^{11}C^{11})$

$= r^1(1 + m^1)C^1 + r^2(1 + m^2)C^2 + \cdots + r^{11}(1 + m^{11})C^{11}$

$= r^1(1 + m^1)(c_1^1X_1 + c_2^1X_2 + \cdots + c_{11}^1X_{11}) + r^2(1 + m^2)(c_1^2X_1 + c_2^2X_2 + \cdots + c_{11}^2X_{11})$
$+ \cdots + r^{11}(1 + m^{11})(c_1^{11}X_1 + c_2^{11}X_2 + \cdots + c_{11}^{11}X_{11})$

I use the same specification as discussed in equation for the agricultural sector for expenditure of this sector. The RHS can be written as

RHS = $C^7(1 + r^7 + t^7)(1 + m^7)$

$= (c_1^7X_1 + c_2^7X_2 + \cdots + c_{11}^7X_{11})(1 + r^7 + t^7)(1 + m^7)$

If LHS = RHS then:

$-A_7 + C^7(1 + r^7 + t^7)(1 + m^7) - TRC_7 - h_7X_{hh} = D_7^{gov} + D_7^{inv} + D_7^{RoW}$

The next equation is for enterprises account. The total income of enterprises consists of factor payments (i.e., labour (I_{ent}^{lab}), capital (I_{ent}^{cap}), and land (I_{ent}^{lnd})) and transfer from the government (I_{ent}^{gov}). In particular, I_{ent}^{lab} is substituted as $p_{ent}^{lab}L$, in which p_{ent}^{lab} is the share of factor payments from labour to enterprises in the total factor payments from labour (L). L is also the total labour income in 11 sectors, thus $L = L^1 + L^2 + \cdots + L^{11}$. Additionally, I substitute L^1 as l^1X_1, in which l^1 is the share of value added of labour in the total gross output of agricultural activity (X_1). Similar steps can be applied for enterprises' income from capital and land. Given available information from SAM, I assume that the shares of factor payments on enterprises (i.e., $p_{ent}^{lab}, p_{ent}^{cap}$, and p_{ent}^{lnd}) are the same in all 11 sectors. The LHS of the equation for enterprises account is as follows:

$$\text{LHS} = I_{ent}^{lab} + I_{ent}^{cap} + I_{ent}^{lnd} + I_{ent}^{gov} = p_{ent}^{lab}L + p_{ent}^{cap}K + p_{ent}^{lnd}N + I_{ent}^{gov}$$

where:

$$L = L^1 + L^2 + \cdots + L^{11} = l^1X_1 + l^2X_2 + \cdots + l^{11}X_{11}$$

$$K = K^1 + K^2 + \cdots + K^{11} = k^1X_1 + k^2X_2 + \cdots + k^{11}X_{11}$$

$$N = N^1 + N^2 + \cdots + N^{11} = n^1X_1 + n^2X_2 + \cdots + n^{11}X_{11}$$

The total expenditure of enterprises (X_{ent}) includes dividends to households (F_{hh}), corporate income tax (F_{tax}), non-tax payments to the government (F_{gov}), savings (F_{sav}), and transfer to the RoW (F_{RoW}). The RHS of this equation is specified as

$$\text{RHS} = F_{hh} + F_{tax} + F_{gov} + F_{sav} + F_{RoW} = X_{ent}$$

If LHS = RHS then:

$$-p_{ent}^{lab}(l^1X_1 + \cdots + l^{11}X_{11}) - p_{ent}^{cap}(k^1X_1 + \cdots + k^{11}X_{11}) - p_{ent}^{lnd}(n^1X_1 + \cdots + n^{11}X_{11}) + X_{ent} = I_{ent}^{gov}$$

or

$$\left(-P_{ent}^{lab}l^1 - p_{ent}^{cap}k^1 - p_{ent}^{lnd}n^1\right)X_1 + \cdots + \left(-P_{ent}^{lab}l^{11} - p_{ent}^{cap}k^{11} - p_{ent}^{lnd}n^{11}\right)X_{11} + X_{ent} = I_{ent}^{gov}$$

Finally, the equation for households is set up similarly as the equation for enterprises account. Total income of households includes factor payments (I_{hh}^{lab}, I_{hh}^{cap}, and I_{hh}^{lnd}), transfer from enterprises (I_{hh}^{ent}), transfer from the government (I_{hh}^{gov}) and remittances from abroad (I_{hh}^{RoW}). In particular, $I_{hh}^{ent} = f_{hh}X_{ent}$ is the dividend from enterprises. The LHS of this equation is specified as

$$\text{LHS} = I_{hh}^{lab} + I_{hh}^{cap} + I_{hh}^{lnd} + I_{hh}^{ent} + I_{hh}^{gov} + I_{hh}^{RoW}$$
$$= p_{hh}^{lab} L + p_{hh}^{cap} K + p_{hh}^{lnd} N + F_{hh} + I_{hh}^{gov} + I_{hh}^{RoW}$$
$$= p_{hh}^{lab}(l^1 X_1 + \dots + l^{11} X_{11}) + p_{hh}^{cap}(k^1 X_1 + \dots + k^{11} X_{11}) + p_{hh}^{lnd}(n^1 X_1 + \dots + n^{11} X_{11}) + f_{hh} X_{ent} + I_{hh}^{gov} + I_{hh}^{RoW}$$

The total expenditure of households (X_{hh}) contains spending on 11 commodities ($H_1, H_2, \dots,$ H_{11}), personal income tax (H_{tax}), and savings (H_{sav}). The RHS of this equation can be written as follows:

$$\text{RHS} = H_1 + H_2 + \dots + H_{11} + H_{tax} + H_{sav} = X_{hh}$$

If LHS = RHS then:

$$-p_{hh}^{lab}(l^1 X_1 + \dots + l^{11} X_{11}) - p_{hh}^{cap}(k^1 X_1 + \dots + k^{11} X_{11}) - p_{hh}^{lnd}(n^1 X_1 + \dots + n^{11} X_{11}) - f_{hh} X_{ent} + X_{hh} = I_{hh}^{gov} + I_{hh}^{RoW}$$

or

$$\left(-p_{hh}^{lab} l^1 - p_{hh}^{cap} k^1 - p_{hh}^{lnd} n^1\right) X_1 + \dots + \left(-p_{hh}^{lab} l^{11} - p_{hh}^{cap} k^{11} - p_{hh}^{lnd} n^{11}\right) X_{11} - f_{hh} X_{ent} + X_{hh} = I_{hh}^{gov} + I_{hh}^{RoW}$$

The system of 13 equations can be rewritten in a matrix format as follows:

$$M_{13\times 13} = \begin{bmatrix} m_1^1 & \cdots & m_1^{13} \\ \vdots & \ddots & \vdots \\ m_{13}^1 & \cdots & m_{13}^{13} \end{bmatrix}$$

$$= \begin{bmatrix} [-a_1^1 + (1 + r^1 + t^1)(1 + m^1)c_1^1] & \cdots & [-a_1^{11} + (1 + r^1 + t^1)(1 + m^1)c_{11}^1] & 0 & -h_1 \\ [-a_2^1 + (1 + r^2 + t^2)(1 + m^2)c_1^2] & \cdots & [-a_2^{11} + (1 + r^2 + t^2)(1 + m^2)c_{11}^2] & 0 & -h_2 \\ \vdots & \ddots & \vdots & \vdots & \vdots \\ [-a_{11}^1 + (1 + r^{11} + t^{11})(1 + m^{11})C_1^{11}] & \cdots & [-a_{11}^{11} + (1 + r^{11} + t^{11})(1 + m^{11})c_{11}^{11}] & 0 & -h_{11} \\ \left(-p_{ent}^{lab} l^1 - p_{ent}^{cap} k^1 - p_{ent}^{lnd} n^1\right) & \cdots & \left(-p_{ent}^{lab} l^{11} - p_{ent}^{cap} k^{11} - p_{ent}^{lnd} n^{11}\right) & 1 & 0 \\ \left(-p_{hh}^{lab} l^1 - p_{hh}^{cap} k^1 - p_{hh}^{lnd} n^1\right) & \cdots & \left(-p_{hh}^{lab} l^{11} - p_{hh}^{cap} k^{11} - p_{hh}^{lnd} n^{11}\right) & -f_{hh} & 1 \end{bmatrix}$$

$$X_{13\times 1} = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_{11} \\ X_{ent} \\ X_{hh} \end{bmatrix}, \qquad E_{13\times 1} = \begin{bmatrix} D_1^{gov} + D_1^{inv} + D_1^{RoW} \\ D_2^{gov} + D_2^{inv} + D_2^{RoW} \\ \vdots \\ D_{11}^{gov} + D_{11}^{inv} + D_{11}^{RoW} \\ I_{ent}^{gov} \\ I_{hh}^{gov} + I_{hh}^{RoW} \end{bmatrix} = \begin{bmatrix} E_1 \\ E_2 \\ \vdots \\ E_{11} \\ E_{ent} \\ E_{hh} \end{bmatrix}$$

Hence, $\boldsymbol{M} \times \boldsymbol{X} = \boldsymbol{E} \Rightarrow \boldsymbol{X} = \boldsymbol{M^{-1}E}$

The notations of all variables in the model are summarized below:

X_j: gross output of production activity *j* (*j*=1, 2, …, 11)

X_{ent}: total enterprise expenditure

X_{hh}: total household expenditure

A_i: total intermediate demand for commodity *i*

A_i^j: intermediate demand for commodity *i* of production activity *j*

D_i^q: final demand for commodity *i* of *q*

C^i: total domestic sales in the market of commodity *i*

C_j^i: domestic sales of products from production activity *j* in the market of commodity *i*

M^i: imports of commodity *i*

TRC^i: transaction costs of commodity *i*

T^i: commodity tax of commodity *i*

I_{ent}^q (or I_{hh}^q): income enterprises (or households) from *q*

L: total income (value added) of labour

K: total income (value added) of capital

N: total income (value added) of land and natural resources

L^j: income (value added) of labour in production activity *j*

K^j: income (value added) of capital in production activity *j*

N^j: income (value added) of land and natural resources in production activity *j*

F_q: spending of enterprises on *q*.

H_q: spending of households on *q*.

H_i: spending of households on commodity *i* (*i*=1, 2, …, 11)

E_i: total exogenous demand of commodity *i*

E_{ent} (or E_{hh}): total exogenous demand of enterprises (or households)

a_i^j: share of intermediate demand for commodity *i* in the total gross output of production activity *j*

c_j^i: share of domestic supply from production activity *j* in the market of commodity *i*,

$\sum_{i=1}^{11} c_j^i = 1$ (*j*=1, 2, …, 11)

m^i: ratio of imports to domestic supply of commodity *i*, $m^i = M^i/C^i$

r^i: ratio of transaction cost to total value of sales of commodity *i*, $r^i = TRC/(C^i + M^i)$

t^i: ratio of commodity tax to total value of sales of commodity *i*, $t^i = T^i/(C^i + M^i)$

p_{ent}^q (or p_{hh}^q): share of factor payment *q* to enterprises (or households)

l^j/ k^j/ n^j: share of value added of labour/capital/land in gross output of production activity *j*

f_q: share of enterprises spending on q in total expenditure of enterprises

h_i: share of household expenditure on commodity i

m: multiplier coefficient in the matrix M

A2.4 Simulation results

I simulate a change in exogenous demand in each of the 11 sectors and solve the system of equations as presented in Appendix A2.3. I assume that a change in exogenous demand or a shock is worth USD 100 million for a straightforward illustration. The linear linkage effects in a SAM-based multiplier analysis imply that the demand shock can be of any number since structural relationships between endogenous accounts are unaffected by the change. For example, the impacts of an exogenous change of USD 100 million in demand is 10-time and 100-time higher than those of USD 10 million and USD 1 million, respectively. Hence, I find new gross output (X_1-X_{11}), enterprises income (X_{ent}), and household income (X_{hh}). Results for 11 scenarios corresponding to 11 sectors are shown Table A2.1.

Table A2.1 **New gross outputs and incomes of households and enterprises (USD millions)**

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{ent}	X_{hh}
S1	56,859.5	21,816.4	123,099.8	7,460.2	1,809.0	44,647.4	178,083.4	23,724.1	21,114.4	21,523.6	40,621.2	79,036.4	214,162.1
S2	56,789.1	21,885.1	123,099.5	7,459.7	1,808.9	44,646.9	178,068.9	23,722.9	21,113.2	21,522.9	40,618.5	79,043.9	214,143.2
S3	56,789.3	21,816.6	123,123.8	7,459.4	1,808.9	44,646.4	178,071.5	23,721.4	21,112.0	21,522.5	40,616.1	79,033.0	214,126.7
S4	56,790.2	21,818.3	123,092.4	7,542.8	1,809.0	44,647.4	178,078.8	23,724.0	21,114.3	21,523.5	40,621.1	79,076.1	214,161.8
S5	56,792.6	21,816.8	123,098.6	7,463.1	1,902.0	44,648.2	178,073.6	23,726.3	21,116.2	21,524.1	40,624.6	79,055.2	214,185.2
S6	56,791.8	21,817.3	123,112.0	7,460.3	1,809.1	44,748.6	178,065.8	23,725.5	21,114.8	21,527.8	40,621.7	79,039.6	214,164.8
S7	56,793.2	21,816.6	123,098.2	7,461.1	1,809.2	44,648.2	178,374.5	23,727.4	21,116.8	21,531.4	40,625.7	79,054.8	214,191.6
S8	56,789.2	21,816.1	123,090.1	7,459.8	1,808.9	44,647.9	178,043.4	23,794.9	21,114.0	21,522.9	40,619.9	79,048.6	214,151.8
S9	56,792.7	21,816.5	123,096.0	7,460.6	1,809.2	44,648.2	178,053.5	23,726.5	21,198.9	21,526.9	40,625.1	79,045.8	214,187.1
S10	56,792.4	21,816.5	123,096.8	7,460.8	1,809.2	44,648.2	178,054.4	23,726.5	21,116.4	21,615.0	40,625.0	79,050.1	214,183.5
S11	56,790.8	21,816.4	123,093.7	7,460.2	1,809.1	44,647.8	178,048.1	23,766.0	21,114.3	21,523.1	40,713.6	79,047.2	214,157.7

Note: X_i is multiplier impact on demand of sector *i* (*i*=1, 2, …, 11), X_{ent} and X_{hh} are enterprises and household expenditure, S_i is scenario in which a change occurs in sector *i*
1-Agriculture, 2-Mining, 3-Manufacturing, 4-Energy, 5-Water, 6-Construction, 7-Transportation, wholesale and retail trade, 8-Finance, banking, insurance, and real estates, 9-Health care, education, and research, 10-Administration and communication, 11-Accommodation, tourism, and other services

Table A2.2 **Self- and cross-sector multiplier impacts on gross output**

	ΔX_1	ΔX_2	ΔX_3	ΔX_4	ΔX_5	ΔX_6	ΔX_7	ΔX_8	ΔX_9	ΔX_{10}	ΔX_{11}
S1	0.760	0.011	0.192	0.023	0.005	0.019	0.573	0.057	0.050	0.031	0.101
S2	0.056	0.697	0.189	0.018	0.004	0.014	0.428	0.045	0.038	0.023	0.074
S3	0.058	0.012	0.432	0.015	0.004	0.009	0.454	0.030	0.026	0.019	0.050
S4	0.067	0.030	0.118	0.849	0.005	0.019	0.527	0.056	0.049	0.029	0.100
S5	0.091	0.014	0.180	0.051	0.935	0.027	0.474	0.080	0.068	0.036	0.135
S6	0.083	0.019	0.314	0.023	0.006	1.032	0.396	0.072	0.054	0.073	0.106
S7	0.096	0.013	0.176	0.032	0.007	0.028	3.483	0.090	0.074	0.109	0.146
S8	0.057	0.008	0.095	0.019	0.004	0.024	0.173	0.765	0.046	0.023	0.088
S9	0.092	0.012	0.154	0.027	0.007	0.028	0.273	0.081	0.895	0.063	0.140
S10	0.089	0.012	0.162	0.029	0.006	0.028	0.283	0.082	0.070	0.945	0.140
S11	0.073	0.010	0.131	0.023	0.005	0.023	0.220	0.476	0.049	0.025	1.025

Note: ΔX_1 is the multiplier impact on gross output of sector *i* (*i*=1, 2,…, 11), S_i is scenario in which a change occurs in sector *i*
1-Agriculture, 2-Mining, 3-Manufacturing, 4-Energy, 5-Water, 6-Construction, 7-Transportation, wholesale and retail trade, 8-Finance, banking, insurance, and real estates, 9-Health care, education, and research, 10-Administration and communication, 11-Accommodation, tourism, and other services

A2.5 Sensitivity tests for changes in sectoral weights

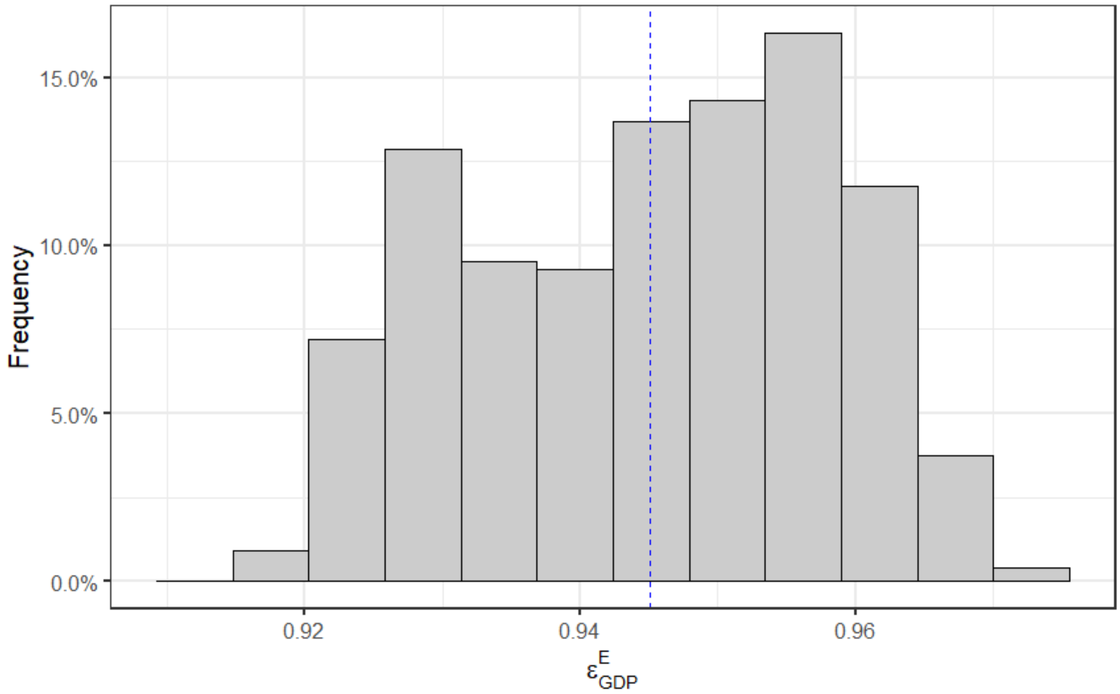

Figure A2.1 **Energy-GDP elasticity with variations of 30% in sectoral weights**

Chapter 3: Energy tax policy and household welfare: A partial equilibrium analysis

3.1 Introduction

Climate change is an urgent and serious concern in many countries (World Bank, 2017). This phenomenon is related to the build-up of heat-trapping greenhouse gases (GHG) in the atmosphere, which mainly comes from human-induced activities including energy, industry, transport, and land use (Stern and Stern, 2007). This not only affects wildlife populations and habitats, but also severely affects people's livelihoods due to changes in temperature and rainfall levels. In particular, climate-related extreme events such as hurricanes, storms, floods and droughts result in lost crops and higher poverty rates in some regions in the world (Michener et al., 1997, Dessai et al., 2004, Webster et al., 2005, Hone and Clutton-Brock, 2007, Stern and Stern, 2007, Hertel and Rosch, 2010, Hunter et al., 2010, Hallegatte et al., 2015).

Mitigating climate change and improving energy-use efficiency are focuses of environmental research (Klein et al., 2005, Omer, 2008, Herring and Sorrell, 2009). Taxation and emissions trading scheme are common instruments that have been implemented in many countries such as the EU, Italy, the US, Canada, and Denmark (Scrimgeour et al., 2005, Tiezzi, 2005, Wier et al., 2005, Rausch et al., 2010, Beck et al., 2015). Although these environmental policies provide an incentive for consumers to switch from 'dirty' goods, the likely economic impacts of environmental taxation are a highly debated topic in the literature. For example, to what extent tax reform is regressive or progressive may largely depend on a country's context and specific characteristics (Labandeira and Labeaga, 1999, Symons et al., 2002). Pressure from the Kyoto Protocol and the recent Paris Agreement has urged countries to conduct empirical analyses to guide policymakers in enacting environmental laws. A challenge for them is to find an optimal solution to cutting GHG emissions while at the same time maximising social welfare.

With energy consumption growing due to industrialisation and urbanisation, developing countries such as Vietnam have paid much attention to climate change and energy conservation issues. The government has implemented various policies, notably the Law on Environmental

Protection Tax (EPT) in 2012 (National Assembly, 2010c). The law aims to change consumer behaviours and reduce their polluting activities by levying taxes on eight groups of commodities, especially energy. During the 2012-2018 period, the government revised the tariff rates on energy products twice to cope with changes in their objectives and the international market (National Assembly Standing Committee, 2015, 2018). The amended law would affect all households both directly and indirectly, especially those that use these energy products intensively in their daily lives. However, the lack of social and economic assessment, especially on the household welfare impacts, coupled with the ambiguous use of tax revenue, contributes to scepticism about the effectiveness of such taxes.

In light of this background, the present chapter examines the effects of a hypothetical increase in energy taxes on household welfare by applying the partial equilibrium analysis. Energy taxes are analysed rather than carbon taxes since they are more practical for the context of Vietnam. The degree of increase in prices for each commodity is different after policy reforms, but the energy price is supposed to increase by 10 per cent as a result of a change in the energy taxes. I use data from the Vietnam Household Living Standard Survey (VHLSS) in 2014. Three measures of household welfare change, namely compensation variation (CV), equivalent variation (EV), and change in consumer surplus (ΔCS) are calculated and compared between the short term and long term. The distributional analysis describes the disproportional incidence of the policy across different household demographics, regions and expenditure levels. Several values of elasticity of energy demand over two periods are employed to verify results in the baseline scenario.

This study makes two main contributions to the existing literature. First, to the best of my knowledge, the partial equilibrium approach employed here has not been applied in other papers for Vietnam. This takes into account household consumption patterns by allowing the differences in elasticity of substitution between energy and non-energy goods across households. Second, I calculate the three measures of changes in household welfare that have been only used separately in previous studies. The results not only confirm the relationship between these measures but can also be used as a comparison with previous studies that employ other models. Based on the findings, the study provides policy recommendations on welfare impacts of the increase in energy taxes to prepare for the implementation of carbon market in the future.

The remainder of the chapter is constructed as follows. Section 3.2 reviews the literature for international experience and Vietnam with a focus on household welfare. Section 3.3 provides background information on energy-related policies and the overall picture of household energy consumption in Vietnam. The methodology, materials, and calibration procedure used in the chapter are described in Section 3.4. Section 3.5 reports the main results and sensitivity analysis. Section 3.6 discusses the policy implications and extensions for further research. Section 3.7 concludes the chapter.

3.2 Literature review

The implementation of environmental protection taxes has significant socio-economic effects. The principal theoretical framework of this issue has been discussed in many papers (Pigou, 1932, Baumol and Oates, 1971, Baumol et al., 1988). A levied tax on negative externality-generating activities would increase social welfare by reducing the costs to society and achieving environmental targets. Each tax policy has advantages and disadvantages that can lead to distinct outcomes. The Eurostat (2013) has classified four main environmental tax bases, including energy taxes, transport taxes, pollution taxes, and resources taxes, of which, energy taxes are primary sources of revenue and receive much policy attention.

In terms of energy taxes, there are controversies surrounding the efficacy of the tax instruments that policy makers should adopt, for example, taxes based on energy content, carbon taxes, subsidies, or a combination of these approaches (Scrimgeour et al., 2005). For example, a petroleum tax has been considered to be less effective than other taxes since higher prices in petroleum products may make consumers switch to other ‘dirty’ energies such as coal. This substitution does not protect the environment and goes against the original purpose of energy conservation (Barker and Rosendahl, 2000). In contrast, others argue that a carbon tax is a more efficient mean to achieve emission reduction targets since it equates marginal abatement costs across different types of pollutants. By taking into account the emission coefficient, a carbon tax is likely to discriminate between energy types based on their carbon content, resulting in a relatively heavier tariff on coal compared with oil and gasoline. This is advantageous in the sense that the fluctuations in price in international and domestic markets do not affect the incentive of emissions reduction, provided that the policy is well designed and monitored (Ekins and Barker, 2001). Additionally, a carbon tax can minimise compliance costs, create continuous incentives for dynamic efficiency, and adapt quickly to a new situation (Pearce, 1991). As a result, carbon taxes have been adopted by many countries recently.

Since there is extensive literature on the effects of environmental taxes, this section focuses solely on household welfare. Some studies compare the household welfare impacts of different tax instruments (Scrimgeour et al., 2005, Solaymani et al., 2015, Solaymani, 2017, Yahoo and Othman, 2017). For instance, Scrimgeour et al. (2005) conclude that although energy and carbon taxes have similar effects on some main macro variables in New Zealand, carbon taxes are more effective in cutting carbon emissions. Notably, the petroleum tax would reduce household consumption by 20 per cent, doubling the figures for energy and carbon taxes. The results suggest that with an already-high tax rate in petroleum products, any increase in taxes would encounter a higher penalty for real household consumption yet achieve a smaller environmental outcome. A similar conclusion is found by Solaymani (2017). He concludes that under revenue recycling, carbon taxes, compared with energy taxes, lead to a larger rise in the welfare of rural and urban households in Malaysia.

Another strand of literature focuses on the distributive effects of environmental taxes on household welfare. Many studies quantify tax burdens and welfare loss at different income levels and demographic groups (Labandeira and Labeaga, 1999, Symons et al., 2002, Tiezzi, 2005, Creedy and Sleeman, 2006, Feng et al., 2010, Renner, 2018). This is a regressive incidence in the sense that poor households that are likely to buy cheaper and less environmentally friendly appliances suffer more negatively than the rich ones. The impacts vary depending on the countries' contexts and characteristics. Symons et al. (2002) investigate the effects of taxes on five European countries, namely France, Italy, Germany, Spain, and the UK. They show that due to different weights of categories in total expenditure, these taxes lead to a regressive incidence for Germany, France, and Spain, but a proportional distribution for Italy and unclear patterns for the UK. Additionally, in using the equivalent variation as an assessment criterion, Creedy and Sleeman (2006) conclude that the distributional effects of a carbon tax in New Zealand are ambiguous. The relative burden is regressive over some ranges of total expenditure, while it is progressive for others.

To what extent the taxes are regressive or progressive may be affected by the households' sources of income and expenditure patterns (Wier et al., 2005, Rausch et al., 2010, Fullerton and Heutel, 2011, Dissou and Siddiqui, 2014, Beck et al., 2015). In detail, Wier et al. (2005)

find that the regressivity of Danish carbon taxes is smaller when using lifetime income (proxy by total expenditure) compared with disposable income. The regressive incidence holds for both direct and indirect tax payments. Moreover, Rausch et al. (2010) show that disregarding allowance allocation schemes, the impact of carbon pricing in the US is proportional to slightly progressive because of discrepancies in income sources across households rather than in expenditure. The progressivity can be clarified by a larger share of government transfers in the total income of lower-income households, which are constant in real terms since transfers are regularly adjusted to inflation. Beck et al. (2015) confirm the dominance of progressive incidence of the income-side effect over the regressive incidence of the spending-side effect in British Columbia (Canada). The regressive distribution is extremely weak or neutral because the share of fossil fuels in total expenditure across households is similar, and hydropower is the primary source of electricity generation in this province.

Many studies consider the distributional effects in revenue recycling scenarios to correct some kinds of market distortions (Brännlund and Nordström, 2004, West and Williams, 2004, Devarajan et al., 2011, Vandyck and Van Regemorter, 2014). Results by West and Williams (2004) confirm the regressivity of increasing the gasoline tax in the US. While using additional tax revenue to lower labour taxes makes the policy less regressive, if the revenue is used as a lump-sum transfer to households, the tax burden becomes progressive. Devarajan et al. (2011) also report the regressive incidence of a carbon tax in South Africa. The welfare costs associated with significant carbon emissions reductions are moderately small, and even negligible if current labour market imperfections are removed.

In the case of Vietnam, there have been several studies analysing the impacts of environmental taxes (Nguyen and Coxhead, 2011, Willenbockel, 2011, Coxhead et al., 2013, Nong, 2018). For example, Willenbockel (2011) measures the impacts of different coal and refined fuel taxes on some real macroeconomic indicators (e.g., investment, household consumption, government consumption, exports, imports, and government revenue) and household welfare. The author reports that household welfare, which is measured by the ratio of Hicksian EV to initial income, decreases significantly by 0.66 and 2.75 per cent on average in the low and the high tax rate scenarios, respectively. In addition, Coxhead et al. (2013) find that the EPT reduces real GDP and aggregate employment while exacerbating poverty. Nonetheless, increased transfers to households from tax revenues are insufficient to compensate for lost jobs, resulting in significant losses for the poorest households.

Investigating the impact of environmental taxes on household welfare in Vietnam remains important for two reasons. First, none of these previous studies have examined the distributional impact of the EPT in Vietnam while taking into account consumption patterns at household level and/or household characteristics. In particular, Willenbockel (2011) uses only macroeconomic data to estimate the impacts on welfare of rural and urban farm and non-farm households across income quintiles, thus, the author cannot incorporate household characteristics in his analysis. Although Nguyen and Coxhead (2011) and Coxhead et al. (2013) link macro model to micro data using a 2006 household survey to make use of household information, they do not concern the welfare impact across demographics. Second, there is a lack of studies that compute several measures of household welfare change. Previous research normally uses one indicator such as Hicksian EV as reported in Dumagan and Mount (1992) and Willenbockel (2011). With a more up-to-date data, this study aims to contribute to the ongoing discussion on the distributional effects of environmental taxes.

3.3 Background

This section presents the background information for Chapter 3. First, it summarises prominent policies for regulation of energy exploration and consumption in Vietnam, including the EPT and its current issues. Second, I provide some insights about household energy consumption patterns across six geographical regions and expenditure levels. This subsection shows the degree of prevalence of some energy goods in residential use and their contribution to household energy expenditure.

3.3.1 Some prominent energy-related policies

The increasing energy demand together with the risk of energy shortages require the government to implement energy-related policies to regulate energy exploration and consumption. For example, one of the most fundamental policies is the Petroleum Law, which was implemented in 1993 and revised in 2000 and 2008 (National Assembly, 1993, 2000, 2008). The law regulates exploration and exploitation activities in the territory, excluding economic zones and continental shelves. In addition, the Electricity Law in 2004 (National Assembly, 2004) and other related articles regulate planning and development investment; electricity saving; electricity market; rights and obligations when using electricity; and protection of electrical equipment, electricity works and safety. Moreover, in 2010, the Law on Energy Efficiency and Conservation promulgated by the National Assembly stipulates policies and measures as well as the rights, obligations and responsibilities of organisations and individuals that encourage the economical and efficient use of energy (National Assembly, 2010b).

Furthermore, tax policies in energy are an essential economic measure to protect the environment. By levying an environmental protection fee in product prices, this measure aims to change consumers' and businesses' behaviours to reduce their polluting activities and to provide revenue for the government. The Law on Environmental Protection Tax is the most prominent policy so far. It was adopted by the National Assembly in November 2010 and was implemented in January 2012. The Law sets tax rates for eight groups of commodities, notably energy (National Assembly, 2010c). The tax base for some main goods is presented in Table 3.1 as follows.

Table 3.1 **Tariff schedule of the EPT applied in 2012**

No	**Goods**	**Calculation unit**	**Tax rate** (USD/unit)
I	**Gasoline, oil, grease**		
1	Gasoline, except ethanol	litre	0.047 -0.188
2	Aircraft fuel	litre	0.047 -0.014
3	Diesel oil	litre	0.024 -0.094
II	**Coal**		
4	Lignite	tonne	0.471 -1.412
5	Anthracite Coal	tonne	0.941 -2.353
III	**Hydrogen chlorofluorocarbon liquid (HCFC)**	kg	0.047 -0.235
IV	**Taxable-plastic bag**	kg	1.412 -2.353
V	**Herbicide which is restricted from use**	kg	0.024 -0.094
VI	**Pesticide which is restricted from use**	kg	0.047 -0.141
VII	**Forest product preservative which is restricted from use**	kg	0.047 -0.141
VIII	**Warehouse disinfectant which is restricted from use**	kg	0.047 -0.141

Source: National Assembly (2010c)

The tariff schedules for different energy groups of commodities have been irrational. The tax structure in 2012 was not constructed on the basis of carbon content. There is a huge difference between these tax rates if they are converted to monetary unit per tonne of carbon dioxide equivalent (tCO_2e). In particular, the environmental taxes are equivalent to USD 0.71/tCO_2e

on coal, USD 20/tCO_2e on diesel, and USD 47/tCO_2e on gasoline, of which the last two numbers are relatively high by international standards (Coxhead et al., 2013). Although gasoline and oil are not the key pollutants, they are the main contributors to the environmental tax revenue. With the tariff levels amended in 2015, the contribution of gasoline and oil to environmental tax revenue increased from 88 per cent in 2012 to 98 per cent in 2016 (Nguyen, 2017a), whereas shares of emissions from coal accounted for the largest part in the total CO_2 emissions from fuel combustion (Figure 3.1). This implies that environmental protection is not the main objective in the design of the EPT.

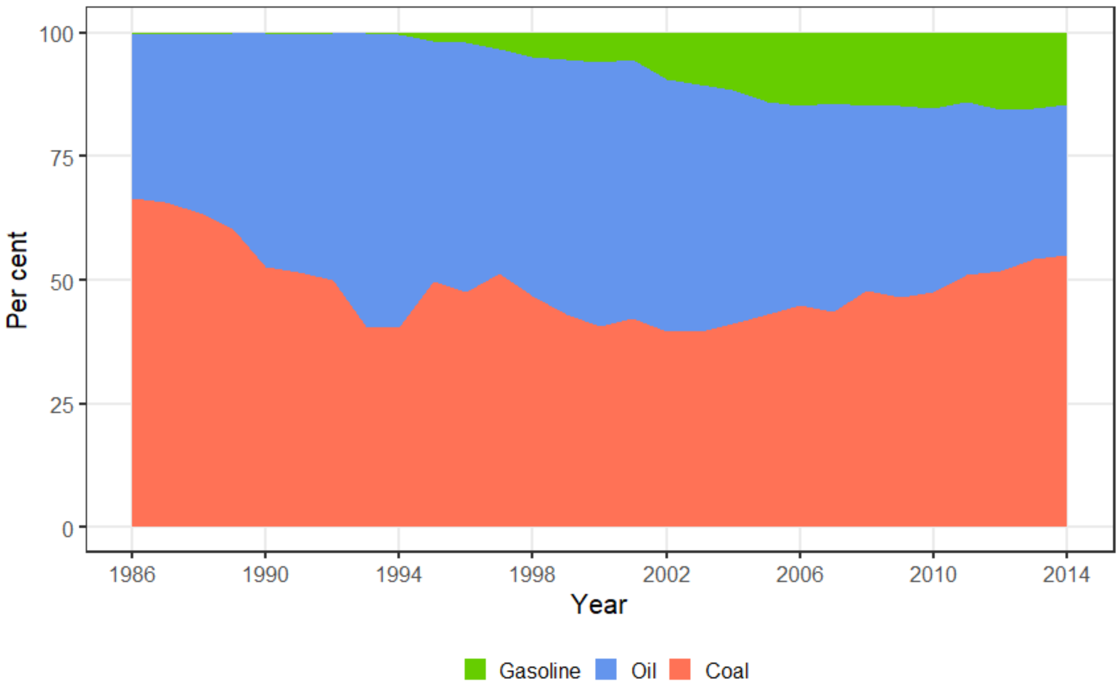

Figure 3.1 **CO_2 emissions from fuel combustion by category 1986-2014**

Source: IEA (2018)

Over the last decade, the government has amended environmental taxes on two occasions. The tax rates on gasoline and oil continued to rise significantly, while the tariff for coal and other pollutants remained at low levels. In 2015, the taxes on gasoline, aircraft fuel, and oil products increased triple compared with those in 2012. Also, the tax rates on gasoline, oil, and grease have been set at the highest level of their tariff schedules since 2019. Taxes for other goods such as coal, HCFC liquid and plastic bags will rise by 30 per cent. The revised law would affect all consumers both directly and indirectly, especially those who use gasoline and oil intensively in their daily lives and production.

3.3.2 Household energy consumption patterns

The VHLSS in 2014 provides some insights on household expenditure and energy patterns. The sampling process of the VHLSS consists of three stages of selecting primary sampling unit, enumeration areas and households according to the 2009 Population Census (Hansen and Nguyen, 2007).[6] I use sampling weight to make the data set representative for the whole country by correcting bias in the sampling process. The sampling weight is calculated for each household and equals the inverse of its probabilities. This method is different from non-weighted calculation when all households' weights in the sample are given the value of 1.

Households across different regions of Vietnam exhibit distinct patterns in their expenditure. Figure 3.2 presents expenditure patterns of rural and urban households in six regions in 2014. On average, food and beverages expenditure accounted for the most substantial part at more than 50 per cent. In particular, rural households in the Northern and Central Coast allocated nearly 60 per cent of their expenditure on food, which was relatively higher than households in other regions. Spending on energy consumption, including fossil fuels and non-fossil fuels, comprised 8.6 per cent of the total expenditure. Households in the Southeast consumed slightly more energy than those in other regions. Education and health expenditure contributed roughly 8.4 per cent, which remained similar across regions. Durable purchases were significantly high in both areas of the Midlands and Northern Mountains when compared with other areas.

[6] The information on sampling procedures and weight estimation of VHLSS 2002 are documented by Hansen and Nguyen (2007). However, I also understand that the same procedures have also been applied in newer surveys.

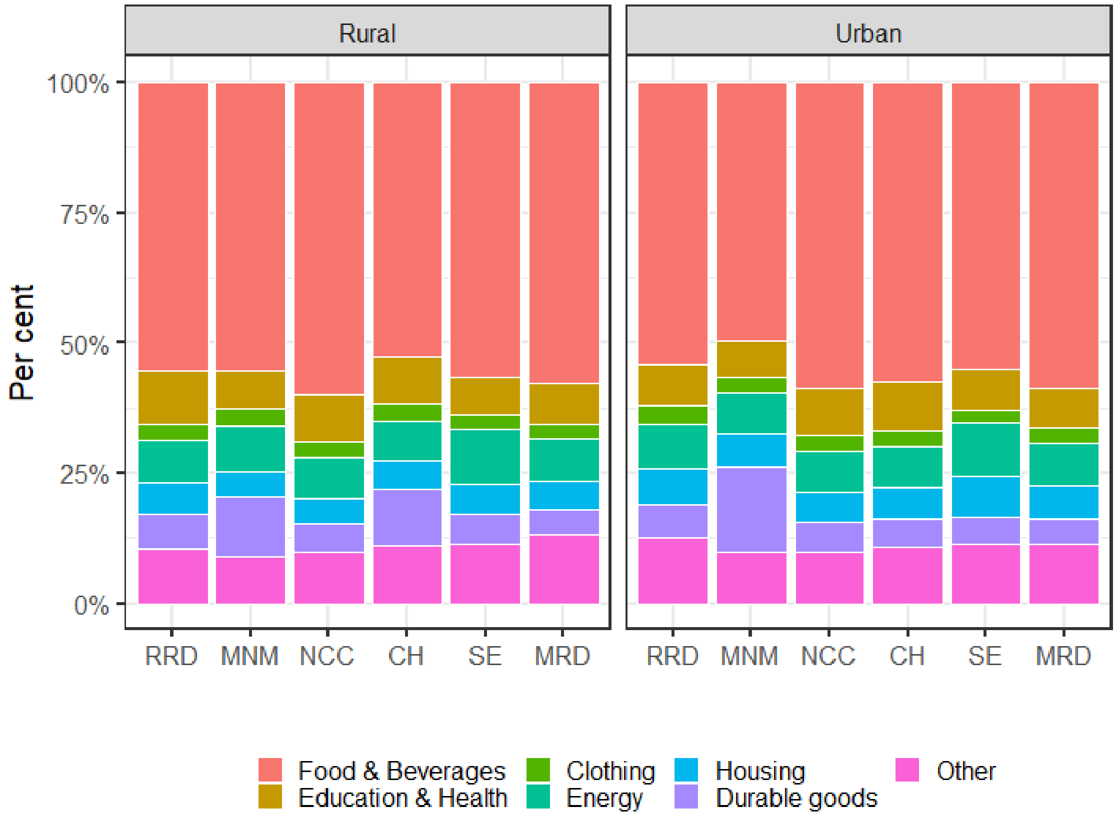

Figure 3.2 **Household expenditure patterns by region**

Note: RRD – Red River Delta, MNM – Midlands and Northern Mountains, NCC – Northern and Central Coast, CH – Central Highlands, SE – Southeast, MRD – Mekong River Delta
Source: Author's calculations from the VHLSS 2014

However, households did not consume all types of energy goods. Table 3.2 presents the popularity of some main energy goods in different regions. Fossil fuels, which cover coal, gasoline, fuel oils, liquefied petroleum gas (LPG), and electricity[7], were used more than non-fossil fuels. With a high electrification rate, electricity was the most common type with usage rate of around 100 per cent in both areas, followed by gasoline (82.1 per cent) and LPG (73.1 per cent). Generally, urban households consumed more of these 'expensive' energies, while rural households preferred 'cheap' and available non-fossil fuels, including firewood, farm by-products and other types of fuels. Notably, 80.5 per cent of households in the rural Midlands and Northern Mountains consumed this energy type.

[7] Electricity is classified as fossil fuel since a large part of electricity is generated from this energy type.

Table 3.2 **Energy usage rate by region (%)**

	Coal	Gasoline	Oil	LPG	Electricity	Firewood
			Rural			
RRD	8.95	73.29	18.47	81.59	100.00	42.71
MNM	1.92	82.33	21.28	34.22	90.88	80.46
NCC	1.22	76.73	30.93	62.44	98.32	66.12
CH	0.62	86.43	17.41	49.16	96.34	59.61
SE	0.43	90.71	32.87	84.08	98.35	25.96
MRD	0.53	74.79	32.51	62.87	99.15	64.37
			Urban			
RRD	21.22	89.74	35.09	91.98	99.88	12.36
MNM	16.38	88.37	18.53	82.29	99.53	35.27
NCC	4.48	88.11	42.46	90.43	100.00	26.18
CH	0.00	92.82	22.44	80.18	100.00	23.53
SE	0.22	92.93	41.08	94.69	99.74	2.97
MRD	1.74	83.45	37.88	83.28	99.57	29.10

Note: RRD – Red River Delta, MNM – Midlands and Northern Mountains, NCC – Northern and Central Coast, CH – Central Highlands, SE – Southeast, MRD – Mekong River Delta
Source: Author's calculations from the VHLSS 2014

Although budget share for energy goods was somewhat similar, energy consumption by category varied between regions (Figure 3.3). In particular, households in the urban areas of the Red River Delta and the Southeast spent almost all their energy budget on fossil fuels. Within the same region, urban households used fewer non-fossil fuels, accounting for well under 6 per cent. Meanwhile, rural families in the Midlands and Northern Mountains spent nearly 29 per cent for non-fossil fuels, which was a big difference compared with their urban counterparts (5.5 per cent).

Figure 3.3 also demonstrates household energy expenditure by category. In detail, gasoline was consumed the most among all energies with its proportion ranging from 39.7 per cent to 54.4 per cent. This may be due to the heavy dependence of commuters on private transportation and intensive use for lighting and cooking. The next energy is electricity, accounting for 29.7 per cent. The figure for families in the urban Red River Delta was recorded with the highest expense on electricity usage at 36.6 per cent. Other fuel oils contributed a minor part of less than 5 per cent in the total energy consumption of households.

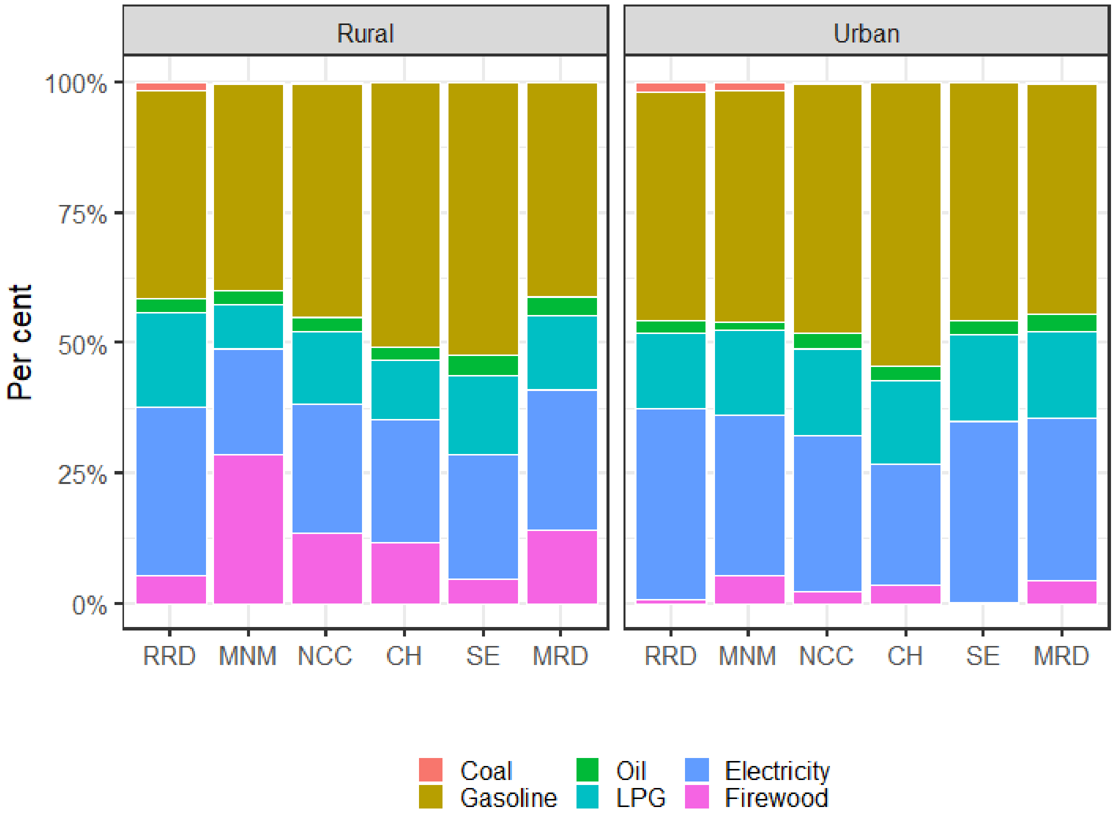

Figure 3.3 **Energy expenditure patterns by region**

Note: RRD – Red River Delta, MNM – Midlands and Northern Mountains, NCC – Northern and Central Coast, CH – Central Highlands, SE – Southeast, MRD – Mekong River Delta
Source: Author's calculations from the VHLSS 2014

Furthermore, energy consumption by category exhibited different patterns between levels of total expenditure (Figure 3.4). The share of energy consumption in total expenditure increased to around 10 per cent at the fourth decile, then decreased gradually as the expenditure level rose. The figure for the richest households was smaller than that for poorer groups. This is because the richest were likely to spend their budget on other goods and services such as durable purchases and recreational activities. By contrast, the poorest consumed mainly 'cheap' energies that did not contribute substantially to their total expenditure. In detail, except for the poorest households, gasoline accounted for the biggest share at 3.8 per cent on average. However, the poorest group consumed firewood the most at nearly 2.7 per cent of their total expenditure. The proportion of electricity did not vary much across deciles, ranging between 2.3 to 2.8 per cent.

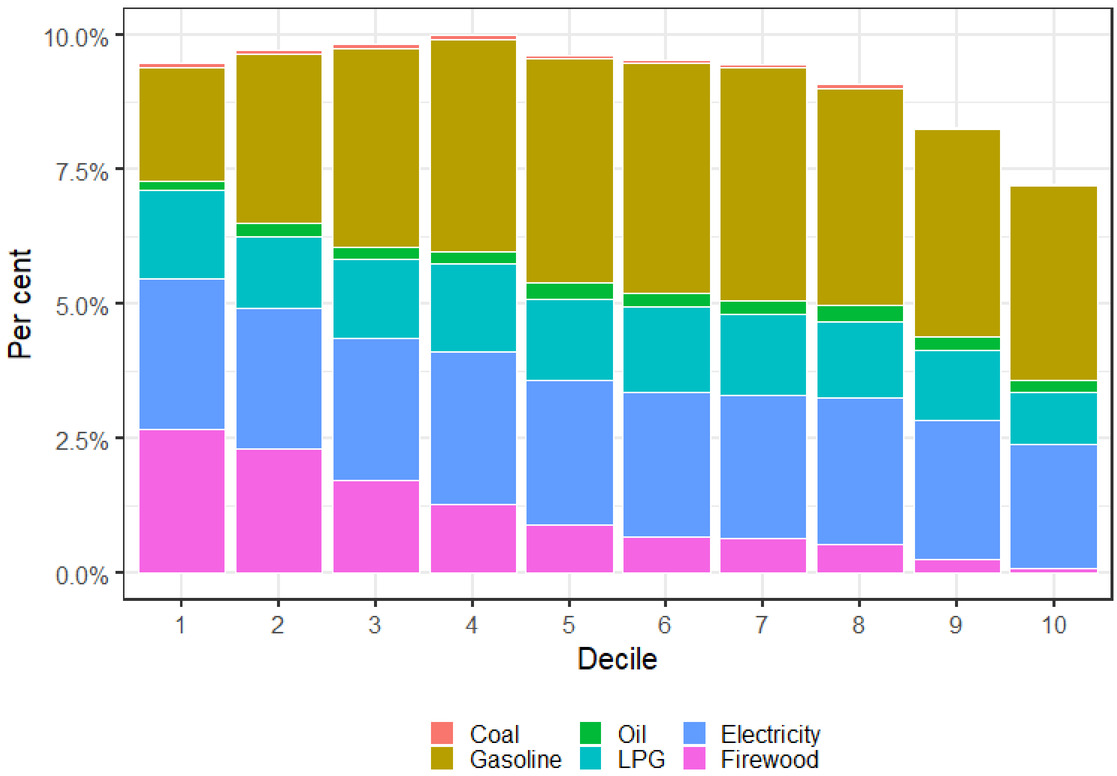

Figure 3.4 **Energy expenditure patterns by expenditure decile**

Source: Author's calculations from the VHLSS 2014

3.4 Methodology and materials

This section describes the methodology and materials used in the chapter. First, I summarise the four main models for evaluating household welfare changes and discuss reasons for selecting my approach. Second, I present the model specification and solutions for utility maximisation and expenditure minimisation problems. The three measures for estimation of household welfare change are given. Third, I describe the survey data and how to manipulate it for further analysis. The last part discusses the calibration of unknown parameters and the calculation of three welfare measures for each observation in the sample.

3.4.1 Methods for distributional impact evaluation

There are four main types of models for evaluating the impacts of a policy in general and a tax reform in particular. A popular approach includes microeconomic models, i.e., partial equilibrium approach, which allow for heterogeneity between agents (e.g., individuals, households, or firms) to be taken into account. For example, in the case of household welfare, this approach uses microeconomic data from households and individuals such as income, expenditure or household characteristics. Some common types of microeconomic models used in previous papers are the static discrete choice model (Givord et al., 2018), the linear expenditure system (Creedy and Sleeman, 2006), and the Almost Ideal Demand System and other related frameworks (Brännlund and Nordström, 2004, West and Williams, 2004, Tiezzi, 2005, Ghalwash, 2007, Barros and Prieto-Rodriguez, 2008, Säll and Gren, 2015, Rosas-Flores et al., 2017, Renner et al., 2018). However, these models do not endogenise the relative prices and cannot analyse the economy-wide effects of public policies.

The second approach includes macroeconomic models. This method requires aggregate data of the whole economy, sectors, or regions such as GDP or government revenue. They are usually in the form of time-series-cross-section econometric models. One framework that is applied in many papers for European countries is the Harmonised European Research for Macro-sectoral and Energy Systems – HERMES (Jansen and Klaassen, 2000, Conefrey et al., 2013, Di Cosmo and Hyland, 2013). This is a macro-sectoral econometric model that is suitable for making short and medium-term forecasts. Another macroeconomic model used to assess the impact of a change in energy taxes is the two-stage translog cost function (Floros and Vlachou, 2005).

The next most common approach in impact analysis is the Input-Output (IO) model. This method is used in environmental economics by many researchers such as (Bach et al., 1994, Metcalf, 2007, Choi et al., 2010, Sugino et al., 2013, Gemechu et al., 2014, Rocchi et al., 2014, Zou et al., 2014, Chen et al., 2015, Choi et al., 2016). The required data for the IO models are easily available from statistics offices. When evaluating the effectiveness of a policy, the model assumes simplicity, linearity and add-up effects and can measure both direct and indirect impacts. The effects can be disaggregated into household units if the IO model is incorporated with household surveys (Labandeira and Labeaga, 1999, Symons et al., 2002, Wier et al., 2005, Kerkhof et al., 2008, Renner, 2018). However, this approach has fixed-coefficients assumptions which do not take into account technical change after a shock outside the model. Although the model is more appropriate for short-term analysis, it provides an upper bound estimate for the impacts (Feng et al., 2018).

The final approach is the computational general equilibrium (CGE) model. This approach provides a more comprehensive picture of the whole economy with the specification of utility and profit functions, the commodity and factor market structures and the demand functions for all goods. This method is applied in welfare evaluation by, for example, Babiker et al. (2003), Manresa and Sancho (2005), Scrimgeour et al. (2005), Devarajan et al. (2011), and Fullerton and Heutel (2011). Nonetheless, the CGE formulation requires a lot of data and parameters, which are difficult to obtain and usually need to be borrowed from other countries. Results from this method are subject to assumptions and include a 'black box'. Similar to the IO model, the CGE model can be integrated with microsimulation to capture heterogeneity and general equilibrium properties to maintain the specific advantages of each approach (Hamilton and Cameron, 1994, Labandeira et al., 2009, Coxhead et al., 2013).

This study applies a partial equilibrium approach for the following reasons. A chosen model needs to satisfy several conditions to answer the research question. It should be a representative model for Vietnam's economy with a particular focus on the energy market. The integration of the micro and the macro models seems to provide an appropriate approach since it can estimate the economy-wide effects (e.g., impacts on GDP, wages, and employment) and disaggregate the impacts into household level (e.g., household incomes and expenditures) (Coxhead et al., 2013). However, the available data for Vietnam is inadequate for the approach. Many parameters and prices for different groups of commodities, especially energy goods, are unavailable. As a result, this study employs the partial equilibrium approach without variations in factor prices and producer substitutions between industries.

3.4.2 Methodology

Evaluation of welfare changes is a crucial part of consumer theory. It helps decision makers evaluate policy impacts and compare between different policies. Many environmental policies can affect consumer welfare through changes in prices that people pay for commodities. The 'ideal' option is to measure the difference in utility before and after a policy. A positive number indicates that the policy is worth doing, while a negative one means the opposite. However, this ordinal measure is more suitable for evaluating a policy by a given consumer since it depends on the preference of that individual. For comparison between the welfare of different consumers, a cardinal measure would be more appropriate since it provides an answer to the question "How much is the consumer better off or worse off?". Thus, this study calculates three measures of welfare change: CV, EV, and ΔCS. All measures are computed in monetary unit by using an expenditure function.

With the application of the partial equilibrium approach, I set up a utility maximisation and an expenditure minimisation problem and then figure out their solutions. Detailed solutions are provided in the Appendix A3.1 and A3.2. Due to data limitation, this study only classifies all goods in the market as energy (E) and non-energy (NE) goods. In addition to purchased goods, a part of consumer's consumption comes from non-purchased sources (e.g., self-subsidy, gift, and donation). The quantity of the non-purchased part is invariant to a price change. It is assumes that the consumer's utility follows a constant elasticity of substitution (CES) function (Arrow et al., 1961). The consumer allocates their income (i.e., budget constraint) between these goods to maximise utility. Given saving unchanged after the policy reform, budget constraint is defined as the total expenditure that the consumer spends on energy and non-energy goods. The utility maximisation problem is

$$v(w, M) = \max_{x} u(x) = \sum_{i=\{NE,E\}} [\alpha_i (x_i + c_i)^r]^{\frac{1}{r}}$$

subject to

$$w'x = M$$

where

x is a vector of quantities of purchased non-energy and energy goods

c is a vector of quantities of non-purchased non-energy and energy goods

w is a vector of prices of non-energy and energy goods

M is the budget constraint of the consumer

α is a vector of budget shares of non-energy and energy goods, $\alpha_i > 0$ and $\sum_{i=\{NE,E\}} \alpha_i = 1$

$r < 1$ and $r \neq 0$ with elasticity of substitution $\sigma = \frac{1}{1-r}$

As the name suggests, this function has a constant rate of substitution between two goods. The greater the value of σ, the easier it is to substitute one good with another. The CES function is a general form of the Cobb-Douglas, the Leontief, and the linear function since it covers all types of returns and allows various values of elasticities. For example, in the Cobb-Douglas utility function, the elasticity of substitution is fixed at unity. The quantity of one good is independent of the price of the other good. Meanwhile, the CES function does not have this restriction, which permits the elasticity to lie between zero and infinity. The quantities and income shares of both goods depend on their relative prices. The Marshallian demand functions for the CES's utility maximisation problem are

$$\begin{cases} x_{NE}^* = \dfrac{M\left(\frac{\alpha_{NE}}{w_{NE}}\right)^\sigma + w_E\left[c_E\left(\frac{\alpha_{NE}}{w_{NE}}\right)^\sigma - c_{NE}\left(\frac{\alpha_E}{w_E}\right)^\sigma\right]}{\sum_{i=\{NE,E\}} w_i\left(\frac{\alpha_i}{w_i}\right)^\sigma} \\ x_E^* = \dfrac{M\left(\frac{\alpha_E}{w_E}\right)^\sigma + w_{NE}\left[c_{NE}\left(\frac{\alpha_E}{w_E}\right)^\sigma - c_E\left(\frac{\alpha_{NE}}{w_{NE}}\right)^\sigma\right]}{\sum_{i=\{NE,E\}} w_i\left(\frac{\alpha_i}{w_i}\right)^\sigma} \end{cases}$$

Instead of solving utility maximisation, the consumer can minimise their expenditure to achieve the required utility. This is the maximum level of utility found in the previous problem. The expenditure minimisation problem is as follows

$$e(w,U) = \min_x w'x$$

subject to

$$u(x) = \sum_{i=\{\text{NE,E}\}} [\alpha_i(x_i + c_i)^r]^{\frac{1}{r}} = U$$

A solution for the minimum expenditure function includes

- Hicksian demand functions:

$$\begin{cases} x_{NE}^h = \dfrac{U\left(\frac{\alpha_{NE}}{w_{NE}}\right)^\sigma}{\left[\sum_{i=\{NE,E\}} w_i\left(\frac{\alpha_i}{w_i}\right)^\sigma\right]^{-\frac{\sigma}{1-\sigma}}} - c_{NE} \\ x_E^h = \dfrac{U\left(\frac{\alpha_E}{w_E}\right)^\sigma}{\left[\sum_{i=\{NE,E\}} w_i\left(\frac{\alpha_i}{w_i}\right)^\sigma\right]^{-\frac{\sigma}{1-\sigma}}} - c_E \end{cases}$$

- Expenditure function:

$$e(w,U) = U\left[\sum_{i=\{NE,E\}} w_i\left(\frac{\alpha_i}{w_i}\right)^\sigma\right]^{\frac{1}{1-\sigma}} - \sum_{i=\{NE,E\}} w_i c_i$$

The above solutions are used to estimate three measures of welfare change. The first measure, CV, is the answer to the question “How much would the government pay (i.e., compensate) the individual to keep them as well off as they were before the policy change?”. This calculates the minimum additional income the consumer needs to get the same level of utility. The second measure, EV, estimates the maximum amount the consumer is willing to sacrifice to keep the price unchanged. It answers the question: “How much would the resident pay to avoid the increase in energy tax?". Both measures are on the left of the Hicksian demand curve and between the old and the new price. Unlike CV and EV, change in consumer surplus is defined as the area to the left of the Marshallian demand curve and also between two price levels. The formulas for these measures are

$$CV = e(w^1, U^0) - M^1 = e\big(w^1, v(w^0, M^0)\big) - w^1 x^1$$

$$EV = M^0 - e(w^0, U^1) = w^0 x^0 - e\big(w^0, v(w^1, M^1)\big)$$

$$\Delta CS = -\int_{w^0}^{w^1} DF(p)dp = -\int_{w^0}^{w^1} A\,p^{\varepsilon} dp$$

where

superscripts 0 and 1 denote periods before and after the policy change

A is a parameter of demand function (DF)

The status of welfare change is assessed based on the signs and magnitudes of these measures. CV and EV always have the same signs no matter how their magnitudes differ (Varian, 1992). Their signs are opposite to that of ΔCS. Given the above formulas, a positive CV or EV (or a negative ΔCS) means a loss in consumer welfare; and a negative CV or EV (or a positive ΔCS) indicates that the consumer benefits from the policy change. The relationship between CV, EV and ΔCS depends on whether it is a normal good. If the good is a normal good, for a price increase, CV > − ΔCS > EV (Figure 3.5). To sum up, they will have a general relationship:

$$\min\{CV, EV\} \leq -\Delta CS \leq \max\{CV, EV\}$$

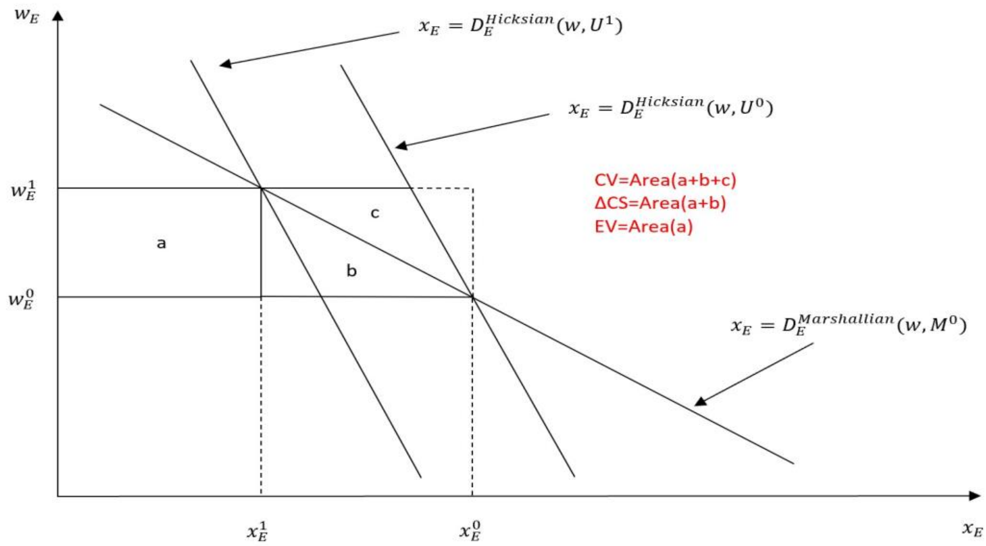

Figure 3.5 **Relationship between CV, EV, and ΔCS of energy good**

Note: The figure is adopted from Varian (1992)

3.4.3 Data source

Chapter 3 uses the VHLSS 2014 to analyse the distributional impact of the EPT. The survey was conducted nation-wide through face-to-face interviews by the General Statistics Office. It monitors and supervises living standards of different population groups in Vietnam for policy-making and socio-economic development planning. The VHLSS 2014 covers information of 9,399 household's characteristics, income, and expenditure patterns, working areas, participation in aid schemes and others in 3,133 communes, which is representative at national, regional and provincial levels.

This study focuses on household expenditure section of the survey, especially energy goods to evaluate the impact of energy taxation in Vietnam. The data is processed to contain all categories of activities that households spend their budget on in one year. The first category is annual expenditure on education and health. The second group includes food and drinks for festive occasions such as the Lunar New Year, Christmas, and Independence Day. These occasions are assumed to take 15 days per year. The next category is recurrent expenditure on food and drinks, which covers around 11.5 months. Non-food items which are reported in one month need to be transformed to consumption for the whole year. Annual consumption, other costs and expenditure on housing, water and waste are already surveyed on the 12-month basis. Finally, spending on durable goods is used to distinguish between long-run and short-run analyses.

To analyse household welfare impacts of the energy tax, this study divides goods in the sample into two groups: energy and non-energy goods. Energy group includes 12 commodities in the questionnaire, which are coal, coal briquette, gasoline, kerosene, mazut oil, diesel oil, lubricant, LPG, natural gas, firewood, farm by-products, and other types of fuels. In addition, other information on household characteristics and regions are used. All monetary values in the study are converted into USD at the exchange rate VND 21,246/USD in 2014 (State Bank of Vietnam, 2014). Table 3.3 summaries the main statistics of variables in the sample.

Table 3.3 **Summary statistics of variables**

Variables	Definition	Mean	Std.dev	Min	Max
Energy	Energy expenditure (USD)	395.32	337.31	0	7215.48
Non-energy in the short term	Non-energy expenditure in the short term which excludes durable goods (USD)	4002.79	2949.48	121.25	38619.98
Non-energy in the long term	Non-energy expenditure in the long term which includes durable goods (USD)	4330.49	3656.57	121.25	69002.50
Gender of household head	1 if a household head is male, 0 otherwise	0.74	0.44	0	1
Marital status of household head	5 statuses: 1-single, 2-married, 3-widowed, 4-divorced, and 5-separated.	2.18	0.53	1	5
Ethnic majority	1 if a household belongs to ethnic majority group, 0 otherwise	0.84	0.37	0	1
Communist Party	1 if a household has member(s) belonging to the Communist Party, 0 otherwise	0.12	0.33	0	1
Farm household	1 if a household is a farm household, 0 otherwise	0.65	0.48	0	1
Poor household	1 if a household is classified as poor, 0 otherwise	0.11	0.31	0	1
Electricity support	1 if a household receives electricity support, 0 otherwise	0.10	0.48	0	1
Regions	6 geographical regions: 1-Red River Delta, 2-Midlands and Northern Mountains, 3-Northern and Central Coast, 4-Central Highlands, 5-Southeast, Mekong 6-River Delta	3.32	1.82	1	6
Urban	1 if a household is located in urban area, 0 otherwise	0.30	0.46	0	1

Note: Number of observations: 9399
Std.dev: Standard deviation

3.4.4 Calibration

This part calibrates unknown parameters for CES utility function from available data in the VHLSS. I calculate relative budget shares of non-energy and energy goods by finding the elasticity of substitution. However, the elasticity σ between the two goods of each household is different depending on their preferences. Households with higher elasticity can easily substitute an energy good for another when taxes on energy products increase. It is assumed that the own-price elasticity of energy demand is constant across all households in the survey. It means that with energy goods every household responds similarly to the policy change regardless of their utility preferences. The own-price elasticity of each good is calculated as follows (see Appendix A3.3 for detailed solution):

$$\varepsilon(w_i, x_i) = \frac{\%\text{ change in } x_i}{\%\text{ change in } w_i} \approx \frac{\partial x_i / x_i \times 100\%}{\partial w_i / w_i \times 100\%} = \frac{\partial x_i}{\partial w_i} \times \frac{w_i}{x_i}$$

where $i = \{NE,E\}$ and

$$\begin{cases} \dfrac{\partial x_{NE}}{\partial w_{NE}} = \dfrac{\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} \left\{-(M + w_E c_E)\left[\sigma \frac{w_E}{w_{NE}}\left(\frac{\alpha_E}{w_E}\right)^{\sigma} + \left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\right] + \left[(1-\sigma) w_E c_{NE}\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right]\right\}}{\left[\sum_{i=\{NE,E\}} w_i \left(\frac{\alpha_i}{w_i}\right)^{\sigma}\right]^2} \\ \dfrac{\partial x_E}{\partial w_E} = \dfrac{\left(\frac{\alpha_E}{w_E}\right)^{\sigma} \left\{-(M + w_{NE} c_{NE})\left[\sigma \frac{w_{NE}}{w_E}\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} + \left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right] + \left[(1-\sigma) w_{NE} c_E\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\right]\right\}}{\left[\sum_{i=\{NE,E\}} w_i \left(\frac{\alpha_i}{w_i}\right)^{\sigma}\right]^2} \end{cases}$$

A corresponding elasticity of substitution σ for each household is estimated given a specific value for the own-price elasticity of energy demand. The objective is to find the root for the function *f* which is the subtraction of the own-price elasticity's formula and the targeted elasticity. It is the intersection between the function *f* and the horizontal axis. With the CES function, σ can be of any value. Before the policy change, the prices of energy and non-energy goods are set at unity. Given the quantities, prices, and elasticity of substitution, I calculate budget shares α_1 and α_2 of the two goods using the following formula:

$$\alpha_i = \frac{w_i (x_i + c_i)^{\frac{1}{\sigma}}}{\sum_{j=\{NE,E\}} w_j \left(x_j + c_j\right)^{\frac{1}{\sigma}}} \quad \text{where } i = \{NE, E\}$$

A utility level of household prior to the policy change is then computed. In the baseline scenario, energy price is supposed to increase by 10 per cent as a result of a change in the energy taxes, while the price of non-energy goods and household expenditure is kept constant. From the new prices, the new quantities for the two goods and its new utility level are found by solving the utility maximisation problem. The expenditure on the new utility level is then calculated. Finally, this study evaluates policy impacts on household welfare based on the results of the three measures CV, EV and ΔCS.

3.5 Results

This section presents the results of the welfare changes after an increase in energy taxes. The first subsection provides the welfare impact per household in the baseline scenario for both short-term and long-term. The next part then discusses welfare changes in households with different characteristics, regions and expenditure levels. The last subsection verifies the results, in which the total welfare and distributional impacts at other price elasticities are evaluated and compared with those in the previous scenario.

3.5.1 Welfare impact per household

In the baseline scenario, I choose a specific value for the own-price elasticity of energy demand. There have been not many studies on the elasticity for Vietnam, although information for developed countries and the world is presented in various papers. Specifically, Vietnam's price elasticities of gasoline and diesel have been reported by Dahl (2012) at −0.26 and −0.22, respectively. Since no other updated data is available, this study uses −0.25 as the own-price elasticity of energy for the analysis.

Given that the total expenditure remains unchanged, the new energy taxes lead to a decline in both energy and non-energy purchases. The non-purchased amounts are assumed to be constant after the policy change. Households would reduce their energy and non-energy consumption by 0.18 unit and 0.55 unit on average. Hence, the quantity of purchased energy consumption would decline by approximately 25 per cent as a result of the 10 per cent increase in its price, which reflects the own-price elasticity of substitution at −0.25.

Table 3.4 presents the welfare impacts as a result of the policy change. Higher prices make all households worse off since they can buy fewer goods with the same budget. In the short run (i.e., without durable goods), the CV of each household lies between approximately USD 0.23 and USD 481.99 with the mean of USD 35.39. Similar figures could be found for EV and ΔCS. These results confirm that energy is a normal good with the relationship CV > − ΔCS > EV. In one year, CV accounts for 1.02 per cent of the total expenditure. As expected, the EV of each household has the same sign compared with CV, but its magnitude is slightly smaller with the mean of USD 35.00. It has almost the same ratio as the first measure. The result from the last measure, ΔCS, confirms that the whole economy is worse off. The consumer surplus decreases by USD 35.20 in one year on average.

In terms of tax revenue, the rise in tax paid is slightly less than the loss in household welfare, which represents a deadweight loss arising from the increase in energy taxes. The government is expected to collect an additional amount of USD 34.78 per year (i.e., 1.00 per cent of the total expenditure) from each household. However, this only evaluates household impacts since other economic effects and environmental benefits such as an increase in health status of the residents or a decrease in GHG emissions are not taken into account.

Furthermore, long-term welfare impact shows similar patterns. CV also has the highest value, followed by the absolute value of ΔCS and EV. The government budget's gain from an individual household in one year is also lower than its welfare loss, as expected. The figures for the long term are somewhat larger than those in the previous case. For a given household, higher consumption in the long term leads to a bigger loss compared with the short term. Proportions of these measures in their total expenditure are smaller, at around 0.89 per cent.

The difference between the two periods is trivial. The main reason is that the elasticities of substitution in both periods are small, which means households do not drastically reduce their energy consumption and substitute for other goods. The new quantity of energy goods in the short term is slightly less than that in the long-term. Another possible reason is the small proportion of purchased energy in total consumption per household. It accounts for 8.9 per cent and 7.9 per cent in the two scenarios, respectively.

Table 3.4 **Welfare impact per household in one year**

	Short-term	**Long-term**
CV (USD)	35.389	35.598
EV (USD)	35.001	35.246
ΔCS (USD)	-35.198	-35.425
Tax revenue (USD)	34.775	35.000
CV/Total expenditure (%)	1.016	0.894
EV/Total expenditure (%)	1.004	0.885
| ΔCS |/Total expenditure (%)	1.010	0.890
Tax revenue/Total expenditure (%)	0.998	0.879

3.5.2 Distributional impacts

Distributional impacts are calculated to see how welfare change varies between different groups of households. Although a multiple linear regression model can control many independent variables at the same time, it is subject to several assumptions such as linear relationships between dependent and independent variables, homoskedasticity and no autocorrelation in the error terms, and independence of observations. In addition, one widely recognised problem with a linear regression model is ‘p-hacking’ (also ‘data mining’, ‘fishing’, or ‘specification searching’) (Leamer, 1978, Leamer and Leonard, 1983, Leamer, 1983, Ridley et al., 2007, Havránek, 2015, Bruns and Ioannidis, 2016). P-hacking refers to practices to generate ‘better’ p-values in studies when there might not be real underlying effects. This can be done by collecting data, performing, and controlling different regression equations with various sets of independent variables until significant results consistent with prior plans of researchers are found. The problem can lead to publication bias. Given this context, I choose a t-test to compare group means and find any statistical evidence that their means are significantly different.

The distributional impacts differ across household characteristics, regions, and other household features. All dependent variables are in logarithm form. The absolute value of ΔCS is used since the logarithm of a negative number does not exist. Interpretation for the last measure is the same as CV and EV, i.e., the positive estimated coefficients mean a higher welfare loss. However, this presents correlation rather than a causal relationship, which does not discuss underlying factors leading to differences between group means. The results are similar in the three measures of welfare changes for both short-term and long-term analyses (Table 3.5 and Table 3.6). Hence, this study interprets the first measure (CV) only.

First, there are discrepancies in welfare change regarding household characteristics. Families with male household heads are expected to have a 23.9 per cent higher CV than others. Households with different marital statuses of the household heads also require various additional income to keep them as well off as they were before the policy change. In detail, CVs of married heads are 32.5-69.8 per cent higher than households of divorced, separated, widowed and single heads. In particular, the welfare loss of the energy tax increase is larger for households that belong to the ethnic majority group (Kinh and Hoa). They need to be compensated 86.1 per cent more than the ethnic minority group. Families having members belonging to the Communist Party are worse off with a higher CV of approximately 55.3 per cent.

Table 3.5 **Welfare impact by household demographic and region in the short term**

	Log(CV)	**Log(EV)**	**Log(| ΔCS |)**
Gender of household head			
Male	0.239***	0.239***	0.239***
Marital status of household head			
Single	−0.698***	−0.697***	−0.698***
Widowed	−0.616***	−0.616***	−0.616***
Divorced	−0.325***	−0.325***	−0.325***
Separated	−0.609***	−0.609***	−0.609***
Ethnics			
Majority	0.861***	0.861***	0.861***
Member of an association			
Communist Party	0.553***	0.553***	0.553***
Household business			
Farm households	−0.505***	−0.505***	−0.505***
Economic condition			
Poor households	−1.346***	−1.344***	−1.345***
Receive electricity support	−1.310***	−1.309***	−1.309***
Regions			
Midlands & Northern Mountains	−0.479***	−0.480***	−0.479***
Northern & Central Coast	−0.236***	−0.235***	−0.235***
Central Highlands	−0.251***	−0.251***	−0.251***
Southeast	0.456***	0.454***	0.455***
Mekong River Delta	−0.261***	−0.260***	−0.261***
Location			
Urban	0.759***	0.759***	0.759***

Welfare impacts also vary for other household features. Welfare loss in farm households is 50.5 per cent less than the non-farm ones. Economic conditions also show substantial discrepancies in welfare change. For instance, around 10 per cent of households in the survey that are classified as poor by the Ministry of Labour, Invalids and Social Affairs have 134.6 per cent lower CV than those that are not. A similar result can be found for households receiving electricity support from the government where they suffer a 131.0 per cent less loss when compared with others.

Moreover, regions are a factor that should be mentioned when analysing the distributional impact. In order to keep their utility unchanged, households in the Southeast need additional income of 44.6 per cent than those in the Red River Delta. However, other remaining regions require a lower compensation to be as well off as before, especially households in the Midlands and Northern Mountains with a lower CV of 47.9 per cent. Households in urban areas have a higher CV by 75.9 per cent compared with their rural counterparts.

Table 3.6 **Welfare impact by household demographic and region in the long term**

	Log(CV)	**Log(EV)**	**Log(| ΔCS |)**
Gender of household head			
Male	0.239***	0.239***	0.239***
Marital status of household head			
Single	−0.700***	−0.699***	−0.700***
Widowed	−0.614***	−0.614***	−0.614***
Divorced	−0.344***	−0.345***	−0.345***
Separated	−0.585***	−0.585***	−0.585***
Ethnics			
Majority	0.866***	0.867***	0.866***
Member of an association			
Communist Party	0.554***	0.553***	0.554***
Household business			
Farm households	−0.509***	−0.509***	−0.509***
Economic condition			
Poor households	−1.355***	−1.354***	−1.354***
Receive electricity support	−1.315***	−1.315***	−1.315***
Regions			
Midlands & Northern Mountains	−0.487***	−0.487***	−0.487***
Northern & Central Coast	−0.236***	−0.236***	−0.236***
Central Highlands	−0.250***	−0.249***	−0.250***
Southeast	0.460***	0.458***	0.459***
Mekong River Delta	−0.264***	−0.264***	−0.264***
Location			
Urban	0.759***	0.758***	0.758***

Finally, the distributional impacts of the energy taxes can be presented through the relationship between the ratio of EV to total expenditure (EV/M) and different expenditure levels (M). An increasing profile indicates progressive incidence, i.e., rich households suffer a bigger loss compared with the poor. Consumption expenditure is used instead of income since households tend to smooth their consumption over life cycles and consume according to permanent income. Hence, the annual income may not be appropriate for quantifying regressivity (Wier et al., 2005). Expenditure is a more reliable indicator of a person's well-being, while income is likely to be under-reported in surveys (Johnson et al., 1990). Figure 3.6 shows the equivalent variation as a percentage of total expenditure across expenditure deciles. In both periods, the ratio increases until the fourth decile and then gradually declines as expenditure level rises. Hence, the energy taxes are neither strictly regressive nor progressive.

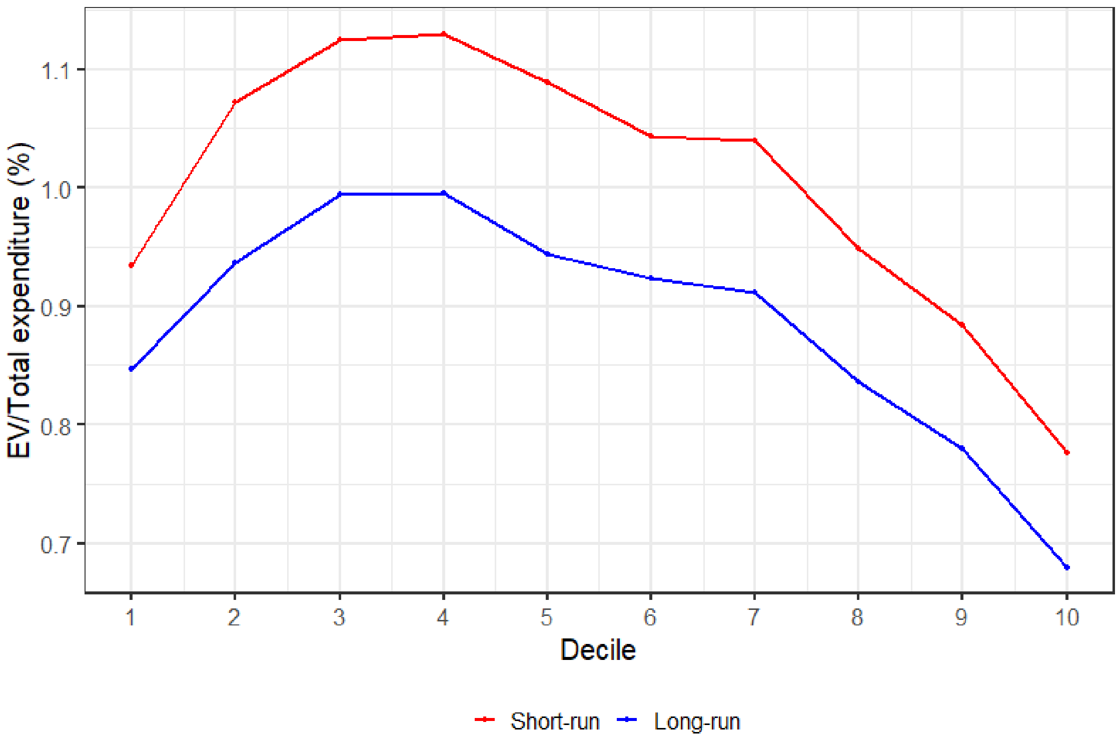

Figure 3.6 **Welfare impact by decile of expenditure**

3.5.3 Sensitivity tests

There is a large literature on price elasticities of developed countries and the world. Some researchers, such as Archibald and Gillingham (1980), Puller and Greening (1999), Kayser (2000), West and Williams (2007), and Sentenac-Chemin (2012), estimate the elasticity of fuel demand for the USA. All of their findings are below -0.55, which means the energy goods are price inelastic. Other papers use panel data of many countries to find price elasticity in the short term and the long-term period for the whole world (Brons et al., 2008, Dahl, 2012, Burke and

Nishitateno, 2013). In general, the long-run elasticities are higher in terms of magnitude, suggesting that in the long term consumers have more time to adjust their behaviours. Hence, they can reduce their consumption of energy goods substantially if there is a price increase.

This study uses different values of elasticities to present a sensitivity analysis. As reported by Dahl (2012), the average worldwide elasticities in the short term and the long term are −0.15 and −0.55. I use these figures and some values within this range for the two periods to evaluate the robustness of the welfare changes. A sensitivity test is necessary to confirm the validity of the results. With a wide range of price elasticity, the study needs to show whether variations in this variable alter the basic conclusion since a fragile inference is not worthy to be taken seriously (Leamer, 1985).

Different elasticities lead to a small change in each household welfare loss. Within the same household, higher price elasticity of energy demand (in terms of magnitude) results in a larger elasticity of substitution between energy and non-energy goods when solving a root for the function f. The welfare loss per household is slightly lower due to a better ability to substitute in response to an increase in energy price. Hence, the relative welfare loss, i.e., the ratios of the three measures to total expenditure, declines as energy goods are less price inelastic.

Sensitivity tests for the distributional impacts by household demographic and region also give similar results. Table 3.7 shows the welfare effects with respect to log(CV) at different elasticities. All the figures have the same signs and are statistically significant at 1 per cent level, though there are minor discrepancies in magnitudes. Estimates of other measures provide consistent results. In general, households that have one of these features are expected to be worse off compared with other groups: having a male, married head, belonging to an ethnic majority group, a member of the Communist Party, having a better economic condition, living in the Southeast region and in the urban areas.

Table 3.7 **Sensitivity tests for welfare impacts in the short term**

ε =	**−0.15**	**−0.35**	**−0.45**	**−0.55**
Gender of household head				
Male	0.253***	0.234***	0.235***	0.233***
Marital status of household head				
Single	−0.800***	−0.681***	−0.686***	−0.700***
Widowed	−0.654***	−0.612***	−0.611***	−0.612***
Divorced	−0.322***	−0.318***	−0.332***	−0.333***
Separated	−0.663***	−0.584***	−0.583***	−0.584***
Ethnics				
Majority	0.834***	0.883***	0.893***	0.892***
Member of an association				
Communist Party	0.570***	0.561***	0.566***	0.565***
Household business				
Farm households	−0.491***	−0.518***	−0.524***	−0.523***
Economic condition				
Poor households	−1.322***	−1.388***	−1.406***	−1.407***
Receive electricity support	−1.282***	−1.346***	−1.365***	−1.365***
Regions				
Midlands & Northern Mountains	−0.447***	−0.510***	−0.519***	−0.522***
Northern & Central Coast	−0.217***	−0.234***	−0.242***	−0.244***
Central Highlands	−0.205***	−0.248***	−0.253***	−0.255***
Southeast	0.402***	0.467***	0.464***	0.463***
Mekong River Delta	−0.267***	−0.260***	−0.263***	−0.263***
Location				
Urban	0.770***	0.763***	0.769***	0.768***

Figure 3.7 presents the sensitivity tests for welfare impacts by decile of expenditure in the short term. The patterns are quite similar to that in the baseline scenario. The ratio for $\varepsilon = -0.15$ reaches the highest value at the fifth decile. In addition, there is a significant difference between the lowest elasticity and other values. At this value, the function f often has no solution, and these observations are dropped out of the sample. This suggests that a very inelastic energy good is not suitable for the economy. With unequal sample sizes at different values of elasticities, the result needs careful interpretation. If I take this issue into account, the welfare loss by decile decreases as the elasticity of energy demand in absolute value increases. Sensitivity analysis for the long-term impacts, which is given in Appendix A3.4, shows consistent outcomes. Therefore, the impacts of an increase in energy taxes are robust across different periods and elasticities.

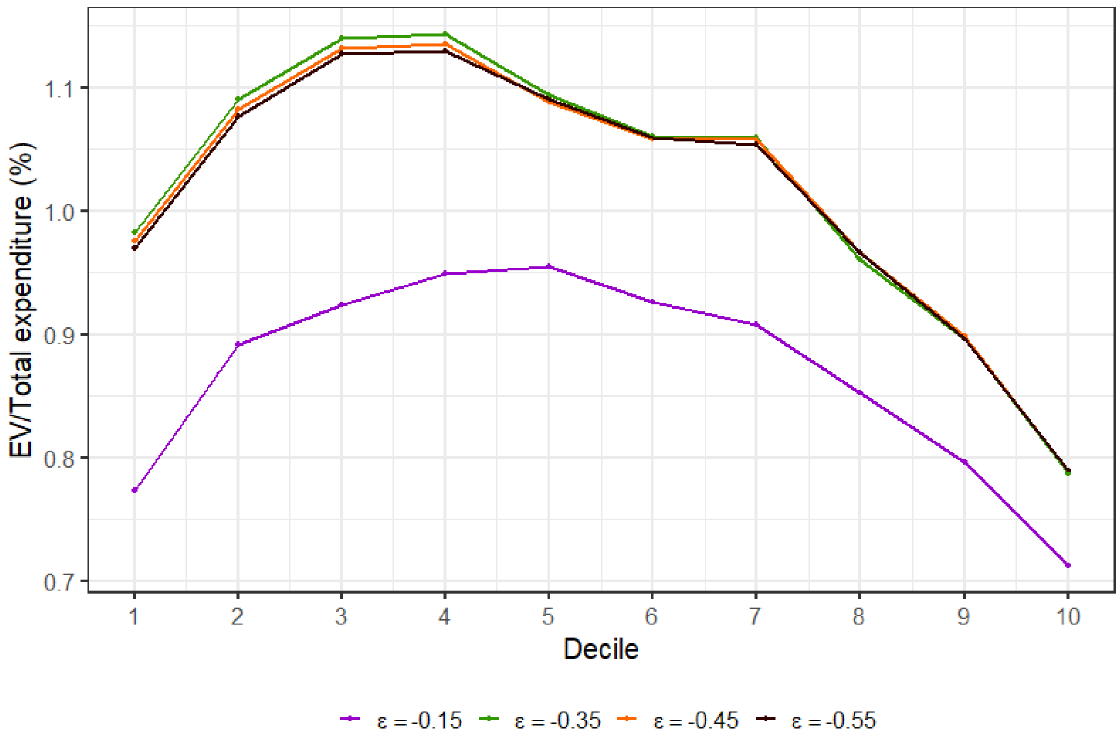

Figure 3.7 **Sensitivity test for welfare impacts by decile in the short term**

3.6 Discussion

Since energy is a necessary good, the impacts of an increase in energy taxes on household welfare are worth discussing. Results from the model show a welfare loss, but the effect is unequal across household groups. The distributional analysis suggests that the impact is more intense in households having a higher fraction of energy expenditure. The middle class incurred the largest loss since the richest spent their budget on other categories such as durable purchases and recreational activities, while the poorest consumed more 'cheap' energies that accounted insignificantly to their total expenditure. In addition, the paper presents another view on the incidence of the policy by comparing the welfare loss between different household demographics and regions. This study has similar findings compared with those of Labandeira and Labeaga (1999) and Creedy and Sleeman (2006).

To what extent the change in environmental policy affects household welfare might be determined by the elasticity of substitution between energy and non-energy goods. It is more difficult for households with low elasticity to substitute away from energy when there is a price increase. In particular, if they are bearing an already low level of energy consumption, they can hardly reduce the spending on this good further due to the potential uncomfortable consequences (Nesbakken, 1999). Although their welfare loss measured in EV, for example, is smaller than that of households with higher energy consumption, when the relative equivalent loss is taken into account (i.e., EV/M), the figure for their loss increases and becomes approximately equal to other groups. The results for EV/M in this study are comparable to findings reported in Willenbockel (2011).

Although the results show small reductions in the welfare impacts per household, they are robust over two periods and a wide range of elasticities. The figures for distributional analysis in sensitivity tests also provide almost the same findings compared with the baseline scenario. However, this chapter does not model macroeconomic variables such as intermediate consumption, investment, and export, nor does it evaluate the consequences of hypothetical taxes on them. Despite households being affected by energy taxation, this does not mean that the taxes are harmful to the economy. The findings only serve as an indicative prediction for policymakers about one of potential impacts. They may adjust the level of energy taxes to be coherent with the objectives and roles of the policy. Hence, this study could help them to determine their decisions in the long-term and support policy positions (Stone et al., 2001). The research provides important policy implications for Vietnam, especially as the country is preparing for the establishment of a carbon market in the steel sector by 2020 (ADB, 2015b). Other countries in the region such as Indonesia and Thailand that have similar plans in developing an emission trading scheme would use the results as a reference for their countries.

The welfare loss may require complementary programs from the government to support the most affected households. The government has implemented some policies to help poor households get enough access to necessary types of energy. One prominent policy is Circular No. 37/2008/TT-BTC in 2008 that provides guidelines for a kerosene subsidy scheme to support ethnic minority households, households of the social insurance policy, and poor households in off-grid areas (Ministry of Finance, 2008). Poor households in on-grid areas can receive a cash transfer from the government (Government Office, 2011b, Ministry of Finance, 2014). However, these systems suffer from inclusion and exclusion errors (La et al., 2017). The complementary programs, hence, should be pro-poor, on target, and not overlap with existing subsidy schemes. Reviewing current laws carefully and determining the right household groups to be supported are must-do tasks of the authorities for a good policy development process.

Establishing an appropriate roadmap for energy tax reform is an indispensable task of the government before implementing any policy. Apart from certain benefits, the government needs to evaluate side effects, especially for lower-income households that usually suffer higher losses. The policy reform should be performed step-by-step with an incremental increase and an interim assessment in each stage. Furthermore, experience gained from small-scale pilots in targeted groups is valuable for the government to conduct large-scale policies. China is a typical example that has prepared carefully for its carbon emissions trading scheme. The Chinese government launched several pilot programs with various designs in 2011 to find an appropriate nationwide mechanism in 2015 while alleviating economic loss (Tang et al., 2015, Munnings et al., 2016).

The results give rise to many considerations and extensions for future research on environmental taxation in Vietnam. Different forms of revenue-recycling may be discussed to give a better policy assessment. The taxes can create a double dividend effect: (i) reducing emissions and (ii) lowering costs in the current tax system (Pearce, 1991). A weak double dividend suggests the use of revenue gains as a lump-sum transfer to households to lessen their loss. This is different from the current supporting schemes in Vietnam in which funds are taken from the state budget and allocated depending on the status of local budgets. Nonetheless, this type of double dividend may not be the most useful mechanism to improve the incidence of the tax. Another option is to use the environmental tax revenue to correct other more distortionary taxes such as income taxes and achieve a strong double dividend (Parry and Bento, 2000, Bor and Huang, 2010, Orlov and Grethe, 2012). The revenue-neutral strategies can result in social welfare improvement for Vietnam.

Moreover, this study can be further extended by comparing it with gains in environmental benefits. It is documented in many papers that emissions from energy goods negatively affect human health and their labour productivity (Goldemberg, 2000, Kampa and Castanas, 2008, Haines et al., 2009). The increase in energy taxes is expected to reduce emissions, which can alleviate health problems relating to air pollution. These assessments can provide a more detailed conclusion about the net benefits of the tax policy.

3.7 Conclusions

This study has investigated the impacts of a hypothetical increase in energy taxes on household welfare using the VHLSS 2014. The results show that at the baseline scenario all households are worse off with the positive values for CV and EV (or a negative ΔCS). As expected, the gain in tax revenue is less than the loss of each household, which represents a deadweight loss. Moreover, household welfare varies across different demographics and regions. Families with one of the following features are worse off compared with other groups: male household head, married household head, in the ethnic majority group, household members in the Communist Party, non-farm households and without electricity support from the government. The distributional impacts by decile of expenditure show that the policy is neither strictly regressive nor progressive.

The sensitivity analysis over different periods and several values of elasticities verifies the results. Compared with the baseline scenario, the welfare impact per household exhibits identical patterns, which does not change much across the range. Furthermore, all the outcomes in the distributional impacts report the same signs and minor variations in magnitudes. The results suggest that the household welfare effects are robust. This raises a question about the importance of complementary programs, including the use of tax revenue to support the most affected households. Future research may consider environmental gains and revenue recycling options to obtain a more comprehensive conclusion about the welfare evaluation of an increase in energy taxes.

Appendix

A3.1 Solutions for utility maximisation problem

The utility maximisation problem is

$$max\, U(x_{NE}, x_E) = [\alpha_{NE}(x_{NE} + c_{NE})^r + \ \alpha_E(x_E + c_E)^r]^{\frac{1}{r}}$$

subject to

$$w_{NE}x_{NE} + w_E x_E = M$$

- Setting up the Lagrangian function

$$\mathcal{L}(x_{NE}, x_E, \lambda) = [\alpha_{NE}(x_{NE} + c_{NE})^r + \alpha_E(x_E + c_E)^r]^{\frac{1}{r}} + \ \lambda[M - (w_{NE}x_{NE} + w_E x_E)]$$

- Deriving the first order conditions:

$$\begin{cases} \dfrac{\partial \mathcal{L}}{\partial x_{NE}} = 0 & (A3.1) \\ \dfrac{\partial \mathcal{L}}{\partial x_E} = 0 & (A3.2) \\ \dfrac{\partial \mathcal{L}}{\partial \lambda} = 0 & (A3.3) \end{cases}$$

From (A3.1):

$$\Rightarrow \frac{1}{r}[\alpha_{NE}(x_{NE} + c_{NE})^r + \ \alpha_E(x_E + c_E)^r]^{\frac{1}{r}-1} \times \ r\alpha_{NE}(x_{NE} + c_{NE})^{r-1} - \ \lambda w_1 = 0$$

$$\Rightarrow [\alpha_{NE}(x_{NE} + c_{NE})^r + \ \alpha_E(x_E + c_E)^r]^{\frac{1}{r}-1} \times \ \alpha_{NE}(x_{NE} + c_{NE})^{r-1} = \ \lambda w_1 \qquad (A3.4)$$

From (A3.2):

$$\Rightarrow [\alpha_{NE}(x_{NE} + c_{NE})^r + \ \alpha_E(x_E + c_E)^r]^{\frac{1}{r}-1} \times \ \alpha_E(x_E + c_E)^{r-1} = \ \lambda w_2 \qquad (A3.5)$$

From (A3.3):

$$\Rightarrow w_{NE}x_{NE} + w_E x_E = M$$

Take (A3.4) divided by (A3.5), I have:

$$\Rightarrow \frac{\alpha_{NE}(x_{NE} + \ c_{NE})^{r-1}}{\alpha_E(x_E + \ c_E)^{r-1}} = \ \frac{w_{NE}}{w_E} \ \ \Rightarrow \frac{x_{NE} + c_{NE}}{x_E + c_E} = \left(\frac{\alpha_{NE}}{\alpha_E}\right)^{\frac{1}{1-r}} \left(\frac{w_{NE}}{w_E}\right)^{-\frac{1}{1-r}}$$

$$\Rightarrow \frac{\alpha_{NE}}{\alpha_E} = \left(\frac{w_{NE}}{w_E}\right)\left(\frac{x_{NE}+c_{NE}}{x_E+c_E}\right)^{\frac{1}{\sigma}} \quad \text{where} \quad \frac{1}{1-r} = \sigma \tag{A3.6}$$

Since α_{NE} and α_E are budget shares of non-energy and energy goods, I have

$$\alpha_{NE} + \alpha_E = 1 \tag{A3.7}$$

From (A3.6) and (A3.7)

$$\Rightarrow \frac{1-\alpha_E}{\alpha_E} = \left(\frac{w_{NE}}{w_E}\right)\left(\frac{x_{NE}+c_{NE}}{x_E+c_E}\right)^{1/\sigma} \Rightarrow \frac{1}{\alpha_E} - 1 = \frac{w_{NE}}{w_E}\frac{(x_{NE}+c_{NE})^{1/\sigma}}{(x_E+c_E)^{1/\sigma}}$$

$$\Rightarrow \frac{1}{\alpha_E} = \frac{w_{NE}}{w_E}\frac{(x_{NE}+c_{NE})^{1/\sigma}}{(x_E+c_E)^{1/\sigma}} + 1 \Rightarrow \frac{1}{\alpha_E} = \frac{w_{NE}(x_{NE}+c_{NE})^{1/\sigma} + w_E(x_E+c_E)^{1/\sigma}}{w_E(x_E+c_E)^{1/\sigma}}$$

$$\Rightarrow \alpha_E = \frac{w_E(x_E+c_E)^{1/\sigma}}{w_{NE}(x_{NE}+c_{NE})^{1/\sigma} + w_E(x_E+c_E)^{1/\sigma}}$$

$$\Rightarrow \alpha_{NE} = \frac{w_{NE}(x_{NE}+c_{NE})^{1/\sigma}}{w_{NE}(x_{NE}+c_{NE})^{1/\sigma} + w_E(x_E+c_E)^{1/\sigma}}$$

$$\Rightarrow \alpha_i = \frac{w_i(x_i+c_i)^{1/\sigma}}{\sum_{i=1}^{N} w_i(x_i+c_i)^{1/\sigma}}$$

From (A3.6)

$$\Rightarrow x_{NE} + c_{NE} = \left(\frac{\alpha_{NE}}{\alpha_E}\right)^{\sigma}\left(\frac{w_{NE}}{w_E}\right)^{-\sigma}(x_E+c_E)$$

$$\Rightarrow x_{NE} = \left(\frac{\alpha_{NE}}{\alpha_2}\right)^{\sigma}\left(\frac{w_{NE}}{w_E}\right)^{-\sigma}(x_E+c_E) - c_{NE}$$

Plug x_{NE} into the budget constraint (A3.3)

$$\Rightarrow w_{NE}\left[\left(\frac{\alpha_{NE}}{\alpha_E}\right)^{\sigma}\left(\frac{w_{NE}}{w_E}\right)^{-\sigma}(x_E+c_E) - c_{NE}\right] + w_E x_E = M$$

$$\Rightarrow w_{NE}\left[\left(\frac{\alpha_{NE}}{\alpha_E}\right)^{\sigma}\left(\frac{w_{NE}}{w_E}\right)^{-\sigma}\right]x_E + w_{NE}c_E\left(\frac{\alpha_{NE}}{\alpha_E}\right)^{\sigma}\left(\frac{w_{NE}}{w_E}\right)^{-\sigma} - w_{NE}c_{NE} + w_E x_E = M$$

$$\Rightarrow x_E\left[w_{NE}\left(\frac{\alpha_{NE}}{\alpha_E}\right)^{\sigma}\left(\frac{w_{NE}}{w_E}\right)^{-\sigma} + w_E\right] + w_{NE}\left[c_E\left(\frac{\alpha_{NE}}{\alpha_E}\right)^{\sigma}\left(\frac{w_{NE}}{w_E}\right)^{-\sigma} - c_{NE}\right] = M$$

$$\Rightarrow x_E = \frac{\left\{M + w_{NE}\left[c_{NE} - \left(\frac{\alpha_{NE}}{\alpha_E}\right)^{\sigma}\left(\frac{w_{NE}}{w_E}\right)^{-\sigma}c_E\right]\right\}\left(\frac{\alpha_E}{w_E}\right)^{\sigma}}{w_{NE}\left(\frac{\alpha_{NE}}{w_E}\right)^{\sigma} + w_E\left(\frac{\alpha_E}{w_E}\right)^{\sigma}}$$

$$\Rightarrow x_E = \frac{M\left(\frac{\alpha_E}{w_E}\right)^{\sigma}}{w_{NE}\left(\frac{\alpha_{NE}}{w_E}\right)^{\sigma} + w_E\left(\frac{\alpha_E}{w_E}\right)^{\sigma}} + \frac{w_{NE}\left[c_{NE}\left(\frac{\alpha_E}{w_E}\right)^{\sigma} - c_E\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\right]}{w_{NE}\left(\frac{\alpha_{NE}}{w_E}\right)^{\sigma} + w_E\left(\frac{\alpha_E}{w_E}\right)^{\sigma}}$$

The Marshallian demand functions for the CES's utility maximisation problem are

$$\begin{cases} x_{NE}^* = \dfrac{M\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} + w_E\left[c_E\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} - c_{NE}\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right]}{\sum_{i=\{NE,E\}} w_i\left(\frac{\alpha_i}{w_i}\right)^{\sigma}} \\ x_E^* = \dfrac{M\left(\frac{\alpha_E}{w_E}\right)^{\sigma} + w_{NE}\left[c_{NE}\left(\frac{\alpha_E}{w_E}\right)^{\sigma} - c_E\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\right]}{\sum_{i=\{NE,E\}} w_i\left(\frac{\alpha_i}{w_i}\right)^{\sigma}} \end{cases}$$

A3.2 Solutions for expenditure minimisation problem

The expenditure minimisation problem is

$$Min\ e = w_{NE}x_{NE} + w_E x_E$$

subject to

$$U(x_{NE}, x_E) = [\alpha_{NE}(x_{NE} + c_{NE})^r + \alpha_E(x_E + c_E)^r]^{\frac{1}{r}}$$

- Setting up the Lagrangian function

$$\mathcal{L}(x_{NE}, x_E, \lambda) = w_{NE}x_{NE} + w_E x_E + \lambda\{U - [\alpha_{NE}(x_{NE} + c_{NE})^r + \alpha_E(x_E + c_E)^r]^{\frac{1}{r}}\}$$

- Deriving the first order conditions:

$$\begin{cases} \dfrac{\partial\mathcal{L}}{\partial x_{NE}} = w_{NE} - \lambda[\alpha_{NE}(x_{NE} + c_{NE})^r + \alpha_E(x_E + c_E)^r]^{\frac{1}{r}-1}\alpha_{NE}(x_{NE} + c_{NE})^{r-1} = 0 & (A3.8) \\ \dfrac{\partial\mathcal{L}}{\partial x_E} = w_E - \lambda[\alpha_{NE}(x_{NE} + c_{NE})^r + \alpha_E(x_E + c_E)^r]^{\frac{1}{r}-1}\alpha_E(x_E + c_E)^{r-1} = 0 & (A3.9) \\ \dfrac{\partial\mathcal{L}}{\partial\lambda} = U - [\alpha_{NE}(x_{NE} + c_{NE})^r + \alpha_E(x_E + c_E)^r]^{\frac{1}{r}} = 0 & (A3.10) \end{cases}$$

From (A3.8) and (A3.9), I have

$$\Rightarrow \frac{w_{NE}}{w_E} = \frac{\alpha_{NE}(x_{NE} + c_{NE})^{r-1}}{\alpha_E(x_E + c_E)^{r-1}}$$

$$\Rightarrow (x_{NE} + c_{NE})^{r-1} = \left(\frac{w_{NE}}{w_E} \times \frac{\alpha_E}{\alpha_{NE}}\right)(x_E + c_E)^{r-1}$$

$$\Rightarrow x_{NE} + c_{NE} = \left(\frac{w_{NE}}{w_E} \times \frac{\alpha_E}{\alpha_{NE}}\right)^{\frac{1}{r-1}}(x_E + c_E)$$

Plug $x_{NE} + c_{NE}$ into $(A3.10)$

$$\Rightarrow U = \left[\alpha_{NE}\left(\frac{w_{NE}}{w_E} \times \frac{\alpha_E}{\alpha_{NE}}\right)^{\frac{r}{r-1}} (x_E + c_E)^r + \alpha_E(x_E + c_E)^r\right]^{\frac{1}{r}}$$

$$\Rightarrow U = (x_E + c_E)\left[\alpha_{NE}{}^{\frac{1}{1-r}}\alpha_E{}^{-\frac{r}{1-r}}w_{NE}{}^{-\frac{r}{1-r}}w_E{}^{\frac{r}{1-r}} + \alpha_E\right]^{\frac{1}{r}}$$

$$\Rightarrow U = \left(\frac{w_E}{\alpha_E}\right)^{\frac{1}{1-r}}\left[w_{NE}\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\frac{1}{1-r}} + w_E\left(\frac{\alpha_E}{w_E}\right)^{\frac{1}{1-r}}\right]^{\frac{1}{r}}(x_E + c_E)$$

$$\Rightarrow U = \left(\frac{w_E}{\alpha_E}\right)^{\frac{1}{1-r}}\left[\frac{\alpha_{NE}{}^{\frac{1}{1-r}}w_{NE}w_E{}^{\frac{1}{1-r}} + \alpha_E{}^{\frac{1}{1-r}}w_E w_{NE}{}^{\frac{1}{1-r}}}{w_{NE}{}^{\frac{1}{1-r}}w_E{}^{\frac{1}{1-r}}}\right]^{\frac{1}{r}}(x_E + c_E)$$

$$\Rightarrow U = \left(\frac{w_E}{\alpha_E}\right)^{\sigma}(\alpha_{NE}{}^{\sigma}w_{NE}{}^{1-\sigma} + \alpha_E{}^{\sigma}w_E{}^{1-\sigma})^{\frac{\sigma}{\sigma-1}}(x_E + c_E)$$

$$\Rightarrow x_E = \frac{U\left(\frac{\alpha_E}{w_E}\right)^{\sigma}}{(\alpha_{NE}{}^{\sigma}w_{NE}{}^{1-\sigma} + \alpha_E{}^{\sigma}w_E{}^{1-\sigma})^{-\frac{\sigma}{\sigma-1}}} - c_2$$

The Hicksian demand functions for the expenditure minimisation problem are

$$\begin{cases} x_{NE}^h = \dfrac{U\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}}{\left[\sum_{i=\{NE,E\}} w_i\left(\frac{\alpha_i}{w_i}\right)^{\sigma}\right]^{-\frac{\sigma}{1-\sigma}}} - c_{NE} \\ x_E^h = \dfrac{U\left(\frac{\alpha_E}{w_E}\right)^{\sigma}}{\left[\sum_{i=\{NE,E\}} w_i\left(\frac{\alpha_i}{w_i}\right)^{\sigma}\right]^{-\frac{\sigma}{1-\sigma}}} - c_E \end{cases}$$

The minimum expenditure is:

$$E^*(w, U) = U[\alpha_{NE}{}^{\sigma}w_{NE}{}^{1-\sigma} + \alpha_E{}^{\sigma}w_E{}^{1-\sigma}]^{\frac{1}{1-\sigma}} - w_{NE}c_{NE} - w_E c_E$$

or $E^*(w, U) = U\left[\sum_{i=\{NE,E\}} w_i\left(\frac{\alpha_i}{w_i}\right)^{\sigma}\right]^{\frac{1}{1-\sigma}} - \sum_{i=\{NE,E\}} w_i c_i$

A3.3 Solution for own-price elasticity

The own-price elasticity of each good is:

$$\varepsilon(w_i, x_i) = \frac{\%\text{ change in } x_i}{\%\text{ change in } w_i} \approx \frac{\partial x_i / x_i \times 100\%}{\partial w_i / w_i \times 100\%} = \frac{\partial x_i}{\partial w_i} \times \frac{w_i}{x_i}$$

I use the Marshalian demand function for x_{NE}

$$x_{NE} = \frac{M\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}}{w_{NE}\left(\frac{\alpha_{NE}}{w_E}\right)^{\sigma} + w_E\left(\frac{\alpha_E}{w_E}\right)^{\sigma}} + \frac{w_E\left[c_E\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} - c_{NE}\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right]}{w_{NE}\left(\frac{\alpha_{NE}}{w_E}\right)^{\sigma} + w_E\left(\frac{\alpha_E}{w_E}\right)^{\sigma}}$$

$$\Rightarrow \frac{\partial x_{NE}}{\partial w_{NE}} = \frac{\left[-\sigma M\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\frac{1}{w_{NE}}\right]\left[w_{NE}\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} + w_E\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right] - \left\{M\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\left[(1-\sigma)\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\right]\right\}}{\left[w_{NE}\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} + w_E\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right]^2} +$$

$$\frac{\left[w_E c_E(-\sigma)\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\frac{1}{w_{NE}}\right]\left[w_{NE}\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} + w_E\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right] - \left\{w_E\left[c_{NE}\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} - c_{NE}\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right]\right\}\left[(1-\sigma)\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\right]}{\left[w_{NE}\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} + w_E\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right]^2}$$

$$= \frac{-(M + w_E c_E)\left[\sigma\left(\frac{w_E}{w_{NE}}\right)\left(\frac{\alpha_{NE}}{w_{NE}}\right)\left(\frac{\alpha_E}{w_E}\right)^{\sigma} + \left(\frac{\alpha_{NE}}{w_{NE}}\right)^{2\sigma}\right] + \left[(1-\sigma)w_E c_{NE}\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right]}{\left[w_{NE}\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} + w_E\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right]^2}$$

$$= \frac{\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\left\{-(M + w_E c_E)\left[\sigma\frac{w_E}{w_{NE}}\left(\frac{\alpha_E}{w_E}\right)^{\sigma} + \left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\right] + \left[(1-\sigma)w_E c_{NE}\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right]\right\}}{\left[w_{NE}\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} + w_E\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right]^2}$$

Hence, the own-price elasticity of two goods are

$$\begin{cases} \dfrac{\partial x_{NE}}{\partial w_{NE}} = \dfrac{\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\left\{-(M + w_E c_E)\left[\sigma\frac{w_E}{w_{NE}}\left(\frac{\alpha_E}{w_E}\right)^{\sigma} + \left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\right] + \left[(1-\sigma)w_E c_{NE}\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right]\right\}}{\left[\sum_{i=\{NE,E\}} w_i\left(\frac{\alpha_i}{w_i}\right)^{\sigma}\right]^2} \\ \dfrac{\partial x_E}{\partial w_E} = \dfrac{\left(\frac{\alpha_E}{w_E}\right)^{\sigma}\left\{-(M + w_{NE} c_{NE})\left[\sigma\frac{w_{NE}}{w_E}\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma} + \left(\frac{\alpha_E}{w_E}\right)^{\sigma}\right] + \left[(1-\sigma)w_{NE} c_E\left(\frac{\alpha_{NE}}{w_{NE}}\right)^{\sigma}\right]\right\}}{\left[\sum_{i=\{NE,E\}} w_i\left(\frac{\alpha_i}{w_i}\right)^{\sigma}\right]^2} \end{cases}$$

A3.4 Sensitivity test in the long term

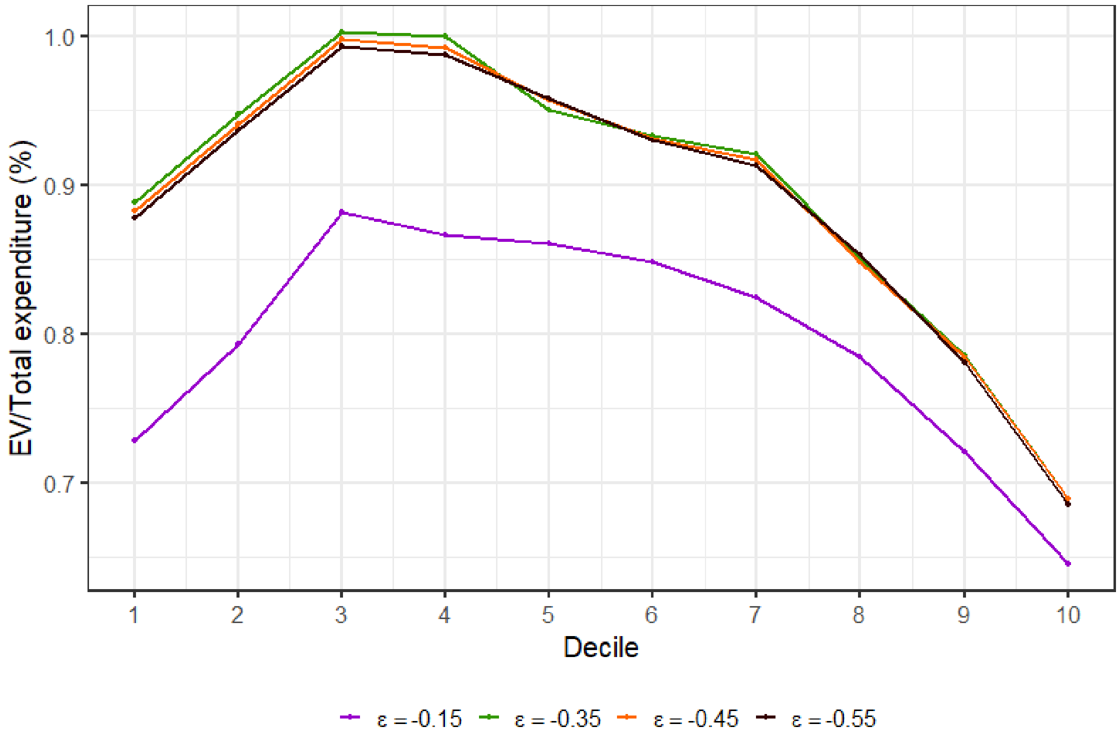

Figure A3.1 **Sensitivity test for welfare impacts by decile in the long term**

Chapter 4: The economics of coal-fired power generation

4.1 Introduction

At present, coal remains the primary energy source for power generation worldwide. The share of coal-based generation accounted for 36 per cent of the overall electricity supply in 2019, which was slightly lower than that of 2018 (IEA, 2020b). However, coal-fired power involves many environmental concerns, such as greenhouse gas (GHG) emissions and air pollution (sulphur oxides, nitrogen oxides, dust, mercury, etc.) (Pettinau et al., 2017). In particular, coal-fired power plants contributed 30 per cent to global CO_2 emissions in 2018 (IEA, 2019b) and 76 per cent to CO_2 emissions from power generation in Europe (Pettinau et al., 2017).

The role of coal-based generation in a national power development strategy varies across countries and regions. For example, in the US and Europe, electricity generated from coal is retiring, mainly due to the substantial expansion of renewable energy and coal-to-gas switching. Germany, which is the largest coal consumer in Europe, is preparing for the transition to a coal-free power sector by 2038 (IEA, 2019d). In Asia, while some countries such as China and India are moving away from coal-based electricity generation, Southeast Asian economies have still relied on coal power to address increasing electricity demand (Clark et al., 2020). For example, the governments of Indonesia and Vietnam have emphasised the vital role of coal-fired power in their power generation mix and subsidized coal-based generation at the expense of renewable energies (Clark et al., 2020).

Coal-fired generation will not be entirely replaced by other energy sources in some countries for a couple of reasons. First, renewable energy has several geographical and technological limits. For example, hydropower and biomass are affected by the limited amount of appropriate land and locations available (De Castro et al., 2011, 2013). Wind and solar power are intermittent renewable energy sources, which requires energy storage and leads to increasing costs (Moriarty and Honnery, 2012). Second, although nuclear power is promising for many countries (Kaygusuz and Sarı, 2003, Adamantiades and Kessides, 2009, OECD and NEA, 2012, Karakosta et al., 2013, Hil Baky et al., 2017, Xie et al., 2017), electricity generation from this energy has reduced in South Korea and Belgium because of new maintenance regulations and safety-related concerns (IEA, 2019c). By comparison, coal-fired power is advantageous in terms of its reliability, safety and reasonable price (Nguyen, 2017d). Therefore, coal is likely to dominate the power generation mix in some developing countries, including Vietnam.

Over the last two decades, electricity consumption in Vietnam has increased dramatically with a rapid rise in electricity intensity. The growth rate of electricity consumption has consistently doubled that of GDP. In the National Power Development Plan (PDP) VII in 2011 and its revised version in 2016, Vietnam's government assigned coal as the primary source of power generation by 2030 to meet increasing demand and address the risk of electricity shortages (Government Office, 2011a, 2016b). In particular, the country aims to have 55,300 megawatts (MW) of coal generation capacity by 2030, equivalent to 42.6 per cent of total power capacity, which requires more coal-fired power plants to be built in the future (Government Office, 2016b).

Given the environmental problems associated with coal-based generation, the consistently dominant position of this electricity source in the country's power development plan is highly questionable. The government has implemented the Environmental Protection Tax (EPT) law[8] since 2012 to encourage consumers to reduce their energy consumption and protect the environment (National Assembly, 2010c). The trivial rates levied on coal compared with those on gasoline and oil, however, bring into question the effectiveness and underlying objectives of the taxes. In particular, the economic objective is likely to dominate the environmental objective in power sector development. Also, little is known about the economic feasibility of these new coal-fired power plants. While investors are concerned about profitability of their investments, the government needs an accurate economic assessment as a foundation in crafting effective management and support policies.

This chapter asserts the economic feasibility of coal-fired power projects by conducting a cost-benefit analysis (CBA). I compile data from the draft of the revised PDP VII (Institute of Energy, 2015), government documents, and published research. Three conventional methods in cost-benefit analysis, namely net present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR), are employed to evaluate the economics of an investment project in two scenarios: (i) with current energy taxes and (ii) with a carbon tax. In addition, this study calculates the levelized cost of electricity (LCOE) in these two cases and compare them to see

[8] Vietnam has currently implemented EPT on some kinds of fuels (e.g., coal and gasoline) and pollutants (e.g., plastic bags) deemed harmful for the environment. The EPT on energy goods are referred to as energy taxes.

how the average price changes after controlling for an environmental factor. Parameters' values used in the CBA are varied to examine the sensitivity of baseline results.

This chapter contributes to the literature on energy issues in two important ways. First, this study presents a case study from a developing country whose power generation relies heavily on fossil fuels. The consideration of an environmental factor in a cost-benefit analysis of coal-fired power plants is critically important since this gives indicative information for policymakers and investors regarding whether to invest in a coal-fired power plant when a carbon tax is implemented as a replacement for the currently low environmental tax. Results from the CBA demonstrate how stricter tax rates affect investment decisions in the power sector. Second, to the best of my knowledge, the relative importance of parameters in the sensitivity analysis has not been discussed previously for Vietnam. This study, which reveals the impacts of an environmental factor and parameters, is the first comprehensive economic assessment of coal-based power generation in Vietnam. The findings are used to provide policy implications for the government to effectively manage and control the electricity market.

The rest of the chapter is structured as follows. Section 4.2 reviews the literature on cost-benefit analysis and LCOE of energy projects. Section 4.3 presents background information on the electricity market in Vietnam. Methodology, including procedure to perform a CBA and three evaluation methods, and data for the paper are described in Section 4.4. Section 4.5 reports main results and sensitivity analysis. A discussion of the findings and some policy implications are presented in Section 4.6, while Section 4.7 concludes the chapter.

4.2 Literature review

Cost-benefit analysis plays a significant role in the decision-making process of energy projects. It is a popular method used in many reports and studies to evaluate whether or not it is worth proceeding with an investment. Governments, courts, and various interest groups, including environmental groups, have widely applied the CBA technique in the appraisal process of a project (Boardman et al., 2011). In economic analysis, costs and benefits related to an investment project are usually converted to a common metric (i.e., the present value) in which the interest rate applied reflects the time value of money. In general, the economic feasibility of an energy project depends on many parameters, thus, policymakers should take these factors into consideration in their power development plans.

Several studies have applied cost-benefit assessment to compare different mutually exclusive scenarios of a country's power sector evolution (Islas et al., 2003, Diakoulaki and Karangelis, 2007). Each scenario is selected to represent specific features of each nation's strategies to develop the power sector. For example, Islas et al. (2003) conduct a CBA for the power sector in Mexico in three scenarios in the period 1996-2025. The authors calculate BCR for each case and conclude that which scenario has a favourable BCR subject to technical and economic parameters, including fossil fuel prices, discount rates, and capital cost evolution. The results show that given current technical and economic conditions, the official scenario with natural gas being the most used fuel has a more economically favourable BCR than the transition scenario where renewables gradually replace gas-based generation. However, the economic viability of the latter scenario increases rapidly when technological change is considered. In addition, Diakoulaki and Karangelis (2007) apply a multicriteria decision analysis and CBA to resolve conflicts between economic, technical, and environmental criteria of four scenarios for the development of the electricity system in Greece. They report that the scenario with the highest use of renewable energy sources is the best option for this country's power sector development.

As a conventional and widely used power generation source, the economics of coal-fired power plants have received much attention of researchers (Madlener and Stoverink, 2012, Venkataraman et al., 2013, Kumar et al., 2015, Zhao et al., 2017). For example, Kumar et al. (2015) adopt the NPV method to examine effects of numerous factors on costs of a coal-fired power plant in India. Plant life, interest rate, and the escalation rate are found to be more sensitive to plant economics than other parameters. In addition, Zhao et al. (2017) evaluate the economics of coal power investment in China using a grading scale (from 'totally unacceptable' to 'super return') based on IRR. They reveal that IRR for coal power generation in most provinces is lower than the average rate of return or even negative, which requires a radical revision of the power development plan.

A couple of studies focus on different technologies that reduce the negative impacts of coal-based power generation on human health and the environment (Tola and Pettinau, 2014, Lee et al., 2019, Wu et al., 2019). Tola and Pettinau (2014) conduct a CBA to compare different coal combustion and gasification technologies. The conventional ultra-supercritical (USC) technology is more profitable than the integrated gasification combined cycle (IGCC) (with an NPV of EUR 190 million versus EUR 54 million). The NPV of all carbon capture and storage

(CCS), i.e., CO_2-free, configurations is negative, though CO_2-free IGCC has a higher NPV than CO_2-free USC. Their results suggest that an investment in the CCS system cannot be economically justified without a satisfactory incentive. In addition, Wu et al. (2019) apply the NPV method to assess air pollution control technologies of coal-fired power plants in China and find the current mainstream scheme leads to long-term economic efficiency loss. By switching to alternative schemes, the NPV is found to be substantial at the national level, and provinces that have coal-fired power plants with larger installed capacities and higher populations obtain higher positive NPV.

With the emergence of other cleaner energy sources, especially renewables, a comparison between economics of different types of power plant is necessary to provide a more comprehensive assessment. Li et al. (2014) use the NPV method and conclude that a reinforced concrete solar chimney power plant can have huge advantages compared with a conventional coal-fired power plant. Their sensitivity analysis using the elasticity method shows that total NPV responds considerably to changes in the solar electricity price and inflation rate, while it is insensitive to variations in the carbon credits price, income tax rate, and interest rate of loans. Locatelli and Mancini (2010) take the carbon tax and electrical energy price into account to compare economic performance between a nuclear, a coal-fired, and a gas-fired power plant. A coal-fired power plant gives the highest NPV if there is no carbon tax, otherwise an investment in a nuclear reactor has the highest outcome.

The implementation of climate policies in general and carbon taxes in particular, therefore, can affect investment decisions and create stranded assets, i.e., investments that do not generate an economic return before their expected economic lifespan as a result of changes in the market and regulations (IEA, 2013). The increases in carbon price over time force power plants to operate at a capacity factor under its optimal point to lower operating costs. If the capacity factor is too low for the plants to cover their fixed and variable operating costs, they have to be prematurely retired (Malik et al., 2020). The unprofitability and premature closure of power plants by high carbon prices are likely to happen in many regions and countries such as the EU, US, China, and India (Kefford et al., 2018, Saygin et al., 2019, Yuan et al., 2019, Malik et al., 2020, Mo et al., 2021, Zhang et al., 2021). For example, Mo et al. (2021) build a real options-based model to measure the risk of newly-constructed coal-fired power projects becoming stranded assets due to carbon pricing in China. Their results show that the expected lifetime of these plants can be reduced by ten years if the carbon price rises to CNY 100/tCO_2, which may cause a loss for investors. Hence, carbon pricing should be taken into consideration in the appraisal process to avoid poor investment decisions.

In addition to CBA, many studies calculate LCOE to examine cost effectiveness of various sources of power generation (Schlaich et al., 2005, Locatelli and Mancini, 2010, De Jong et al., 2015, Leal et al., 2017, Fan et al., 2019), different technologies of coal-based generation (Pettinau et al., 2017, Park et al., 2018), and coal-fired plants in different provinces (Zhao et al., 2017). Their results on LCOE are diverse depending on techno-economic parameters included in their calculations, but the LCOE of a coal-fired power plant is generally higher than that of renewable energies such as solar and wind power (Schlaich et al., 2005, De Jong et al., 2015, Leal et al., 2017), and especially higher than the LCOE of nuclear power if a carbon tax is introduced (Locatelli and Mancini, 2010). Regarding technologies of coal generation, Pettinau et al. (2017) report that while USC without CCS technology has the lowest LCOE, IGCC becomes more competitive than USC in CO2-free systems.

In the context of Vietnam, studies on the economics of coal-based generation have been limited. Truong et al. (2016) use the NPV method and compare the economic feasibility between a combined heat and power plant and a coal-fired power plant in Ninh Binh. Cogeneration is found to have higher economic benefits (higher NPV of USD 1,508,000) and positive externalities by reducing emissions (e.g., improvement in public health). In addition, Ha-Duong and Nguyen-Trinh (2017) discuss the potential of CCS technology in coal generation in Vietnam, in which LCOE is one indicator for consideration. They show that the LCOE of the high CCS scenario is only slightly higher than the baseline if there is an annual reduction of 1.8 per cent in CCS technology costs for construction as well as operating and maintenance (O&M). However, as far as I know, there are no studies examining the impacts of carbon taxation and techno-economic parameters on the economics of coal-fired power plants in Vietnam.

4.3 Background

This section provides background to the power sector in Vietnam with a focus on coal power. First, I present general information regarding the current situation of the electricity market, including electricity consumption and electricity efficiency, in comparison with several Asian countries. Second, I describe the importance of coal power in the national power development strategy and prominent regulations implemented by the authorities to regulate the electricity market.

4.3.1 Vietnam's electricity sector

Electricity has become a vital energy type for Vietnam over the last several decades. The share of electricity in the total final energy consumption increased from 22.2 per cent in 2010 to 29.6 per cent in 2015 (Ministry of Industry and Trade, 2017). Starting at only 6.5 Terawatt-hours (TWh) in 1990, electricity consumption gradually increased to 22.9 TWh in 2000 and then jumped fourfold to 89.9 TWh after one decade. Electricity consumption in recent years has increased dramatically, especially in 2015 at just under 20 per cent. The rapid growth was attributed to the continuous and increased electricity use in industrial and residential sectors. Industry consumption accounted for 58.6 per cent of the total consumption in 2017, while the figures for the residential, commercial, and public service, and agriculture sectors were 33.4 per cent, 5.5 per cent, and 2.5 per cent respectively.[9]

Electricity consumption per capita in Vietnam has increased substantially since 1990 (Figure 4.1). The average annual growth rate over the 1990-2014 period was recorded at 12 per cent, from 95.3 kilowatt-hours (kWh)/person to 1,423.7 kWh/person in 2014. At the end of the period, electricity consumption per capita in Vietnam was equal to 30.6 per cent, 36.3 per cent, and 45.5 per cent of the figures in Malaysia, Thailand, and the world average, while it was higher than in Indonesia, the Philippines, Myanmar, and Cambodia. The significant increase was a result of improvements in electrification rate and income. In particular, the share of population using electricity in Vietnam was impressively high with 99.4 per cent of communes having access to the national electricity grid in 2012 (ADB, 2015a).

[9] Author's calculation from IEA (2020a)

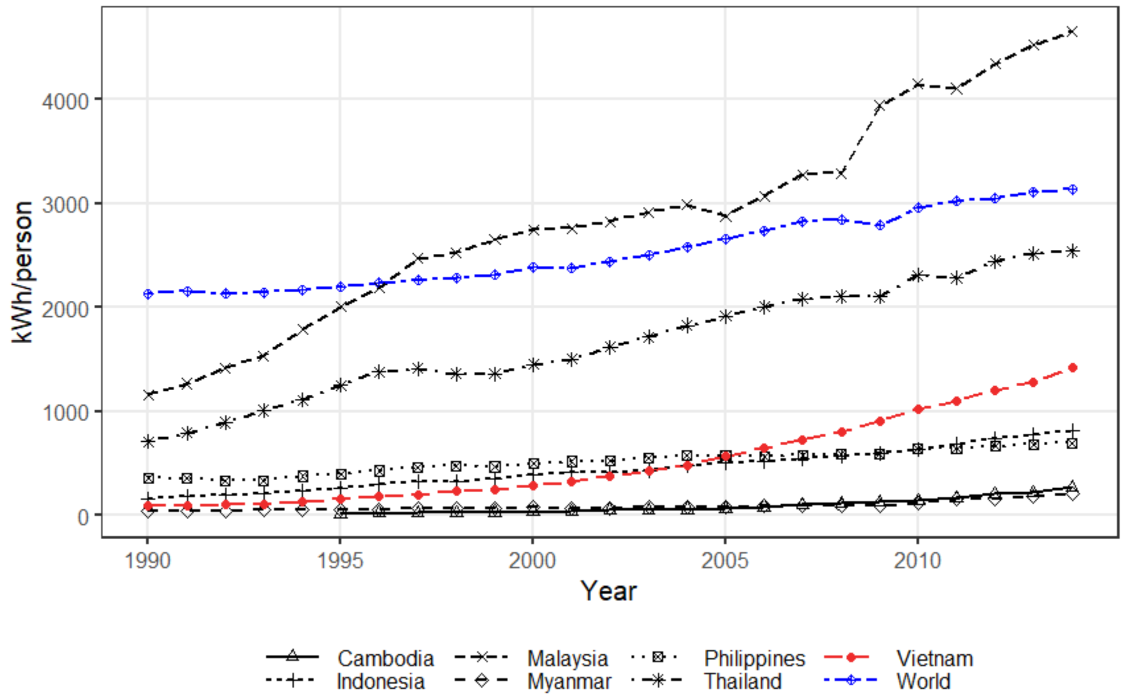

Figure 4.1 **Electricity consumption per capita, 1990-2014 (kWh)**

Source: World Bank (2020)

Electricity intensity, which is estimated as the ratio of electricity use to GDP (kWh/USD 2016 constant PPP), in Vietnam is considerably high when compared with some Asian countries (Figure 4.2). Starting from 0.06 kWh/USD in 1990, Vietnam's electricity intensity increased to just under 0.3 kWh/USD in 2017. One reason for this rapid increase is the substantial and consistent growth of electricity consumption, which doubled that of GDP. In particular, the industry has the fastest-growing electricity intensity, which is much greater than that in the agriculture and the service sectors (Hien, 2019).

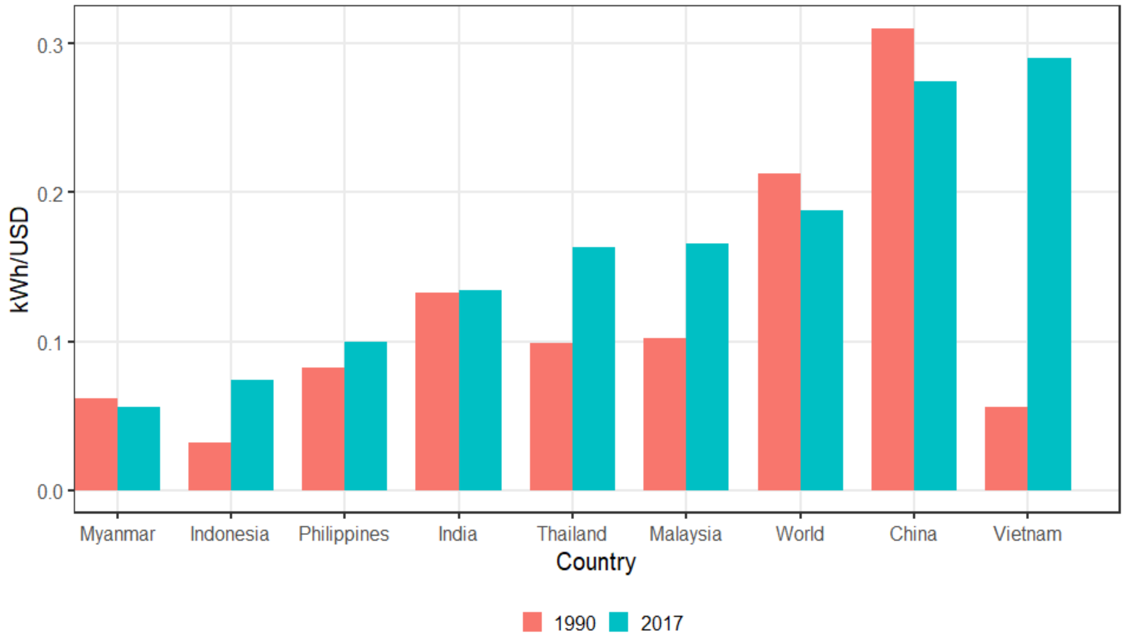

Figure 4.2 **Electricity intensity, 2010-2017 (kWh/constant USD PPP 2016)**

Source: Author's calculation from IEA (2020a) and World Bank (2020).

4.3.2 Role of coal-fired power generation

Electricity is a secondary energy type that can be generated from primary energy sources (e.g., coal, oil, natural gas, biofuels, hydro, and wind). In 2017, approximately 18.1 per cent of the total primary energy supply was transformed into secondary energies, of which 14.1 per cent was for electricity. In particular, shares of coal, oil, and natural gas used for power generation were 45.6 per cent, 1.4 per cent, and 86.6 per cent, respectively.[10] Figure 4.3 describes the fuel mix of electricity generation in Vietnam during 1990-2017 period. The proportion of wind energy in 2017 was very modest, at about 0.2 per cent (323 gigawatt-hours (GWh)), while hydropower was noticeable at roughly 44.8 per cent (88,982 GWh). Over time, the importance of hydropower has gradually reduced, which makes room for coal-fired power to rise.

[10] Author's calculations from IEA (2020a)

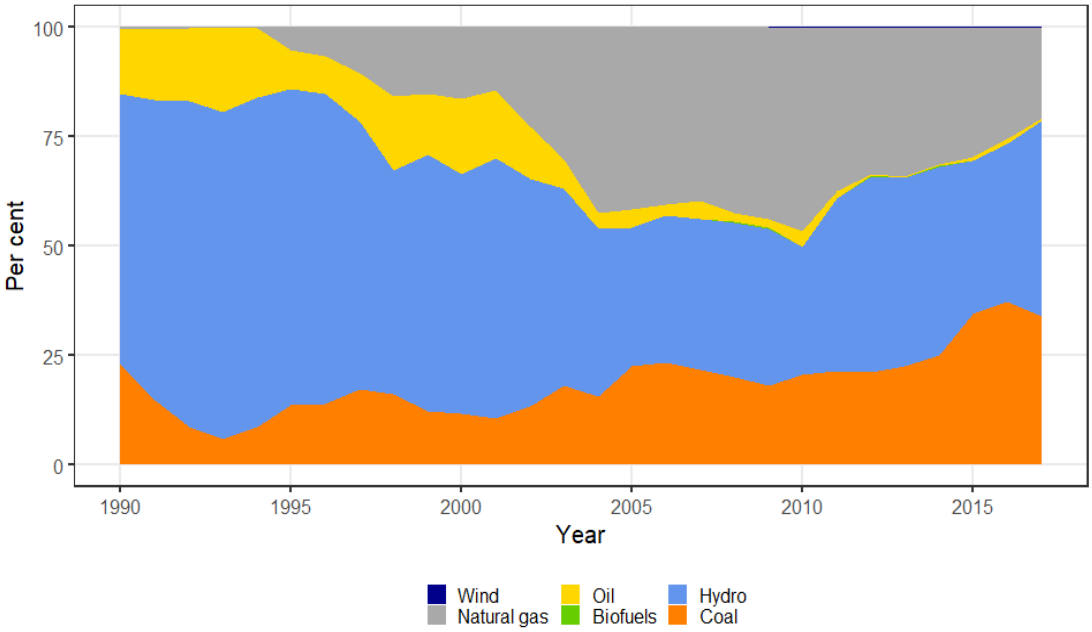

Figure 4.3 **Electricity generation by sources 1990-2017 (%)**

Source: IEA (2020a)

Coal is a conventional and main source of electricity generation. By 2017, the total installed electricity capacity of Vietnam was more than 46 gigawatts (GW), of which coal-fired power capacity was 17 GW, accounting for about 37 per cent. Out of 191.6 billion kWh of total electricity generated, 62.6 billion kWh (32.7 per cent) were from coal (Nguyen, 2020). The total installed capacity of plants using domestic coal is 14,971 MW, which requires 41-47 million tonnes of coal to generate 90-97 billion kWh annually. In addition, three new coal-fired power plants, namely Vinh Tan 1, Thai Binh 2, and An Khanh 2, can potentially consume 8.7-9.4 million tonnes per annum (Nguyen, 2019).

Increasing coal consumption produces a large quantity of GHG emissions. Most old plants in Vietnam use pulverised coal and circulating fluidised bed on anthracite and sub-bituminous coal to generate electricity (Lai and Nguyen, 2017). Coal is the largest emitter for most emissions (such as sulphur dioxide, nitrogen oxides, particulate matter with aerodynamic diameters ≤10 μm and diameters ≤2.5 μm, and organic carbon) with the contribution of around 65-99 per cent to the total emissions from thermal power plants. Emission factors are reported to be highest for coal-based compared with gas-based power generation (Lai and Nguyen, 2017). However, due to relatively low production cost, large capacity, and flexible construction site, coal is still a dominant energy source in Vietnam (Truong, 2017).

The significant role of coal-fired power in the national electricity market has been emphasised in many government documents. The PDP VII projects that electricity generation from coal-fired power plants will account for 46.8 per cent of total electricity output by 2020 and 56.4 per cent by 2030 (Government Office, 2011a). Next, the revised PDP VII removes 17 coal-fired power projects from the national power plan to fit to the economic development and orientation of the country in a new period (Government Office, 2016b). Nonetheless, coal-based generation is still expected to contribute the largest share to the total installed capacity and output by 2030 (43 per cent and 53 per cent, respectively). Additionally, due to changes in macroeconomic conditions, the government decided to stop nuclear power projects (National Assembly, 2016). Therefore, coal-fired power in Vietnam's electricity balance remains crucial and will not be easily replaced over the next several decades.

The expansion of the electricity market requires the government to promulgate regulations to control the electricity price. In particular, the Ministry of Industry and Trade (2014) regulates methods of determining electricity generation costs between electricity generating units (seller) and the Vietnam Electricity-EVN (buyer). Recently, the Ministry of Industry and Trade (2019) has promulgated a ceiling price for electricity generation of coal-fired power plants and hydroelectric plants in 2019. These documents are the basis for the EVN and electricity generating units to negotiate actual electricity prices compliant with current regulations.

4.4 Methodology and materials

This section presents the methods and materials for the paper. The first subsection summarises steps to perform a CBA of an energy project. I then demonstrate three widely used methods in CBA with a discussion of their main advantages and disadvantages. Lastly, I present parameters used in the CBA of a coal-fired power plant and their data sources.

4.4.1 Procedure to perform a CBA

CBA is an analytical instrument for assessing the welfare change from a project by estimating its benefits and costs expressed in a monetary unit. It also allows comparisons between different options and initiatives within the appraisal process (Transport and Infrastructure Council, 2018). The approach guides decision makers to choose among possible actions, e.g., the least-cost project. Hence, conducting a CBA of a new infrastructure project is necessary to provide a quantitative assessment since investments in energy infrastructure affect energy security and social welfare of a country.

This section summarises fundamental steps to conduct a CBA of an energy infrastructure project based on guidelines from European Commission (2015). The first step is to understand the context of the project implementation since sustainability and performance depend largely on various external factors. Context elements that can have impacts on energy projects include socio-economic-political trend (e.g., GDP growth, income disposal, demographic change, energy intensity); geographical factors (e.g., weather and climate conditions, types and quantity of energy sources); political, institutional, and regulatory factors (e.g., political factors affecting the energy market); existing service market conditions (e.g., structure of the market, tariff, and energy price system); and existing technical service conditions (e.g., volumes of energy production).

The next tasks are to identify objectives and details of energy projects. The role of a project is to address problems of the energy system, which can be the development of a new plant to meet increasing electricity demand, to reduce import dependency, or to diversify energy supply sources. The following step is project identification which shows the details of the proposed project. Two main focuses in project identification are energy supply and distribution as well as methods to improve energy efficiency.

Before a project is implemented, energy demand and supply are factors that need to be evaluated and projected. This step is especially essential for projects of electricity generation because of limited capacities to store excess electricity. Some main factors affecting energy demand are economic trend, demographic dynamics, weather and climatic conditions, tariff system, and energy efficiency developments. Additionally, researchers need to predict fuel mix generation. Energy supply is subject to fuel price dynamics, political decisions, incentives, environmental requirements, and market structure. The predictions of supply and demand should be estimated at different scenarios of environmental conditions and technological alternatives.

The main task of a CBA is to estimate social benefits and costs of an energy project. In economic costs, an investment cost is one of the most significant parts, which usually includes land acquisition, technological plant installations and equipment, and information technology.

For an electricity project, the investment cost can be presented as cost per capacity installed (e.g., USD/kilowatt (kW)), which allows for comparisons between similar projects. Additionally, the next costs that are taken into account are O&M costs. Depending on whether the costs vary with the amount of energy generation or not, they are classified into fixed and variable O&M costs. Fixed costs usually include cost for public concessions fees, labour costs, and periodic maintenance costs. Variable costs contain energy fuel costs, variable overheads, and utilities. Furthermore, the construction and operation of a plant lead to a change in GHG emissions (e.g., CO_2, methane, and nitrous oxide) and air pollutant. The externalities can be measured by using their shadow price and compared with the business-as-usual scenario.

Regarding economic benefits of new power projects, the most prominent and direct one is to increase and diversify energy supply to meet the growing energy demand. The willingness to pay for increased energy consumption is estimated to evaluate this benefit. The energy generated can vary between different levels of consumption, time, and types of users. It also contributes to the improvement of a country's energy security and reliability. Other potential benefits are the improvement of energy efficiency and variations in GHG emissions. After evaluating the benefits and costs related to the project, the last step in a CBA is to perform a sensitivity analysis to see how sensitive the results are in response to variations in one or more parameters, such as energy demand, costs, and estimated willingness to pay. This can provide important implications for investors and the government in the appraisal process.

4.4.2 Evaluation techniques in CBA

A few studies present various techniques to assess the economic desirability of investment projects. Remer and Nieto (1995a, 1995b) classify 25 methods into five types, which are net present value method, rate of return methods, ratio methods, pay-back methods, and accounting methods. The authors discuss advantages and disadvantages of each method and provide various examples to illustrate how the methods are applied in different scenarios. This chapter applies the first three methods to evaluate costs and benefits associated with a power project.

The first method, net present value criterion method, is widely used in many studies and reports. The NPV of a project is defined as the difference between the present value of the benefits, PV(B), and the present value of the costs, PV(C) (Boardman et al., 2011):

$$NPV = PV(B) - PV(C) \tag{4.1}$$

Typically, a project lasts for several years, which needs discounting to convert future values to present values. The total present value of the benefits is the sum of the present value of the benefits each year. If the benefits start from the first year of the project (year 0), the total present value of the benefits is calculated as follows:

$$PV(B) = \frac{B_1}{(1+r)^0} + \frac{B_2}{(1+r)^1} + \cdots + \frac{B_T}{(1+r)^T} = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} \tag{4.2}$$

where B_t is the benefits received in year *t* for *t=0,1,…,T* and *r* is the interest rate.

Similarly, if C_t is the costs incurred in year *t for t=0,1,…,T,* the total present value of the costs is

$$PV(C) = \frac{C_1}{(1+r)^0} + \frac{C_2}{(1+r)^1} + \cdots + \frac{C_T}{(1+r)^T} = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \tag{4.3}$$

A project is worthwhile if the result is positive; otherwise, it is rejected. The investor is indifferent if NPV is zero. If there are several mutually exclusive projects, the one with higher NPV will be generally chosen. Different projects should be compared using the same interest rate and over equal life spans (Remer and Nieto, 1995a).

In ratio methods, benefit-to-cost ratio (BCR) is a criterion for the desirability of a project. The benefits must outweigh the costs, which means that a conventional BCR greater than one is equivalent to a positive NPV. Since one project can last for many years, both project's costs and benefits should be discounted to present value. The ratio represents the present benefits obtained per unit of present cost. The formula for a conventional BCR is presented as

$$\frac{B}{C} = \frac{PV(B)}{PV(C)} \tag{4.4}$$

In addition to NPV and BCR, the internal rate of return (IRR) method can be used for project evaluation. IRR is a measure that calculates the interest rate at which the NPV equals zero. This method is also known as the rate of return method, interest rate of return, or break-even rate of return. To decide whether the project is acceptable or not, one can compare the rate of return method with the market interest rate. The decision-makers choose the project with the

IRR greater than the interest rate. If the IRR equals the interest rate, the investor is indifferent to the project. Besides, it is essential to pay attention to the initial cost. If mutually exclusive projects are favourable and have the same initial investments, the one with higher IRR is preferred.

$$PV(B) - PV(C) = \sum_{t=0}^{T} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+i)^t} = 0 \tag{4.5}$$

where i is the discount rate that makes NPV equal 0.

Nonetheless, the direct application of these methods may lead to inconsistent results in some cases. For instance, if mutually exclusive projects incur different initial costs, the project with higher NPV may have lower BCR and lower IRR. It requires an adequate application of a different technique, which is commonly known as an incremental analysis (Remer and Nieto, 1995b, OECD, 2006, Pasqual et al., 2013). The project with the lowest initial investment (e.g., project A) is evaluated first. Then the analysis evaluates the one with the second-lowest initial costs (e.g., project B) and calculates whether the difference project, i.e., project (B-A), is beneficial. This method requires examining the rate of return of the incremental investment to provide a consistent conclusion. The latter project should be selected when this project and the difference one yield higher rates of return compared with the discount rate.

The three methods have some advantages and disadvantages. NPV has been regarded as the principal criteria as it provides a better understanding of profitability. However, NPV depends heavily on the interest rate, so a conclusion may change when an interest rate varies. For example, an increase in the interest rate may lower NPV since investors have to pay costs upfront and gain benefits later. Similarly, BCR also varies with the interest rate as it appears in both the formula's numerator and denominator. The IRR, by contrast, produces the same results even though the interest rate changes. Using this method does not guarantee the existence or the uniqueness of a root. It is essential to determine the correct break-even rate for a project evaluation when there are several values of IRR. Besides, IRR method only provides a relative percentage measure that does not take into account the scale of investment (Remer and Nieto, 1995a).

Moreover, LCOE is one important indicator to evaluate the cost effectiveness of an electricity project. This is a transparent tool to measure the cost of electricity generation. Investors or plant owners can compare unit costs of different technologies, hence, rank their competitiveness (IEA et al., 2015, Fan et al., 2019). LCOE is referred to as a representative of an electricity price that would balance cash flows over the lifetime of an energy project. In other words, it is the average electricity price that makes the NPV to equal zero or to obtain a break-even point. LCOE is determined by the point at which the PV of the revenue is equal to the PV of the costs. If costs of a project start from year t=0, the equation for LCOE, adapted from Branker et al. (2011), is as follows:

$$\sum_{t=0}^{T}\left(\frac{LCOE_t}{(1+r)^t}\times E_t\right)=\sum_{t=0}^{T}\frac{C_t}{(1+r)^t} \tag{4.6}$$

where E_t is the electricity volume generated each year measured in kWh/year. It is generally determined by multiplying the average number of operating hours per year with the capacity of a coal-fired plant.

By assuming LCOE is the average electricity price, which is constant per year, the equation (4.6) can be rearranged as

$$LCOE=\frac{\sum_{t=0}^{T}C_t/(1+r)^t}{\sum_{t=0}^{T}E_t/(1+r)^t} \tag{4.7}$$

4.4.3 Data source

This study compiles parameters from different sources to conduct the CBA. The values and sources of all parameters are presented in Table 4.1. Data on initial investment, fuel price, fixed and variable O&M costs, and lifespan is taken from the Institute of Energy (2015). Information on coal consumption is collected from EVN (2019), which provides more updated information about fuel efficiency in electricity generation than the revised PDP VII. With superior technology, the energy efficiency of coal-fired power plants improves, leading to a decline in emission factor or CO_2 emission per kWh generated (Bui, 2017). CO_2 price, provided in Luckow et al. (2015), is assumed to increase gradually over its lifespan. Electricity price is collected from the Ministry of Industry and Trade (2019) but has some adjustments to accommodate other related fees.

Table 4.1 **Parameters in CBA of a coal-fired power plant**

Parameters	Value	Source
Life span (years)	30	Institute of Energy (2015)
Operation time (hours/year)	6,500	Ministry of Industry and Trade (2014)
Investment (USD/kW)	1,850	Institute of Energy (2015)
Coal consumption (g/kWh)	425	EVN (2019)
Coal price (USD/ton)	80 including the energy taxes, 78.72 otherwise	Institute of Energy (2015)
Emission factor (tCO_2/MWh)	0.95, 0.9, and 0.8 for 2020, 2025 and 2030 onwards	Bui (2017)
CO_2 price (USD/tCO_2)	18, 20, 25, 35, and 45 for 2020, 2025, 2030, 2040 and 2050	Luckow et al. (2015)
Fixed O&M (USD/kW/year)	45	Institute of Energy (2015)
Share of major repair cost (%)	62.5	Ministry of Industry and Trade (2014)
Share of labour cost (%)	37.5	Ministry of Industry and Trade (2014)
Variable O&M (USD/MWh)	3	Institute of Energy (2015)
Electricity price (USD/kWh)	0.08	Ministry of Industry and Trade (2019)
Inflation rate (%/year)	3.2	Assumptions from GSO (2018, 2019, 2020)
Interest rate (%/year)	8	Nguyen et al. (2019)

In addition, the interest rate and inflation rate are crucial parameters in all cash flows over the lifespan of a plant. The loan interest rate for energy projects is used to discount future values of costs and benefits to present values. This study chooses an interest rate of 8 per cent (Nguyen et al., 2019). Lastly, the inflation rate is determined based on the average of recent figures from General Statistics Office (GSO). The inflation rate of Vietnam in recent years has been kept at a low level and even lower than the target set by the National Assembly. It has been well controlled at 3.53 per cent, 3.54 per cent, and 2.79 per cent in 2017, 2018, and 2019, respectively (GSO, 2018, 2019, 2020). It is assumed that the inflation rate is kept at 3.2 per cent over the plant operation. All monetary values used in the study are converted into 2019 USD at the exchange rate VND 23,350/USD (Ministry of Industry and Trade, 2019).

4.5 Results

This section reports cost-benefit assessment of coal-fired power generation. I first summary projections of electricity demand and power generation mix in Vietnam. Second, a detailed CBA of a coal-fired power plant is presented by calculating all costs and benefits related to its construction and operation. Third, I conduct a sensitivity analysis for the parameters used in the CBA to show their effects on the economic feasibility of a power project.

4.5.1 The future of electricity in Vietnam

The electricity market in Vietnam will enlarge significantly over the next several decades. This study presents five scenarios, each of which has different assumptions about electricity intensity over the 2020-2050 period: (i) electricity intensity increases by 2 per cent/year until 2020 and 1 per cent/year until 2030 and keeps the same until 2050; (ii) electricity intensity growth equals half of the average intensity growth over 2008-2017; (iii) electricity intensity growth equals one third of the average intensity growth over 2008-2017; (iv) there is no change in electricity intensity; and (v) electricity intensity reduces by 1 per cent/year.[11] The method for projecting Vietnam's electricity demand in the next 30 years is given in Appendix A4.1.

Figure 4.4 presents the electricity demand forecasts in five scenarios over 2020-2050 period. Scenario 2 has the highest values for electricity demand projection, while the lowest values can be found in Scenario 5. In Scenario 1, for example, the demand is expected to rise by roughly fivefold from 241.0 billion kWh in 2020 to 523.7 billion kWh in 2030 and 1,146.5 billion kWh in 2050. Although the volume continues to increase, there will be a reduction in the growth rate of electricity demand. The average growth rates during periods 2021-2030, 2031-2040, and 2041-2050 are projected to be 8.1 per cent, 5 per cent, and 3 per cent on average. Given slower population growth, electricity demand per capita tends to increase. From 2,286.5 kWh in 2020, each person is expected to consume 10,423.5 kWh in the next 30 years.

[11] In the electricity demand projection, growth rates of GDP per capita over 2020-2050 are taken from the Institute of Energy (2015) and EREA and DEA (2019). Population growth forecasts are collected from GSO (2016). These two variables are assumed to be the same in all scenarios.

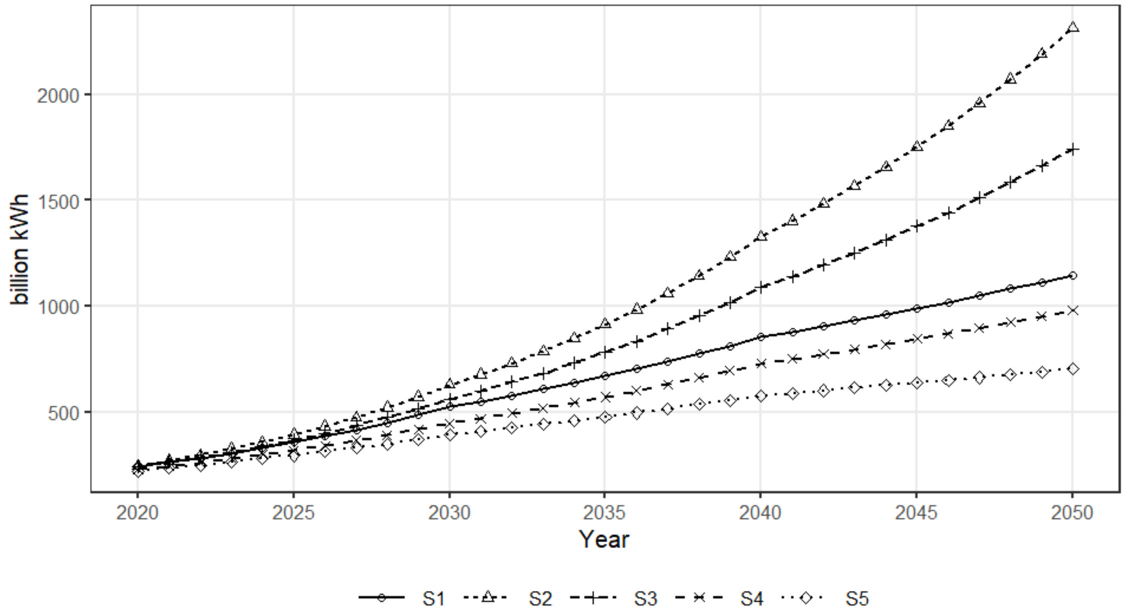

Figure 4.4 **Electricity demand projections in different scenarios, 2020 – 2050**

To meet increasing demand, electricity generation in Vietnam needs to grow accordingly. As mentioned in the revised PDP VII, electricity capacity in 2030 is projected to rise threefold compared with that in 2017, reaching 132,254 MW. Electricity output will also increase significantly in the next 30 years, from 265 billion kWh in 2020 to 572 billion kWh in 2030 and 1,051 billion kWh in 2050 (Government Office, 2015, 2016b, EREA and DEA, 2019).

The power generation mix in Vietnam will undergo several changes in the future. In terms of capacity, coal-fired power will surpass hydro and become the largest contributor at 43 per cent in 2030. Renewable energy sources are expected to play a more important role with a share of 21 per cent, which doubles the figure in 2020. Regarding electricity output, coal-fired power will reduce its share gradually from 2025 onwards, although it is still one of the main power supply sources. It will account for 55 per cent by 2025 but then will decline to 53.2 per cent by 2030 (Government Office, 2016b). By contrast, electricity generation from renewable resources will increase from 10.7 to 33 per cent over the 2030-2050 period. There is a reduction in the contribution of hydropower from 25.2 per cent in 2020 to 10 per cent in 2050 (EREA and DEA, 2019) due to the possibility of being exploited in the next several years. The share of natural gas is likely to increase in 2030 to replace nuclear power which was abandoned in 2016 (National Assembly, 2016, Nguyen, 2017b). Imported electricity will be kept at a low level to guarantee the energy security of the country.

Given the growth in electricity demand, Vietnam needs an appropriate plan to increase power capacity and volume from 2020. If the structure of power demand is the same as power supply, coal power will account for 53.2 per cent of future electricity consumption by 2030 or equivalent to 279 billion kWh if Scenario 1 happens.[12] However, according to the IEA (2020a), only 67.5 billion kWh was generated from coal in 2017. The difference between the two periods, i.e., 211.07 billion kWh, requires the construction of more coal-fired plants in the future.

Recently constructed coal-fired power plants usually have a large capacity. For example, Vung Ang 1 and Vinh Tan 4, which began operation in 2015 and 2019, have two turbines with a total capacity of 1,200 MW. A representative coal-fired power plant is assumed to have a capacity of 1,200 MW and operate 6,500 hours per year (i.e., equivalent to the capacity factor of 75 per cent). If each plant can generate 7,800,000 MWh of electricity, 27 new plants are required in 2030 to meet the power demand from coal in Scenario 1. The volume of electricity demand stated in the Government Office (2016b) is slightly higher by about 9 per cent, so the number of new plants needed by 2030 in Scenario 1 is comparable.

4.5.2 Cost-benefit analysis of a coal-fired power plant

This study estimates costs and benefits of a new coal-fired power plant over its lifespan of 30 years. Economic costs related to the establishment of a plant in Vietnam consist of initial investment, fuel consumption (i.e., coal), fixed and variable O&M, environmental cost (i.e., current energy taxes or CO_2 taxes). The initial investment includes construction and installation, equipment, project management and construction investment consultancy, resettlement compensation, interest during construction, and value-added tax. The construction and equipment include the investment for the fuel port. The average investment for construction in coal-fired power projects accounts for 25-30 per cent, and equipment accounts for about 50-60 per cent of the total investment (Institute of Energy, 2015). The initial investment of a power plant with an average capacity of 1,200 MW (2 × 600 MW) is USD 1,850/kW. It takes about four years for a coal-fired power plant to be built and go into operation.[13] The total investment is distributed at 35 per cent, 35 per cent, 20 per cent, and 10

[12] Results from Scenario 1 are used to calculate the number of coal-fired power plants needed to meet future electricity demand. However, I conduct CBA for a single plant, so different outcomes in other scenarios do not affect the analysis.

[13] For example, Vinh Tan 4 and Thai Binh were built from 2014 and started to operate in 2019.

per cent over the construction period (ACIL Allen, 2014), so the current values of investment (Inv_t) for the first four years are USD 777 million, USD 777 million, 444 million, and USD 222 million. The construction is assumed to start in 2020 (base year t=0), thus, the present value of the initial investment is

$$PV_{Inv} = \sum_{t=0}^{3} \frac{Inv_t}{(1+r)^t} = \text{USD } 2{,}053.3 \text{ million}$$

where r is the interest rate.

Coal consumption per year, which is included in variable costs, is a critical contribution to the costs of an energy project. Recently, coal-fired power plants in Vietnam have applied advanced technologies such as USC to reduce emissions and improve efficiency of the power generation. This study assumes that after 2020, newly constructed power plants will use USC technology, which consumes coal at the rate of 0.425 kg/kWh, i.e., each ton of coal can generate 2,352.9 kWh. Hence, the plant needs 3.3 million tons of coal per year to generate 7,800 million kWh. At the coal price of USD 80/ton, the coal consumption is USD 265.2 million/year. However, I assume that due to inflation rate i=3.2 per cent the costs of coal consumption increase annually. Since the plant will start to operate in 2024 after four years of construction, the total PV of the coal consumption costs is as follows

$$PV_{Coal1} = \sum_{t=4}^{33} \frac{Coal_4(1+i)^{t-4}}{(1+r)^t} = \text{USD } 3{,}264.6 \text{ million}$$

Environmental costs related to the electricity generation process should also be considered since the emissions from the power plants affect human health and contribute to climate change. The energy taxes are levied on final goods, so the PV_{Coal1} has already included the taxes. Under the current EPT scheme, coal used for power plants incurs a tax rate of VND 30,000/tonne from 2019 (National Assembly Standing Committee 2018), equivalent to about USD 1.3/tonne. According to the Institute of Energy (2015), the coal price is USD 80 in the base year. Hence, the tax accounts for about 1.6 per cent of the total price per tonne.[14] The study assumes that in the future, this proportion remains the same, i.e., the energy taxes increase according to the rise in coal price. This chapter then analyses another scenario when

[14] With the old tax rate, the EPT accounts for nearly 1.4 per cent of the total coal price (Nguyen, 2017c).

a carbon tax is introduced as a replacement for the current energy taxes. In the second case, coal price excludes the energy taxes, thus $PV_{Coal2} < PV_{Coal1}$:

$$PV_{Coal2} = \sum_{t=4}^{33} \frac{Coal_4(1+i)^{t-4}}{(1+r)^t} = \text{USD } 3{,}212.3 \text{ million}$$

The carbon tax of coal consumption is computed separately as follows. Power plants are expected to release fewer emissions by using more advanced technology. Emission factor of CO_2 is 0.95 tCO_2/MWh, 0.90 tCO_2/MWh and 0.80 tCO_2/MWh for the year 2020, 2025, and 2030 onwards. The CO_2 prices are expected to increase gradually, from USD 18/tCO_2 in 2020 to USD 20/tCO_2, USD 25/tCO_2 USD 35/tCO_2 and USD 45/tCO_2 in 2025, 2030, 2040 and 2050. The current values of annual environmental costs (*Emiss*) are $Emiss_4$= USD 133.4 million in 2024, $Emiss_5$=USD 140.4 million in 2025-2029, $Emiss_{10}$=USD 156.0 million in 2030-2039, $Emiss_{20}$=USD 218.4 million in 2040-2049, and $Emiss_{30}$=USD 280.8 million in 2050-2053.[15] Its corresponding PV over 30 years of plant lifetime is calculated as

$$PV_{Emiss} = \frac{Emiss_4}{(1+r)^4} + \sum_{t=5}^{9} \frac{Emiss_5}{(1+r)^t} + \sum_{t=10}^{19} \frac{Emiss_{10}}{(1+r)^t} + \sum_{t=20}^{29} \frac{Emiss_{20}}{(1+r)^t} + \sum_{t=30}^{33} \frac{Emiss_{30}}{(1+r)^t}$$
$$= \text{USD } 1{,}473.1 \text{ million}$$

Other financial costs and economic benefits are also calculated in a CBA. Annual fixed O&M costs do not vary with the amount of electricity generated and are assumed to be USD 45/kW/year. I divide fixed O&M costs into major repair costs and other expenses (Rep_t) and labour costs (Lab_t) according to the ratio regulated in Ministry of Industry and Trade (2014). The major repair costs contribute 62.5 per cent, while the labour costs account for 37.5 per cent of the total fixed O&M costs per year. However, in economic analyses, the labour costs should be re-estimated by using a shadow wage to reflect the social opportunity cost of labour. A conversion factor is applied to translate the observed market wages into shadow wages (European Commission, 2015). The study uses a coefficient of 0.80 for the analysis (Del Bo et al., 2011). The PV of fixed costs are

$$PV_{Rep} = \sum_{t=4}^{33} \frac{Rep_4(1+i)^{t-4}}{(1+r)^t} = \text{USD } 415.5 \text{ million}$$

[15] The subscripts in these variables indicate the year that benefits or costs are calculated.

$$PV_{Lab} = \sum_{t=4}^{33} \frac{Lab_4(1+i)^{t-4}}{(1+r)^t} = \text{USD 199.4 million}$$

Variable O&M costs, on the other hand, depend on the volume of electricity generation. The costs are expected to be USD 3/MWh. The costs also start from year 2024 and are discounted to the present values as

$$PV_{VOM} = \sum_{t=4}^{33} \frac{VOM_4(1+i)^{t-4}}{(1+r)^t} = \text{USD 288.1 million}$$

Hence, the PV of the total costs is

$$PV_C = \sum_{t=0}^{33} \frac{C_t}{(1+r)^t} = PV_{Inv} + PV_{Coal} + PV_{Emiss} + PV_{Rep} + PV_{Lab} + PV_{VOM}$$

PV_{C1}=USD 6,220.8 million in the first case when there is no carbon tax and PV_{C2}=USD 7,641.7 million when the carbon tax is implemented as a substitution for the current EPT.

Finally, one benefit of a newly constructed coal-fired power plant is to increase electricity generation to meet energy demand. The volume of electricity each year (E_t) is 7,800 million kWh. The total power generated over the project lifetime is discounted for calculation of LCOE as

$$PV_E = \sum_{t=4}^{33} \frac{E_t}{(1+r)^t} = 69{,}707.0 \text{ million kWh}$$

The price of coal-fired power is generally higher than hydroelectricity but lower than electricity from liquefied natural gas and renewable energies such as wind power or solar power (Vietnam Energy, 2017). The electricity's ceiling price of a 1,200 MW coal-fired power plant is VND 1,677.02/kWh (excluding VAT, seaport dues and shared infrastructure), equivalent to USD 0.0718/kWh. Given prices mentioned in Truong et al. (2016) and Vietnam Energy (2017), I assume that the electricity price used for the analysis is USD 0.08/kWh, including all other fees. The revenue (B) in the first year of operation will be USD 624 million. If the current value of the revenue grows 3.2 per cent annually due to inflation, the total PV of the benefit is

$$PV_B = \sum_{t=4}^{33} \frac{B_4(1+i)^{t-4}}{(1+r)^t} = \text{USD 7,681.4 million}$$

Table 4.2 summarises the main results of the two scenarios. In the first scenario when there is no carbon tax, the NPV of the project is USD 1,460.5 million, suggesting that the project should be accepted and worth implementing. The results of BCR and IRR confirm the conclusion from the NPV method. If a carbon tax is implemented, all the figures reduce significantly. The NPV is positive at USD 39.6 million and benefit-cost ratio (BCR) is just over 1. The IRR declines compared with the first scenario and is only slightly greater than the interest rate. Additionally, this study calculates the LCOE to evaluate the cost effectiveness of the project. The LCOEs of the two cases are USD 0.09/kWh and USD 0.11/kWh, a difference of USD 0.02/kWh.

Table 4.2 **Cost-benefit analysis of a coal-fired power plant**

	S1: No carbon tax	**S2: Carbon tax**
PV of costs (USD million)	6,220.8	7,641.7
PV of benefits (USD million)	7,681.4	7,681.4
NPV (USD million)	1,460.5	39.6
BCR	1.23	1.01
IRR (%)	12.59	8.14
LCOE (USD/kWh)	0.09	0.11

This study also conducts a CBA in the two scenarios for a gas-fired power plant, a cleaner but more expensive energy source.[16] This indeed provides additional evidence for the impact of environmental taxes on the economic feasibility of an energy project. Detail of data source and results of the calculation are given in Appendix A4.2. The results show that the introduction of a carbon tax reduces NPV, BCR, and IRR of the project significantly, and investors can even suffer loss. Also, electricity price from gas-based generation is quite high, which increases the average electricity price of the country.

[16] Results should not be used for comparison between coal-based and gas-based generation since they operate in different lifespan (30 years versus 25 years).

4.5.3 Sensitivity analysis

Given the possibility of economic fluctuations, it is essential to conduct a sensitivity analysis to see how the economics of coal-fired power generation change as a result of variations in the parameters. There are three scenarios (low, base, and high) for 11 parameters[17] (operation time, inflation rate, discount rate, initial investment, coal consumption, coal price, major repair costs, labour costs, variable O&M costs, electricity price, and plant lifetime) to calculate NPV, BCR, and LCOE. Values for the low and high scenarios are given in Table 4.3.

Table 4.3 **Scenarios for sensitivity analysis**

	Low	**High**
Plant lifetime (years)	20	40
Operation time (hours/year)	5,038	7,500
Initial investment (USD/kW)	1,422	2,144
Coal consumption (g/kWh)	325	474
Coal price (USD/ton)	55	120
Major repair costs (USD/kW/year)	20	40
Labour costs (USD/kW/year)[18]	8	16
Variable O&M (USD/MWh)	2	5
Electricity price (USD/kWh)	0.065	0.091
Inflation rate (%/year)	0.6	4
Discount rate (%/year)	6	10

Plant lifetime and operation hours are the first parameters to be considered. A coal-fired power plant can operate for 20 years (National Coal Council, 2004) or up to 40 years (Lazard, 2018, Fan et al., 2019). This chapter uses 20 years and 40 years of plant lifetime in the sensitivity analysis. According to the Institute of Energy (2015), the average operation hours per year of a coal-fired power plant is only 5,038 hours. In the high scenario, a plant can operate up to 7,500 hours per year when the country faces an electricity shortage (Nguyen, 2017d).

[17] I exclude plant capacity in my sensitivity tests since it affects all costs and benefits at the same proportional rate, thus the BCR and LCOE remain the same.
[18] Labour costs are adjusted using conversion rate of 0.8.

It is important to take in to account the generation technology since it affects initial investment and energy efficiency of an energy project. In detail, investments per kWh of some thermal power technologies are USD 1,422/kWh (sub-C), USD 1,689/kWh (SC), USD 1,867/kWh (USC), and USD 2,144/kWh (IGCC) (Nguyen, 2020). Hence, the possible range for initial investment is from USD 1,422/kWh to USD 2,144/kWh. Coal-fired power plants are likely to apply more advanced technology in the future, which requires less coal consumption per kWh. The Institute of Energy (2015) mentions that after 2020, the calorific value of coal can be 5300 kcal/kg and the heat rate is 1720 kcal/kWh, i.e., one plant needs 325 gram of coal to generate 1 kWh of electricity, and in 2019 imported coal required per kWh is 474 gram (Ministry of Industry and Trade, 2019). This study uses these numbers in low and high scenarios for the sensitivity analysis.

Moreover, variations of other parameters are taken from different published papers. Coal price may fluctuate depending on prices in the international market and exploitation's situation in Vietnam. After the economic crisis, coal price surged to USD 100-120/tonne in 2010-2012, then reduced dramatically to USD 55-60/tonne (Nguyen, 2017d). Thus, coal price is assumed to fluctuate between USD 55/ton and USD 120/ton. The values of fixed and variable O&M costs vary depending on types of coal and level of technology. I assume that the major repair costs can take values from USD 20/kW/year to USD 40/kW/year, and the figures for labour costs are USD 10/kW/year and USD 20/kW/year with adjustments to reflect social opportunity cost. Variable costs fluctuate between USD 2/MWh and USD 5/MWh (Lazard, 2018). Furthermore, the high and low scenarios for electricity price of a new coal-fired power plant are USD 0.065/kWh and USD 0.091/kWh (EIA, 2020b).

Variations of the inflation rate and discount rate are considered for the sensitivity analysis. The inflation rate in Vietnam recently has been well controlled by the government. It was kept lower than 4 per cent, and the consumer price index in Vietnam in 2015 was 0.6 per cent. These figures are used in the sensitivity analysis. Finally, I assume that the interest rate can vary between 6 per cent/year and 10 per cent/year.

Figure 4.5 presents histograms of NPV and BCR with the blue dashed lines representing mean values. The average NPV is USD -355.6 million, suggesting the projects are not worthwhile proceeding. The maximum and minimum values of NPV are USD 9,354.4 million and USD -5,939.3 million, respectively. The average BCR is about 0.95, while the maximum and minimum BCR are 2.04 and 0.43. The case with the highest value of NPV also has the highest BCR, which involves low values of cost-related parameters (initial investment, coal consumption, coal price, major repair costs, labour costs, and variable O&M costs) and high values of benefit-related parameters (facility lifetime, operation hours, and electricity price).

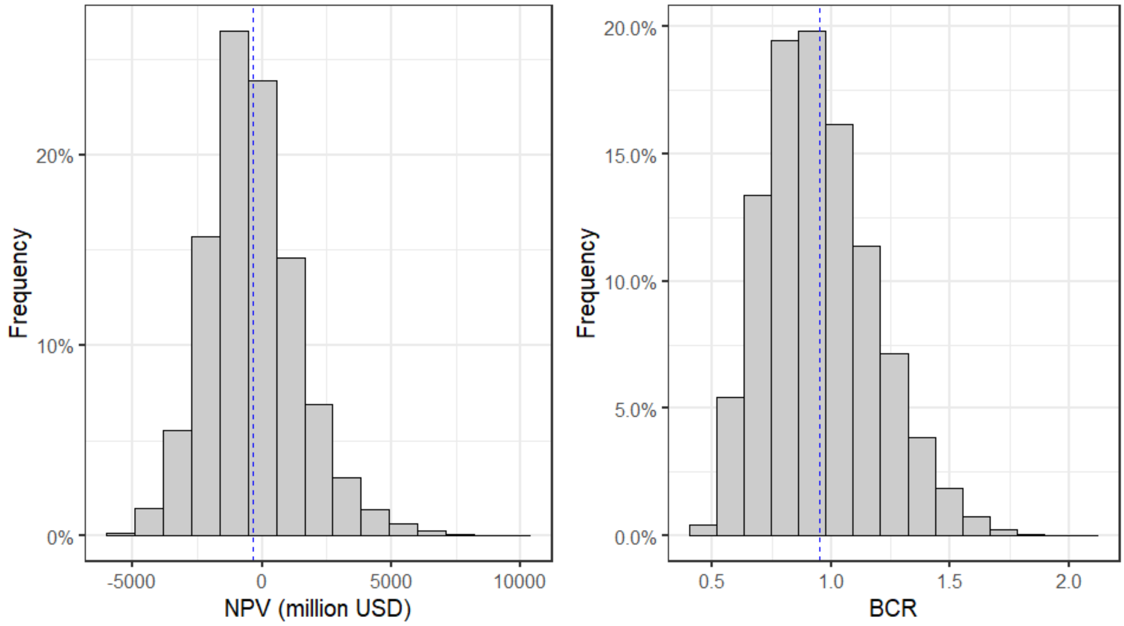

Figure 4.5 **Histogram for NPV and BCR**

Figure 4.6 presents a tornado diagram for BCR and LCOE. A tornado diagram shows how the results change when one parameter varies and other parameters remain constant. Coal price and electricity price have the highest impacts on the BCR of a coal-fired power plant, followed by the inflation rate and coal consumption per kWh. Costs-related parameters such as coal price, coal consumption per kWh, initial investment, major repair costs, labour costs, and variable O&M costs affect the BCR negatively, i.e., the higher these variables are, the lower BCR compared with the base case. For instance, if the coal price is USD 120/tonne, the BCR would be approximately 0.82, or the investor suffers a loss. Variable O&M and fixed O&M costs seem not to have significant impacts on the BCR. Similarly, the coal price is the main factor affecting average electricity price, LCOE. However, the initial investment seems to play a more substantial role in determining LCOE (Figure 4.7).

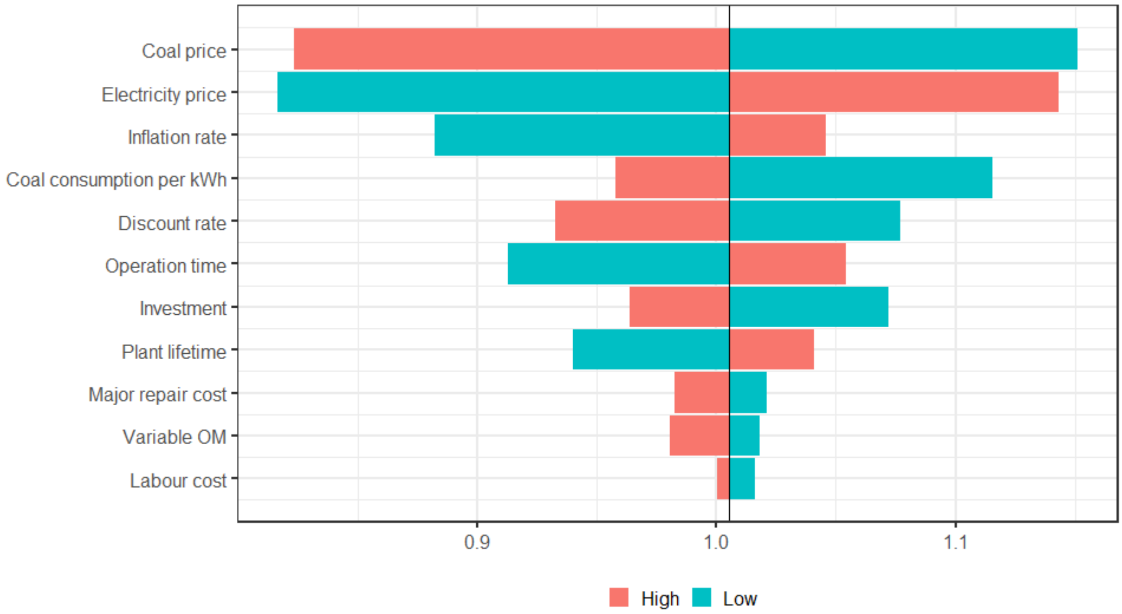

Figure 4.6 **Tornado graph for BCR**

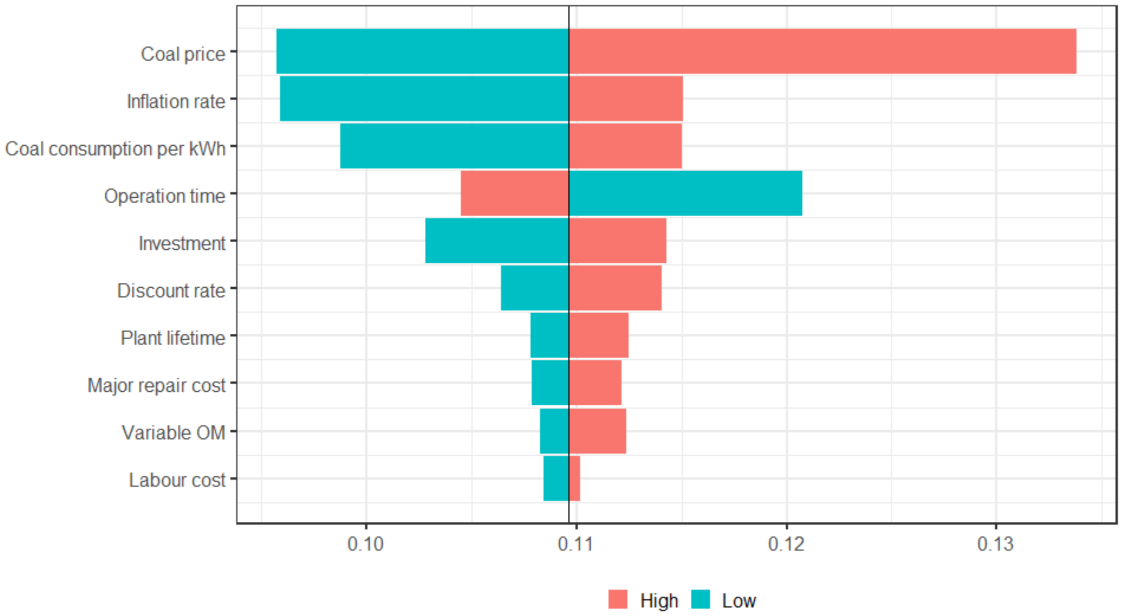

Figure 4.7 **Tornado graph for LCOE**

4.6 Discussion

In the next decades, coal will be one of the main sources of power supply in Vietnam (Government Office, 2016a), although coal-fired power generation releases GHG emissions and fly ash into the environment. The share of the remaining power sources will increase gradually, but they will not be able to fully replace coal power soon, particularly in a developing country with limited capital like Vietnam. The country has currently relied on coal power to ensure electricity security in the context of increasing electricity demand.

However, there is a significant change in net benefit when a carbon tax is implemented. Given the low EPT levels, the construction of new coal-fired power plants is acceptable from an economic perspective. However, it is indeed misguided to state that the projects are worth proceeding with without taking a carbon tax into account. The BCR reduces significantly to 1 when a carbon tax is introduced, suggesting that the investment project is not as profitable as expected. Similar result can be found in Locatelli and Mancini (2010). The comparison of the CBA in two scenarios provide indicative information for the government and investors about the fundamental role of environmental taxes on the economics of power plants in the long-term.

Furthermore, the average cost of electricity generation also increases with the introduction of a carbon tax. LCOE in this study is relatively consistent with those calculated by Nguyen (2017d), who also indicates the importance of environmental fees to LCOE. The author finds that if the government imposes a carbon tax on coal at the same rate as it does on gasoline (USD 36.4/tCO_2), at the coal price of USD 60/ton, then there is an increase by USD 0.031/kWh in LCOE of coal power. His calculation is slightly higher than my result.

The difference in the two scenarios of CBA suggests that the environmental factor has not received adequate attention in the power development plan of Vietnam. Currently, the government has chosen economic development at the cost of environmental quality. It also indicates the importance of reasonable tax rates. The current tax rate on coal is low compared with its detrimental effects on the environment and human health. The law on EPT imposes a larger penalty on ‘cleaner’ energies such as gasoline and oil while ignoring the main contributor to air pollution (i.e., coal). The situation raises questions about the effectiveness of the energy taxes and requires an amendment to ensure the environmental objectives to be achieved.

The findings provide policy implications for decision-makers in Vietnam and other developing countries that have a similar power development strategy. In the future, many countries are seeking to apply carbon taxes on polluting activities and establish an emission trading scheme between countries. Vietnam should not be an exception to the trend. In this case, the energy tax rates should be well determined to reflect the carbon content of the goods and activities. The inclusion of external costs such as health and environmental damages in the total costs of electricity generation may reorient the country's power development strategy from coal-fired power generation to other cleaner supply sources such as natural gas and renewable energies (Nguyen, 2008).

The sensitivity analysis suggests that investment in coal-fired power projects does not bring many net benefits as expected. Most scenarios provide a negative NPV or BCR of less than unity when the environmental factor is taken into account. Compared with other energy sources and technological schemes, coal-fired power plants seem to have a lower NPV (Li et al., 2014, Truong et al., 2016, Wu et al., 2019). Although the vital role of coal in electricity generation is undeniable, it is highly questionable if this energy source will still be leading in the national power development master plan in the next decades.

Moreover, the tornado graph in the sensitivity analysis shows the relative importance of parameters in the CBA, suggesting factors that the government can intervene in to control and manage the electricity market. For instance, if there is an electricity shortage, the government may require coal-fired power plants to increase capacity factor since many plants operate below their maximum capacity (7,500 hours per year). The relative importance of these parameters is comparable to findings reported in some previous studies (Kaldellis and Gavras, 2000, Kaldellis et al., 2005, Li et al., 2014, Fan et al., 2019). Not surprisingly, coal price leads to a substantial variation in BCR and LCOE as coal is the primary input for coal-fired power plants. The coal price is also the most significant factor affecting the LCOE of coal-fired power plants in China (Fan et al., 2019).

Finally, technology is also a crucial factor in power generation, especially in the coal-fired power industry. On the one hand, an application of more advanced technology reduces coal consumption per kWh, thus lowering costs and increasing the net benefit of the investment project. On the other hand, coal-based generation will still dominate the power generation mix in Vietnam in the next several decades. In this context, the integration of these plants with CCS systems may be a potential solution for reducing emissions and alleviating other harmful effects on the environment (Ha-Duong and Nguyen-Trinh, 2017, Pettinau et al., 2017). This will contribute to the rational and sustainable use of this valuable ‘black gold’ resource.

4.7 Conclusion

This chapter has conducted an economic assessment for coal-fired power generation in Vietnam. Data from the revised PDP VII, government documents, and published research were collected to perform the analysis. I used three methods, NPV, BCR, and IRR, to assess the economic feasibility of power plants. The results report a positive NPV in the case of the current energy taxes, indicating that the project is acceptable. Conclusions from the BCR and the IRR are in line with the NPV method. However, when carbon taxation is implemented, all figures reduce significantly, making investors indifferent to the project or suffer loss. Calculations from the LCOE also show an increase in the latter case as the levied carbon tax rate is higher than the current energy tax level.

The sensitivity analysis shows the relative importance of 11 parameters in determining the economic viability of a power project. The highest NPV and BCR are achieved with low values of cost-related parameters and high values of benefit-related ones. In particular, coal price and electricity price have the most substantial impacts on BCR, followed by the inflation rate and energy efficiency. Variable O&M and fixed O&M costs do not affect the BCR significantly. The sensitivity analysis of the LCOE also reports coal price as the main factor affecting the average price of electricity. This implies the uncertainty of an investment project if there are any changes in one of these parameters. The relative importance of the parameters provides a reference for the government in managing the electricity market, particularly coal-fired power.

To what extent coal should be the main source of electricity supply in Vietnam is highly questionable. Currently, there is a trade-off between economic objectives and environmental objectives. However, improving environmental quality is also a vital target for Vietnam, in which projects should take environmental factors into their investment decisions. If coal-fired power projects are not economically desirable when the carbon tax is applied, the government may consider other forms of power generation to address increasing electricity demand or improve technology to alleviate harmful effects of coal-based generation on the environment.

Appendix

A4.1 Methodology for electricity demand forecasting

In order to forecast electricity demand, I apply a simple methodology based on the idea of IPAT identity. The IPAT identity was first introduced in Ehrlich and Holdren (1971), in which they examine the impact of population growth on the environment. The IPAT identity decomposes total impact into three factors – population, affluent and technology as follows:

$$I = P * A * T$$

where

I is the total impact
P is population
A is affluence per capita
T is technology

If *I* is measured in volume of energy use, *P* is number of persons, *A* is GDP per capita, and *T* is ratio of energy use to GDP (i.e., energy intensity), the IPAT identity can be rewritten as

$$Energy\ use = Populaion * \frac{GDP}{Population} * \frac{Energy\ use}{GDP}$$

Since IPAT is an accounting identity, *I* must always be equal to the multiplicative product of *P*, *A*, and *T*. According to the identity, energy demand is driven by three factors rather than a single indicator. The first component, population, represents for social development. A country with higher population growth is expected to have a larger increase in energy demand. Another driver is affluent or level of economic development, which is shown by GDP per capita. This variable has a similar effect as the total population, i.e., countries with a higher growth rate of income per capita also have more significant energy demand increase. The last component, technology indicates the level of energy efficiency. It shows how much energy needed to produce one unit of GDP. Hence, energy consumption will be lower if energy efficiency rises.

The idea of IPAT identity can be applied in energy or electricity demand projections (Raghuvanshi et al., 2006, Morales-Acevedo, 2014). If electricity demand is forecasted, electricity intensity is applied instead of energy intensity. Electricity is less than energy intensity since it is a portion of energy intensity. The formula for electricity demand can be written as follows:

$$Electricity\ use = Population \times \frac{GDP}{Population} \times \frac{Electricity\ use}{GDP} = P \times GDPC \times I_E$$

where $GDPC$ is gross domestic product per capita and I_E is electricity intensity. If the evolutions of these variables are predicted, the electricity demand can be estimated.

A4.2 Cost-benefit analysis of a gas-fired power plant

Table A4.1 **Parameters in CBA of a gas-fired power plant**

Parameters	Value	Source
Life span (years)	25	Institute of Energy (2015)
Operation time (hours/year)	6000	Ministry of Industry and Trade (2014)
Investment (USD/kW)	1050	Institute of Energy (2015)
Heat rate (Btu/kWh)	7732	EIA (2020a)
Gas price (USD/MBtu)	10.39	Luong Bang (2020)
Emission factor compared with coal-fired power generation (%)	40	Ozone Layer Protection and Low Carbon Economy Development Center (2020)
Fixed O&M (USD/kW/year)	7.5	Institute of Energy (2015)
Share of major repair cost (%)	69.7	Ministry of Industry and Trade (2014)
Share of labour cost (%)	30.3	Ministry of Industry and Trade (2014)
Variable O&M (USD/MWh)	1.5	Institute of Energy (2015)
Electricity price (USD/kWh)	0.1	Luong Bang (2020)

Note: This table presents parameters that are used for a typical gas-fired power plant. Other parameters are assumed to be the same as in the baseline scenario and can be taken from Table 4.1.

Table A4.2 **Cost-benefit analysis of a gas-fired power plant**

	S1: No carbon tax	S2: Carbon tax
PV of costs (USD million)	11,314.8	12,015.2
PV of benefits (USD million)	11,789.6	11,789.6
NPV (USD million)	474.7	-225.6
BCR	1.04	0.98
IRR (%)	10.8	6.6
LCOE (USD/kWh)	0.013	0.14

Chapter 5: The impact of international trade on energy efficiency

5.1 Introduction

International trade plays a critical role in the world economy. Since the financial crisis in 2008, global trade has continued to expand gradually with a higher average growth rate compared with that of gross domestic product (GDP). In 2017, merchandise trade volume was recorded to have increased by 4.7 per cent, while the export value of goods rose by 11 per cent (WTO, 2018). Generally, trade has impacted various aspects of the economy such as economic growth, productivity, and employment (see, e.g., Yamada (1998), Yanikkaya (2003), Aydiner-Avsar and Onaran (2010), Sakyi et al. (2015), Feenstra et al. (2019), and for a literature review Singh (2010)).

With the emerging awareness of climate change, academics and policymakers have focussed their attention on the trade-environment nexus, particularly the impact of export on energy efficiency. This is still a highly debated topic in the literature because the notion of whether international trade is beneficial for the environment is an ambiguous one. The gains-from-trade hypothesis suggests a positive effect of international trade. Trade promotes managerial and technological innovation. Multinational companies tend to bring clean technologies from developed countries into developing countries (Frankel and Rose, 2005). Firms that participate in international markets may have more access to energy-saving technologies (Roy and Yasar, 2015). However, there are race-to-the-bottom and pollution-haven hypotheses for the opposite effect of international trade on the environment. Open-to-trade countries may relax environmental regulatory standards due to fear of losing international competitiveness. Also, developing countries may adopt loose environmental regulations to attract multinational companies and export products that require pollution (Frankel and Rose, 2005). Hence, exporting firms that benefit from higher demands for their products, especially from intermediate or low-end markets, may have fewer incentives for green innovations.

The debate is also unsettled in terms of empirical analysis. Using macro-level data, while Antweiler et al. (2001) report a pro-environment effect of trade liberalisation, the impact varies across sectors and countries (Managi et al., 2009, Zheng et al., 2011). The nexus is also worth estimating at the firm-level data to understand firms' heterogeneity across their export status.

The influence on the environment of international trade is diverse. It can be positive (Albornoz et al., 2009, Cui et al., 2016), negative (Kaiser and Schulze, 2003), negligible (Dardati and Saygili, 2012), and mixed (Cole et al., 2008, Batrakova and Davies, 2012, Roy and Yasar, 2015, Cui and Qian, 2017), depending on countries, time, and econometric techniques.

Estimating the causal effect of international trade on environmental performance is not straightforward because there are possibly two-way relationships. Previous studies find that exporting encourages energy efficiency through improved management practice (Bloom et al., 2010, Bloom and Van Reenen, 2010). By contrast, efficient firms may self-select into becoming exporters (Melitz, 2003), and more productive firms have higher environmental efficiency (Kreickemeier and Richter, 2014). For this reason, estimates using the ordinary least squares (OLS) method are biased and inconsistent. To control for the self-selection biases and inconsistencies, several approaches have been applied in the literature. Examples include instrumental variables (IV) (Managi et al., 2009, Girma and Hanley, 2015, Roy and Yasar, 2015), propensity score matching (Cui and Qian, 2017), and propensity score matching with difference-in-differences (Batrakova and Davies, 2012).

This chapter examines the impact of participation in international supply chains, i.e., exporting goods or services, on Vietnamese firms' energy efficiency. Energy intensity is used as a proxy of firms' energy efficiency where energy intensity is measured as the ratio of energy cost to total variable costs. The higher energy intensity is, the lower energy efficiency a firm has. I apply an endogenous switching regression (ESR) model to overcome drawbacks of the previous methods, which are the assumption of systematic indifference across export status and requirement of panel data. The following hypotheses will be tested: (i) that the decision of firms to (or not to) export is not endogenously correlated to their energy intensity and (ii) firms that decide to (or decide not to) export face indifferent impacts on energy intensity when compared with the other group. Two rounds of the small and medium enterprise (SME) surveys in the manufacturing sector in 2011 and 2013 are used to construct a cross-sectional data. I calculate average treatment effects for exporting and non-exporting firms, i.e., the impact of exporting on energy intensity level and check the robustness of the results.

This study makes a twofold contribution to the literature. To the best of my knowledge, it supplies the first empirical evidence on the impact of exporting on energy efficiency in Vietnam. For this reason, these findings provide important policy implications in the context that Vietnam has a growing position in global trade, but still, it has a higher energy intensity than those of some ASEAN countries (World Bank, 2020). Furthermore, the study confirms the endogeneity of firms' energy efficiency and their participation in international supply chains. The ESR models can estimate separately the effect of exporting on the energy performance of exporting and non-exporting firms (if they were to export). Thus, the findings highlight a structural difference between the two groups of firms.

The remainder of the study proceeds as follows. Section 5.2 reviews literature on the impacts of the environment on exporting and vice versa. Section 5.3 summarises background information on energy performance and main programs to promote energy efficiency of Vietnamese enterprises. The conceptual framework, including theoretical model and empirical specification for the estimation, is introduced in Section 5.4. Section 5.5 presents data sources and descriptive statistics of sampled firms. Empirical results and robustness checks are shown in Section 5.6. Section 5.7 discusses key findings and provides some policy implications. Section 5.8 concludes.

5.2 Literature review

In this section, I review previous studies on the trade-environment nexus. The literature can be broadly categorized into two groups. The first group focuses on the influence of environmental performance on international trade, and the second concerns the effect of exporting on environmental performance. Overall, previous studies report mixed and inconclusive results with both aggregate- and micro-level datasets.

5.2.1 The impact of environmental performance on exports

The impact of environmental performance on exports can be investigated in the so-called pollution-haven hypothesis. This hypothesis argues that stringent environmental regulations in developed countries shift pollution-intensive sectors to less-regulated economies. Some empirical studies do not support the pollution-haven hypothesis (Tobey, 1990, Jaffe et al., 1995, Jänicke et al., 1997, Xu, 1999). For example, Xu (1999) analyses data from 34 countries over the period 1965-1995 and reports that stringent environmental standards were implemented in most developed countries in the two decades covering 1970s and 1980s, but their export performance of environmentally sensitive goods remained more or less similar over the 1960s-

1990s periods. In addition, Jaffe et al. (1995) conclude that pollution abatement costs only account for a small component in total production costs and are uncorrelated to trade flows.

By contrast, other studies find a significant effect of environmental regulations on trade flows (Robison, 2001, Ederington and Minier, 2003, Ederington et al., 2005, Levinson and Taylor, 2008). For example, Ederington and Minier (2003) argue that treating the level of environmental regulation as being exogenous leads to a trivial correlation between environmental regulation and trade patterns in previous studies. Indeed, the authors model the level of environmental regulation as an endogenous variable and demonstrate a significantly larger impact on trade flows compared with those reported previously in the literature. In addition to endogeneity, Levinson and Taylor (2008) claim that unobserved heterogeneity of countries or industries in cross-sectional data also influences the correlation between the two variables. They use data on regulations and trade with Canada and Mexico over the period 1977-1986 and reveal that in the US, industries with increased abatement costs tend to have the largest rise in net imports.

In addition, several studies apply other measures of environmental quality to investigate its impact on export. Findings are also diverse. Sadorsky (2012), Shahbaz et al. (2013), and Shahbaz et al. (2014) use country-level data and report a positive bidirectional relationship between the two variables in South American countries, China, and a group of 91 countries. By contrast, Lean and Smyth (2010) find no evidence of a Granger causality between electricity consumption and exports. Studies at the firm level also report mixed results. For example, Galdeano-Gómez (2010) uses panel data from 73 firms over the 1994-2005 period and show a positive impact of firms' environmental performance on their export. Montalbano and Nenci (2019) use firm-level data from Latin American countries to show that energy efficiency positively affects export status for large firms and several specific sectors. The authors define energy efficiency as the inverse of energy intensity, in which energy intensity is calculated in three alternative ways: (i) the ratio of annual energy costs to total annual sales, (ii) the ratio of annual energy costs to annual value added, and (iii) the ratio of annual energy costs to total cost of the variable inputs.

5.2.2 The impact of exports on environmental performance

The second group of studies focuses on whether or not there is a causal impact of exporting on environmental performance. There are no conclusive theories on this question. On the one hand, the gains-from-trade hypothesis supports the positive effect of international trade on environmental performance for two reasons. First, international trade can encourage managerial and technological innovation, such as energy-saving technologies, which is correlated with environmental performance. Second, multinational companies are likely to bring clean and more advanced production techniques from developed countries to developing ones (Frankel and Rose, 2005). On the other hand, international trade can harm environmental performance. The so-called race-to-the-bottom hypothesis argues that open-to-trade countries may relax environmental regulatory standards due to fear of losing international competitiveness. Also, the pollution-haven hypothesis suggests that developing countries may adopt loose environmental standards to attract multinational companies and export pollution-intensive goods (Frankel and Rose, 2005).

Some studies attempt to examine the impact of international trade on environmental performance, and results vary across countries (Antweiler et al., 2001, Cole and Elliott, 2003, Frankel and Rose, 2005, Managi et al., 2009). For instance, Managi et al. (2009) provide a comprehensive study for both OECD and non-OECD countries on the impact of trade openness on three types of emissions. They reveal that trade openness reduces air pollutions of OECD countries, while it has a detrimental effect on only one pollutant in non-OECD countries. The result is dependent on the signs and sizes of trade-induced scale-technique effect and trade-induced composition effect.

The impact of exports on environmental performance also differs across economic sectors within one country (Zheng et al., 2011, Zhao and Lin, 2020). For example, Zheng et al. (2011) use data from 20 industrial sub-sectors in China over the period 1999-2007 and find that greater exports leads to an increase in energy intensity, though the effect varies in both sign (positive or negative) and magnitude across sub-sectors. Their findings imply that that there is no ‘one size fits all’ export policy that reduces all sectoral energy intensity. Therefore, policies aimed at improving energy efficiency should take into account the characteristics of different sub-sectors.

Some previous studies also use micro-level data to examine the heterogeneity between exporting and non-exporting firms (Kaiser and Schulze, 2003, Cole et al., 2006, Holladay, 2008, Albornoz et al., 2009, Cole et al., 2013, Cui et al., 2016, Cui and Qian, 2017, Richter and Schiersch, 2017). These studies employ several alternative environmental performance metrics, e.g., environmental management systems, spending on environmental expenses, emissions level, and emission intensity. Again, findings are diverse. Some report positive impacts (Cole et al., 2006, Holladay, 2008, Albornoz et al., 2009, Cole et al., 2013, Cui et al., 2016, Richter and Schiersch, 2017), while some reveal negative and mixed impacts (Kaiser and Schulze, 2003, Cui and Qian, 2017). In particular, Cui and Qian (2017) show heterogeneity across different sectors, including pollution abatement capital expenses, trade costs, capital intensity and other factors, in the impact of export status on the emission intensity of facilities. The authors find robust evidence that supports the superior environmental performance of exporting firms compared with non-exporting ones for all types of air pollutants, but only in some industries.

Mixed results are reported in some studies where the authors use energy intensity as a proxy of energy efficiency, closely related to my work. In particular, Dardati and Saygili (2012) examine the impact of export status on energy intensity for Chilean firms and show that the impact is insignificant. Also, Batrakova and Davies (2012) use a panel dataset from Irish firms over the 1991-2007 period to investigate the difference in energy intensity between exporters and non-exporters. Their result demonstrates that being an exporter is positively correlated to energy intensity for low energy-intensive firms and negatively correlated to energy intensity for high-energy-intensive ones.

The impact of being an exporter on environmental performance also differs across energy types. Cole et al. (2008) use data from manufacturing firms in Ghana over the period 1991-1997 and show that exporting reduces fuel intensity while increasing electricity intensity, although the estimated coefficient for the latter variable is statistically insignificant. A similar result can be found in a study conducted by Roy and Yasar (2015) who employ a panel data from Indonesian manufacturing firms. The authors define relative energy intensity as the difference between fuel intensity and electricity intensity and conclude that exporting reduces the use of fuels relative to electricity, which is a clean form of energy (Cole et al., 2008).

5.3 Energy performance in Vietnam

The energy sector in Vietnam has expanded dramatically in recent decades to meet the rapid population growth and economic development. This sector has contributed substantially to Vietnam's economic achievement by facilitating the industrialisation and modernisation processes of the country. Both energy exploitation and final energy consumption of Vietnam have increased rapidly over the last two decades. In particular, total final energy consumption rose by almost 1.5 times in the 2006-2015 period, of which electricity had the highest growth rate compared with other energy types (Ministry of Industry and Trade, 2017).

However, energy intensity in Vietnam is relatively higher than other ASEAN countries with similar economic development. Figure 5.1 presents energy intensity, measured as the total primary energy in megajoule (MJ) divided by GDP (USD 2011 purchasing power parity (PPP)), for some ASEAN countries in 1990 and 2015. Energy intensity of Vietnam decreased slightly over the period and was the highest in 2015. There were significant reductions in energy intensity of Myanmar and Cambodia, suggesting improvements in energy efficiency levels of these countries.

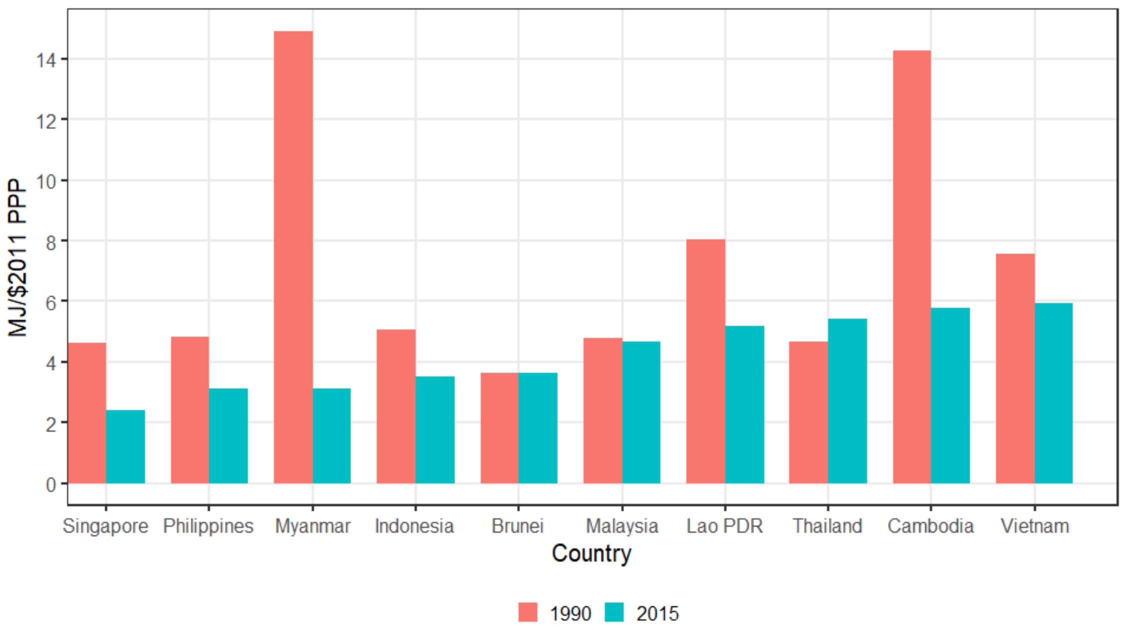

Figure 5.1 **Energy intensity (MJ/ USD 2011 PPP)**

Source: World Bank (2020)

Moreover, the energy consumption of enterprises in Vietnam is relatively inefficient. Currently, electricity cost usually accounts for a substantial part in the total production cost of manufacturing firms (Phuong Huyen, 2020). One obstacle for Vietnamese SMEs in consuming energy efficiently is their old technologies, particularly up to 53 per cent of SMEs use technologies older than 6 years (Quang Loc, 2017). Thus, Vietnamese enterprises would have high energy-saving potential if technical regulations are implemented. For instance, about 40 per cent of energy use could be saved by improvements in air conditioning, auxiliary and office equipment, lighting, and elevator systems (Le, 2019).

Vietnam has launched several policies and intervention programs to improve energy efficiency and conservation. One of the most important policies is the Law on Economical and Efficient Use of Energy, which sets the legal and policy framework for rights, obligations, and responsibilities of different agents to use energy efficiently and economically (National Assembly, 2010a). In addition, the National Targeted Program on Energy Efficiency and Conservation (Phase I: 2006–2010, Phase II: 2012–2015, and Phase III: 2019-2030) has helped enterprises to improve their energy performance. Each phase has different targets and objectives that suit Vietnam's economic development level. During 2011-2015 the government spent about VND 349 billion (USD 15 million) to assist enterprises to invest in high-energy efficient machines and facilities. The program supported up to 30 per cent of the total investment costs but no more than VND 7 billion (USD 0.3 million) for one firm. Evaluation results showed that a total of 10,610 kilotonnes of oil equivalent (Ktoe) (i.e., 5.65 per cent) was saved by the implementation of the program (Ministry of Industry and Trade, 2017).

An important energy program which targets the SMEs is entitled 'Promoting Energy Conservation in Small and Medium Enterprises' in the period 2006-2010. This program is funded by the United Nations Development Programme with a total budget of nearly USD 40 million. The program was designed to support energy management activities and energy efficiency technologies in five main sectors (brick production, ceramics, textiles, pulp and paper, and food processing). About 500 SMEs participated in the program, and the actual saving was 232 Ktoe or equivalent to a reduction of 944 thousand tonnes of carbon dioxide (Nguyen, 2015).

Recently, the World Bank has committed to spending USD 158 million on the Vietnam Energy Efficiency for Industrial Enterprises project to improve energy efficiency in the industrial sector. The project allows industrial enterprises to borrow money to upgrade their machines, equipment, and buy new facilities for energy saving in their production process. The project aims to help enterprises to cut their production costs and emission level released to the atmosphere (Nong et al., 2020b).

5.4 Conceptual framework

This section provides the conceptual framework for the analysis. To highlight the choice of ESR model, I first present a mini review of models employed in previous studies to address the endogeneity problem between exporting and firms' energy efficiency. The next subsection describes the theoretical framework and empirical specification of the ESR model. Finally, I present the approach to estimate the average treatment effects and heterogeneity effects on energy efficiency.

5.4.1 Addressing the endogeneity problem in export status

Identification of the causal effect between export status and firms' energy performance is likely subject to endogeneity because there are two-way relationships. Exporting encourages energy efficiency through improved management practice (Bloom et al., 2010, Bloom and Van Reenen, 2010). Nonetheless, the self-selection hypothesis states that efficient firms with high labour productivity are likely to participate in international supply chains (Melitz, 2003) as they are able to bear the entry costs to foreign markets (Clerides et al., 1998, Bernard and Wagner, 2001). More productive firms also exhibit higher environmental efficiency (Kreickemeier and Richter, 2014). In addition, firms can self-select to join foreign markets based on unobserved factors such as R&D activity, management quality, training and experience of managers, creditworthiness, and differences in consumer preferences across destination countries (Barrios et al., 2003b, Cole et al., 2008, Manova, 2013, Bao et al., 2014, Holladay, 2016). These factors can affect not only export status (decision) but also the energy performance of firms (Roy and Yasar, 2015).

Many studies have shown specific data types and variables to address the endogeneity of export status. In the best scenario, the problem of causal inference can be resolved if researchers can collect counterfactual outcomes of experimental data through randomised control trials (Miguel and Kremer, 2004). However, not many surveys can provide this information. Cole et al. (2006) argue that the endogeneity problem is less serious than in studies that use data at the industry and country levels since the export status of firms is unlikely to be associated with their management of domestic environmental obligations.

Researchers have used several methods to resolve endogeneity problem from non-random selection of exporting. Some apply the IV approach in their analyses (Managi et al., 2009, Girma and Hanley, 2015, Roy and Yasar, 2015). For instance, Girma and Hanley (2015) use contemporaneous and lagged values of imported input ratios as instruments for export status of firms. Roy and Yasar (2015) employ an IV model based on differencing approach (Pitt and Rosenzweig, 1990), in which the authors subtract the two cost share equations and report the impact of exporting on fuel use relative to electricity use. This approach is commonly applied when traditional exclusion restrictions or instruments are not available.

Other studies employ the propensity score matching method (Rosenbaum and Rubin, 1983) to investigate the impacts of exporting on environmental performance (Batrakova and Davies, 2012, Cui and Qian, 2017). This method calculates the probability of export status using a set of observable characteristics and attributes, which then matches the exporting and non-exporting groups based on these covariates. In particular, Batrakova and Davies (2012) use the matching method combined with a difference-in-difference approach and report the negative impact of export status on energy intensity. They argue that the combination of these techniques can address selection bias and control for time-invariant unobserved characteristics of firms. The combined approach requires a panel sample to run.

The matching technique, however, has two main drawbacks. Firstly, when the method is used alone, it does not control for unobserved factors that affect the export status. The method only assumes that once observed factors are controlled in the matching procedure, exporting decision is random and uncorrelated with the outcome variables (Abdulai and Huffman, 2014). Nonetheless, there possibly exist systematic differences between outcomes of the two groups even after conditioning on observed variables since export decision may base on unmeasured characteristics (Smith and Todd, 2005). Secondly, the main objective of the probit or logit model in matching technique is to balance the observed distribution of covariates in the two groups rather than to provide estimates on the determinants of export status, as recommended by Abdulai and Huffman (2014). Thus, if the selection process is based on unobservable factors that simultaneously affect the exporting decision and the outcome variables, this will lead to an omitted variables problem.

I choose ESR models for this case study because this approach can take into account self-selection of non-experimental studies. First, compared with the matching technique, the ESR model can control for observed and unobserved characteristics potentially affecting the decision to export of firms and the outcomes (Abdulai and Huffman, 2014). Second, the switching technique often generates better results than the IV method since it takes into account structural differences between exporters and non-exporters regarding the impacts on energy intensity (Alene and Manyong, 2007). If firms' characteristics have differential effects on energy intensity, separate equations for two groups need to be specified. Finally, the ESR model can work when only cross-sectional data is available.

5.4.2 Theoretical basis and empirical specification of an ESR model

This subsection presents the switching regression technique for export decision and energy intensity of firms. This method proposed by Lee (1982) controls for selection bias from unobservable characteristics, in which selectivity is treated as a missing-variables problem (Fuglie and Bosch, 1995). This technique assumes that firms can choose between having export activities or serving only domestic markets. The ESR model uses a probit regression to examine the determinants of export decision (i.e., selection equation) and separate equations to model energy intensity conditional on a specified function of the export decision (i.e., outcome equations for exporters and non-exporters).

There are two statuses in the switching regression technique. Status 1 and 0 correspond respectively to exporting and non-exporting. Let Y_E and Y_N be the energy intensity of firms according to each status. The energy intensity equations can be written as follows:

$$\begin{aligned} &\text{Status 1 (exporters):} && Y_{Ei} = \boldsymbol{X}_i'\boldsymbol{\beta}_E + u_{Ei} \\ &\text{Status 0 (non-exporters):} && Y_{Ni} = \boldsymbol{X}_i'\boldsymbol{\beta}_N + u_{Ni} \end{aligned} \tag{5.1}$$

where $\boldsymbol{X}_i$ is a vector of explanatory variables (firms' labour productivity, capital intensity, human capital level and other characteristics), $\boldsymbol{\beta}_E$ and $\boldsymbol{\beta}_N$ are vectors of parameters, u_{Ei} and u_{Ni} are the error terms that are independent and identically distributed with mean 0 and variances σ_E^2 and σ_N^2.

However, the dummy variable of export decision is considered not exogenous. A firm decides to export when the expected utility of exporting is greater than that of not exporting. Let denote D_i^* be the difference in expected utility between the two statuses, which also represents propensity to export. D_i^* is a latent variable that can be modelled as a function of the observed factors as follows

$$D_i^* = \boldsymbol{Z}_i'\boldsymbol{\gamma} + u_{Di} \qquad (5.2)$$

where $\boldsymbol{Z_i}$ is a vector of observed characteristics and attributes that have impact on the export decision, $\boldsymbol{\gamma}$ is a vector of estimated parameters, u_{Di} is the error term with mean zero and variance σ_D^2 to include measurement errors and unobserved factors.

Although D_i^* is unobservable, D_i that represents the actual choice made by firm i can be observed as follows

$$\begin{aligned} D_i &= 1 \text{ if } D_i^* > 0 \\ D_i &= 0 \text{ if } D_i^* \leq 0 \end{aligned} \qquad (5.3)$$

The ESR model divides firms into two groups to capture the differences in responses of the exporters and non-exporters. The energy intensity of the two groups conditional on the export decision is specified as

$$\begin{aligned} Y_{Ei} &= \boldsymbol{X}_i'\boldsymbol{\beta}_E + u_{Ei} \text{ if } D_i = 1 \\ Y_{Ni} &= \boldsymbol{X}_i'\boldsymbol{\beta}_N + u_{Ni} \text{ if } D_i = 0 \end{aligned} \qquad (5.4)$$

Variables in vectors $\boldsymbol{X}$ in (5.4) and vectors $\boldsymbol{Z}$ in (5.2) can overlap, but the identification strategies require that variables in $\boldsymbol{X}$ are a subgroup of those in **Z**. In other words, at least one variable in $\boldsymbol{Z}$ is excluded from $\boldsymbol{X}$. $\boldsymbol{\beta}_E$ and $\boldsymbol{\beta}_N$ are allowed to be different, suggesting that impact of each characteristic or attribute varies depending on export decision of firms.

In a self-selection problem, the covariances between the error terms of the equations of export decision (u_D) and the impact on energy intensity (u_E and u_N) may be nonzero due to unobservable factors. It is assumed that u_D, u_E , and u_N have a tri-variate normal distribution with zero mean and a non-singular covariance matrix:

$$Cov(u_D, u_E, u_N) = \begin{pmatrix} \sigma_D^2 & \sigma_{DE} & \sigma_{DN} \\ \sigma_{ED} & \sigma_E^2 & . \\ \sigma_{ND} & . & \sigma_N^2 \end{pmatrix} \qquad (5.5)$$

where $var(u_D) = \sigma_D^2$, $var(u_E) = \sigma_E^2$, $var(u_N) = \sigma_N^2$, $cov(u_E, u_N) = \sigma_{EN}$, $cov(u_E, u_D) = \sigma_{ED}$, $cov(u_N, u_D) = \sigma_{ND}$. It can be assumed that $\sigma_D^2 = 1$. Since Y_{Ei} and Y_{Ni} cannot be unobserved at the same time, the covariance between u_E and u_N is presented as dots in the covariance matrix. The errors terms u_E and u_N, conditional on sample selection model, have nonzero expected values. Therefore, OLS estimates of $\boldsymbol{\beta}_E$ and $\boldsymbol{\beta}_N$ suffer from sample selectivity bias. The expected values of the truncated error terms $(u_E|D = 1)$ and $(u_N|D = 0)$ are as follows

$$\begin{aligned} E(u_{Ei}|D_i = 1) &= \sigma_{ED}\frac{\phi(\boldsymbol{Z}_i'\boldsymbol{\gamma})}{\Phi(\boldsymbol{Z}_i'\boldsymbol{\gamma})} = \sigma_{ED}\lambda_{Ei} \\ E(u_{Ni}|D_i = 0) &= \sigma_{ND}\frac{-\phi(\boldsymbol{Z}_i'\boldsymbol{\gamma})}{1-\Phi(\boldsymbol{Z}_i'\boldsymbol{\gamma})} = \sigma_{ND}\lambda_{Ni} \end{aligned} \tag{5.6}$$

where $\phi(.)$ and $\Phi(.)$ are the probability density and cumulative distribution functions of the standard normal distribution. The ratio of ϕ and Φ evaluated at $\boldsymbol{Z'\gamma}$ are the inverse Mills ratio ($\lambda_{Ei} = \frac{\phi(\boldsymbol{Z}_i'\gamma)}{\Phi(\boldsymbol{Z}_i'\gamma)}$ and $\lambda_{Ni} = \frac{-\phi(\boldsymbol{Z}_i'\gamma)}{1-\Phi(\boldsymbol{Z}_i'\gamma)}$). The two terms are included in equation (5.4) to address selection bias

$$\begin{aligned} Y_{Ei} &= \boldsymbol{X}_{\boldsymbol{Ei}}'\boldsymbol{\beta}_E + \sigma_{ED}\lambda_{Ei} + \varepsilon_{Ei} \text{ if } D_i = 1 \\ Y_{Ni} &= \boldsymbol{X}_{\boldsymbol{Ni}}'\boldsymbol{\beta}_N + \sigma_{ND}\lambda_{Ni} + \varepsilon_{Ni} \text{ if } D_i = 0 \end{aligned} \tag{5.7}$$

where error terms ε_E and ε_N have conditional zero mean.

The correlation between the error terms in equations (5.2) and (5.4), ρ, have important meanings. If either $\rho_{ED} = \sigma_{ED}/\sigma_E\sigma_D$ or $\rho_{ND} = \sigma_{ND}/\sigma_N\sigma_D$ is statistically significant, the error terms in the equations of export status and energy intensity are correlated. There is evidence of an endogenous switch in the model to reject the null hypothesis of the absence of selection bias.

5.4.3 Average treatment effects

Results from the ESR model can be used to calculate conditional expectations and average treatment effects of exporting (Lokshin and Sajaia, 2004). I compare the expected energy intensity of firms that actually exported (actual exporters), firms that did not export (actual non-exporters) and the counterfactual cases in which the exported firms did not export, and the non-exported firms exported. The average treatment effects of participating into international supply chains on energy intensity are shown in Table 5.1.

Table 5.1 **Average treatment effects of export status**

Subsample	Decision stage		Treatment effects
	To export	Not to export	
Exporting firms	$E[Y_{Ei}\|D_i = 1]$	$E[Y_{Ni}\|D_i = 1]$	ATT
Non-exporting firms	$E[Y_{Ei}\|D_i = 0]$	$E[Y_{Ni}\|D_i = 0]$	ATU

Note:
ATT: Average treatment effect (i.e., export status) on the treated (i.e., firms that exported)
ATU: Average treatment effect (i.e., export status) on the untreated (i.e., firms that did not export)

where

$$\begin{aligned} E[Y_{Ei}|D_i = 1] &= \boldsymbol{X'_{Ei}\beta_E} + \sigma_{ED}\lambda_{Ei} \\ E[Y_{Ni}|D_i = 0] &= \boldsymbol{X'_{Ni}\beta_N} + \sigma_{ND}\lambda_{Ni} \\ E[Y_{Ni}|D_i = 1] &= \boldsymbol{X'_{Ei}\beta_N} + \sigma_{ND}\lambda_{Ei} \\ E[Y_{Ei}|D_i = 0] &= \boldsymbol{X'_{Ni}\beta_E} + \sigma_{ED}\lambda_{Ni} \end{aligned} \tag{5.8}$$

The detailed calculation of Table 5.1 is defined as follows. The ATT is the effect of exporting on energy intensity of firms that actually exported, which is specified as the difference in energy intensity of actual exporters when they exported and did not export. Similarly, the ATU is calculated as the difference in energy intensity of actual non-exporters when they exported and did not export.

$$\begin{aligned} ATT &= E[Y_{Ei}|D_i = 1] - E[Y_{Ni}|D_i = 1] = \boldsymbol{X'_{Ei}}(\boldsymbol{\beta}_E - \boldsymbol{\beta}_N) + (\sigma_{ED} - \sigma_{ND})\lambda_{Ei} \\ ATU &= E[Y_{Ei}|D_i = 0] - E[Y_{Ni}|D_i = 0] = \boldsymbol{X'_{Ni}}(\boldsymbol{\beta}_E - \boldsymbol{\beta}_N) + (\sigma_{ED} - \sigma_{ND})\lambda_{Ni} \end{aligned} \tag{5.9}$$

The endogenous switching model assumes that unobserved factors have different impacts on exporters and non-exporters. For instance, in the formula of ATT, the difference in effects $\sigma_{ED} - \sigma_{ND}$ and the inverse Mills ratio λ_{Ei} are included to control for unobserved factors. Thus, the estimated ATT can be interpreted as the impacts of exporting decision rather than unobserved effects (Abdulai and Huffman, 2014).

5.5 Data and descriptive statistics

This section describes the data used in the study. First, I describe the sampling procedure of SME surveys and discuss their representativeness for the Vietnamese SMEs in the manufacturing sector. The second subsection presents descriptive statistics and a comparison of characteristics and attributes between exporters and non-exporters. I also discuss reasons for choosing the set of independent variables in the estimation process with citing relevant literature.

5.5.1 Data

This study uses SME surveys of firms in the manufacturing sector. The surveys were conducted by the Central Institute for Economic Management in collaboration with the Institute of Labour Science and Social Affairs, the Department of Economics of the University of Copenhagen, United Nations University-World Institute for Development Economics Research, and the Royal Embassy of Denmark in Vietnam. The surveys were carried out in ten provinces, including Hanoi, Hai Phong, Ho Chi Minh City, Ha Tay, Phu Tho, Nghe An, Quang Nam, Khanh Hoa, Lam Dong, and Long An.

The sampling of SME surveys follows the same procedure. The sampling frame excludes state-owned and FDI enterprises in the manufacturing sector. Each SME survey consists of in-depth interviews with around 2,500 non-state and household enterprises about their previous operating year in which their population frame is based on two data sources of the General Statistics Office of Vietnam (GSO)[19] and on-site identification. Selection of firms was taken in two steps. Firstly, in each province, districts were chosen such that the number of selected districts was proportional to the number of districts in each province. Secondly, firms in each district were randomly selected from the population list of formal non-state and manufacturing firms (Hanna Berkel et al., 2020). Since the Enterprise census conducted by the GSO includes only firms with fixed professional premises, the number of household businesses reported in the SME surveys is underestimated. Thus, it is not strictly representative of the household dimension in Vietnam (Rand and Torm, 2012, Rand et al., 2014).

Furthermore, the informal household businesses were randomly selected alongside the formal ones. The enumerators were asked to find informal firms within each chosen site. The on-site identification can result in bias since relatively competitive and productive informal businesses were likely to operate in areas where formal firms were located. Hence, the surveys may only cover several specific types of firms, and the informal group in the surveys is not representative of Vietnam's informal sector (Rand et al., 2012, Rand and Torm, 2012, Rand et al., 2014, Rand, 2020). Formal household businesses are considered to be sampled more appropriately with census data information compared with informal ones (Rand, 2020).

[19] The Establishment Census 2002 (GSO, 2004) and the Industrial Survey 2004-2006 (GSO, 2007)

Given the sampling procedure of the surveys, I extract data for this chapter as follows. First, I focus only on formally registered enterprises in the analysis. The small number of exporters that are household business and/or informal firms (less than five firms) are insufficient to show variations. Secondly, I use two SME surveys conducted in 2011 and 2013 because the 2015 survey does not have information about energy consumption, and the surveys 2005-2009 do not cover instrumental variables for the export status of firms. Thirdly, since a regression equation for exporters is conducted separately, I create cross-sectional data from the two surveys to improve the variation among exporting firms. Firms in the survey 2011 can be different to those in 2013, thus, a dummy variable takes the value of 1 if firms are interviewed in the latter round and 0 otherwise. The sample in the baseline analysis includes 1746 firms, in which there are 73 exporting firms interviewed in 2011 and 67 exporting firms in 2013. All monetary values used in the analysis are converted into 2010 USD at the exchange rate VND 18,613/USD (World Bank, 2020).

5.5.2 Descriptive statistics

Table 5.2 presents the descriptive statistics of firms' characteristics. Energy intensity is used as a proxy of firms' energy efficiency (Cole et al., 2008, Batrakova and Davies, 2012, Roy and Yasar, 2015). I use the cost-share approach, measured as the ratio of energy costs to total variable costs of a firm in the last operating year, to calculate energy intensity. Energy costs include electricity and fuel costs. Total variable costs are computed as the sum of expenditure on energy, water, labour, and raw materials used in production. This measure uses costs of variable inputs rather than output or value added in its computations to avoid the concerns over endogeneity with the productivity variable (Roy and Yasar, 2015, Montalbano and Nenci, 2019). The average energy intensity of firms is 0.054, that is, the cost of energy is USD 54 per USD 1000 of variable costs. The main variable of interest is the dummy for direct export which takes the value of 1 if a firm exports directly, and 0 otherwise. This number does not cover those who only export indirectly to intermediary firms. There are 8 per cent of firms that export in the sample.

Table 5.2 **Summary statistics of variables in the sample**

Variable	Definition	Mean	Std.dev	Min	Max
Energy intensity	The ratio of energy cost to total variable costs of a firm	0.05	0.07	0.00	0.94
Exporter	1 if a firm exports, 0 otherwise	0.08	0.272	0	1
Labour productivity	Total output per unit of labour (USD thousand)	18.91	24.00	0.81	255.20
Capital intensity	Total fixed assets per unit of labour (USD thousand)	19.49	30.96	0.03	395.42
Professional labour share	Percentage of professional workers (having a university or a college degree) in the total labour of a firm (%)	8.89	8.46	0	77.14
Female share	Percentage of female workers in the total labour of a firm (%)	39.02	23.88	0	141.67
Training	1 if a firm has training for new workers, 0 otherwise	0.13	0.34	0	1
Firm size	1 if firm size is micro, 2 if firm size is small, and 3 if firm size is medium	1.83	0.67	1	3
Firm age	Age of a firm	10.17	8.07	1	75
Innovation	1 if a firm has innovation activities, 0 otherwise	0.41	0.49	0	1
Credit constraint	1 if a firm has credit constraint, 0 otherwise	0.36	0.48	0	1
Location	1 if a firm is located in a city, 0 otherwise	0.66	0.48	0	1
Import share	Percentage of raw materials and other inputs imported	4.65	16.72	0	99.64
International certificate	1 if a firm has an internationally recognised quality certification, 0 otherwise	0.19	0.39	0	1

This study chooses other explanatory variables that would affect the export decision of firms based on economic theories and previous empirical evidence. Labour productivity, which is measured as the total output per unit of labour, is one of the most widely used variables. This variable is expected to have a positive effect on the export decision (Delgado et al., 2002, Barrios et al., 2003a, Rankin et al., 2006, Srinivasan and Archana, 2011). The second explanatory variable is capital intensity, which is calculated as the ratio of total fixed assets to the number of workers. The coefficient of this variable can be inconclusive as increasing capital stocks reduces productivity which in turn makes firms less likely to export. By contrast, firms who are more capital-intensive are more likely to export (Rankin et al., 2006). This variable is generally found to have a positive effect on export decision (Barrios et al., 2003a, Rankin et al., 2006).

I include some human capital variables that can affect the export decision of firms. Skill level of workers, which is measured as the percentage of professional workers who have a university and/or a college degree in the total labour of a firm, is expected to have a positive impact on export status (Aggrey et al., 2010, Montalbano and Nenci, 2019). A dummy variable for training, which takes the value of 1 if firms normally (more than 50 per cent of the cases) conduct training for new workers, and 0 otherwise, is an indicator for human capital acquisition. Only 13 per cent of firms in the sample have training for new workers. The training dummy is expected to have a positive effect on exports since training may improve the learning process and accumulate additional skills (Dueñas-Caparas, 2006, Aggrey et al., 2010). The proportion of female employees in total labour, which represents non-production labour (Roy and Yasar, 2015), is expected to decrease firms' probability of exporting.

I also include several variables of firm demographics and geographic. Firm size is a categorical variable with values of 1, 2, and 3 representing micro, small and medium enterprises. Firms are classified into the three categories based on a definition of Rand and Tarp (2020): micro firms have fewer than 10 employees, small firms are composed of between 10 and 49 employees, and medium firms have from 50 up to 300 employees. Bigger sized firms are expected to have a positive impact on export status (Barrios et al., 2003a, Montalbano and Nenci, 2019). Additionally, firm age is included in the estimation to represent experience of firms. Previous studies report mixed results on the sign of this variable (Roberts and Tybout, 1997, Barrios et al., 2003a, Sjöholm, 2003). The average age of firms in the sample is ten years. Location dummy, which takes the value of 1 if a firm is located in a city (Hanoi, Hai Phong, Ho Chi Minh City) and 0 otherwise, represents a market variable. Firms in big cities usually have more advantages compared with their counterparts. In the sample, 66 per cent of firms are located in the three big cities.

The two other firm-specific variables, innovation and credit constraint, are likely to affect the export propensity. Innovation is considered as a vital indicator for firm-level competitiveness. Following Nguyen et al. (2008), I define a firm having innovation activities if it either introduces new product groups, makes any improvements to existing products or introduces new production processes and new technology. Forty-one per cent of firms have innovation activities in their previous operating years. This variable is expected to affect the export status of firms positively (Nguyen et al., 2008). Another control variable included in the model is a dummy of credit constraint. I define this variable based on a study of Kinghan et al. (2020), in which credit constraint is a composite of credit rationed and discourage borrowers. Firms are considered as being credit rationed if they had applied but was rejected for a formal loan. Discouraged borrowers are those who did not apply for a loan due to inadequate collateral, too difficult process, too high interest rates, fear of indebtedness, and already being in heavy indebtedness. Thirty-six per cent of firms in the sample suffer from credit constraint. This variable is expected to have a negative impact on export status (Minetti and Zhu, 2011).

Moreover, I include two additional variables in the estimation of export status, namely import share and whether the firm has an international certificate for quality control. Import share is a determinant of the export decision since importers are generally also the exporters. There is a high correlation between import and export decision of firms (Srinivasan and Archana, 2011, Girma and Hanley, 2015). The average import share in the total inputs is 4.7 per cent. Firms with international certificates for quality control (e.g., ISO certificate) are more likely to export than their peers (Correa et al., 2011). There are about 19 per cent of firms in the sample owning an international certificate.

Table 5.3 summaries differences in attributes of exporters and non-exporters with their t-statistics. Explanatory variables in the regression of the export decision are assumed to affect energy intensity of firms. The significance of t-statistics indicates differences between two groups. The average energy intensity of exporters was 0.038, a 0.017 point lower than that of non-exporters. This difference suggests that export decision may play a vital role in improving the energy efficiency of firms.

Table 5.3 **Characteristics of exporters and non-exporters**

	Exporters	Non-exporters	Difference
Energy intensity	0.038	0.055	-0.017***
Labour productivity	27.114	18.189	8.924***
Capital intensity	18.724	19.557	-0.833
Professional labour share	8.529	8.922	-0.393
Female share	51.749	37.907	13.842***
Training	0.264	0.117	0.147***
Firm size	2.414	1.776	0.638***
Firm age	11.621	10.039	1.583**
Innovation	0.536	0.403	0.133***
Credit constraint	0.250	0.364	-0.114***
Location	0.707	0.651	0.056
Import share	24.972	2.878	22.095***
International certificate	0.829	0.134	0.694***

Note: * $p<0.10$, ** $p<0.05$, *** $p<0.01$

Moreover, there are significant differences between exporting and non-exporting firms in most characteristics except for capital intensity, professional labour share and location. Exporting firms are generally more labour productive than non-exporting ones with a difference of USD 8,920. More productive firms are likely to install energy-efficient technologies, which in turn improves energy performance (Batrakova and Davies, 2012). I also include the level of capital intensity with the idea that capital intensive production is generally more energy-intensive and hence has higher energy intensity (Cole et al., 2008). However, there is no statistical difference in this dimension among exporters and non-exporters.

The two groups of firms can be distinguished based on some indicators of human capital. Higher professional labour share is expected to reduce energy intensity since firms with a large proportion of skilled workforce are more likely to obtain technologically advanced production process and thus better environmental management (Cole et al., 2006). Nonetheless, values of this variable are similar between exporting and non-exporting firms. Meanwhile, exporters generally conduct more training for new workers with a difference of 0.15 point. The proportion of female employees also shows a significant disparity between exporters and non-exporters. The female share in the former group is 52.3 per cent compared with 37.7 per cent in the latter.

Furthermore, the two groups differ significantly in other characteristics and attributes. It can be observed from the table that exporters are typically larger, younger, and more innovative.

In particular, the share of exporting firms having innovation activities is 54 per cent, which is 13.7 percentage points higher than their peers. Besides, exporters have less credit constraint with a difference of 0.11 points. Although I assume that import share and owning an international certificate do not impact energy intensity of firms other than export channel, there are differences between the two groups. The former has higher import share of raw materials and international certificates than the latter.

5.6 Empirical results

This section provides empirical results for the ESR model. First, I present the estimates of determinants of exporting and its impacts on firms' energy efficiency. I calculate the effects of export status and unobserved factors on firms' energy performance. The sensitivity analysis uses another measure of energy intensity and different models to check the robustness of the baseline findings.

5.6.1 Determinants of exporting and its impacts on energy intensity

The ESR model examines the export decision and its impacts on energy intensity of firms. The estimation of the model can be proceeded by using two-stage approach to estimate each equation at a time. However, the method generates heteroskedastic residuals and requires cumbersome adjustments to obtain consistent standard errors (Abdulai and Huffman, 2014). Therefore, I employ the full information maximum likelihood approach proposed by Lokshin and Sajaia (2004) that fits both equations simultaneously to overcome the drawbacks of the previous approach. Results of the ESR model are presented in Table 5.4, in which the second column shows estimates for the selection equation and the last two columns provide results for the outcome equations.

Table 5.4 **Parameters estimates of export status and energy intensity (Energy cost/Variable costs)**

		Energy cost/Variable costs	
Variable	**Selection**	**Exporters**	**Non-exporters**
Labour productivity	0.006***	-0.0005***	-0.001***
	(0.002)	(0.0001)	(0.0001)
Capital intensity	-0.001	0.0002**	0.0002***
	(0.002)	(0.0001)	(0.0001)
Professional labour share	-0.012	-0.0002	-0.0002
	(0.008)	(0.0005)	(0.0002)
Training	0.025	0.002	-0.001
	(0.151)	(0.007)	(0.006)
Female share	0.013***	0.0001	-0.0001
	(0.003)	(0.0001)	(0.0001)
Firm size	0.441***	0.004	-0.006*
	(0.101)	(0.006)	(0.003)
Firm age	0.011	-0.001**	-0.0001
	(0.007)	(0.0004)	(0.0002)
Innovation	0.151	-0.0003	-0.002
	(0.126)	(0.007)	(0.004)
Credit constraint	-0.066	-0.007	-0.004
	(0.133)	(0.007)	(0.004)
Location	-0.164	0.006	-0.002
	(0.134)	(0.007)	(0.004)
Food beverage	0.026	0.013	0.028***
	(0.157)	(0.009)	(0.005)
Fabricated metal	-0.100	-0.009	-0.019***
	(0.218)	(0.013)	(0.005)
Year 2013	-0.173	0.011	-0.008**
	(0.126)	(0.007)	(0.004)
Import share	0.014***		
	(0.002)		
International certificate	1.516***		
	(0.128)		
Constant	-3.683***	0.022	0.086***
	(0.329)	(0.025)	(0.008)
σ_E		0.0348***	
		(0.0024)	
ρ_{ED}		0.3628*	
		(0.2071)	
σ_N			0.0724***
			(0.0013)
ρ_{ND}			0.1752**
			(0.0734)
Log Likelihood	1,941.487		
χ^2 - Statistic for overidentification	1.767		
p-value	[0.184]		
LR test of independent equations	5.94*		
p-value	[0.051]		

Note: Standard errors are in parentheses and p-values are in square brackets; *p<0.1; **p<0.05; ***p<0.01

As discussed previously, model identification requires that at least one variable in the selection equation does not appear in the two outcome equations, i.e., the estimation of impacts on energy intensity. Import share of inputs and international certificate for quality control are used as identifying instruments, and as such dropped from the outcome equations. The F-statistics from the joint test on the strength of the two instrumental variables in the selection equations is approximately 260.513 (p-value <0.01), thus, the null hypothesis of weak instruments is rejected. Hansen-J statistic for the overidentification test is 1.767 (p-value = 0.184), so there is not enough evidence to reject the null hypothesis of exogenous instruments. The uncorrelation between the instruments and model residuals suggests that the instruments affect firms' energy intensity only through export decision.

Import share and owning an international certificate are drivers of export decision. Estimated coefficients in the selection equation indicate impacts of these variables on propensity to export, which can be interpreted as in normal probit model. Both coefficients are positive and statistically significant at 1 per cent level. In particular, firms which have higher import inputs and acquire internationally recognised certificates are more likely to become exporters. The results are consistent with findings from Srinivasan and Archana (2011) and Correa et al. (2011).

Regarding other variables in the selection equation, labour productivity and capital intensity have opposite impacts on export status. Labour productivity is positive and statistically significantly different from zero, indicating that higher productive firms tend to serve foreign markets. Capital intensity, on the other hand, is negatively associated with the firms' export status. The negative sign shows that more capital-intensive firms are less likely to become exporters. This variable is not statistically significant though.

Estimated coefficients of firm size and proportion of female are statistically significant. Firm size has a positive impact on export status, meaning that larger firms have more probabilities of becoming exporters. In other words, if a micro firm expands and becomes a small or medium firm, they are more likely to participate in international markets. It is surprising that the share female workers has a positive association with export status. The result implies an important role of female employment in firm operation. Exporting firms generally have high-performance productions with newer technologies and skill upgrading. Female employees in these business environments are multiskilled workers (Jackson and Pearson, 2005), thus is positively correlated to the export decision.

Other remaining firms' attributes have statistically insignificant estimates. While coefficients for training, firm age, innovation, and credit constraint report signs as expected, professional labour share and location have unexpected signs. It can be observed from the table that firms with higher share of skilled labour and located in big cities are less likely to export. I also include dummy variables for sectors to capture sector-specific characteristics.[20] However, estimated coefficients of sector and year dummies are statistically insignificant even at 10 per cent level, suggesting that these factors may not have strong effects on the propensity to export.

Regarding the outcome equations, there are some similarities in the impacts of these factors on energy intensity of exporters and non-exporters. Coefficients of labour productivity are significantly negative at 1 per cent level in both equations. It implies that more productive firms are expected to have lower energy intensity since they are more likely to invest in energy-efficient technologies. Capital intensity, however, has a positive impact on energy intensity. Firms with more capital-intensive production process are also more energy-intensive on average, i.e., less energy efficient. These outcomes are in line with previous results reported in Batrakova and Davies (2012) and Cole et al. (2008).

However, some differences in outcomes between the two groups can be found. In terms of firms' demographic characteristics, firm age and firm size influence the energy performance of exporters and non-exporters differently. Although estimated coefficients for firm age have negative signs in outcome equations of both groups, it is only significant at 5 per cent level for exporters. While more experienced (older) exporting firms tend to have lower energy intensity, age makes no difference in energy intensity of non-exporters. By contrast, firm size is expected to reduce energy intensity of non-exporters. Similarly, year and sector dummies affect energy efficiency level of the latter group. Non-exporting firms in fabricated metal sector and in 2013 have lower energy intensity compared with those being in other sectors and in 2011. All estimated coefficients of these variables for exporters are insignificant. The remaining variables do not affect energy intensity of both groups.

[20] Sectors in the sample can be grouped into three categories: food and beverages, fabricated metal products, and other sectors.

Other reported statistics are important to assess the necessity of the ESR model. ρ_{ED} and ρ_{ND} are statistically significant, suggesting that self-selection exists in both groups of firms. There is evidence to reject the first hypothesis since energy intensity is endogenously correlated with export decision. Firms with below (or above) average energy intensity self-select into exporting (or not exporting). The result also implies that the effect of export decision on energy intensity cannot be estimated correctly using only observed characteristics as unobservable factors significantly influence the export decision. Some methods such as OLS and propensity score matching, thus, are not appropriate.

Finally, the likelihood ratio test for the independence of selection and outcome equations is statistically different at 10 per cent level. It confirms that Vietnamese SMEs should be distinguished in two different groups based on export status. Hence, I also reject the second hypothesis and conclude the effectiveness of the ESR model in the study.

5.6.2 Effects of export status on firms' energy performance

The estimates for average effects of export status on energy intensity levels are presented in Table 5.5. The expected energy intensity of exporters is 0.038, while it is about 0.055 for non-exporters. Nonetheless, this simple comparison can be misleading and make researchers conclude that on average energy intensity of exporting firms is 0.017 (31.5 per cent) less than that of non-exporting firms.

Unlike the above mean difference which may have been affected by unobserved factors, the ATT and ATU take into account selection bias since exporting and non-exporting firms may be systematically different. These effects are negative and statistically significant for both groups of firms. A reduction of 40.2 per cent in energy intensity is found for exporters. Similarly, the energy intensity of non-exporters would be 0.032 points (that is 58.6 per cent) lower if in the counterfactual case they exported. This reduction can be attributed to their decision to participate in international supply chains. The results indicate a positive impact of exporting decision on the energy efficiency of firms. In terms of magnitude, the impact of export status is larger for actual non-exporters relative to actual exporters.

Table 5.5 **Impacts of export status on energy intensity (Energy cost/Variable costs)**

Subsample	Decision stage		Treatment effects
	To export	**Not to export**	
Exporting firms	0.0378	0.0633	ATT=-0.0254***
	(0.0014)	(0.0016)	(0.0012)
Non-exporting firms	0.0228	0.0552	ATU=-0.0323***
	(0.0004)	(0.0005)	(0.0004)

Note: Standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01

5.6.3 Robustness checks

In the first sensitivity analysis, I estimate the ATT and ATU for another measure of energy intensity. This variable is measured as the ratio of energy cost to output. The full estimation for determinants of export status and its impacts on energy intensity is provided in the Appendix A5. In general, the result confirms the necessity of an endogenous switching model. The covariance terms ρ_{ED} and ρ_{ND} are statistically significant at 10 and 5 per cent level. Thus, self-selection does exist in both groups. The likelihood ratio test reports the independence of the three equations, which suggests splitting the sample into two groups based on firms' export status.

Table 5.6 presents the effects of export decision on energy intensity of exporting and non-exporting firms. Similar to the previous measure of energy intensity, export decision is found to have reduced energy intensity or to improve energy efficiency of firms as both the ATT and ATU are negative and statistically significant. Once again, the impact of export decision on non-exporting firms is indeed larger than on exporting firms.

Table 5.6 **Impacts of export status on energy intensity (Energy cost/Output)**

Subsamples	Decision stage		Treatment effects
	To export	**Not to export**	
Exporting firms	0.0285	0.0475	ATT=-0.0190***
	(0.0010)	(0.0011)	(0.0008)
Non-exporting firms	0.0190	0.0418	ATU=-0.0228***
	(0.0003)	(0.0004)	(0.0003)

Note: Standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01

Furthermore, I estimate the impact of export status on energy intensity using different methods. OLS, IV and fixed effects with instrumental variables (FE-IV) methods are employed, in which OLS and IV estimation use the pooled sample as in the baseline model, while a panel dataset of the two survey rounds is created for the FE-IV model. Import share and international certificate are used as instrumental variables for export decision of firms. Results of the sensitivity analysis by various models are presented in Table 5.7.

Table 5.7 **Sensitivity analysis using different models**

	Dependent variable		
	Energy cost/Variable costs		
	OLS	**IV**	**FE-IV**
Exporter	-0.009	-0.029**	-0.062*
	(0.007)	(0.014)	(0.033)
Labour productivity	-0.001***	-0.001***	-0.0003***
	(0.0001)	(0.0001)	(0.0001)
Capital intensity	0.0002***	0.0002***	0.00001
	(0.0001)	(0.0001)	(0.0001)
Professional labour share	-0.0002	-0.0002	0.0002
	(0.0002)	(0.0002)	(0.0003)
Training	-0.002	-0.001	-0.011*
	(0.005)	(0.005)	(0.006)
Female share	-0.0001*	-0.0001	-0.0002
	(0.0001)	(0.0001)	(0.0001)
Firm size	-0.006**	-0.005	-0.010
	(0.003)	(0.003)	(0.006)
Firm age	-0.0001	-0.0001	-0.00004
	(0.0002)	(0.0002)	(0.001)
Innovation	-0.002	-0.002	0.002
	(0.004)	(0.004)	(0.004)
Credit constraint	-0.004	-0.005	-0.001
	(0.004)	(0.004)	(0.004)
Location	-0.001	-0.001	0.002
	(0.004)	(0.004)	(0.067)
Food beverage	0.026***	0.027***	0.092***
	(0.005)	(0.005)	(0.024)
Fabricated metal	-0.019***	-0.019***	-0.0001
	(0.005)	(0.005)	(0.011)
Year 2013	-0.007*	-0.007*	-0.005
	(0.004)	(0.004)	(0.004)
Constant	0.087***	0.083***	0.076
	(0.007)	(0.008)	(0.047)
Observations	1,746	1,746	1,268
F Statistic	9.871*** (df = 14; 1731)		37.422***

Note: Standard errors in parentheses; * p<0.10, ** p<0.05, *** p<0.01

Estimates of different approaches provide relatively consistent outcomes. The results of the OLS estimation are presented in the second column. Being an exporter has a statistically insignificant and negative impact on energy intensity. However, OLS estimates assume that export decision is exogenous while it is likely to be endogenously determined. This method would lead to a misleading conclusion that there is no difference in the energy intensity of exporting and non-exporting firms. For the two remaining methods, being an exporter is found to improve the energy performance of firms with a reduction in energy intensity of 0.029-0.062 points. All estimated coefficients are statistically significant at either 10 or 5 per cent level. However, it should be noted that these models do not take into account potential heterogeneity between exporting and non-exporting firms.

5.7 Discussion

As far as I know, this is the first paper to examine the impact of export decision on energy efficiency using firm-level data in Vietnam. The average treatment effects for both exporters and non-exporters are statistically significant and negative, suggesting that being an exporter reduces energy intensity. The result is consistent with those reported in the literature for both developed and developing countries (Cole et al., 2008, Batrakova and Davies, 2012, Roy and Yasar, 2015). Firms improve their energy efficiency when participating in international supply chains since exporters are likely to adopt more advanced and cleaner technology (Kaiser and Schulze, 2003, Bustos, 2011, Batrakova and Davies, 2012, Roy and Yasar, 2015), which is generally energy-saving. This in turn reduces their energy intensity.

Self-selection does exist in both exporters and non-exporters, which indicates that the decision to export and not to export is likely dependent on firms' energy efficiency. Indeed, Vietnamese SMEs that are more efficient exhibit higher energy performance and have a higher probability of participating in foreign markets. This finding is opposite to result reported by Batrakova and Davies (2012) who show no evidence of more energy-efficient firms self-selecting into exporting. However, their study investigates the relationship between exporting and energy intensity for firms in a developed country (Ireland) using a different method (a probit model for export status with a lag of energy intensity as an explanatory variable). Thus, different results are expected and understandable.

Regarding other explanatory variables, estimates of the ESR model also provides quite consistent outcomes to the literature (Delgado et al., 2002, Barrios et al., 2003a, Rankin et al., 2006, Greenaway et al., 2007, Srinivasan and Archana, 2011, Bayar, 2018), although many of them are statistically insignificant. In outcome equations, there are some differences in the impacts of explanatory variables on energy intensity. However, estimates for labour productivity and capital intensity are robust and similar to findings reported by Batrakova and Davies (2012) and Cole et al. (2008).

The results from this study provide some policy implications. The government should implement environmental policies and programs with more focus on enterprises, especially SMEs since they comprise more than 97 per cent of the total businesses in Vietnam (Nguyen et al., 2020). The positive effect of export status on energy efficiency suggests the necessity of mechanisms to encourage non-exporters to participate in foreign markets and gain benefits from international competition and standards. Policies that promote exporting should also improve labour productivity, increase female workers in the labour force, and encourage firms to acquire a recognised international certificate.

In addition, the positive effect of participation in international supply chains on energy efficiency at the firm level encourages Vietnam to participate in free trade agreements (FTAs) with other countries. Bilateral or multilateral FTAs are designed to remove trade barriers, promote economic integration, and potentially improve environmental standards for participating countries. Participation in FTAs can be beneficial for the environment, depending on agreement types (e.g., Nemati et al. (2019)). New FTAs such as the one with the European Union enable the country to adopt clean technology and create a framework for sustainable development. Vietnam has the right to regulate the targeted environmental protection level, which requires the country to mitigate impacts on the environment while cooperating with the European Union (Stockhaus, 2017). This may contribute to the success of an energy conservation strategy in Vietnam and the reduction of carbon emissions of 8 to 25 per cent by 2030 as a commitment under the Paris Agreement.

5.8 Conclusion

One of the prominent concerns over globalisation is whether international trade is good for the environment. This study has contributed to the ongoing debate by investigating the impact of export status on energy efficiency using firm-level data. I constructed a cross-sectional dataset from Vietnamese SMEs surveys in 2011 and 2013. In order to address the potential self-selection bias arising from export decision, an endogenous switching model was employed. The model controlled for both observed and unobserved characteristics of firms that affected decision to export as well as captured heterogeneity between exporting and non-exporting firms.

The ESR model estimated the determinants of export decision and its impacts on energy intensity simultaneously. The results in the selection equation show that firms with higher labour productivity, more employees, and a higher proportion of female employees are likely to participate in international markets. Estimated coefficients for import share of inputs and international certificate of quality control are statistically significant and positively correlated to export status of firms. In the outcome equations, the effects of many explanatory variables on exporting and non-exporting firms differ, except for labour productivity and capital intensity variables.

There is enough evidence to reject both hypotheses. The statistical significance of the correlation terms indicates the existence of an endogenous switch since there are correlations between error terms of selection and outcome equations. The self-selection does occur in both groups of firms, which suggests that firms with below (or above) average energy intensity self-select into exporting (or not exporting). Also, the likelihood ratio test confirms that the sample should be divided into two distinct groups based on their export decision due to structural differences between exporting and non-exporting firms.

In general, export decision is found to be beneficial for firms' energy efficiency. The average treatment effects for both groups are statistically significant and negative. When switching from non-export to export status, firms will have less energy intensity in their production process, which indicates an improvement in energy efficiency level. Hence, being an exporter is found to be pro-environment. The effect is larger for non-exporting firms than for exporting ones. The results are relatively robust regardless of energy intensity measure and models used. This study provides policy implications for the government, which are to encourage the participation of firms in foreign markets and promote free trade agreements with other countries.

Appendix

A5 Sensitivity analysis with a different measure of energy intensity

Table A5.1 **Parameters estimates of export status and energy intensity (Energy cost/Output)**

		Energy cost/Output	
Variable	**Selection**	**Exporters**	**Non-exporters**
Labour productivity	0.006***	-0.0004***	-0.0004***
	(0.002)	(0.0001)	(0.0001)
Capital intensity	-0.001	0.0002**	0.0001***
	(0.002)	(0.0001)	(0.00004)
Professional labour share	-0.012	-0.0002	-0.0001
	(0.008)	(0.0003)	(0.0002)
Training	0.021	0.001	-0.002
	(0.151)	(0.005)	(0.004)
Female share	0.013***	0.00001	-0.0001*
	(0.003)	(0.0001)	(0.0001)
Firm size	0.441***	0.004	-0.002
	(0.101)	(0.004)	(0.002)
Firm age	0.011	-0.001**	-0.0001
	(0.007)	(0.0003)	(0.0002)
Innovation	0.152	-0.0001	-0.0004
	(0.127)	(0.005)	(0.003)
Credit constraint	-0.063	-0.005	-0.002
	(0.133)	(0.005)	(0.003)
Location	-0.164	0.005	-0.003
	(0.135)	(0.005)	(0.003)
Food beverage	0.022	0.012**	0.020***
	(0.157)	(0.006)	(0.004)
Fabricated metal	-0.099	-0.008	-0.015***
	(0.218)	(0.009)	(0.004)
Year 2013	-0.180	0.010**	-0.004
	(0.126)	(0.005)	(0.003)
Import share	0.014***		
	(0.002)		
International certificate	1.520***		
	(0.127)		
Constant	-3.684***	0.016	0.061***
	(0.330)	(0.016)	(0.006)
σ_E		0.0244***	
		(0.0016)	
ρ_{ED}		0.3257*	
		(0.1780)	
σ_N			0.0534***
			(0.0009)
ρ_{ND}			0.1572**
			(0.0725)
Log Likelihood	2,476.897		
χ^2 - Statistic for overidentification	1.841		
p-value	[0.175]		
LR test of independent equations	5.63*		
p-value	[0.060]		

Note: Standard errors are in parentheses and p-values are in square brackets; *p<0.1; **p<0.05; ***p<0.01

Chapter 6: Conclusion

6.1 Key findings

The thesis has provided a comprehensive picture of the economics of energy in Vietnam. The four substantive chapters focused on (i) the energy-GDP nexus from a macroeconomic perspective, (ii) the microeconomic impact of environmental taxes on household welfare, (iii) the economics of coal-based power generation, and (iv) the energy efficiency of firms in relation to international trade. Each chapter applied a distinct technique appropriate to the research question, including general equilibrium modelling, partial equilibrium modelling combined with statistical analysis, cost-benefit analysis, and econometric analysis, respectively.

Understanding the energy-GDP nexus and the role of the energy sector in the economy are necessary for policymakers to manage the energy market and implement energy-related policies. Chapter 2 provided an estimate for energy-GDP indicators using a bottom-up approach that controls for sectoral interdependences in its calculation. In general, a change in sectoral GDP creates impacts on different aspects of the economy such as household and enterprises income, total GDP, and gross output. The magnitudes of the impacts vary across sectors depending on their contribution to the national economy. This chapter also computed the energy-GDP multiplier and elasticity as proxies for aggregate energy efficiency of Vietnam. The results emphasize the importance of the energy sector in the country's economic development and the relatively close linkages between the energy sector and other sectors.

Furthermore, Chapter 3 attended to concerns regarding energy issues in Vietnam from consumption perspective by examining the impacts of a hypothetical increase in environmental taxes on household welfare. A rise in energy prices from a tax reform reduces household welfare. The magnitudes of the changes are diverse across different demographics and geographical regions depending on households' elasticity of substitution between energy and non-energy goods. The environmental taxes in Vietnam are found to be neither strictly regressive nor progressive, and the third and fourth household groups by decile of expenditure suffer the most significant loss. The total increase in tax revenue for the government, however, cannot offset the total welfare reduction from households, suggesting a deadweight loss in the economy. The results are robust regardless of short-term or long-term analyses and different own-price elasticities of energy.

Environmental taxes also play a critical role in the power generation sector. As reported in Chapter 4, current energy taxes lead to the profitability of coal-based power generation. The law on environmental protection taxes sets a trivial tax rate on coal, an energy type with the highest carbon content compared with other fossil fuels (e.g., oil and gas). Power projects are no longer as profitable as expected and can even suffer a loss if carbon taxes, which impose a heavier penalty on coal consumption based on its carbon content, are introduced. Among various factors, the economics of a power project are considerably sensitive to coal price and electricity price, while they are less sensitive to changes in operating and maintenance costs. This suggests the uncertainty of a power project due to economic parameters.

Finally, this thesis provides another key finding on the energy efficiency of Vietnam. As a complement to Chapter 2, Chapter 5 examined energy efficiency in relation to international trade at the firm level. The results show that firms self-select into becoming exporters or choosing to serve the domestic market alone. Firms with below (or above) average energy intensity are likely to export (or not to export). Participation in international supply chains helps firms to improve their energy efficiency, yet the magnitudes vary across export status due to systematic differences between exporting and non-exporting firms. The results are robust in all specifications using different energy intensity measures and models, confirming the pro-environment effect of international trade among Vietnamese SMEs in the manufacturing sector.

6.2 Policy implications

A number of policy implications can be drawn from the empirical findings in this thesis. The first focuses on the development strategy of the energy sector. As revealed in Chapter 2, due to linkages among sectors in the economy, any policies that aim to increase economic growth can have economy-wide impacts. An expansionary policy in one sector is associated with changes in others, including the energy sector. However, the energy sector in Vietnam, particularly electricity generation, has been dominated by fossil fuels, which is the main source of greenhouse gas (GHG) emissions. Therefore, the government needs to promote a green transformation of the energy sector from fossil fuels to renewables. Although energy demand continues to increase, the green transformation will contribute to a decline in CO_2 emissions level released from energy consumption. An appropriate fuel mix helps the country to achieve green growth and sustainable development as well as prevent further climate change.

Second, there is a need to reform the environmental protection taxes, particularly tax rates on energy. The current energy taxes have failed to achieve the primary target of protecting the environment and have created a favourable economic condition for the development of coal-based power generation, as discussed in Chapter 4. Given the substantial contribution of coal in the total energy consumption and power generation sector, the reformed tax rates should be well determined to reflect the carbon content of energies, i.e., imposing a higher penalty on coal compared with gasoline and oil. This can reduce the consumption of 'dirty' fossil fuels and reorient the national power development strategy from coal-based generation to other cleaner supply sources such as natural gas and renewables.

Third, the possible welfare impacts of energy taxes in Chapter 3 suggest that the government should establish an appropriate roadmap for reform in environmental taxes and develop complementary programs to support the most affected household groups. Tax reform should be conducted step-by-step with incremental changes in tax rates and interim assessments. One possible strategy is to conduct small-scale pilots to gain experience and evaluate preliminary effects before implementing a large-scale policy. Also, complimentary programs should be pro-poor, on target, and not overlap with existing subsidy schemes. This requires a careful review of current policies and identification of the right groups to avoid wasteful government spending.

Finally, the government should encourage technological innovation to improve the country's energy efficiency and environmental performance. Results from Chapter 2 indicate that technology is particularly crucial for high energy-intensive sectors to lower their energy consumption and overall emissions. Additionally, as discussed in Chapter 4, the application of more advanced technology in coal-based power plants, which reduces coal consumption per unit of electricity generated and releases ash more effectively, is likely to alleviate detrimental effects on the environment. Also, in Chapter 5, the innovation variable has negative impact on energy intensity, although the coefficient is statistically insignificant. Therefore, throughout the thesis, innovation in production processes is suggested to improve energy efficiency at both the aggregate and micro levels.

6.3 Suggestions for future research

Several potentially fruitful extensions for future research have emerged from this thesis. A more detailed study, which disaggregates the energy sector into different energies such as fossil fuels and non-fossil fuels, would be of significant value, as the elasticity with respect to GDP of different energy types is likely to vary (Burke and Csereklyei, 2016). Therefore, the disaggregation would provide a more detailed estimation for the energy-GDP relationship.

There is also a potential for research on different forms of revenue-recycling options to achieve a double dividend effect of energy taxes (Pearce, 1991, Parry and Bento, 2000, Bor and Huang, 2010, Orlov and Grethe, 2012). The revenue-neutral strategies can lead to social welfare improvement for Vietnam. Research on the impacts of either lump-sum transfer from environmental taxes' revenue or the use of other more distortionary taxes such as income taxes to alleviate household welfare loss is worth proceeding (Parry and Bento, 2000, Bor and Huang, 2010, Orlov and Grethe, 2012). The results in Chapter 3 can be extended further with a comparison between welfare loss and the environmental benefits of the tax reform. Due to the negative effects of emissions from energy goods on human health and labour productivity, the tax reform could be expected to reduce emissions and alleviate health problems related to air pollution. This should be considered when examining the total impacts of the environmental tax law.

Moreover, significant opportunities arise for additional research that focuses on the trade-environment nexus. In particular, the surveys used in Chapter 5 cover only a small number of SMEs in Vietnam, and the number of exporting firms is insufficient to provide sectoral estimates since the number of exporting firms in each sector is quite small. An analysis with a bigger dataset could potentially be suitable for sectoral disaggregation to control firms' heterogeneity across sectors. Also, further research should focus on exporting destinations in trade-environment nexus. The impacts of participation in international supply chains on energy efficiency are likely to vary across exporting destinations depending on environmental regulations and types of free trade agreements that importing countries have (e.g., Nemati et al. (2019). This would provide a more complete conclusion about the relationship between international trade and energy at the firm level in Vietnam.

References

Abdulai, A. & Huffman, W. 2014. The adoption and impact of soil and water conservation technology: An endogenous switching regression application. *Land Economics,* 90**,** 26-43.

ACIL Allen 2014. Fuel and technology cost review: report to Australian Energy Market Operator (AEMO). Brisbane, Queensland: ACIL Allen Consulting PTY Ltd.

Adamantiades, A. & Kessides, I. 2009. Nuclear power for sustainable development: Current status and future prospects. *Energy Policy,* 37**,** 5149-5166.

Adams, F. G. & Miovic, P. 1968. On Relative Fuel Efficiency and the Output Elasticity of Energy Consumption in Western Europe. *The Journal of Industrial Economics,* 17**,** 41-56.

ADB 2015a. Assessment of Power Sector Reforms in Vietnam.

ADB 2015b. Emissions trading scheme and their linking: challenges and opportunities in Asia and the Pacific. Philippines.

Aggrey, N., Eliab, L. & Joseph, S. 2010. Determinants of export participation in east African manufacturing firms. *Current Research Journal of Economic Theory,* 2**,** 55-61.

Akram, R., Chen, F., Khalid, F., Ye, Z. & Majeed, M. T. 2020. Heterogeneous effects of energy efficiency and renewable energy on carbon emissions: Evidence from developing countries. *Journal of Cleaner Production,* 247**,** 119122.

Albornoz, F., Cole, M. A., Elliott, R. J. R. & Ercolani, M. G. 2009. In search of environmental spillovers. *World Economy,* 32**,** 136-163.

Alene, A. D. & Manyong, V. M. 2007. The effects of education on agricultural productivity under traditional and improved technology in northern Nigeria: an endogenous switching regression analysis. *Empirical Economics,* 32**,** 141-159.

Ali, K., Bakhsh, S., Ullah, S., Ullah, A. & Ullah, S. 2020. Industrial growth and CO 2 emissions in Vietnam: the key role of financial development and fossil fuel consumption. *Environmental Science and Pollution Research***,** 1-13.

Allan, G., McGregor, P. & Swales, K. 2011. The importance of revenue sharing for the local economic impacts of a renewable energy project: A social accounting matrix approach. *Regional Studies,* 45**,** 1171-1186.

Allan, G. J., Lecca, P., McGregor, P. G. & Swales, J. K. 2014. The economic impacts of marine energy developments: A case study from Scotland. *Marine Policy,* 43**,** 122-131.

Ang, B. W. 1987a. A cross-sectional analysis of energy—output correlation. *Energy Economics,* 9**,** 274-286.

Ang, B. W. 1987b. Energy-output ratios and sectoral energy use: The case of Southeast Asian countries. *Energy Policy,* 15**,** 262-282.

Ang, B. W. 1991. A statistical analysis of energy coefficients. *Energy Economics,* 13**,** 93-110.

Ang, B. W. 2006. Monitoring changes in economy-wide energy efficiency: From energy–GDP ratio to composite efficiency index. *Energy Policy,* 34**,** 574-582.

Ang, J. B. 2007. CO2 emissions, energy consumption, and output in France. *Energy Policy,* 35**,** 4772-4778.

Antweiler, W., Copeland, B. R. & Taylor, M. S. 2001. Is free trade good for the environment? *American Economic Review,* 91**,** 877-908.

Apergis, N. & Payne, J. E. 2009a. Energy consumption and economic growth in Central America: Evidence from a panel cointegration and error correction model. *Energy Economics,* 31**,** 211-216.

Apergis, N. & Payne, J. E. 2009b. Energy consumption and economic growth: Evidence from the Commonwealth of Independent States. *Energy Economics*, 31**,** 641-647.
Archibald, R. & Gillingham, R. 1980. An Analysis of the Short-Run Consumer Demand for Gasoline Using Household Survey Data. *The Review of Economics and Statistics,* 62**,** 622-628.
Arimura, T. H., Hibiki, A. & Katayama, H. 2008. Is a voluntary approach an effective environmental policy instrument?: A case for environmental management systems. *Journal of Environmental Economics and Management,* 55**,** 281-295.
Arrow, K. J., Chenery, H. B., Minhas, B. S. & Solow, R. M. 1961. Capital-Labor Substitution and Economic Efficiency. *The Review of Economics and Statistics,* 43**,** 225-250.
Asghar, Z. 2008. Energy-GDP relationship: a causal analysis for the five countries of South Asia. *Applied Econometrics and International Development,* 8.
Aydin, C. & Esen, Ö. 2018. Reducing CO2 emissions in the EU member states: Do environmental taxes work? *Journal of Environmental Planning and Management***,** 1-25.
Aydiner-Avsar, N. & Onaran, Ö. 2010. The determinants of employment: A sectoral analysis for Turkey. *The Developing Economies,* 48**,** 203-231.
Azam, M. 2020. Energy and economic growth in developing Asian economies. *Journal of the Asia Pacific Economy,* 25**,** 447-471.
Babiker, M. H., Metcalf, G. E. & Reilly, J. 2003. Tax distortions and global climate policy. *Journal of Environmental Economics and Management,* 46**,** 269-287.
Bach, S., Kohlhaas, M. & Praetorius, B. 1994. Ecological tax reform even if Germany has to go it alone. *Economic Bulletin,* 31**,** 3-10.
Balcilar, M., Bekun, F. V. & Uzuner, G. 2019. Revisiting the economic growth and electricity consumption nexus in Pakistan. *Environmental Science and Pollution Research,* 26**,** 12158-12170.
Bao, Q., Shao, M. & Song, L. 2014. Is Export Spillover Localized in China. *Review of Development Economics,* 18**,** 218-230.
Barker, T. & Rosendahl, K. E. 2000. Ancillary Benefits of GHG Mitigation in Europe: SO2, NOx and PM10 reductions from policies to meet Kyoto targets using the E3ME model and Externe valuations. *Ancillary Benefits and Costs of Greenhouse Gas Mitigation***,** 413-450.
Barrios, S., Görg, H. & Strobl, E. 2003a. Explaining firms' export behaviour: R&D, spillovers and the destination market. *Oxford Bulletin of Economics and Statistics,* 65**,** 475-496.
Barrios, S., Görg, H. & Strobl, E. 2003b. Explaining Firms’ Export Behaviour: R&D, Spillovers and the Destination Market. *Oxford Bulletin of Economics & Statistics,* 65**,** 475-496.
Barros, C. P. & Prieto-Rodriguez, J. 2008. A revenue-neutral tax reform to increase demand for public transport services. *Transportation Research Part A: Policy and Practice,* 42**,** 659-672.
Batrakova, S. & Davies, R. B. 2012. Is there an environmental benefit to being an exporter? Evidence from firm-level data. *Review of World Economics,* 148**,** 449-474.
Baumol, W. J., Baumol, W. J., Oates, W. E., Bawa, V. S., Bawa, W. & Bradford, D. F. 1988. *The theory of environmental policy,* Cambridge university press.
Baumol, W. J. & Oates, W. E. 1971. The use of standards and prices for protection of the environment. *The economics of environment.* Springer.
Bautista, R. M., Robinson, S. & El-Said, M. 1999. Alternative industrial development paths for Indonesia: SAM and CGE analyses.
Bayar, G. 2018. Estimating export equations: a survey of the literature. *Empirical Economics,* 54**,** 629-672.

Beck, M., Rivers, N., Wigle, R. & Yonezawa, H. 2015. Carbon tax and revenue recycling: Impacts on households in British Columbia. *Resource and Energy Economics,* 41**,** 40-69.
Belke, A., Dobnik, F. & Dreger, C. 2011. Energy consumption and economic growth: New insights into the cointegration relationship. *Energy Economics,* 33**,** 782-789.
Bergquist, A.-K., Söderholm, K., Kinneryd, H., Lindmark, M. & Söderholm, P. 2013. Command-and-control revisited: Environmental compliance and technological change in Swedish industry 1970–1990. *Ecological Economics,* 85**,** 6-19.
Bernard, A. B. & Wagner, J. 2001. Export Entry and Exit by German Firms. *Weltwirtschaftliches Archiv,* 137**,** 105-123.
Bhattacharyya, S. C. 2011. *Energy economics: concepts, issues, markets and governance,* Springer Science & Business Media.
Binh, P. T. 2011. Energy consumption and economic growth in Vietnam: Threshold cointegration and causality analysis. *International Journal of Energy Economics and Policy,* 1**,** 1-17.
Bizer, K. & Julich, R. 1999. Voluntary agreements - trick or treat? *European Environment,* 9**,** 59-66.
Bloom, N., Genakos, C., Martin, R. & Sadun, R. 2010. Modern management: good for the environment or just hot air? *The economic journal,* 120**,** 551-572.
Bloom, N. & Van Reenen, J. 2010. Why do management practices differ across firms and countries? *Journal of Economic Perspectives,* 24**,** 203-224.
Boardman, A., Greenberg, D. H., Vining, A. R. & Weimer, D. L. 2011. *Cost-Benefit Analysis: Concepts and Practice,* London, Prentice Hall.
Bor, Y. J. & Huang, Y. 2010. Energy taxation and the double dividend effect in Taiwan's energy conservation policy-an empirical study using a computable general equilibrium model. *Energy Policy,* 38**,** 2086-2100.
Borges, A. M. 1986. Applied general equilibrium models: an assessment of their usefulness for policy analysis. *OECD Economic Studies,* 7**,** 7-43.
Branker, K., Pathak, M. J. M. & Pearce, J. M. 2011. A review of solar photovoltaic levelized cost of electricity. *Renewable and Sustainable Energy Reviews,* 15**,** 4470-4482.
Brännlund, R. & Nordström, J. 2004. Carbon tax simulations using a household demand model. *European Economic Review,* 48**,** 211-233.
Breisinger, C., Thomas, M. & Thurlow, J. 2009. *Social accounting matrices and multiplier analysis: An introduction with exercises,* Intl Food Policy Res Inst.
Brons, M., Nijkamp, P., Pels, E. & Rietveld, P. 2008. A meta-analysis of the price elasticity of gasoline demand. A SUR approach. *Energy Economics,* 30**,** 2105-2122.
Bruns, S. B. & Ioannidis, J. P. 2016. P-curve and p-hacking in observational research. *PloS one,* 11**,** e0149144.
Bui, H. P. 2017. Coal-fired power: Waste and cooling water. *Vietnam Energy* [Online]. Available: http://nangluongvietnam.vn/news/vn/nhan-dinh-phan-bien-kien-nghi/phan-bien-kien-nghi/vi-sao-viet-nam-can-phat-trien-nhiet-dien-than-bai-9.html [Accessed 10 June 2020].
Burfisher, M. E., Robinson, S., Thierfelder, K. & Center, W. W. Modeling OECD Agricultural Programs in a Global Context. Empirical Trade Policy Conference, Washington, DC, 2003.
Burke, P. J. & Csereklyei, Z. 2016. Understanding the energy-GDP elasticity: A sectoral approach. *Energy Economics,* 58**,** 199-210.
Burke, P. J. & Nishitateno, S. 2013. Gasoline prices, gasoline consumption, and new-vehicle fuel economy: Evidence for a large sample of countries. *Energy Economics,* 36**,** 363-370.

Bustos, P. 2011. Trade liberalization, exports, and technology upgrading: Evidence on the impact of MERCOSUR on argentinian firms. *American Economic Review,* 101**,** 304-340.
Carbone, J. C. & McKenzie, K. J. 2016. Going Dutch? The impact of falling oil prices on the Canadian economy. *Canadian Public Policy,* 42**,** 168-180.
Chandran, V. G. R., Sharma, S. & Madhavan, K. 2010. Electricity consumption-growth nexus: The case of Malaysia. *Energy Policy,* 38**,** 606-612.
Chen, Y., Han, B. & Liu, W. 2016. Green technology innovation and energy intensity in China. *Natural Hazards,* 84**,** 317-332.
Chen, Z. M., Liu, Y., Qin, P., Zhang, B., Lester, L., Chen, G., Guo, Y. & Zheng, X. 2015. Environmental externality of coal use in China: Welfare effect and tax regulation. *Applied Energy,* 156**,** 16-31.
Choi, J. K., Bakshi, B. R. & Haab, T. 2010. Effects of a carbon price in the U.S. on economic sectors, resource use, and emissions: An input-output approach. *Energy Policy,* 38**,** 3527-3536.
Choi, J. K., Bakshi, B. R., Hubacek, K. & Nader, J. 2016. A sequential input–output framework to analyze the economic and environmental implications of energy policies: Gas taxes and fuel subsidies. *Applied Energy,* 184**,** 830-839.
Clark, R., Zucker, N. & Urpelainen, J. 2020. The future of coal-fired power generation in Southeast Asia. *Renewable and Sustainable Energy Reviews,* 121**,** 109650.
Clerides, S. K., Lach, S. & Tybout, J. R. 1998. Is learning by exporting important? Micro-dynamic evidence from Colombia, Mexico, and Morocco. *Quarterly Journal of Economics,* 113**,** 903-947.
Cole, M. A. & Elliott, R. J. R. 2003. Determining the trade-environment composition effect: The role of capital, labor and environmental regulations. *Journal of Environmental Economics and Management,* 46**,** 363-383.
Cole, M. A., Elliott, R. J. R., Okubo, T. & Zhou, Y. 2013. The carbon dioxide emissions of firms: A spatial analysis. *Journal of Environmental Economics and Management,* 65**,** 290-309.
Cole, M. A., Elliott, R. J. R. & Shimamoto, K. 2006. Globalization, firm-level characteristics and environmental management: A study of Japan. *Ecological Economics,* 59**,** 312-323.
Cole, M. A., Elliott, R. J. R. & Strobl, E. 2008. The environmental performance of firms: The role of foreign ownership, training, and experience. *Ecological Economics,* 65**,** 538-546.
Conefrey, T., Fitz Gerald, J. D., Valeri, L. M. & Tol, R. S. J. 2013. The impact of a carbon tax on economic growth and carbon dioxide emissions in Ireland. *Journal of Environmental Planning and Management,* 56**,** 934-952.
Cornillie, J. & Fankhauser, S. 2004. The energy intensity of transition countries. *Energy Economics,* 26**,** 283-295.
Correa, P., Dayoub, M. & Francisco, M. 2011. Trade liberalization and 'export response': Whither complementary reforms? *The Journal of International Trade & Economic Development,* 20**,** 379-400.
Coxhead, I., Wattanakuljarus, A. & Nguyen, C. V. 2013. Are carbon taxes good for the poor? A general equilibrium analysis for Vietnam. *World Development,* 51**,** 119-131.
Creedy, J. & Sleeman, C. 2006. Carbon taxation, prices and welfare in New Zealand. *Ecological Economics,* 57**,** 333-345.
Csereklyei, Z., Rubio-Varas, M. d. M. & Stern, D. I. 2016. Energy and economic growth: the stylized facts. *The Energy Journal,* 37.

Cui, J., Lapan, H. & Moschini, G. 2016. Productivity, Export, and Environmental Performance: Air Pollutants in the United States. *American Journal of Agricultural Economics,* 98**,** 447-467.
Cui, J. & Qian, H. 2017. The effects of exports on facility environmental performance: Evidence from a matching approach. *Journal of International Trade and Economic Development,* 26**,** 759-776.
Dagher, L. & Yacoubian, T. 2012. The causal relationship between energy consumption and economic growth in Lebanon. *Energy Policy,* 50**,** 795-801.
Dahl, C. A. 2012. Measuring global gasoline and diesel price and income elasticities. *Energy Policy,* 41**,** 2-13.
Dardati, E. & Saygili, M. 2012. Multinationals and environmental regulation: Are foreign firms harmful? *Environment and Development Economics,* 17**,** 163-186.
De Castro, C., Mediavilla, M., Miguel, L. J. & Frechoso, F. 2011. Global wind power potential: Physical and technological limits. *Energy Policy,* 39**,** 6677-6682.
De Castro, C., Mediavilla, M., Miguel, L. J. & Frechoso, F. 2013. Global solar electric potential: A review of their technical and sustainable limits. *Renewable and Sustainable Energy Reviews,* 28**,** 824-835.
De Jong, P., Kiperstok, A. & Torres, E. A. 2015. Economic and environmental analysis of electricity generation technologies in Brazil. *Renewable and Sustainable Energy Reviews,* 52**,** 725-739.
Del Bo, C., Fiorio, C. & Florio, M. 2011. Shadow Wages for the EU Regions. *Fiscal Studies,* 32**,** 109-143.
Delgado, M. A., Fariñas, J. C. & Ruano, S. 2002. Firm productivity and export markets: a non-parametric approach. *Journal of International Economics,* 57**,** 397-422.
Dessai, S., Adger, W. N., Hulme, M., Turnpenny, J., Köhler, J. & Warren, R. 2004. Defining and experiencing dangerous climate change. *Climatic change,* 64**,** 11-25.
Devarajan, S., Go, D. S., Robinson, S. & Thierfelder, K. 2011. Tax policy to reduce carbon emissions in a distorted economy: Illustrations from a South Africa CGE model. *B.E. Journal of Economic Analysis and Policy,* 11.
Di Cosmo, V. & Hyland, M. 2013. Carbon tax scenarios and their effects on the Irish energy sector. *Energy Policy,* 59**,** 404-414.
Diakoulaki, D. & Karangelis, F. 2007. Multi-criteria decision analysis and cost–benefit analysis of alternative scenarios for the power generation sector in Greece. *Renewable and Sustainable Energy Reviews,* 11**,** 716-727.
Dissou, Y. & Siddiqui, M. S. 2014. Can carbon taxes be progressive? *Energy Economics,* 42**,** 88-100.
Doroodian, K. & Boyd, R. 2003. The linkage between oil price shocks and economic growth with inflation in the presence of technological advances: A CGE model. *Energy Policy,* 31**,** 989-1006.
Dueñas-Caparas, T. S. 2006. Determinants of export performance in the Philippine manufacturing sector. PIDS Discussion Paper Series.
Dumagan, J. C. & Mount, T. D. 1992. Measuring the consumer welfare effects of carbon penalties: Theory and applications to household energy demand. *Energy Economics,* 14**,** 82-93.
Ederington, J., Levinson, A. & Minier, J. 2005. Footloose and pollution-free. *Review of Economics and Statistics,* 87**,** 92-99.
Ederington, J. & Minier, J. 2003. Is environmental policy a secondary trade barrier? An empirical analysis. *Canadian Journal of Economics,* 36**,** 137-154.
Ehrlich, P. R. & Holdren, J. P. 1971. Impact of population growth. *Science,* 171**,** 1212-1217.
EIA 2020a. Average operating heat rate for selected energy sources.

EIA 2020b. Levelized Cost and Levelized Avoided Cost of New Generation Resources AEO2020.
Ekins, P. & Barker, T. 2001. Carbon taxes and carbon emissions trading. *Journal of Economic Surveys,* 15**,** 325-376.
Engle, R. F. & Granger, C. W. 1987. Co-integration and error correction: representation, estimation, and testing. *Econometrica: journal of the Econometric Society***,** 251-276.
EREA & DEA 2019. Vietnam Energy Outlook Report 2019.
Eren, B. M., Taspinar, N. & Gokmenoglu, K. K. 2019. The impact of financial development and economic growth on renewable energy consumption: Empirical analysis of India. *Science of the Total Environment,* 663**,** 189-197.
European Commission 2015. Guide to Cost-Benefit Analysis of Investment Projects. Luxembourg, European Union.
Eurostat 2013. Environmental taxes - A statistical guide. *Manuals and guidelines.* European Union.
EVN. 2019. Can Vietnam develop super clean coal thermal power like Japan? *Vietnam Electricity* [Online]. Available: https://www.evn.com.vn/d6/news/Viet-Nam-co-the-phat-trien-nhiet-dien-than-sieu-sach-nhu-Nhat-Ban-6-8-24753.aspx [Accessed 10 June 2020].
Fan, J. L., Wei, S., Yang, L., Wang, H., Zhong, P. & Zhang, X. 2019. Comparison of the LCOE between coal-fired power plants with CCS and main low-carbon generation technologies: Evidence from China. *Energy,* 176**,** 143-155.
Fan, Y., Jiao, J. L., Liang, Q. M., Han, Z. Y. & Wei, Y. M. 2007. The impact of rising international crude oil price on China's economy: An empirical analysis with CGE model. *International Journal of Global Energy Issues,* 27**,** 404-424.
Fathurrahman, F., Kat, B. & Soytaş, U. 2017. Simulating Indonesian fuel subsidy reform: a social accounting matrix analysis. *Annals of Operations Research,* 255**,** 591-615.
Feenstra, R. C., Ma, H. & Xu, Y. 2019. US exports and employment. *Journal of International Economics,* 120**,** 46-58.
Feng, K., Hubacek, K., Guan, D., Contestabile, M., Minx, J. & Barrett, J. 2010. Distributional effects of climate change taxation: The case of the UK. *Environmental Science and Technology,* 44**,** 3670-3676.
Feng, K., Hubacek, K., Liu, Y., Marchán, E. & Vogt-Schilb, A. 2018. Managing the distributional effects of energy taxes and subsidy removal in Latin America and the Caribbean. *Applied Energy,* 225**,** 424-436.
Fernihough, A. & O'Rourke, K. H. 2014. Coal and the European industrial revolution. National Bureau of Economic Research.
Floros, N. & Vlachou, A. 2005. Energy demand and energy-related CO2 emissions in Greek manufacturing: Assessing the impact of a carbon tax. *Energy Economics,* 27**,** 387-413.
Foran, B. & Poldy, F. 2002. Future Dilemmas: Options to 2050 for Australia's population, technology, resources and environment. *CSIRO Sustainable Ecosystems Resource Futures Program Working Paper Series.* Canberra, Australia.
Frankel, J. A. & Rose, A. K. 2005. Is trade good or bad for the environment? sorting out the causality. *Review of Economics and Statistics,* 87**,** 85-91.
Fuglie, K. O. & Bosch, D. J. 1995. Economic and environmental implications of soil nitrogen testing: A switching-regression analysis. *American Journal of Agricultural Economics,* 77**,** 891-900.
Fullerton, D. & Heutel, G. 2011. Analytical general equilibrium effects of energy policy on output and factor prices. *B.E. Journal of Economic Analysis and Policy,* 10.
Galdeano-Gómez, E. 2010. Exporting and environmental performance: A firm-level productivity analysis. *World Economy,* 33**,** 60-88.

Gallardo, A. & Mardones, C. 2013. Environmentally extended social accounting matrix for Chile. *Environment, Development and Sustainability,* 15**,** 1099-1127.
Garrett-Peltier, H. 2017. Green versus brown: Comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model. *Economic Modelling,* 61**,** 439-447.
Gemechu, E. D., Butnar, I., Llop, M. & Castells, F. 2014. Economic and environmental effects of CO2 taxation: an input-output analysis for Spain. *Journal of Environmental Planning and Management,* 57**,** 751-768.
Ghalwash, T. 2007. Energy taxes as a signaling device: An empirical analysis of consumer preferences. *Energy Policy,* 35**,** 29-38.
Gilmartin, M. & Allan, G. 2015. Regional Employment Impacts of Marine Energy in the Scottish Economy: A General Equilibrium Approach. *Regional Studies,* 49**,** 337-355.
Girma, S. & Hanley, A. 2015. How Green are Exporters? *Scottish Journal of Political Economy,* 62**,** 291-309.
Givord, P., Grislain-Letrémy, C. & Naegele, H. 2018. How do fuel taxes impact new car purchases? An evaluation using French consumer-level data. *Energy Economics,* 74**,** 76-96.
Goldemberg, J. 2000. *World energy assessment: Energy and the challenge of sustainability*, United Nations Development Programme, New York.
Government Office 2011a. Decision 1208/QD-TTg dated July 21, 2011 on approval of the national master plan for power development in the 2011-2020 period with considerations to 2030. Hanoi, Vietnam.
Government Office 2011b. Decision No. 268/QD-TTg on the electricity retail price tariff.
Government Office 2015. Decision No. 2068/QD-TTg on Development Strategy of Renewable Energy of Vietnam by 2030 with a Vision to 2050. Hanoi, Vietnam.
Government Office 2016a. Decision 403/QD-TTg on approving the adjusted master plan on development of Vietnam's coal industry through 2020, with prospects toward 2030. Hanoi, Vietnam.
Government Office 2016b. Decision 428/QD-TTg on the Approval of the Revised National Power Development Master Plan for the 2011-2020 period with the Vision to 2030. Hanoi, Vietnam.
Gozgor, G., Lau, C. K. M. & Lu, Z. 2018. Energy consumption and economic growth: New evidence from the OECD countries. *Energy,* 153**,** 27-34.
Greenaway, D., Guariglia, A. & Kneller, R. 2007. Financial factors and exporting decisions. *Journal of International Economics,* 73**,** 377-395.
Griffin, J. M. & Steele, H. B. 1986. *Energy economics and policy*, Elsevier.
GSO 2004. Results of Establishment Census of Vietnam 2002, Volume 2-Business Establishments. Hanoi: Statistical Publishing House
GSO 2007. The real situation of enterprises through the results of surveys conducted in 2004, 2005, 2006. Hanoi: Statistical Publishing House
GSO 2016. *Vietnam population forecasts 2014-2049,* Hanoi, Vietnam News Agency Publishing House.
GSO. 2018. Socio-economic situation in the fourth quater and the whole year 2017. *General Statistics Office* [Online]. Available: https://www.gso.gov.vn/en/data-and-statistics/2019/10/report-social-and-economic-situations-in-2017/ [Accessed 5/11/2018].
GSO. 2019. Socio-economic situation in the fourth quater and the whole year 2018. Available: https://www.gso.gov.vn/en/data-and-statistics/2020/01/socio-economic-situation-in-the-fourth-quarter-and-the-whole-year-2019/ [Accessed 5/11/2020].

GSO. 2020. Socio-economic situation in the fourth quater and the whole year 2019. Available: https://www.gso.gov.vn/en/data-and-statistics/2020/01/socio-economic-situation-in-the-fourth-quarter-and-the-whole-year-2019/ [Accessed 5/11/2020].
Ha-Duong, M. & Nguyen-Trinh, H. A. 2017. Two scenarios for carbon capture and storage in Vietnam. *Energy Policy,* 110**,** 559-569.
Haines, A., McMichael, A. J., Smith, K. R., Roberts, I., Woodcock, J., Markandya, A., Armstrong, B. G., Campbell-Lendrum, D., Dangour, A. D. & Davies, M. 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. *The Lancet,* 374**,** 2104-2114.
Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D. & Vogt-Schilb, A. 2015. *Shock waves: managing the impacts of climate change on poverty*, The World Bank.
Hamilton, K. & Cameron, G. 1994. Simulating the distributional effects of a Canadian carbon tax. *Canadian Public Policy/Analyse de Politiques,* 20**,** 385-399.
Hanna Berkel, John Rand, Finn Tarp & Neda Trifković 2020. The Vietnam SME Data, 2005–15. *In:* John Rand & Finn Tarp (eds.) *Micro, small, and medium enterprises in Vietnam.* United Kingdom: Oxford University Press.
Hansen, H. & Nguyen, T. 2007. *Market, Policy and Poverty Reduction in Vietnam*, Vietnam Culture and Information Publishing House.
Hartono, D. & Resosudarmo, B. P. 2008. The economy-wide impact of controlling energy consumption in Indonesia: An analysis using a Social Accounting Matrix framework. *Energy Policy,* 36**,** 1404-1419.
Havránek, T. 2015. Measuring intertemporal substitution: The importance of method choices and selective reporting. *Journal of the European Economic Association,* 13**,** 1180-1204.
Hawkins, J. & Hunt, J. D. 2019. Development of environmentally extended social accounting matrices for policy analysis in Alberta. *Economic Systems Research,* 31**,** 114-131.
Henriques, C. O., Coelho, D. H. & Cassidy, N. L. 2016. Employment impact assessment of renewable energy targets for electricity generation by 2020—An IO LCA approach. *Sustainable Cities and Society,* 26**,** 519-530.
Herring, H. & Sorrell, S. 2009. Energy efficiency and sustainable consumption. *The Rebound Effect, Hampshire*.
Hertel, T. W. & Rosch, S. D. 2010. *Climate change, agriculture and poverty*, The World Bank.
Hien, P. 2019. Excessive electricity intensity of Vietnam: Evidence from a comparative study of Asia-Pacific countries. *Energy Policy,* 130**,** 409-417.
Hil Baky, M. A., Rahman, M. M. & Islam, A. K. M. S. 2017. Development of renewable energy sector in Bangladesh: Current status and future potentials. *Renewable and Sustainable Energy Reviews,* 73**,** 1184-1197.
Holladay, J. S. 2016. Exporters and the Environment. *Canadian Journal of Economics/Revue canadienne d'économique,* 49**,** 147-172.
Holladay, S. 2008. *Are Exporters Mother Nature's Best Friends?*, Center for Economic Analysis, Department of Economics, University of Colorado at Boulder.
Hone, J. & Clutton-Brock, T. H. 2007. Climate, food, density and wildlife population growth rate: Forum. *Journal of Animal Ecology,* 76**,** 361-367.
Hunter, C. M., Caswell, H., Runge, M. C., Regehr, E. V., Amstrup, S. C. & Stirling, I. 2010. Climate change threatens polar bear populations: A stochastic demographic analysis. *Ecology,* 91**,** 2883-2897.
IEA 2013. World Energy Outlook 2013. Paris.
IEA 2018. Data and Statistics.
IEA 2019a. Data and Statistics.
IEA 2019b. Global Energy & CO2 Status Report 2019. Paris.

IEA 2019c. Nuclear Power in a Clean Energy System. Paris.
IEA 2019d. Tracking Power 2019. Paris: IEA.
IEA 2020a. Data and Statistics.
IEA 2020b. Tracking Power 2020. Paris: IEA.
IEA, NEA & OECD 2015. Projected Costs of Generating Electricity 2015 Edition. *IEA OECD NEA.* International Energy Agency, Nuclear Energy Agency and Organization for Economic Co-operation and Development.
Inkley, D., Anderson, M. G., Blaustein, A. R., Burkett, V., Felzer, B., Griffith, B., Price, J. & Root, T. L. 2004. Global climate change and wildlife in North America. *Technical review***,** 1-26.
Institute of Energy 2015. The Revised National Power Development Master Plan for the 2011-2020 period with the Vision to 2030. Ministry of Industry and Trade.
Isa, Z., Al Sayed, A. R. M. & Kun, S. S. 2015. Review paper on economic growth – Aggregate energy consumption nexus. *International Journal of Energy Economics and Policy,* 5**,** 385-401.
Ishwaran, M., King, W., Haigh, M., Lee, T. & Nie, S. 2017. Developments in Global Natural Gas Consumption. *In:* DRC, S. a. (ed.) *China's Gas Development Strategies.*
Islas, J., Manzini, F. & Martínez, M. 2003. Cost-benefit analysis of energy scenarios for the Mexican power sector. *Energy,* 28**,** 979-992.
Jackson, C. & Pearson, R. 2005. *Feminist visions of development: gender analysis and policy*, Routledge.
Jaffe, A. B., Peterson, S. R., Portney, P. R. & Stavins, R. N. 1995. Environmental regulation and the competitiveness of US manufacturing: what does the evidence tell us? *Journal of Economic literature,* 33**,** 132-163.
Jänicke, M., Binder, M. & Mönch, H. 1997. 'Dirty industries': Patterns of change in industrial countries. *Environmental and resource economics,* 9**,** 467-491.
Jansen, H. & Klaassen, G. 2000. Economic impacts of the 1997 EU energy tax: Simulations with three EU-wide models. *Environmental and Resource Economics,* 15**,** 179-197.
JICA 2008. The study on national energy master plan in Viet Nam.
Johansen, S. 1991. Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. *Econometrica: journal of the Econometric Society***,** 1551-1580.
Johnson, M., McKay, A. D. & Round, J. I. 1990. *Income and expenditure in a system of household accounts. Concepts and estimation,* World Bank.
Kaiser, K. & Schulze, G. G. 2003. International competition and environmental expenditures: empirical evidence from Indonesian manufacturing plants.
Kaldellis, J. K. & Gavras, T. J. 2000. The economic viability of commercial wind plants in Greece A complete sensitivity analysis. *Energy Policy,* 28**,** 509-517.
Kaldellis, J. K., Vlachou, D. S. & Korbakis, G. 2005. Techno-economic evaluation of small hydro power plants in Greece: A complete sensitivity analysis. *Energy Policy,* 33**,** 1969-1985.
Kampa, M. & Castanas, E. 2008. Human health effects of air pollution. *Environmental pollution,* 151**,** 362-367.
Karakosta, C., Pappas, C., Marinakis, V. & Psarras, J. 2013. Renewable energy and nuclear power towards sustainable development: Characteristics and prospects. *Renewable and Sustainable Energy Reviews,* 22**,** 187-197.
Karkacier, O. & Gokalp Goktolga, Z. 2005. Input–output analysis of energy use in agriculture. *Energy Conversion and Management,* 46**,** 1513-1521.
Kaygusuz, K. & Sarı, A. 2003. Renewable energy potential and utilization in Turkey. *Energy Conversion and Management,* 44**,** 459-478.

Kayser, H. A. 2000. Gasoline demand and car choice: estimating gasoline demand using household information. *Energy Economics,* 22**,** 331-348.
Kefford, B. M., Ballinger, B., Schmeda-Lopez, D. R., Greig, C. & Smart, S. 2018. The early retirement challenge for fossil fuel power plants in deep decarbonisation scenarios. *Energy Policy,* 119**,** 294-306.
Kerkhof, A. C., Moll, H. C., Drissen, E. & Wilting, H. C. 2008. Taxation of multiple greenhouse gases and the effects on income distribution. A case study of the Netherlands. *Ecological Economics,* 67**,** 318-326.
Kinghan, C., Newman, C. & O'Toole, C. 2020. Capital Allocation, Credit Access, and Firm Growth. *In:* John Rand & Finn Tarp (eds.) *Micro, Small, and Medium Enterprises in Vietnam.* United Kingdom: Oxford University Press.
Klein, R. J., Schipper, E. L. F. & Dessai, S. 2005. Integrating mitigation and adaptation into climate and development policy: three research questions. *Environmental science & policy,* 8**,** 579-588.
Kostka, G. 2016. Command without control: The case of China's environmental target system. *Regulation and Governance,* 10**,** 58-74.
Kraft, J. & Kraft, A. 1978. On the Relationship Between Energy and GNP. *The Journal of Energy and Development,* 3**,** 401-403.
Kreickemeier, U. & Richter, P. M. 2014. Trade and the environment: The role of firm heterogeneity. *Review of International Economics,* 22**,** 209-225.
Kumar Mandal, S. & Madheswaran, S. 2010. Causality between energy consumption and output growth in the Indian cement industry: An application of the panel vector error correction model (VECM). *Energy Policy,* 38**,** 6560-6565.
Kumar, R., Sharma, A. K. & Tewari, P. C. 2015. Cost analysis of a coal-fired power plant using the NPV method. *Journal of Industrial Engineering International,* 11**,** 495-504.
La, H. A., Nguyen, T. K. T. & Nguyen, T. 2017. Distributional and Poverty Impacts of Mitigation Measures of a Revised Incremental Block Tariff (IBT) and Social Assistance Cash Transfer Scheme - The Case of Vietnam. *Report prepared under Phase 4 of UNDPs research and policy dialogue of Fossil Fuel Fiscal Policy Reform.*
Labandeira, X. & Labeaga, J. M. 1999. Combining Input-Output Analysis and Micro-Simulation to Assess the Effects of Carbon Taxation on Spanish Households. *Fiscal Studies,* 20**,** 305-320.
Labandeira, X., Labeaga, J. M. & Rodríguez, M. 2009. An integrated economic and distributional analysis of energy policies. *Energy Policy,* 37**,** 5776-5786.
Lai, N. H. & Nguyen, T. K. O. 2017. Assessment of national emissions of air pollutants and climate forcers from thermal power plants and industrial activities in Vietnam. *Atmospheric Pollution Research,* 8**,** 503-513.
Lazard 2018. Lazard's levelized cost of energy analysis. Lazard Ltd.,.
Le, P. V. 2019. Energy demand and factor substitution in Vietnam: evidence from two recent enterprise surveys. *Journal of Economic Structures,* 8**,** 1-17.
Leal, F. I., Rego, E. E. & de Oliveira Ribeiro, C. 2017. Levelized cost analysis of thermoelectric generation in Brazil: A comparative economic and policy study with environmental implications. *Journal of Natural Gas Science and Engineering,* 44**,** 191-201.
Leamer, E. & Leonard, H. 1983. Reporting the fragility of regression estimates. *The Review of Economics and Statistics***,** 306-317.
Leamer, E. E. 1978. *Specification searches: Ad hoc inference with nonexperimental data,* John Wiley & Sons Incorporated.
Leamer, E. E. 1983. Let's take the con out of econometrics. *The American Economic Review,* 73**,** 31-43.
Leamer, E. E. 1985. Sensitivity analyses would help. *American Economic Review,* 75**,** 308-313.

Lean, H. H. & Smyth, R. 2010. On the dynamics of aggregate output, electricity consumption and exports in Malaysia: Evidence from multivariate Granger causality tests. *Applied Energy,* 87**,** 1963-1971.
Lee, L. F. 1982. Some Approaches to the Correction of Selectivity Bias. *Review of Economic Studies,* 49**,** 355-372.
Lee, S. H., Lee, T. H., Jeong, S. M. & Lee, J. M. 2019. Economic analysis of a 600 mwe ultra supercritical circulating fluidized bed power plant based on coal tax and biomass co-combustion plans. *Renewable Energy,* 138**,** 121-127.
Lenzen, M. & Schaeffer, R. 2004. Environmental and social accounting for Brazil. *Environmental and Resource Economics,* 27**,** 201-226.
Levinson, A. & Taylor, M. S. 2008. Unmasking the pollution haven effect. *International Economic Review,* 49**,** 223-254.
Li, W., Wei, P. & Zhou, X. 2014. A cost-benefit analysis of power generation from commercial reinforced concrete solar chimney power plant. *Energy Conversion and Management,* 79**,** 104-113.
Li, Y., Su, B. & Dasgupta, S. 2018. Structural path analysis of India's carbon emissions using input-output and social accounting matrix frameworks. *Energy Economics,* 76**,** 457-469.
Liang, Q. M., Fan, Y. & Wei, Y. M. 2007. Carbon taxation policy in China: How to protect energy- and trade-intensive sectors? *Journal of Policy Modeling,* 29**,** 311-333.
Lin, B. & Jiang, Z. 2011. Estimates of energy subsidies in China and impact of energy subsidy reform. *Energy Economics,* 33**,** 273-283.
Lise, W. & Van Montfort, K. 2007. Energy consumption and GDP in Turkey: Is there a co-integration relationship? *Energy Economics,* 29**,** 1166-1178.
Liu, J., Li, J. & Yao, X. 2019. The economic effects of the development of the renewable energy industry in China. *Energies,* 12.
Liu, W. & Li, H. 2011. Improving energy consumption structure: A comprehensive assessment of fossil energy subsidies reform in China. *Energy Policy,* 39**,** 4134-4143.
Locatelli, G. & Mancini, M. 2010. Small–medium sized nuclear coal and gas power plant: A probabilistic analysis of their financial performances and influence of CO2 cost. *Energy Policy,* 38**,** 6360-6374.
Lokshin, M. & Sajaia, Z. 2004. Maximum likelihood estimation of endogenous switching regression models. *The Stata Journal,* 4**,** 282-289.
Luckow, P., Stanton, E. A., Fields, S., Biewald, B., Jackson, S., Fisher, J. & Wilson, R. 2015. 2015 carbon dioxide price forecast. Cambridge.
Luong Bang. 2020. Billions of dollars to build gas-fired power plants, who can afford to buy the high prices? (Hàng tỷ USD xây nhà máy điện khí, bán giá cao ai đủ sức mua). Available: https://vietnamnet.vn/vn/kinh-doanh/dau-tu/hang-ty-usd-xay-nha-may-dien-khi-ban-gia-cao-ai-du-suc-mua-661276.html.
Ma, C. & Stern, D. I. 2008. China's changing energy intensity trend: A decomposition analysis. *Energy Economics,* 30**,** 1037-1053.
Madlener, R. & Koller, M. 2007. Economic and CO2 mitigation impacts of promoting biomass heating systems: An input–output study for Vorarlberg, Austria. *Energy Policy,* 35**,** 6021-6035.
Madlener, R. & Stoverink, S. 2012. Power plant investments in the Turkish electricity sector: A real options approach taking into account market liberalization. *Applied Energy,* 97**,** 124-134.
Malik, A., Bertram, C., Despres, J., Emmerling, J., Fujimori, S., Garg, A., Kriegler, E., Luderer, G., Mathur, R., Roelfsema, M., Shekhar, S., Vishwanathan, S. & Vrontisi, Z. 2020. Reducing stranded assets through early action in the Indian power sector. *Environmental Research Letters,* 15.

Managi, S., Hibiki, A. & Tsurumi, T. 2009. Does trade openness improve environmental quality? *Journal of Environmental Economics and Management,* 58**,** 346-363.
Manova, K. 2013. Credit constraints, heterogeneous firms, and international trade. *Review of Economic Studies,* 80**,** 711-744.
Manresa, A. & Sancho, F. 2005. Implementing a double dividend: Recycling ecotaxes towards lower labour taxes. *Energy Policy,* 33**,** 1577-1585.
Melitz, M. J. 2003. The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica,* 71**,** 1695-1725.
Menegaki, A. N. 2011. Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis. *Energy Economics,* 33**,** 257-263.
Menegaki, A. N. 2014. On energy consumption and GDP studies; A meta-analysis of the last two decades. *Renewable and Sustainable Energy Reviews,* 29**,** 31-36.
Metcalf, G. E. 2007. Corporate tax reform: Paying the bills with a carbon tax. *Public Finance Review,* 35**,** 440-459.
Michener, W. K., Blood, E. R., Bildstein, K. L., Brinson, M. M. & Gardner, L. R. 1997. Climate change, hurricanes and tropical storms, and rising sea level in coastal wetlands. *Ecological Applications,* 7**,** 770-801.
Miguel, E. & Kremer, M. 2004. Worms: Identifying impacts on education and health in the presence of treatment externalities. *Econometrica,* 72**,** 159-217.
Miller, R. & Blair, P. 2009. Input-Output Analysis: Foundations and Extensions 2nd Ed. Cambridge University Press.
Minetti, R. & Zhu, S. C. 2011. Credit constraints and firm export: Microeconomic evidence from Italy. *Journal of International Economics,* 83**,** 109-125.
Ministry of Finance 2008. Circular No. 37/2008/TT-BTC on guidelines for a kerosene subsidy scheme to support ethnic minority households, households of the social insurance policy, and poor households in off-grid areas.
Ministry of Finance 2014. Circular 190/2014/TT-BTC on implementation of power charge support policies for poor households and social policy entitled households.
Ministry of Industry and Trade 2014. Circular 56/2014/TT-BCT on method of determination of electricity generation costs, sequence of inspection of power purchase agreement (PPA) Hanoi, Vietnam.
Ministry of Industry and Trade 2017. Vietnam Energy Outlook Report 2017.
Ministry of Industry and Trade 2019. Decision 281/QD-BCT on Power generation price range in 2019. Hanoi, Vietnam.
Mo, J., Cui, L. & Duan, H. 2021. Quantifying the implied risk for newly-built coal plant to become stranded asset by carbon pricing. *Energy Economics,* 99.
Montalbano, P. & Nenci, S. 2019. Energy efficiency, productivity and exporting: Firm-level evidence in Latin America. *Energy Economics,* 79**,** 97-110.
Morales-Acevedo, A. 2014. Forecasting future energy demand: Electrical energy in Mexico as an example case. *Energy Procedia,* 57**,** 782-790.
Morelli, G. & Mele, M. 2020. Energy consumption, CO2 and economic growth nexus in Vietnam. *International Journal of Energy Economics and Policy,* 10**,** 443-449.
Moriarty, P. & Honnery, D. 2012. What is the global potential for renewable energy? *Renewable and Sustainable Energy Reviews,* 16**,** 244-252.
Morilla, C. R., Díaz-Salazar, G. L. & Cardenete, M. A. 2007. Economic and environmental efficiency using a social accounting matrix. *Ecological Economics,* 60**,** 774-786.
Munnings, C., Morgenstern, R. D., Wang, Z. & Liu, X. 2016. Assessing the design of three carbon trading pilot programs in China. *Energy Policy,* 96**,** 688-699.
National Assembly 1993. Law No. 18-L/CTN on Petroleum.

National Assembly 2000. Law No. 19/2000/QH10 on amending and supplementing a number of articles of the Petroleum Law.
National Assembly 2004. Law No. 28/2004/QH11 on Electricity.
National Assembly 2008. Law No. 10/2008/QH12 on amending and supplementing a number of articles of the Petroleum Law.
National Assembly 2010a. Law No. 50/2010/QH12 on Economical and Efficient Use of Energy.
National Assembly 2010b. Law No. 50/2010/QH12 on Energy Efficiency and Conservation
National Assembly 2010c. Law No. 57/2010/QH12 on Environmental Protection Tax.
National Assembly 2016. Resolution 31/2016/QH14 on stopping Ninh Thuan nuclear power plant project.
National Assembly Standing Committee 2015. Resolution No. 888a/2015/UBTVQH13 on amendments and supplements to the Resolution No. 1269/2011/UBTVQH12 on environmental protection tax schedule. Hanoi, Vietnam.
National Assembly Standing Committee 2018. Resolution 579/2018/UBTVQH14 on the Environmental Protection Tax. Hanoi, Vietnam.
National Assembly Standing Committee 2018. Resolution no 579/2018/UBTVQH14 on the Environmental Protection Tariff. Hanoi, Vietnam.
National Coal Council 2004. Opportunities to expedite the construction of new coal-based power plants. Washington DC.
Nemati, M., Hu, W. & Reed, M. 2019. Are free trade agreements good for the environment? A panel data analysis. *Review of Development Economics,* 23**,** 435-453.
Nesbakken, R. 1999. Price sensitivity of residential energy consumption in Norway. *Energy economics,* 21**,** 493-515.
Nguyen, A. N., Pham, N. Q., Nguyen, C. D. & Nguyen, N. D. 2008. Innovation and exports in Vietnam's SME sector. *European Journal of Development Research,* 20**,** 262-280.
Nguyen, A. T. 2019. Assurance of power supply in unusal conditions. *Vietnam Energy* [Online]. Available: http://nangluongvietnam.vn/news/vn/nhan-dinh-phan-bien-kien-nghi/truoc-nguy-co-thieu-dien-ky-1-nguon-cung-trong-dieu-kien-bat-thuong.htmls.
Nguyen, C. N. 2020. Coal-fired power in the world and Vietnam: Current situation - development trend. *Environmental protection in the exploitation, processing and use of coal, minerals and petroleum.*
Nguyen, D. A. T. 2017a. Is it for the environment? (Có thực vì môi trường?). *Vietnam Energy* [Online]. Available: https://tuoitre.vn/co-thuc-vi-moi-truong-1308615.htm [Accessed 5/11/2018].
Nguyen, D. L. 2015. A critical review on energy efficiency and conservation policies and programs in Vietnam. *Renewable and Sustainable Energy Reviews,* 52**,** 623-634.
Nguyen, K. Q. 2008. Internalizing externalities into capacity expansion planning: The case of electricity in Vietnam. *Energy,* 33**,** 740-746.
Nguyen, M. B. 2013. Viet Nam Country Report. *In:* Kimura, S. (ed.) *Analysis on Energy Saving Potential in East Asia,*. ERIA Research Project Report 2012-19: EIRA.
Nguyen, M. H. 2017b. An alternative to Ninh Thuan nuclear power. *Vietnam Energy* [Online]. Available: http://nangluongvietnam.vn/news/vn/nhan-dinh-phan-bien-kien-nghi/phan-bien-kien-nghi/ve-mot-phuong-an-thay-the-dien-hat-nhan-ninh-thuan.html [Accessed 12 March 2020].
Nguyen, M. H. & Bui, H. N. 2020a. Energy consumption - Economic growth nexus in vietnam: An ARDL approach with a structural break. *Journal of Asian Finance, Economics and Business,* 7**,** 101-110.

Nguyen, M. H. & Bui, H. N. 2020b. Revisiting the relationship between energy consumption and economic growth nexus in Vietnam: new evidence by asymmetric ARDL cointegration. *Applied Economics Letters***,** 1-7.

Nguyen, P. A., Uong, T. A. T. & Nguyen, Q. D. 2020. How Small-and Medium-Sized Enterprise Innovation Affects Credit Accessibility: The Case of Vietnam. *Sustainability,* 12**,** 9559.

Nguyen, T. C. 2014. Vietnam energy resources and its ability to meet economic development (Tài nguyên năng lượng Việt Nam và khả năng đáp ứng nhu cầu phát triển kinh tế). *Vietnam Energy* [Online]. Available: http://nangluongvietnam.vn/news/vn/nhan-dinh-phan-bien-kien-nghi/phan-bien-kien-nghi/tai-nguyen-nang-luong-viet-nam-va-kha-nang-dap-ung-nhu-cau-nen-kinh-te.html [Accessed 5/11/2018].

Nguyen, T. C. 2017c. Vietnam's coal price situation and consequences. *Vietnam Energy* [Online]. Available: http://nangluongvietnam.vn/news/vn/than-khoang-san-viet-nam/thuc-trang-gia-thanh-than-viet-nam-va-nhung-he-luy-ky-1.html [Accessed 10 February 2020].

Nguyen, V., Nguyen, L., Vo, C. & Phan, B. 2019. Green Scenarios for Power Generation in Vietnam by 2030. *Engineering, Technology & Applied Science Research,* 9**,** 4019-4026.

Nguyen, V. C. & Coxhead, I. 2011. Vietnam's environment protection tax: Possible impacts and incidence. *Journal of Economics and Development,* 13**,** 5-18.

Nguyen, V. V. 2017d. The necessity of coal thermal power in Vietnam's power development strategy. *Vietnam Energy* [Online]. Available: http://nangluongvietnam.vn/news/vn/nhan-dinh-phan-bien-kien-nghi/phan-bien-kien-nghi/vi-sao-viet-nam-can-phat-trien-nhiet-dien-than-bai-9.html [Accessed 10 June 2020].

Nilsson, L. J. 1993. Energy intensity trends in 31 industrial and developing countries 1950–1988. *Energy,* 18**,** 309-322.

Nong, D. 2018. General equilibrium economy-wide impacts of the increased energy taxes in Vietnam. *Energy Policy,* 123**,** 471-481.

Nong, D., Nguyen, T. H., Wang, C. & Van Khuc, Q. 2020a. The environmental and economic impact of the emissions trading scheme (ETS) in Vietnam. *Energy Policy,* 140**,** 111362.

Nong, D., Siriwardana, M., Perera, S. & Nguyen, D. B. 2019. Growth of low emission-intensive energy production and energy impacts in Vietnam under the new regulation. *Journal of Cleaner Production,* 225**,** 90-103.

Nong, D., Wang, C. & Al-Amin, A. Q. 2020b. A critical review of energy resources, policies and scientific studies towards a cleaner and more sustainable economy in Vietnam. *Renewable and Sustainable Energy Reviews,* 134**,** 110117.

OECD 2006. *Cost-Benefit Analysis and the Environment: Recent Developments,* Paris, OECD Publishing.

OECD & NEA 2012. Nuclear energy and renewables: System effects in low-carbon electricity systems.

Olsson, L., Opondo, M., Tschakert, P., Agrawal, A., Eriksen, S. E., Ma, S., Perch, L. N. & Zakieldeen, S. A. 2014. Livelihoods and poverty. *In:* Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E., Chatterjee, M., Ebi, K. L., Estrada, Y. O., Genova, R. C., Girma, B., Kissel, E. S., Levy, A. N., MacCracken, S., Mastrandrea, P. R. & White, L. L. (eds.) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Omer, A. M. 2008. Energy, environment and sustainable development. *Renewable and sustainable energy reviews,* 12**,** 2265-2300.

Omri, A. 2014. An international literature survey on energy-economic growth nexus: Evidence from country-specific studies. *Renewable and Sustainable Energy Reviews,* 38**,** 951-959.
Orlov, A. & Grethe, H. 2012. Carbon taxation and market structure: A CGE analysis for Russia. *Energy Policy,* 51**,** 696-707.
Ou, P., Huang, R. & Yao, X. 2016. Economic impacts of power shortage. *Sustainability (Switzerland),* 8.
Ozone Layer Protection and Low Carbon Economy Development Center 2020. On the study and development of emission factor (EF) for Vietnamese electrical grid in 2018. Department of Climate Change.
Ozturk, I. 2010. A literature survey on energy–growth nexus. *Energy Policy,* 38**,** 340-349.
Park, S., Kim, J., Yoon, M., Rhim, D. & Yeom, C. 2018. Thermodynamic and economic investigation of coal-fired power plant combined with various supercritical CO2 Brayton power cycle. *Applied Thermal Engineering,* 130**,** 611-623.
Parry, I. W. H. & Bento, A. M. 2000. Tax deductions, environmental policy, and the 'double dividend' hypothesis. *Journal of Environmental Economics and Management,* 39**,** 67-96.
Pasqual, J., Padilla, E. & Jadotte, E. 2013. Technical note: Equivalence of different profitability criteria with the net present value. *International Journal of Production Economics,* 142**,** 205-210.
Pastén, R., Saens, R. & Contreras Marin, R. 2015. Does energy use cause economic growth in Latin America? *Applied Economics Letters,* 22**,** 1399-1403.
Payne, J. E. 2009. On the dynamics of energy consumption and output in the US. *Applied Energy,* 86**,** 575-577.
Payne, J. E. 2010a. A survey of the electricity consumption-growth literature. *Applied Energy,* 87**,** 723-731.
Payne, J. E. 2010b. Survey of the international evidence on the causal relationship between energy consumption and growth. *Journal of Economic Studies*.
Pearce, D. 1991. The role of carbon taxes in adjusting to global warming. *The economic journal,* 101**,** 938-948.
Perman, R., Ma, Y., McGilvray, J. & Common, M. 2014. *Natural resource and environmental economics,* Pearson Education.
Pettinau, A., Ferrara, F., Tola, V. & Cau, G. 2017. Techno-economic comparison between different technologies for CO2-free power generation from coal. *Applied Energy,* 193**,** 426-439.
Phrakhruopatnontakitti, Watthanabut, B. & Jermsittiparsert, K. 2020. Energy consumption, economic growth and environmental degradation in 4 asian countries: Malaysia, Myanmar, Vietnam and Thailand. *International Journal of Energy Economics and Policy,* 10**,** 529-539.
Phuong Huyen. 2020. Energy saving: The self-problem of enterprises (Tiết kiệm năng lượng: Vấn đề tự thân của doanh nghiệp). *National energy efficiency program* [Online]. [Accessed 3/11/2020].
Pigou, M. A. 1932. *The economics of welfare,* London: Macmillan.
Pitt, M. M. & Rosenzweig, M. R. 1990. Estimating the Intrahousehold Incidence of Illness: Child Health and Gender-Inequality in the Allocation of Time. *International Economic Review,* 31**,** 969-989.
Prins, M. J., Ptasinski, K. J. & Janssen, F. J. J. G. 2003. Thermodynamics of gas-char reactions: first and second law analysis. *Chemical Engineering Science,* 58**,** 1003-1011.
Puller, S. L. & Greening, L. A. 1999. Household adjustment to gasoline price change: an analysis using 9 years of US survey data. *Energy Economics,* 21**,** 37-52.

Pyatt, G. 1988. A SAM approach to modeling. *Journal of Policy Modeling,* 10**,** 327-352.
Pyatt, G. & Round, J. I. 1979. Accounting and fixed price multipliers in a social accounting matrix framework. *The Economic Journal,* 89**,** 850-873.
Pyatt, G. & Round, J. I. 1985. *Social accounting matrices: A basis for planning,* The World Bank.
Quang Loc. 2017. Supporting small and medium enterprises to use energy efficiently (Hỗ trợ doanh nghiệp nhỏ và vừa sử dụng năng lượng hiệu quả). *Vietnam economic news* [Online]. [Accessed 5/11/2020].
Raghuvanshi, S. P., Chandra, A. & Raghav, A. K. 2006. Carbon dioxide emissions from coal based power generation in India. *Energy Conversion and Management,* 47**,** 427-441.
Rahman, M. M. & Velayutham, E. 2020. Renewable and non-renewable energy consumption-economic growth nexus: New evidence from South Asia. *Renewable Energy,* 147**,** 399-408.
Rand, J. 2020. Are Politically Connected Firms Less Constrained in Credit
Markets? *In:* John Rand & Finn Tarp (eds.) *Micro, small, and medium enterprises in Vietnam.* United Kingdom: Oxford University Press.
Rand, J. & Tarp, F. (eds.) 2020. *Micro, Small, and Medium Enterprises in Vietnam*: Oxford University Press.
Rand, J., Tarp, F. & Trifkovic, N. 2012. Characteristics of the Vietnamese business environment: Evidence from a SME survey in 2011. *Central Institute for Economic Management (CIEM): Hanoi, Vietnam*.
Rand, J., Tarp, F. & Trifkovic, N. 2014. Characteristics of the Vietnamese Business Environment: Evidence from a Survey in 2013.
Rand, J. & Torm, N. 2012. The Benefits of Formalization: Evidence from Vietnamese Manufacturing SMEs. *World Development,* 40**,** 983-998.
Rankin, N., Söderbom, M. & Teal, F. 2006. Exporting from manufacturing firms in Sub-Saharan Africa. *Journal of African Economies,* 15**,** 671-687.
Rao, M., Ciorba, U., Trovato, G., Notaro, C. & Ferrarese, C. 2018. Estimating an energy-social accounting matrix for Italy. *The New Generation of Computable General Equilibrium Models: Modeling the Economy.*
Rausch, S., Metcalf, G. E., Reilly, J. M. & Paltsev, S. 2010. Distributional implications of alternative U.S. greenhouse gas control measures. *B.E. Journal of Economic Analysis and Policy,* 10.
Remer, D. S. & Nieto, A. P. 1995a. A compendium and comparison of 25 project evaluation techniques. Part 1: Net present value and rate of return methods. *International Journal of Production Economics,* 42**,** 79-96.
Remer, D. S. & Nieto, A. P. 1995b. A compendium and comparison of 25 project evaluation techniques. Part 2: Ratio, payback, and accounting methods. *International Journal of Production Economics,* 42**,** 101-129.
REN21 2017. Renewables 2017 Global Status Report. Paris.
Renner, S. 2018. Poverty and distributional effects of a carbon tax in Mexico. *Energy Policy,* 112**,** 98-110.
Renner, S., Lay, J. & Greve, H. 2018. Household welfare and CO2 emission impacts of energy and carbon taxes in Mexico. *Energy Economics,* 72**,** 222-235.
Requate, T. 2005. Dynamic incentives by environmental policy instruments—a survey. *Ecological Economics,* 54**,** 175-195.
Richter, P. M. & Schiersch, A. 2017. CO2 emission intensity and exporting: Evidence from firm-level data. *European Economic Review,* 98**,** 373-391.

Ridley, J., Kolm, N., Freckelton, R. & Gage, M. 2007. An unexpected influence of widely used significance thresholds on the distribution of reported P-values. *Journal of evolutionary biology,* 20**,** 1082-1089.

Roberts, M. J. & Tybout, J. R. 1997. The Decision to Export in Colombia: An Empirical Model of Entry with Sunk Costs. *American Economic Review,* 87**,** 545-564.

Robinson, S. & Roland-Holst, D. W. 1988. Macroeconomic structure and computable general equilibrium models. *Journal of Policy Modeling,* 10**,** 353-375.

Robison, H. D. 2001. Industrial pollution abatement: The impact on balance of trade. *The Economics of International Trade and the Environment.*

Rocchi, P., Serrano, M. & Roca, J. 2014. The reform of the European energy tax directive: Exploring potential economic impacts in the EU27. *Energy Policy,* 75**,** 341-353.

Rosas-Flores, J. A., Bakhat, M., Rosas-Flores, D. & Fernández Zayas, J. L. 2017. Distributional effects of subsidy removal and implementation of carbon taxes in Mexican households. *Energy Economics,* 61**,** 21-28.

Rosenbaum, P. R. & Rubin, D. B. 1983. The central role of the propensity score in observational studies for causal effects. *Biometrika,* 70**,** 41-55.

Round, J. 2003. Social accounting matrices and SAM-based multiplier analysis. *The impact of economic policies on poverty and income distribution: Evaluation techniques and tools,* 14**,** 261-276.

Roy, J. & Yasar, M. 2015. Energy efficiency and exporting: Evidence from firm-level data. *Energy Economics,* 52**,** 127-135.

Sadorsky, P. 2012. Energy consumption, output and trade in South America. *Energy Economics,* 34**,** 476-488.

Sakyi, D., Villaverde, J. & Maza, A. 2015. Trade openness, income levels, and economic growth: The case of developing countries, 1970–2009. *The Journal of International Trade & Economic Development,* 24**,** 860-882.

Salim, R. A., Hassan, K. & Shafiei, S. 2014. Renewable and non-renewable energy consumption and economic activities: Further evidence from OECD countries. *Energy Economics,* 44**,** 350-360.

Säll, S. & Gren, I. M. 2015. Effects of an environmental tax on meat and dairy consumption in Sweden. *Food Policy,* 55**,** 41-53.

Sánchez-Chóliz, J., Duarte, R. & Mainar, A. 2007. Environmental impact of household activity in Spain. *Ecological Economics,* 62**,** 308-318.

Saudi, M. H. M., Sinaga, O., Roespinoedji, D. & Ghani, E. K. 2019. The impact of technological innovation on energy intensity: Evidence from Indonesia. *International Journal of Energy Economics and Policy,* 9**,** 11-17.

Saygin, D., Rigter, J., Caldecott, B., Wagner, N. & Gielen, D. 2019. Power sector asset stranding effects of climate policies. *Energy Sources, Part B: Economics, Planning and Policy,* 14**,** 99-124.

Schlaich, J., Bergermann, R., Schiel, W. & Weinrebe, G. 2005. Design of commercial solar updraft tower systems - Utilization of solar induced convective flows for power generation. *Journal of Solar Energy Engineering, Transactions of the ASME,* 127**,** 117-124.

Schumacher, D. 1985. *Energy: crisis or opportunity?: an introduction to energy studies,* Macmillan International Higher Education.

Scrimgeour, F., Oxley, L. & Fatai, K. 2005. Reducing carbon emissions? the relative effectiveness of different types of environmental tax: The case of New Zealand. *Environmental Modelling and Software,* 20**,** 1439-1448.

Sentenac-Chemin, E. 2012. Is the price effect on fuel consumption symmetric? Some evidence from an empirical study. *Energy Policy,* 41**,** 59-65.

Shahbaz, M., Khan, S. & Tahir, M. I. 2013. The dynamic links between energy consumption, economic growth, financial development and trade in China: Fresh evidence from multivariate framework analysis. *Energy Economics,* 40**,** 8-21.
Shahbaz, M., Nasreen, S., Ling, C. H. & Sbia, R. 2014. Causality between trade openness and energy consumption: What causes what in high, middle and low income countries. *Energy Policy,* 70**,** 126-143.
Shrestha, R. M. & Marpaung, C. O. P. 1999. Supply- and demand-side effects of carbon tax in the Indonesian power sector: an integrated resource planning analysis. *Energy Policy,* 27**,** 185-194.
Singh, T. 2010. Does international trade cause economic growth? A survey. *The World Economy,* 33**,** 1517-1564.
Sjöholm, F. 2003. Which Indonesian firms export? The importance of foreign networks. *Papers in Regional Science,* 82**,** 333-350.
Smith, J. A. & Todd, P. E. 2005. Does matching overcome LaLonde's critique of nonexperimental estimators? *Journal of Econometrics,* 125**,** 305-353.
Sohag, K., Begum, R. A., Abdullah, S. M. S. & Jaafar, M. 2015. Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia. *Energy,* 90**,** 1497-1507.
Solaymani, S. 2017. Carbon and energy taxes in a small and open country. *Global Journal of Environmental Science and Management,* 3**,** 51-62.
Solaymani, S., Kardooni, R., Yusoff, S. B. & Kari, F. 2015. The impacts of climate change policies on the transportation sector. *Energy,* 81**,** 719-728.
Solaymani, S. & Kari, F. 2014. Impacts of energy subsidy reform on the Malaysian economy and transportation sector. *Energy Policy,* 70**,** 115-125.
Srinivasan, T. N. & Archana, V. 2011. Determinants of export decision of firms. *Economic and Political Weekly,* 46**,** 49-58.
State Bank of Vietnam 2019. Annual report 2018.
Stavins, R. N. 2003. Chapter 9 - Experience with Market-Based Environmental Policy Instruments. *In:* Mäler, K.-G. & Vincent, J. R. (eds.) *Handbook of Environmental Economics.* Elsevier.
Stern, D. I. 1993. Energy and economic growth in the USA. A multivariate approach. *Energy Economics,* 15**,** 137-150.
Stern, D. I. 1997. Limits to substitution and irreversibility in production and consumption: A neoclassical interpretation of ecological economics. *Ecological Economics,* 21**,** 197-215.
Stern, D. I. 2020. Energy and economic growth. *In:* Soytas, U. & Sarı, R. (eds.) *Routledge Handbook of Energy Economics.* Taylor & Francis Group.
Stern, N. & Stern, N. H. 2007. *The economics of climate change: the Stern review,* cambridge University press.
Stockhaus, H. 2017. The EU-Vietnam Free Trade Agreement - A Successful Attempt to Protect Vietnam's Environment While Pushing for Economic Integration? *Journal for European Environmental and Planning Law,* 14**,** 208-222.
Stone, D., Maxwell, S. & Keating, M. Bridging research and policy. An International Workshop Funded by the UK Department for International Development Radcliffe House, Warwick University, 2001. 16-17.
Subrahmanya, M. H. B. & Kumar, R. S. 2011. Technological innovations and energy intensity of machine tool SMEs in Bangalore: Do process innovations contribute to energy efficiency? *International Journal of Energy Technology and Policy,* 7**,** 519-536.
Sugino, M., Arimura, T. H. & Morgenstern, R. D. 2013. The effects of alternative carbon mitigation policies on Japanese industries. *Energy Policy,* 62**,** 1254-1267.

Sultan, Z. A. & Alkhateeb, T. T. Y. 2019. Energy consumption and economic growth: The evidence from India. *International Journal of Energy Economics and Policy,* 9**,** 142-147.
Swenson, D. & Eathington, L. 2006. Determining the regional economic values of ethanol production in Iowa considering different levels of local investment. Department of Economics, College of Agriculture, Iowa State University.
Symons, E. J., Speck, S. & Proops, J. L. R. 2002. The distributional effects of carbon and energy taxes: The cases of France, Spain, Italy, Germany, and UK. *European Environment,* 12**,** 203-212.
Tamba, J. G., Nsouandélé, J. L., Fopah Lélé, A. & Sapnken, F. E. 2017. Electricity consumption and economic growth: Evidence from Cameroon. *Energy Sources, Part B: Economics, Planning and Policy,* 12**,** 1007-1014.
Tan, C. C. & Tan, S. 2018. Energy consumption, Co2 emissions and economic growth: A causality analysis for Malaysian industrial sector. *International Journal of Energy Economics and Policy,* 8**,** 254-258.
Tang, C. F., Tan, B. W. & Ozturk, I. 2016. Energy consumption and economic growth in Vietnam. *Renewable and Sustainable Energy Reviews,* 54**,** 1506-1514.
Tang, L., Wu, J., Yu, L. & Bao, Q. 2015. Carbon emissions trading scheme exploration in China: A multi-agent-based model. *Energy Policy,* 81**,** 152-169.
Tang, X., Zhang, B., Wei, X. & Höök, M. 2013. Employment impacts of petroleum industry in China: An input-output analysis. *International Journal of Global Energy Issues,* 36**,** 116-129.
Thorbecke, E. 1994. Intersectoral linkages and their impact on rural poverty alleviations: A social accounting matrix approach, Austria. United Nations Industrial Development Organization.
Tiezzi, S. 2005. The welfare effects and the distributive impact of carbon taxation on Italian households. *Energy Policy,* 33**,** 1597-1612.
Tobey, J. A. 1990. The Effects of Domestic Environmental Policies on Patterns of World Trade: An Empirical Test. *Kyklos,* 43**,** 191-209.
Tola, V. & Pettinau, A. 2014. Power generation plants with carbon capture and storage: A techno-economic comparison between coal combustion and gasification technologies. *Applied Energy,* 113**,** 1461-1474.
Tran, Q. M. 2019. Projection of fossil fuel demands in Vietnam to 2050 and climate change implications. *Asia & the Pacific Policy Studies,* 6**,** 208-221.
Transport and Infrastructure Council 2018. Australian transport assessment and planning guidelines: Cost benefit analysis. Canberra, Commonwealth of Australia.
Truong, D. N. 2017. Coal is a key power source to ensure national energy security. *Vietnam Energy* [Online]. Available: http://nangluongvietnam.vn/news/vn/nhan-dinh-phan-bien-kien-nghi/phan-bien-kien-nghi/vi-sao-viet-nam-can-phat-trien-nhiet-dien-than-bai-14.html [Accessed 12 June 2020].
Truong, H. A., Tran, A. H. & Ha, M. D. 2016. Socio-economic impacts of co-firing in Vietnam: The case of Ninh Binh Coal Power Plant. *Handbook of biomass investment in Vietnam 2016.* Clean Energy and Sustainable Development Laboratory.
Ucan, O., Aricioglu, E. & Yucel, F. 2014. Energy consumption and economic growth nexus: Evidence from developed countries in Europe. *International Journal of Energy Economics and Policy,* 4**,** 411-419.
United Nations 1982. Concepts and Methods in Energy Statistics.
Van Wyk, L., Saayman, M., Rossouw, R. & Saayman, A. 2015. Regional economic impacts of events: A comparison of methods. *South African Journal of Economic and Management Sciences,* 18**,** 155-176.

Vandyck, T. & Van Regemorter, D. 2014. Distributional and regional economic impact of energy taxes in Belgium. *Energy Policy*, 72**,** 190-203.

Varian, H. 1992. *Microeconomic Analysis*, 3rd edition, W. W. Norton & Company, Inc.

Venkataraman, S., Jordan, G., O'Connor, M., Kumar, N., Lefton, S., Lew, D., Brinkman, G., Palchak, D. & Cochran, J. 2013. Cost-Benefit Analysis of Flexibility Retrofits for Coal and Gas-Fueled Power Plants. National Renewable Energy Laboratory.

Venn, F. 2016. *The oil crisis*, Routledge.

Vietnam Energy. 2017. Coal fired power and power market in Vietnam. *Vietnam Energy* [Online]. Available: http://nangluongvietnam.vn/news/vn/nhan-dinh-phan-bien-kien-nghi/phan-bien-kien-nghi/vi-sao-viet-nam-can-phat-trien-nhiet-dien-than-bai-2.html [Accessed 13 March 2020].

Vuong, D. H. 2016. Outstanding achievements in economic development (Những thành tựu nổi bật trong phát triển kinh tế). *Nhan dan* [Online]. Available: https://nhandan.com.vn/tin-tuc-su-kien/nhung-thanh-tuu-noi-bat-trong-phat-trien-kinh-te-252150 [Accessed 5/11/2018].

Webster, P. J., Holland, G. J., Curry, J. A. & Chang, H.-R. 2005. Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science*, 309**,** 1844-1846.

Wesseh, P. K., Jr. & Lin, B. 2018. Optimal carbon taxes for China and implications for power generation, welfare, and the environment. *Energy Policy*, 118**,** 1-8.

West, S. E. & Williams, R. C. 2004. Estimates from a consumer demand system: implications for the incidence of environmental taxes. *Journal of Environmental Economics and Management*, 47**,** 535-558.

West, S. E. & Williams, R. C. 2007. Optimal taxation and cross-price effects on labor supply: Estimates of the optimal gas tax. *Journal of Public Economics*, 91**,** 593-617.

Wier, M., Birr-Pedersen, K., Jacobsen, H. K. & Klok, J. 2005. Are CO2 taxes regressive? Evidence from the Danish experience. *Ecological Economics*, 52**,** 239-251.

Willenbockel, D. 2011. Environmental tax reform in Vietnam: An ex ante general equilibrium assessment.

Winarno, T. & Drebenstedt, C. 2016. Indonesia economic output and employment impact of low rank coal utilization: An input output analysis. *XVIII International Coal Preparation Congress: 28 June-01 July 2016 Saint-Petersburg, Russia.*

Wolde-Rufael, Y. 2004. Disaggregated industrial energy consumption and GDP: The case of Shanghai, 1952-1999. *Energy Economics*, 26**,** 69-75.

World Bank 2017. Climate action: Take urgent action to combat climate change and its impacts. *Atlas of Sustainable Development Goals 2017: From World Development Indicators.*

World Bank 2020. World Development Indicators.

Worrell, E., Price, L. & Martin, N. 2001. Energy efficiency and carbon dioxide emissions reduction opportunities in the US iron and steel sector. *Energy*, 26**,** 513-536.

Wrigley, E. A. 2013. Energy and the English industrial revolution. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 371**,** 20110568.

WTO 2018. World trade statistical review 2018.

Wu, D., Ma, X., Zhang, S. & Ma, J. 2019. Are more economic efficient solutions ignored by current policy: Cost-benefit and NPV analysis of coal-fired power plant technology schemes in China. *Ecological Indicators*, 103**,** 105-113.

Wu, Y. 2012. Energy intensity and its determinants in China's regional economies. *Energy Policy*, 41**,** 703-711.

Xie, H., Yu, Y., Wang, W. & Liu, Y. 2017. The substitutability of non-fossil energy, potential carbon emission reduction and energy shadow prices in China. *Energy Policy*, 107**,** 63-71.

Xie, J. 2000. An environmentally extended social accounting matrix: Conceptual framework and application to environmental policy analysis in China. *Environmental and Resource Economics,* 16**,** 391-406.
Xu, T., Baosheng, Z., Lianyong, F., Masri, M. & Honarvar, A. 2011. Economic impacts and challenges of China's petroleum industry: An input–output analysis. *Energy,* 36**,** 2905-2911.
Xu, X. 1999. Do stringent environmental regulations reduce the international competitiveness of environmentally sensitive goods? A global perspective. *World Development,* 27**,** 1215-1226.
Yahoo, M. & Othman, J. 2017. Carbon and energy taxation for CO2 mitigation: a CGE model of the Malaysia. *Environment, Development and Sustainability,* 19**,** 239-262.
Yamada, H. 1998. A note on the causality between export and productivity:: an empirical re-examination. *Economics Letters,* 61**,** 111-114.
Yanikkaya, H. 2003. Trade openness and economic growth: a cross-country empirical investigation. *Journal of Development Economics,* 72**,** 57-89.
Yoo, S. H. & Kim, Y. 2006. Electricity generation and economic growth in Indonesia. *Energy,* 31**,** 2890-2899.
Yu, E. S. H. & Jin, J. C. 1992. Cointegration tests of energy consumption, income, and employment. *Resources and Energy,* 14**,** 259-266.
Yuan, J., Guo, X., Zhang, W., Zhou, J. & Qin, C. 2019. Stranded Coal Power Assets in China: A Case Study of Jilin Province. *Emerging Markets Finance and Trade*, 55**,** 2673-2688.
Zhang, W., Zhou, Y., Gong, Z., Kang, J., Zhao, C., Meng, Z., Zhang, J., Zhang, T. & Yuan, J. 2021. Quantifying stranded assets of the coal-fired power in China under the Paris Agreement target. *Climate Policy*.
Zhao, C., Zhang, W., Wang, Y., Liu, Q., Guo, J., Xiong, M. & Yuan, J. 2017. The economics of coal power generation in China. *Energy Policy,* 105**,** 1-9.
Zhao, H. & Lin, B. 2020. Impact of foreign trade on energy efficiency in China's textile industry. *Journal of Cleaner Production,* 245**,** 118878.
Zhao, Y.-H. 2011. The Study of Effect of Carbon Tax on the International Competitiveness of Energy-intensive Industries: An Empirical Analysis of OECD 21 Countries, 1992-2008. *Energy Procedia,* 5**,** 1291-1302.
Zhao, Y., Zhang, Y. & Wei, W. 2021. Quantifying international oil price shocks on renewable energy development in China. *Applied Economics,* 53**,** 329-344.
Zheng, Y., Qi, J. & Chen, X. 2011. The effect of increasing exports on industrial energy intensity in China. *Energy Policy,* 39**,** 2688-2698.
Zou, Y., Song, J. N., Mizunoya, T., Yabar, H. & Higano, Y. 2014. Research on Environmental tax to affect the economic development and GHG mitigation in Beijing, China. *Applied Mechanics and Materials.*