School of Economics, Finance and Property
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Assessing the Potential of Interfuel Substitution and Energy Efficiency as Environmental Policy Instruments in Selected Asian Countries

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This thesis is presented for the
Degree of Doctor of Philosophy
of
Curtin University

June 2020

DECLARATION

To the best of my knowledge and belief this thesis contains no material previously published by any person except where due acknowledgement has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Signature: Cristina L. Alfonso

Date: 7 April 2020

ACKNOWLEDGMENTS

I would like to thank my supervisors Professor Helen Cabalu-Mendoza and Dr Julian Inchauspe for their untiring support in this research. Their insightful comments and guidance on my methodology and research direction have been invaluable. I also appreciate their advice on administrative matters relating to my study.

Likewise, I am grateful to Professor Ronald Ripple who has devoted long hours to discuss my ideas and assumptions. He encouraged me to think critically on pertinent issues. I also thank Professor Mark Harris for his helpful comments on one of my chapters as well as for introducing me to useful economic software.

I extend my appreciation to the Higher Degree by Research administration for providing an intellectually stimulating space to write my dissertation. In particular, I thank Assistant Professor Fay Rola-Rubzen for her encouragement, hosting relevant seminars and assisting students in the research process. I am also grateful to Jennifer Anne Goodison for keeping a safe and clean office environment for postgraduate students.

I would also like to thank all the wonderful friends who made my stay in Australia interesting and fun. They helped me feel inspired and motivated to see this research through. Lastly, I sincerely thank my family for believing in my ability to complete this project and supporting me through it. I am especially grateful to my brother, Emmanuel Alfonso SJ, for his invaluable support of this goal. I dedicate my work to my loving father and mother.

ABSTRACT

Climate change poses a threat to the economic development of countries in Asia. This thesis investigates the effects of several climate change mitigation policies targeting levels of carbon dioxide emissions (CO2) on economic growth and development. The focus is on two types of policy: interfuel substitution and energy efficiency measures. Interfuel substitution refers to the ability of an economy to shift its energy consumption from one type of fuel to a less carbon-intensive one. Energy efficiency policies on the other hand refer to measures that minimize the use of energy used to produce some level of output. The resulting changes in the energy mix preferences from these policies are hypothesized to affect economic growth in empirical analyses. A slowdown in economic growth induced by such policies is not desirable for developing countries in Asia and may cause the policies to fail. Hypotheses that align with this central idea are tested in three empirical chapters in this dissertation. While a vast amount of both theoretical and empirical economic literature has been dedicated to discussing carbon tax and trading mechanisms as instruments, not enough attention has been given to fuel substitution and efficiency economic issues as combined in this thesis. The countries studied include China, Japan, Korea and some members of the Association of Southeast Asian Nations (ASEAN), namely Indonesia, Malaysia, Singapore, Thailand and the Philippines.

The first empirical chapter explores the feasibility of inter-fuel substitution as an instrument to mitigate climate change. The low cost of extracting coal has made it the most widely used fossil fuel in most countries under study. However, different fuels emit different amounts of CO2 in relation to the energy they produce when burned. Coal produces more CO2 emissions per unit of energy than natural gas and oil. The carbon emission factor which determines the carbon content of each fuel is 28.8 tC/TJ for coal compared to oil (20 tC/TJ) and natural gas (15.3 tC/TJ) (IEA, 2014). For each Asian country, the economic and environmental impacts of fuel switching are investigated on two fronts: (1) substituting natural gas and oil for coal and (2) substituting natural gas for oil.

The following questions are addressed:

1. How do energy fuels affect output?
2. What are the fuel substitution elasticities?
3. What are the environmental consequences (in terms of carbon dioxide emissions reduction) of substituting a cleaner fuel for coal?
4. How do Asian countries differ in their responses to fuel substitution?

The model uses a translog production function to assess the relationships between output and different production input factors. Results from translog ridge regressions are used to compute output and substitution elasticities. These elasticities are used to finally compute for the amount of carbon emissions reduced or gained following fuel substitution.

Generally, the estimated output elasticities of fossil fuels are low. This result indicates that the demand for these energy inputs is generally inelastic and will not affect output greatly when the quantity consumed changes. Hence, fuel substitution as a climate change mitigation strategy does not generally disrupt economic growth significantly in the economies under consideration. These findings provide some guidance to policy makers with regard to using fuel substitution policies as climate change mitigation policies.

The second empirical chapter investigates the effectiveness of energy efficiency measures to lower carbon emissions. There are two ways that this is done: (1) a panel regression following the Environmental Kuznets Curve (EKC) specification, and (2) a decomposition analysis empirical approach. The EKC hypothesis postulates an inverted-U-shaped relationship between different pollutants and per capita income. This chapter establishes that as a country grows it generates more pollution, until a threshold turning point is reached and beyond which residents demand a cleaner environment through government policies and incentives while the economy grows. Energy efficiency is included as an explanatory variable in this EKC specification. The second empirical test decomposes the factors affecting carbon dioxide emissions into carbon intensity of energy, energy share, energy efficiency, industry structure and the scale effect. The analysis for each country is implemented in four sub-periods, namely, 1980–1989, 1990–1999, 2000-2006, and 2007-2014. This chapter also looks into the sectoral contribution of energy efficiency to CO2 emissions taking the machinery and textile sectors as case studies.

The findings reveal that energy efficiency effectively lowers carbon emissions. The EKC panel regression analysis shows that a 1% improvement in energy efficiency lowers carbon emissions by 0.7% on average. The decomposition analysis of carbon emissions for each country confirms the negative relationship between energy efficiency and carbon emissions. On a sectoral basis, energy efficiency successfully lowered carbon emissions in the machinery sector with China showing the highest contribution. Meanwhile, in the textile sector, most countries have lowered carbon emissions through energy efficiency except for the Philippines and Japan.

The third empirical chapter examines the dynamic properties of the relationship between fuel substitution and energy efficiency measures on output. These policies are distortionary and affect the composition of energy consumption and output through various

channels. The overall causality of the relationship between energy consumption and Gross Domestic Product (GDP) is analyzed to determine the economic effects of a change in consumption of the different energy sources on economic output. Four causal hypotheses are considered:

1. Unidirectional causality from energy consumption to economic growth suggesting that energy efficiency measures will lower GDP growth;
2. Unidirectional causality from GDP to energy consumption, implying that the energy efficiency policies which result in changes in energy consumption will not affect GDP;
3. Bi-directional causality between energy consumption and economic growth which shows that the change in either variable will feedback on the other, and
4. No causality between energy consumption and GDP.

The methodology employed to undertake the analysis consists of a panel vector error correction model which tests causality hypothesis between GDP, investment, employment, primary energy consumption of oil, natural gas and coal. The empirical findings show that a short-run unidirectional causality exists from GDP to labor; from capital to labor; from coal consumption to labor; from oil consumption to capital; from GDP to coal consumption; and from oil consumption to gas consumption. A short-run bi-directional causality exists only for oil consumption and GDP. More importantly, a long-run bidirectional relationship exists between GDP and coal and between GDP and natural gas. The short-run finding proves the importance of coal in Asian economies while the long-run finding identifies a policy solution for lowering carbon emissions.

The overall conclusion of this thesis is that fuel substitution and energy efficiency measures can be used as effective policies for reducing carbon emissions from fossil fuels, and policy implementation issues are discussed in the final chapter. To induce sustainable fuel switching, a pre-requisite is that energy subsidies should be eliminated so the market can reflect the true equilibrium price of coal, oil and gas, so that taxes or other policies could then be applied to achieve environmental targets through fuel-switching. Also, investment in energy efficiency is low in Asia and should be increased. Adopting fuel switching or energy efficiency policies however, can bring about changes in the energy mix which in turn will affect economic growth. The small output elasticity estimated for each fuel indicates that the economic disruption is minimal.

Key Words: Environmental Policy; Economic Growth; Inter-Fuel Substitution; Fuel Efficiency; CO2 Emissions; Energy Causality; Environmental Kuznets Curve (EKC)

JEL Classification: Q43, Q48, Q52, Q54, Q58

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LIST OF KEY ACRONYMS

ADF	Augmented Dickey Fuller
ADB	Asian Development Bank
APEC	Asia Pacific Economic Cooperation
ASEAN	Association of Southeast Asian Nations
CDM	Clean Development Mechanism
CO2	Carbon Dioxide
EKC	Environmental Kuznets Curve
ETS	Emissions Trading System
EU	European Union
GDP	Gross Domestic Product
GHG	Green House Gases
GNP	Gross National Product
IEA	International Energy Agency
IPS	Im, Pesaran and Shin
ktoe	Kilotonne of Oil Equivalent
kW	Kilo-Watt
kWh	Kilowatt hour
LLC	Levin-Lin-Chu
LM	Lagrange Multiplier
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
Mmboe	Million barrels of oil equivalent
MT	Million Tonnes
Mtoe	Million Tonnes of Oil Equivalent
OECD	Organization for Economic Co-operation and Development
OLS	Ordinary Least Squares
PP	Phillips-Perron
TJ	Tera Joules
toe	Tonnes of Oil Equivalent
UNFCCC	United Nations Framework Convention on Climate Change
VAR	Vector Autoregression
VEC	Vector Error Correction

Chapter 1 : Introduction

1.1 Background

Climate change has become a pressing environmental concern globally. It has been associated with anthropogenic emissions of greenhouse gases (GHG) which have climbed to their highest level in recent years. Human activities caused 1°C warming above pre-industrial levels in 2017 (IPCC 2019). Furthermore, around 78% of the increase in GHG emissions from 1970 to 2010 has been attributed to fossil fuel combustion and industrial processes (IPCC 2014). Interfuel substitution and energy efficiency are two ways to reduce carbon emissions, and hence mitigate global warming. Interfuel substitution refers to the replacement of inefficient and polluting fuel with a cleaner fuel. Fuel substitution policies are implemented in the power generation, industry and transportation sectors. Energy efficiency refers to producing the same level of output using lower levels of energy. Government policies include promotion of energy efficient appliances and green lighting, setting energy efficiency standards for buildings and pushing for green transport. These policies can be used to mitigate carbon emissions which cause climate change.

This thesis examines interfuel substitution and energy efficiency in the following Asian countries: China, Korea, Japan and the members of the Association of Southeast Asian Nations (ASEAN), namely Singapore, Thailand, Philippines, Malaysia and Indonesia. These countries are in the process of moving their energy mix towards greater consumption of gas and renewable energy. In addition, energy efficiency measures are also being implemented. However, there is a dearth of studies regarding the efficacy of these policies in these countries. Interfuel substitution studies in Asia have been concentrated in China while research in other Asian countries are limited (Ma, Oxley, Gibson, and Kim, 2008; Ma, Oxley, Gibson, and Kim, 2008; Smyth, Kumar Narayan, and Shi, 2012). Likewise, research on energy efficiency in Asia other than China are scarce (Malla, 2008; Atici, 2012; Saboori, Sulaiman, and Mold, 2012). This thesis quantifies the economic impacts of interfuel substitution and energy efficiency policies including their potential for reducing CO2 emissions. It presents findings that policy makers and researchers can use to compare alternative policy scenarios for Asian economies. This is achieved through estimation of various elasticities, hypothetical scenarios, short- and long-run dynamic empirical analysis and some industry-specific analysis. This thesis investigates the magnitude of the economic effects associated with implementation of policies relating to fuel substitution and fuel efficiency. The analysis extends to quantifying the amount of carbon dioxide reduction after the switch.

1.2 Objectives

The main research question that this thesis aims to answer is: Can interfuel substitution and energy efficiency as climate change mitigation policies in Asia lower carbon emissions without significantly affecting countries' economic growth?

In the first empirical chapter, Chapter 3, there are two stages in evaluating the feasibility of interfuel substitution. The first is estimating the output elasticities. This shows how much the different fossil fuels affect output. The second stage is computing the substitution elasticities. This determines the capability of an economy to switch from one fuel to another. Finally, using the estimated elasticities of substitution, the amount of change in carbon dioxide emissions is computed as one fuel is substituted for another. Hence, the objectives of this research are to answer these questions:

(1) How do energy fuels affect output? (Output elasticity.)

(2) Is it possible to substitute a less carbon-emitting fuel for another in an economy? (Substitution elasticity.)

(3) What is the impact on the level of carbon dioxide emissions of substituting a cleaner fuel for coal?

(4) How do Asian countries differ in their responses to fuel substitution?

Energy efficiency is studied by relating it to the Economic Kuznets Curve (EKC). The EKC describes the relationship between income and emissions as following an inverted U shape curve. In the developmental process, high growth at the start generates a high level of pollution. Over time however, as incomes rise, people demand a cleaner environment and with effective regulations and technology, environmental conditions improve. While the shape of the EKC may indicate an energy efficiency policy, energy efficiency is added as an explanatory variable under the classic EKC equation to directly measure its impact.

A decomposition analysis approach is also employed to track the effect of energy efficiency on CO2 emissions. This methodology uses a set of indicators such as carbon intensity, energy share and energy intensity to determine each country's effectiveness in curtailing carbon emissions. Energy intensity is used to represent energy efficiency. Moreover, a sectoral approach is undertaken which looks at the relationship between energy efficiency and CO2 emissions of fossil fuels in two sectors: machinery and textile.

The chapter on energy efficiency aims to answer these questions:

(1) Can the EKC explain energy efficiency of industries?

(2) Does an industry's carbon emission reflect the energy efficiency reforms?

(3) What are the turning points where carbon emissions fell or rose during the time period and what were the causes of this?

(4) What are the country specific measures that can lower carbon emissions?

The changes in the energy mix because of interfuel substitution and energy efficiency will affect a country’s GDP. Therefore, this paper also investigates the relationship between energy consumption and GDP. There are four types of economic linkages between them. A unidirectional causality from energy consumption to economic growth implies that policies to lower energy consumption will adversely affect growth. On the other hand, unidirectional causality running from real GDP to energy consumption gives more leeway for energy conservation policies as this will not have a negative effect on economic growth. Bi-directional causality between energy consumption and economic growth indicates feedback on the changes in each variable. Lastly, there might be an absence of causality between energy consumption and GDP.

The literature (Stern, 2000; Asafu-Adjaye, 2007; Murray and Nan, 1992; Payne ,2009) reveals no conclusive relationship between energy consumption and GDP. The studies use different time frames, countries covered and econometric techniques. Moreover, the studies variously focus on either the demand side or the supply side frame work. Thus, this section will answer the following:

(1) What is the relationship between output and energy in Asia?

(2) What is the relationship between energy conservation/energy efficiency measures and economic growth and performance?

(3) Which fuel can affect output significantly and what is its implication for fuel substitution?

(4) How long does the disequilibrium caused by a shock in energy last?

Several methodologies are employed to analyse these topics. The interfuel substitution methodology uses ridge regression on a transcendental logarithmic (translog) cost function. The ridge regression addresses the multicolinearity problems in OLS regression and avoids erroneous test results. The computation of the environmental effects requires the calculation of carbon dioxide emissions of each fuel. For this, the carbon content of each fuel is determined. Finally, the substitution elasticities help in determining the change in the fuels which will in turn affect the levels of carbon dioxide emissions. The analysis of energy efficiency based on the EKC and decomposition approach tracks the trajectory of carbon emissions and identifies the turning point where carbon emissions declined. The research identifies policies and developments that may have caused carbon emissions to fall. Finally, the dynamic interaction between output and energy consumption are studied with a panel vector error correction model to determine the direction of causality. The research breaks down the changes into short-run and long-run effects. An impulse response function is also applied to observe how economic variables respond to shocks.

1.3 Contribution to the Literature

In general the research shows in three chapters that fuel substitution and energy efficiency are effective instruments to lower carbon emissions without derailing the economy. The results reconcile some of the work of researchers in the vast literature with conflicting conclusions (Ma and Stern, 2008; Smyth, Kumar Narayan, and Shi, 2012; Saboori, Sulaiman, and Mohd, 2012; Song, Zhang, and Wang, 2013; Abosedra and Baghestani, 1991; Ghosh, 2010). This research helps to integrate the three concepts of fuel substitution,energy efficiency and macroeconomic development that is treated separately in the literature. Specifically, here are the contributions of each chapter:

Chapter 3 analyses the interfuel and interfactor substitution among capital, labor, oil, coal and gas. This contributes to the literature as most studies include electricity as a variable in the equation (Ma, Oxley, Gibson, and Kim, 2008; Smyth, Kumar Narayan, and Shi, 2012; Serletis, Timilsina, and Vasetsky, 2010; Wesseh Jr et al., 2013). Electricity is not included because it is composed of the three fossil fuels and on a national level perspective, it may lead to double counting. This chapter also aims to expand the literature outside China to include Southeast Asian countries. The most important contribution of the study is it calculates the changes in the amount of the substitute fuel in a scenario where a polluting fuel declines at 10% and computes the corresponding changes (increase/decrease) in the carbon emission after the substitution. This scenario analysis is unique to this research and has never been encountered in the literature.

Chapter 4 uses EKC analysis to study the effects of energy efficiency and trade openness in carbon emissions of the manufacturing sector. The EKC literature in Asia have not identified these as variables. The EKC framework is suitable for measuring the effects of energy efficiency as it will directly show the influence of this variable on carbon emissions as well as its influence on the threshold point. On the other hand, the trade openness variable shows the strength of the pollution haven hypothesis which states that manufacturing companies relocate to developing countries where environmental regulations are less strict, which is reflected in the trade flows of a country. To further the discussion, Chapter 4 uses another methodology, the decomposition technique, to determine exactly the source of carbon emissions. This has been applied on a national and sectoral basis. The second methodology supports the conclusion of the former which is that energy efficiency can lower carbon emissions.

Lastly, the causality between energy consumption and GDP in Asian countries has been studied extensively (Ang, 2008; Glasure, 2002; Bloch, Rafiq, and Salim, 2012; Shiu and Lam, 2004, Niu, Ding, Li and Luo, 2011; Mahadevan and Asafu-Adjaye, 2007). However, the literature has not explored causality when the energy variable is disaggregated according to the different sources of energy: coal, oil, and gas. This chapter intends to fill this gap, to investigate how these sources of energy affect output, employment and private investment in selected Asian countries.

1.4 Thesis Organization

Chapter 2 provides an overview of economic trends and statistics in selected Asian countries' energy use, carbon emissions and the policies adopted by each country with regards to fuel substitution and energy efficiency. The next three chapters each explore economic aspects of climate change mitigation, namely interfuel substitution (Chapter 3), energy efficiency (Chapter 4) and the dynamic relationship between GDP and energy consumption (Chapter 5). Chapter 6 concludes with some policy recommendations and suggestions for future research.

In every chapter the significance and innovation of the research is first discussed. Then a review of literature ensues detailing the specific strategies adopted by each paper with some detailed comments and observations. The theoretical concepts and methodology are then introduced and an analysis of the empirical results is offered. Finally, the conclusion includes a short summary and analysis of the whole chapter as well as some insights into policy.

Some traditional dissertations contain a separate literature review chapter which explains in length other research on the topic. In this work, the literature review is included in each chapter to provide a background for the empirical work that follows. This way of presenting the literature review ensures continuity of ideas within each chapter.

The chapters are self-contained and each has a different theme. At the end, the conclusion explains the linkages of the various chapters to answer the main research questions. Figure 1.1 presents a schematic diagram of the chapters.

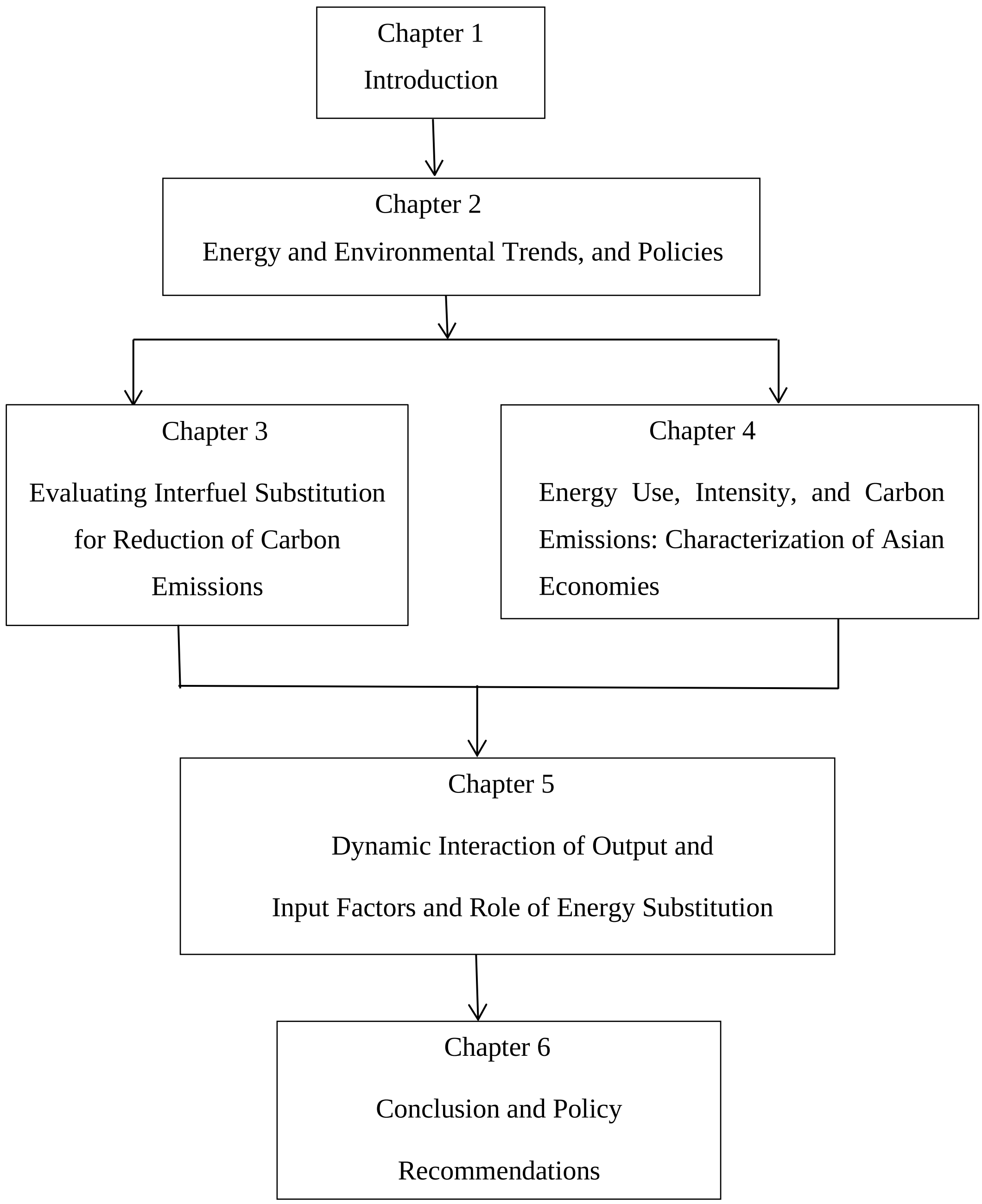


Figure 1.1 Structure of the Study

Chapter 2 : Energy and Environmental Trends, and Policies

2.1 Introduction

Climate change mitigation policies may take many different forms. This chapter provides an overview of the most important policies in the Asian economies studied in this thesis, with aid of some data analysis. Discussion about energy and carbon emissions data as well as government policies implemented are necessary to determine the status quo and set benchmarks. It will also indicate the direction of policies of these economies.

The major climate change mitigation policies adopted in Asia are the Clean Development Mechanism (CDM) of the United Nations Framework Convention on Climate Change (UNFCCC), carbon pricing, fuel substitution and energy efficiency measures. The CDM supports efforts by industrialized countries to meet their carbon emissions targets by allowing them to invest in emission reduction projects in developing countries. These projects earn them credits to supplement their emission reduction initiatives in their home countries. Carbon pricing refers to measures to put a price on carbon emissions such as a carbon tax and an emissions trading system. Fuel substitution is the ability to switch from a pollution emitting fuel such as coal to a cleaner fuel like natural gas. An industry is energy efficient if it can produce the same level of output using less energy. Hence, energy efficiency as a policy can minimize the cost of using energy while reducing carbon emissions.

Among these climate change mitigation options, this thesis focuses on fuel substitution and energy efficiency. There are a number of reasons for this focus. First is the dearth of literature on fuel substitution and energy efficiency in Asia. Second is that CDM combines different types of carbon mitigation projects which include fuel substitution and energy efficiency. Lastly, to determine the effectiveness of carbon pricing in reducing carbon emissions entails longer processing time in coordination, testing and study.

This chapter contains four sections. First, the trends in carbon emissions and energy consumption are discussed. Secondly, current energy and environmental policies are enumerated and elaborated. Thirdly, explanation on the choice of interfuel substitution and energy efficiency as the focus of the dissertation are discussed. The fourth and final section is the conclusion which gives a summary of this chapter

2.2 Trends in Carbon Emissions and Energy Consumption in Asian Countries

2.2.1 Energy Production by Country and by Fuel

Coal is the largest produced fuel in China followed by oil and gas (Table 2.1). From 1981 to 2016 coal production grew by 442% from 310.8 million of oil tons equivalent (Mtoe) in 1981 to 1685 Mtoe in 2016. This growth rate is only exceeded by coal production in Indonesia which jumped from 0.2 Mtoe in 1981 to 255.7 Mtoe in 2016. Indonesia's fuel production is also dominated by coal followed by gas and oil. Thailand's coal production also rose from 0.5 Mtoe in 1981 to 4.3 Mtoe in 2016. In contrast, Japan's coal production declined from 11.1 Mtoe in1981 to 0.7 Mtoe in 2016. Likewise, there was a steep fall in coal production in Korea from 8.7 Mtoe in 1981 to 0.8 Mtoe in 2016. China maintained its lead in oil production with 199.7 Mt in 2016, up by 88.5% from 106.0 Mt in 1980. Indonesia was the second oil producer with 43 Mt in 2016. However, oil production has dwindled significantly since 1981 by 46%. In contrast, Malaysia and Thailand posted substantial increase in their oil production which reached 32.7 Mt and 17.6 Mt in 2016, respectively. Among the fossil fuels, gas production in China grew the most from 13.3 Mtoe in 1980 to 124.6 Mtoe in 2016. Indonesia, Malaysia and Thailand also exhibited increased gas production. Moreover, Thailand produced more gas than oil or coal in 2016. At the same time, Malaysia's gas production also exceeded its oil production. In contrast, Japan and Korea have no gas or oil production and very limited coal production. Singapore does not produce any fuel.

Table 2.1 Energy Production by Country and by Fuel

	Coal (Mtoe)		Oil (Mt)		Natural Gas (Mtoe)	
	1981	2016	1980	2016	1981	2016
China	310.8	1685.7	106	199.7	13.3	124.6
Japan	11.1	0.7				
Korea	8.7	0.8				
Indonesia	0.2	255.7	79	43	16.7	62.7
Malaysia			13.2	32.7	2.2	66.5
Philippines						
Singapore						
Thailand	0.5	4.3	0.1	17.6	0.2	34.7

Note: Thailand Oil and Gas starts at 1981.

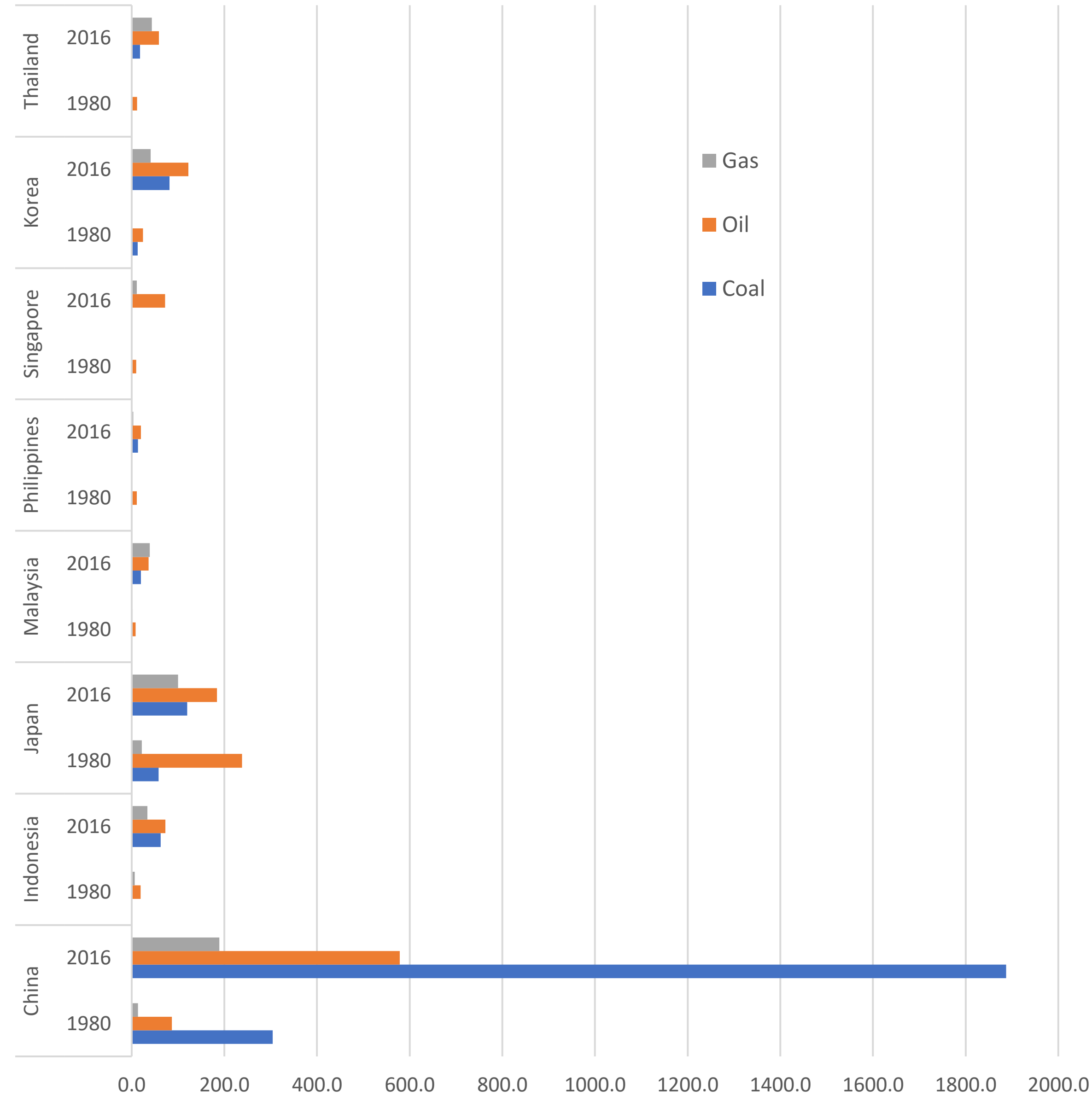
Source: British Petroleum (2018).

2.2.2 Energy Consumption by Country

From Figure 2.1 it can be seen that China's energy consumption is dominated by coal. China's coal consumption rose from 304.3 Mtoe in 1980 to 1,887.6 Mtoe in 2016, at an annual growth rate of 5.3% on average. Oil is the second most consumed fuel in China: it reached 578.7 Mtoe in 2016 growing by an annual average rate of 5.2%. Of all fossil fuels, natural gas has the highest average growth rate of approximately 8% jumping from 13.3 Mtoe in 1980 to 189.3 Mtoe in 2016.

Except for China, most of the countries studied are dependent primarily on oil as their energy source. In 1980, Singapore's economy used oil as its only energy source. By 2016 Singapore's oil consumption reached 72.2 Mtoe and remains the main source of energy. Likewise, Indonesia's oil consumption rose from 18.9 Mtoe in 1980 to 72.6 in 2016 at an average growth rate of 4.1%. Other countries dependent on oil are Japan, Korea, Thailand and the Philippines. However, Japan's oil consumption declined from 237.8 Mtoe in 1980 to 184.3 Mtoe in 2016, a 22.5% reduction.

Natural gas is the least consumed fuel but its consumption is rising over time. In 1980 Malaysia was consuming more oil than gas. However, by 2016 gas consumption compared to oil consumption was slightly higher at 38.7 Mtoe. Japan's gas consumption grew annually by 5% on average exceeding the growth rate for coal and oil within the study period. Gas usage in Thailand is also catching up with gas consumption reaching 43.5 Mtoe in 2016 to oil's 59 Mtoe.



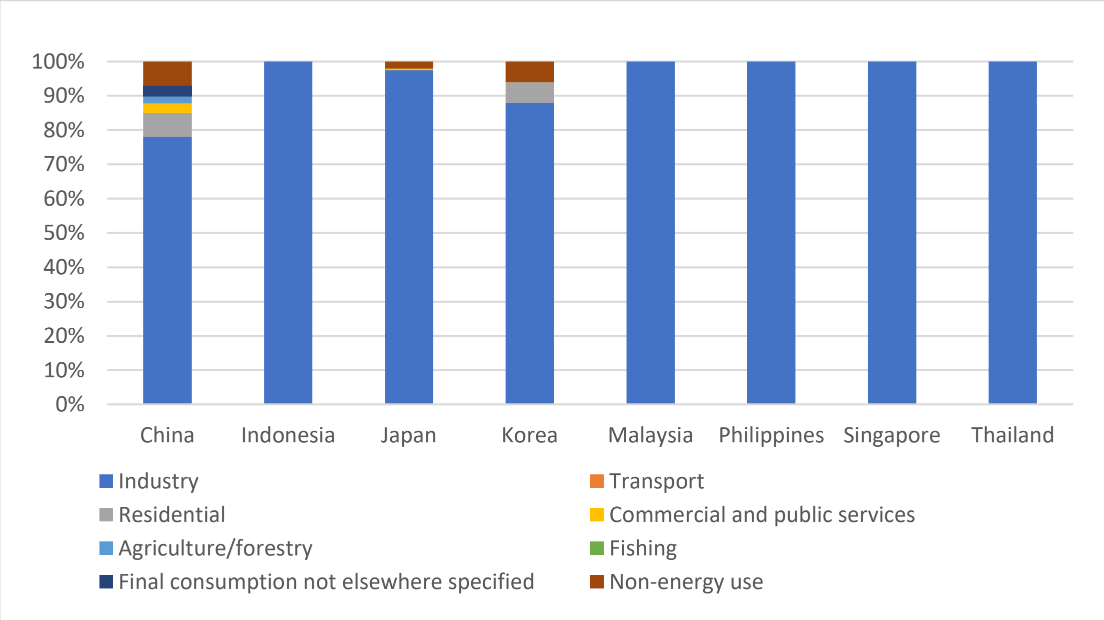
	China		Indonesia		Japan		Malaysia		Philippines		Singapore		Korea		Thailand	
	1980	2016	1980	2016	1980	2016	1980	2016	1980	2016	1980	2016	1980	2016	1980	2016
Gas	13.3	189.3	6.3	33.9	21.7	100.1	2.2	38.7	0.0	3.4	0.0	11.3	0.0	40.9	0.0	43.5
Oil	86.7	578.7	18.9	72.6	237.8	184.3	8.2	36.3	10.9	19.9	9.6	72.2	24.1	122.1	11.6	59.0
Coal	304.3	1887.6	0.3	62.7	58.2	119.9	0.1	19.9	0.1	13.5	0.0	0.4	13.2	81.6	0.5	17.7

Source: British Petroleum (2018).

Figure 2.1 Energy Consumption by Country, 1980 & 2016 (in Mtoe)

2.2.3 Energy Consumption by Sector and Country

For most countries coal is mainly used in the industry sector (Figure 2.2). Indonesia, Malaysia, Philippines, Singapore and Thailand have posted 100% coal consumption in industry in 2016. Japan used 98% of coal in its industry sector and only 2% for non-energy use. Korea attributes coal usage of 88% to the industry sector and the rest to the residential sector (5.9%) and non-energy use (6.1%). China's coal usage in the industry sector reached 78%. The other sectors with high coal consumption are the residential and non-energy use sectors which posted 6.9% and 7%, respectively.



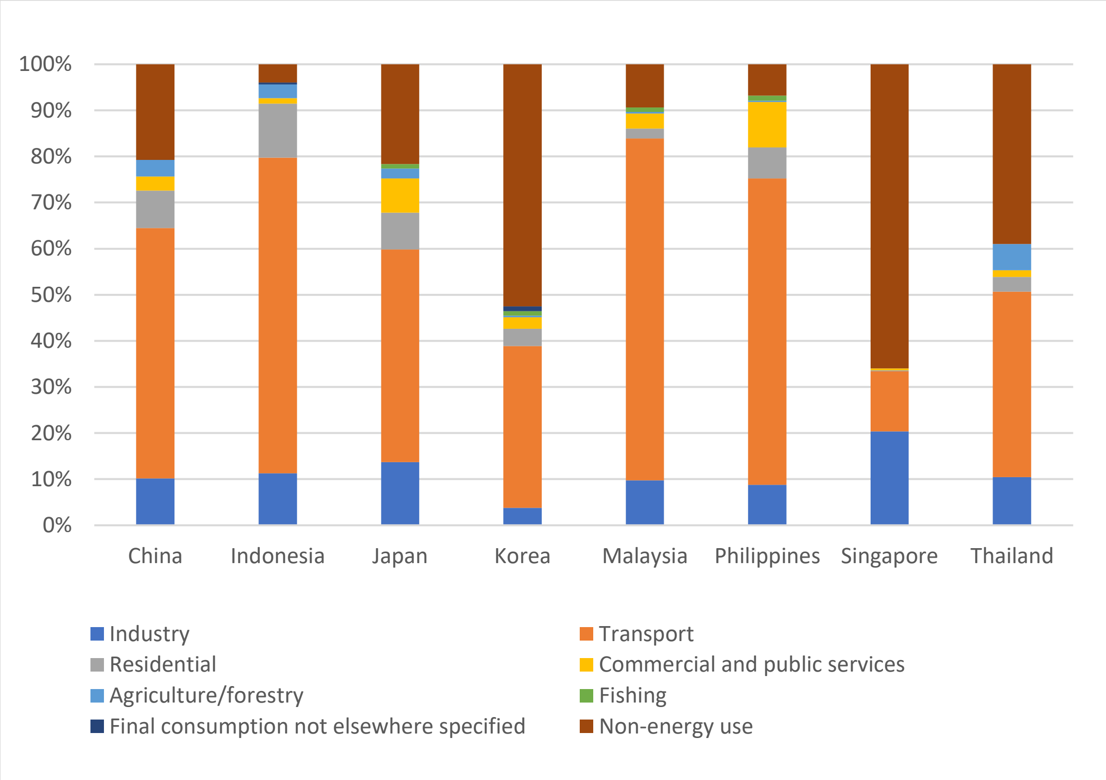
Note: Non-energy use includes fuels which are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel.

Source: OECD (2020).

Figure 2.2 Coal Consumption by Sector and Country, 2016

In these Asian countries oil is mostly consumed in the transport sector in 2016. Malaysia, Indonesia and the Philippines are the top consumers at 74%, 69%, 72% and 66% of the total national oil consumption, respectively (Figure 2.3). Thailand's oil consumption is divided between transport (40%), non-energy use (39%) and industry (10%). China's oil consumption in transportation is 54%, with substantial use also in the non-energy use (21%), industry (10%) and residential sectors (8%). Japan's oil consumption in the transport sector at 46% is the highest followed by non-energy use sector and industry sector at 22% and 14%, respectively. For Korea, non-energy oil consumption at 53% exceeds the transport sector which used 35% oil in 2016. Among these countries only Singapore consumes more oil in industry at

20% compared to that of the transport sector (13%). However, the non-energy use sector has the highest oil consumption in 2016 at 66%.

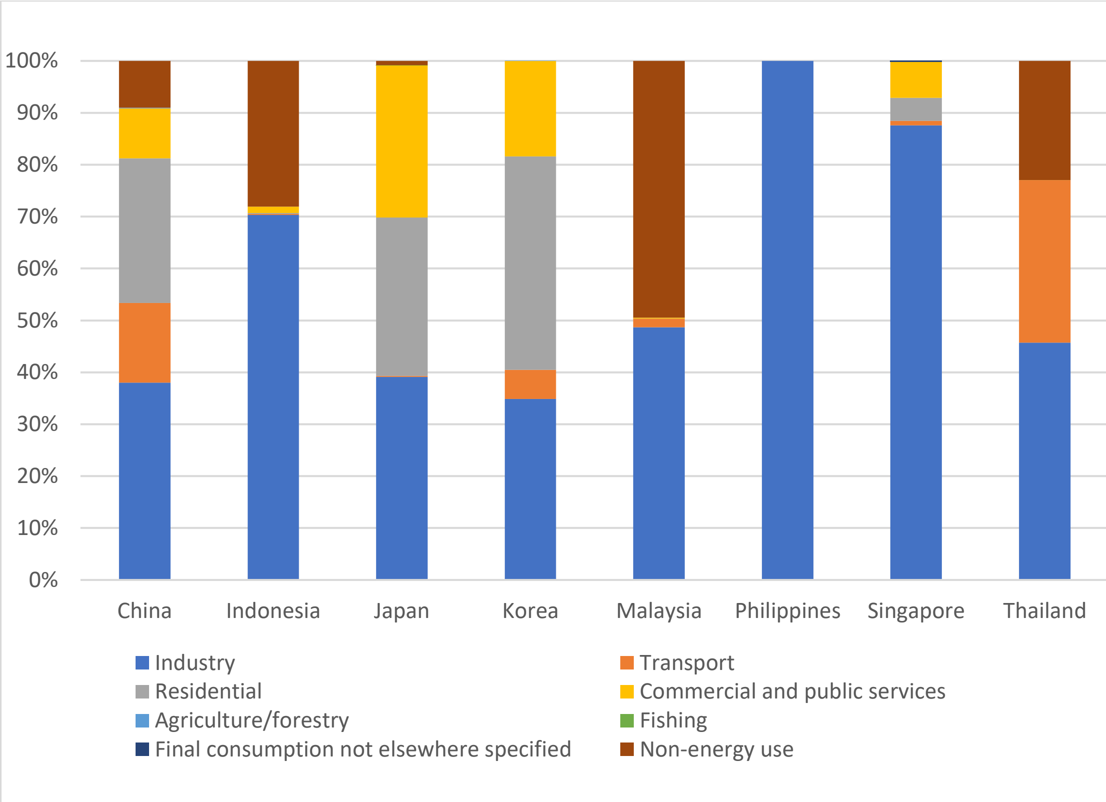


Note: Non-energy use includes fuels which are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel.

Source: OECD (2020).

Figure 2.3 Oil Consumption by Sector and Country, 2016

In 2016, gas consumption in most countries is concentrated in the industry sector (Figure 2.4). The Philippines has 100% gas utilization in the industry sector. Indonesia and Singapore also have very high gas utilization in industry reaching 70% and 88%, respectively. In Malaysia, final gas consumption is divided between the industry sector (49%) and non-energy use (49%). China's industry sector has 38% of total gas usage followed by the residential sector (28%) and the transport sector (15%). Japan's gas consumption is divided among the industry sector (39%), residential (31%) and commercial and public services (29%). Unlike other countries, the residential sector in Korea uses the highest proportion of gas at 41% of total gas consumption, followed by industry (35%). Among ASEAN countries, only Thailand consumes a substantial amount of gas in its transport sector at 31% of total. However, it is still the industry sector which utilizes the most gas (46%).



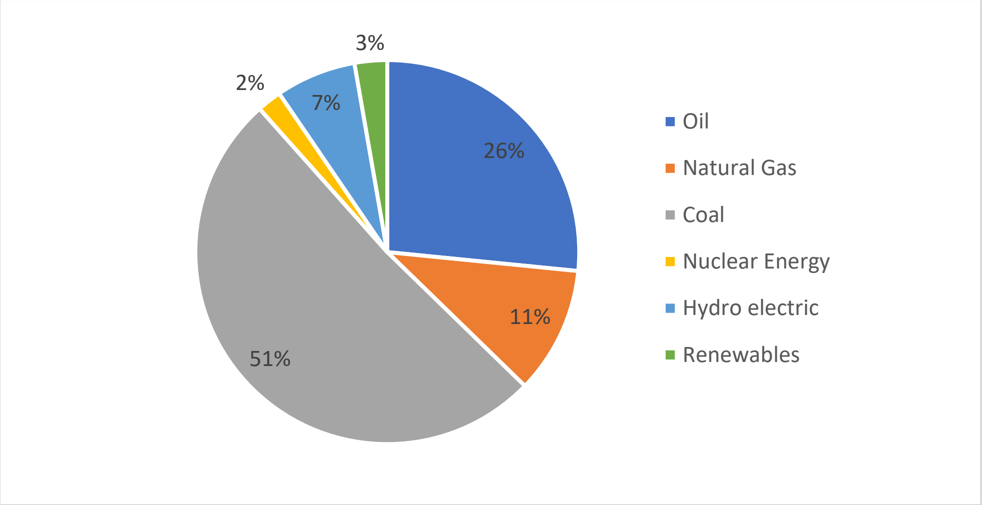
Note: Non-energy use includes fuels which are used as raw materials in the different sectors and are not consumed as a fuel or transformed into another fuel.

Source: OECD (2020).

Figure 2.4 Gas Consumption by Sector and Country, 2016

2.2.4 Renewable Energy Consumption

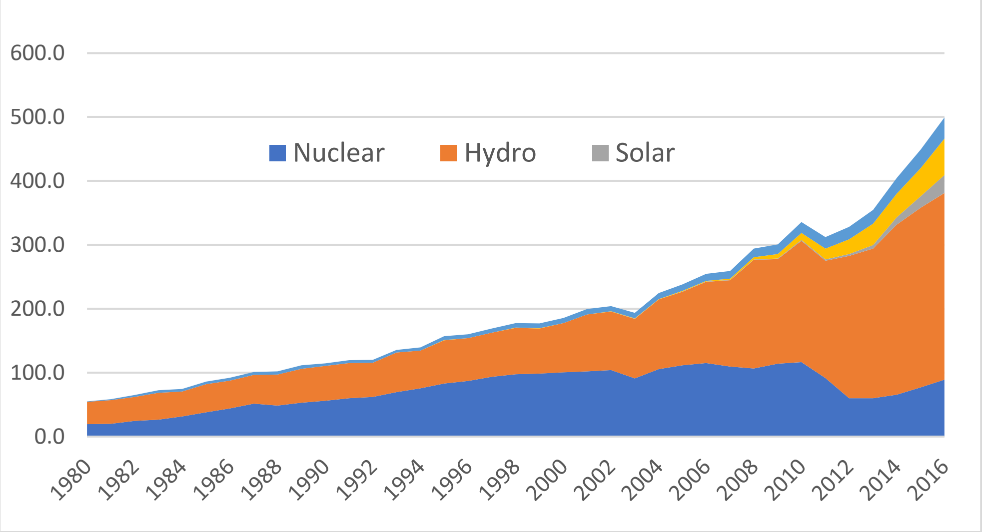
Among the non-fossil energy sources, hydroelectricity contributes the highest share in primary energy consumption, in 2016 reaching 7% (Figure 2.5). Nuclear energy generates 2% while renewables accounts for 3% of total primary energy consumption. Figure 2.6 shows the development of renewable energy consumption since 1980. Nuclear energy and hydroelectricity have long been utilized while other consumption of renewable energy from wind, solar, geothermal and biomass are recent. There are only three countries which have nuclear energy: Japan, China and South Korea. Prior to 2011, Japan produced most of the nuclear power with 50+ main reactors. However, after the tsunami incident in 2011 energy production from nuclear power fell significantly. Hydro power is generated in all the countries studied except Singapore. The highest consumer of hydro power is China while among the ASEAN countries, Indonesia and the Philippines are the biggest consumers. The uptake of solar power started in 1990 for China, Japan and Korea. For ASEAN countries, solar power consumption took off in 2005. In terms of wind energy, China leads in utilizing wind energy in the region. Renewables such as geothermal and biomass are also consumed predominantly by China and Japan.



Note: Renewables include wind, geothermal, solar, biomass and waste; Countries include China, Indonesia, Japan, Korea, Malaysia, Thailand, Philippines, Singapore.

Source: British Petroleum (2018).

Figure 2.5 Primary Energy Consumption by Fuel, 2016



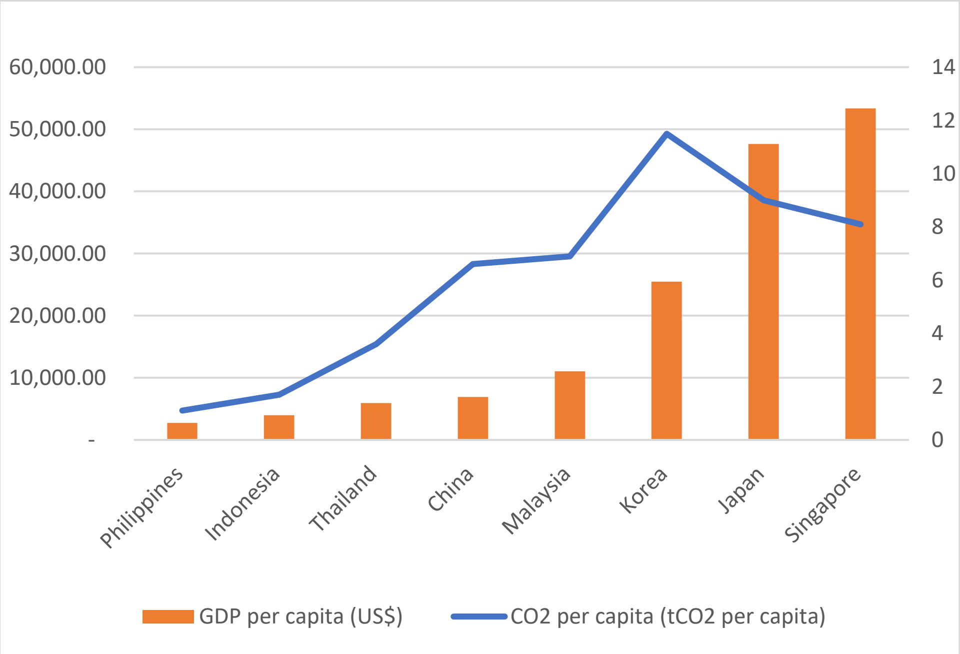
Note: Other refers to geothermal, biomass; Countries include China, Indonesia, Japan, Korea, Malaysia, Thailand, Philippines, Singapore.

Source: British Petroleum (2018).

Figure 2.6 Renewable Energy Consumption, 1980-2016

2.2.5 CO2 Emissions per Capita and per Capita GDP

In Figure 2.7 Korea's GDP per capita is more than half of Japan's (US$25,484.04) but its emissions in 2016 exceeded the latter with 11.5 tCO2 per capita emissions. Japan had the second highest per capita carbon emissions of 9 tCO2 as well as the second highest GDP per capita of US$47,660.89. Singapore recorded the highest GDP per capita of US$53,353.84 but was only the third highest polluter with 8.1 tCO2 emissions. China's GDP per capita in 2016 was US$6,894.46 while its CO2 emissions reached 6.6 tCO2. Malaysia's carbon emissions in 2016 stood at 6.9 tCO2 while its GDP per capita was US$11,038.87. Indonesia's and Thailand's carbon emissions per capita were 1.7 tCO2 and 3.6 tCO2, respectively. The Philippines had the lowest GDP per capita at US$ 2,752.11 and the lowest CO2 emissions per capita at 1.1 t CO2.



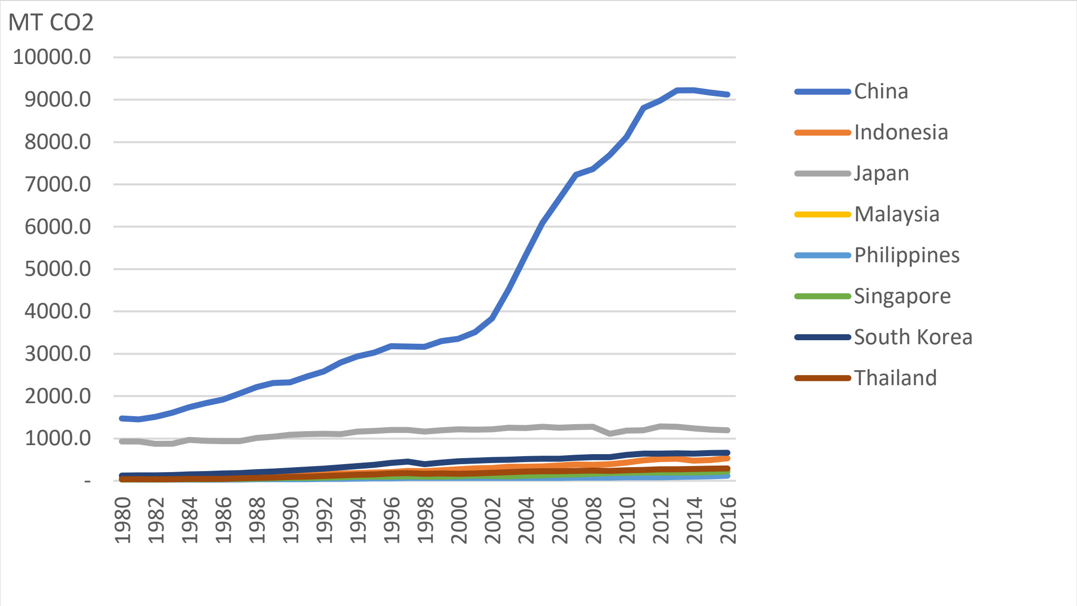
Source:World Bank (2018), OECD (2019).

Figure 2.7 CO2 Emissions Per Capita by Per Capita GDP, 2016

2.2.6 CO2 Emissions by Country

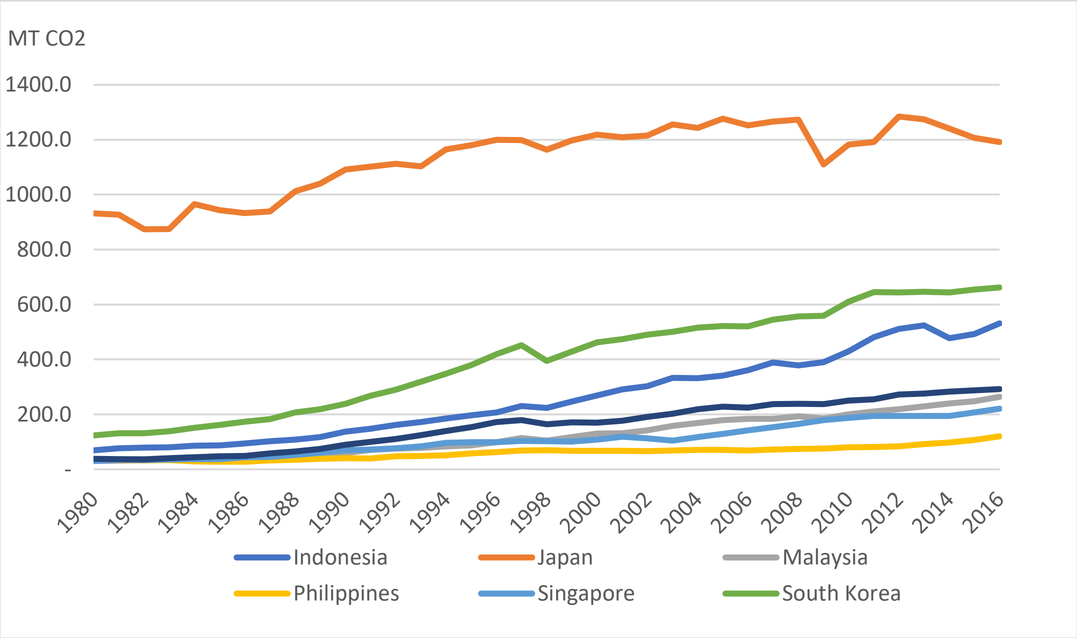
The following discussion analyzes Asian countries' carbon dioxide emissions from fossil fuel use only. China is the highest emitter among the Asian countries (Figure 2.8). From 1,473.3 MT of CO2 in 1980 emissions rose to 9,123.0 MT of CO2 in 2016. In comparison, Japan which is the second highest emitter, only emitted 1,191.2 MT of CO2 in 2016, up from 931.7 MT in 1980. Among the ASEAN countries, Indonesia is the highest emitter of carbon dioxide (Figure 2.9). Starting from 69.2 MT in 1980 emissions in Indonesia reached 531.4 MT in 2016. The lowest emitter is the Philippines which logged 119.9 MT of CO2 emissions in

2016, up from 34.7 MT of CO_2 in 1980. On average, Malaysia has the largest average annual growth rate at 6.4% from 1980 to 2016 (Figure 2.10). It was followed by Indonesia and Singapore at 6.1% and 5.7%, respectively. In contrast, carbon emissions in China grew by 5.2%, annually. The smallest increase was recorded in Japan with only 0.7% on average.



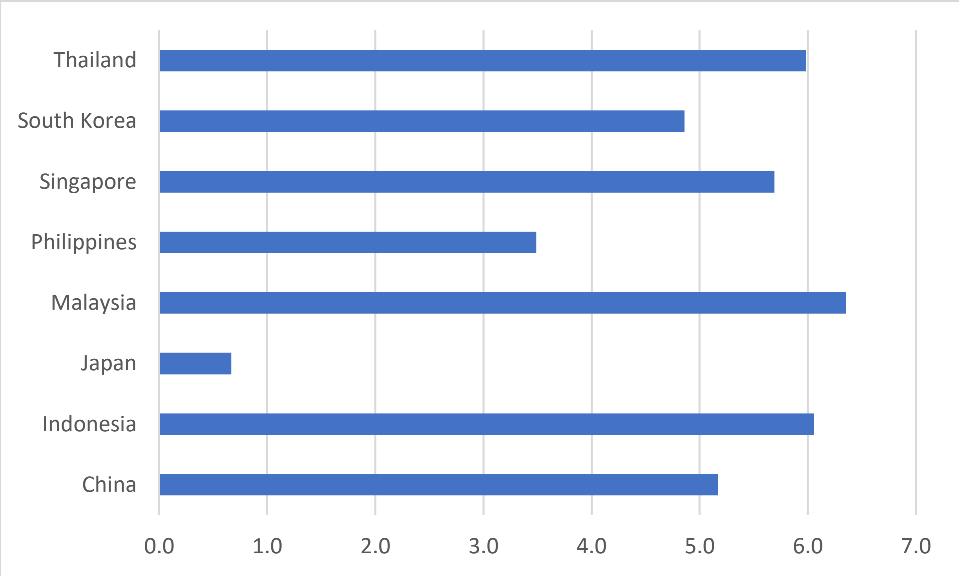
Source: British Petroleum (2018)

Figure 2.8 CO_2 Emissions by Country, 2016



Source: British Petroleum (2018).

Figure 2.9 CO_2 Emissions by Country (excluding China)



Source: British Petroleum (2018).

Figure 2.10 CO2 Emissions by Country Average Annual Growth Rate (1980-2016)

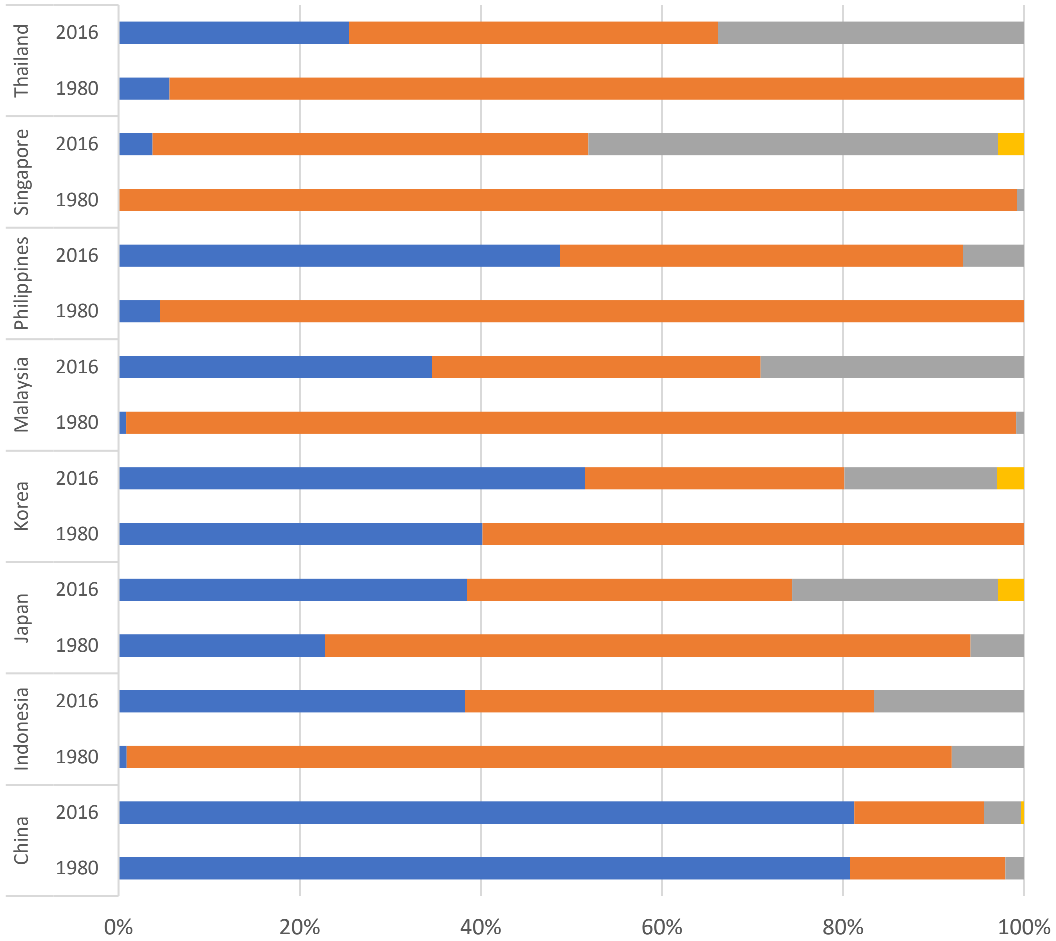
2.2.7 CO2 Emissions by Fuel by Country

In China, coal burning produces most of the carbon emissions followed by oil and then gas (Figure 2.11). Beginning at 1,101 MT of CO2 in 1980, coal consumption generated 7,358 MT of carbon emissions in 2016, an increase of almost 6% annually. Following coal, oil emissions have grown by an average of 5.5% annually to 1298 Mt CO2 in 2016. However, other countries produce the highest carbon emissions from the consumption of oil . Indonesia's carbon emissions from oil consumption rose from 61.6 MT of CO2 in 1980 to 205.3 MT of CO2 in 2016. Likewise, Thailand's carbon emissions from oil usage jumped from 32 MT of CO2 in 1980 to 100 MT in 2016. Singapore, which consumed mostly oil, recorded a 2% average annual increase of carbon emissions from 12.5 MT in 1980 to 21.8 MT of CO2 in 2016. Malaysia's oil emissions have also risen but not as much as coal and gas emissions. In contrast, Japan's carbon emissions from oil declined from 620.7 MT in 1980 to 412.4 MT in 2016. However, its coal and gas emissions have increased.

Carbon dioxide emissions from coal in Korea and the Philippines have risen steeply by 2016. From 50.5 Mt CO2 in 1980, Korea's emissions climbed to 303.3 Mt CO2 in 2016. The Philippines had 1.5 Mt CO2 of coal emissions in 1980 which reached to 55.9 MT CO2 by 2016. Likewise, Malaysia's coal emissions grew from just 0.2 Mt in 1980 to 74.8 Mt by 2016. Japan's coal emissions exceeded oil emissions in 2016 and reached 441 Mt CO2.

Emissions from gas are on the rise as well. China's carbon emission from gas leads this selected Asian group with 370.4 MT in 2016, followed by Japan with 260.9. Among the

ASEAN countries Thailand and Indonesia have the highest gas emissions with 82.6 T CO2 and 75.5 MT CO2, respectively. In 2016, Singapore's gas emissions at 20.5 Mt CO2 closely follows its oil emissions at 21.8 Mt CO2.



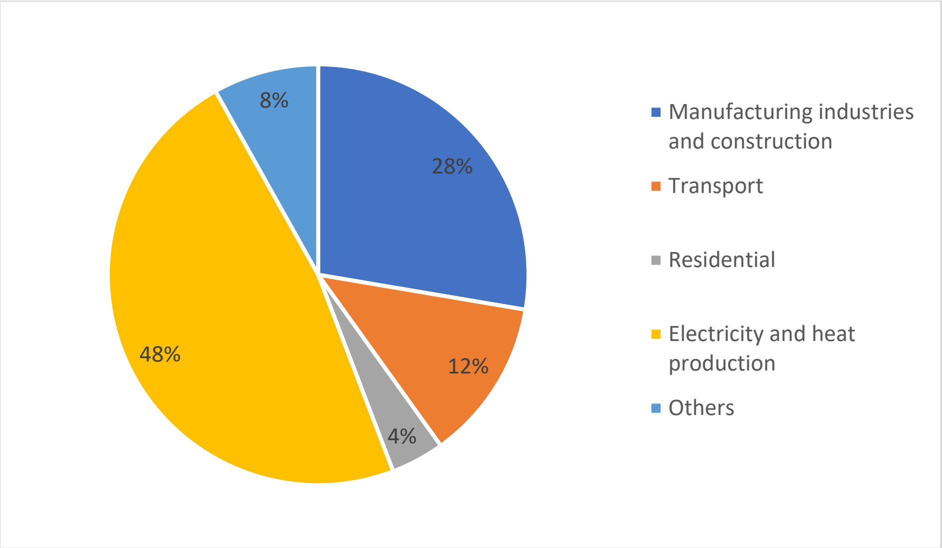
	China		Indonesia		Japan		Korea		Malaysia		Philippines		Singapore		Thailand	
	1980	2016	1980	2016	1980	2016	1980	2016	1980	2016	1980	2016	1980	2016	1980	2016
Coal	1101	7358	0.6	174.1	198.4	441	50.5	303.3	0.2	74.8	1.5	55.9	0	1.7	1.9	62.2
Oil	234.3	1298	61.6	205.3	620.7	412.4	75.1	169	23.3	78.4	31.1	51.1	12.5	21.8	31.9	99.7
Gas	28.1	370.4	5.4	75.5	51.5	260.9	0	99	0.2	62.9	0	7.7	0.1	20.5	0	82.6
Other	0	30.4	0	0	0	32.8	0	17.8	0	0	0	0	0	1.3	0	0

Source: OECD (2019).

Figure 2.11 CO2 Emissions by Fuel and by Country, 1980-2016 (Table in MT CO2)

2.2.8 CO2 Emissions by Sector

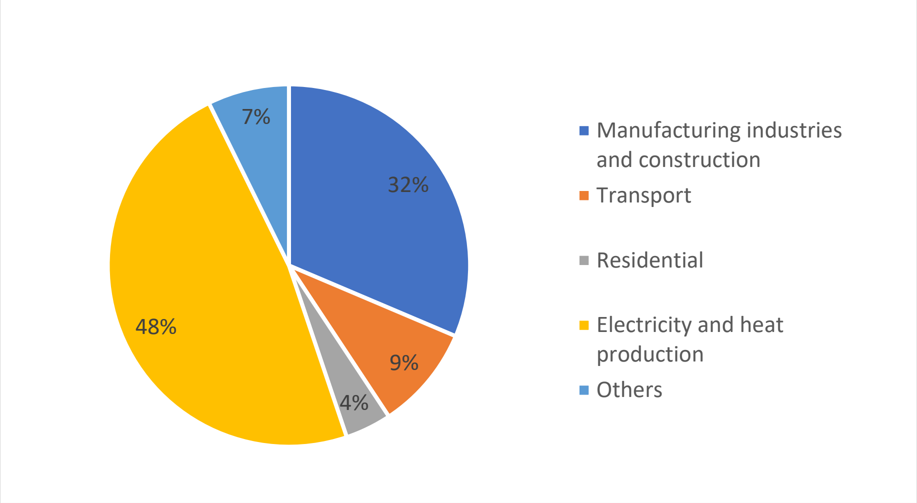
The electricity and heat sector contributes 48% to CO2 emissions in Asia (Figure 2.12). The second source of carbon emissions is the industrial sector which recorded 28% of CO2 emissions in 2016. The transport sector produced 12% of CO2 emissions while the residential sector emitted 4% of total CO2 emissions. This pattern is reflected in the disaggregation of CO2 emissions in China (Figure 2.13). Electricity and heat account for 48% of CO2 emissions followed by industry with 32% and transport with 9%. The residential sector contributes only 4% to the total carbon emission in China. Meanwhile, ASEAN countries emits 42% Mt CO2 from the electricity and heat production sectors (Figure 2.14). This is followed by 29% Mt of CO2 from Transport. Manufacturing industries and construction is the third highest emitter with 18% Mt of CO2. The residential sector accounts for 9% Mt CO2 of emissions which is higher than carbon emissions from China's residential sector.



Note: Countries include China, Indonesia, Japan, Korea, Malaysia, Thailand, Philippines, Singapore.

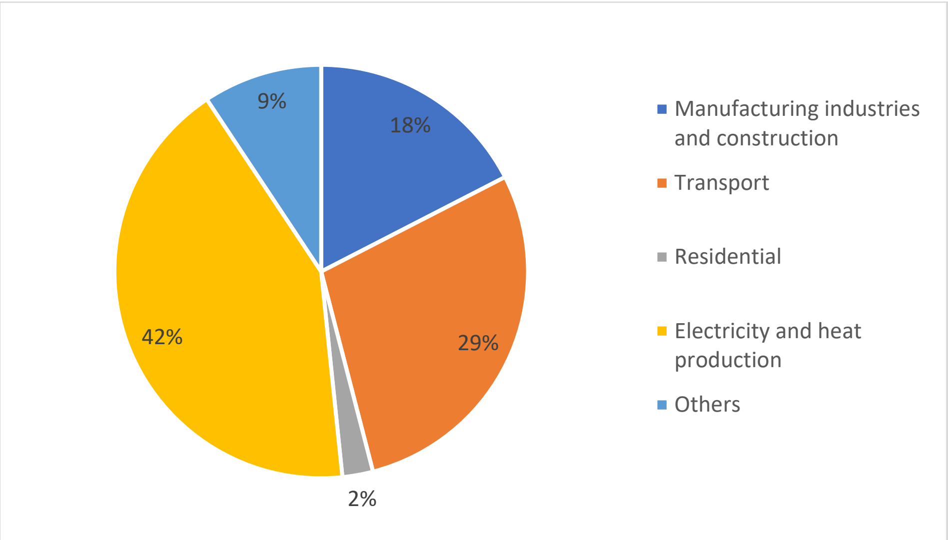
Source: OECD (2019).

Figure 2.12 CO2 Emissions of Selected Asian Countries by Sector, 2016



Source: OECD (2019).

Figure 2.13 CO2 Emissions in China by Sector, 2016



Source: OECD (2019).

Figure 2.14 CO2 Emissions in ASEAN by Sector, 2016

2.3 Energy and Environmental Policies of Asian Countries

2.3.1 Carbon Pricing

Among the countries covered in this research, China, Japan and Korea have taken early initiatives to price carbon. Singapore is the only ASEAN member which has imposed a carbon tax on emissions. The tax is currently being implemented and applied on companies that emit 25,000 tCO2e or more of greenhouse gas (GHG) emissions annually. The tax includes six GHG namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). From 2019 to 2023, the carbon tax will be at $5/tCO2e to allow companies to make adjustments and execute energy efficiency plans. However, by 2030 the tax will be between $10/tCO2e and $15/tCO2e in order to incorporate climate change developments and other significant economic developments (NCCS, 2018).

China aims to lower its carbon emissions per unit of GDP in 2020 to 40-45 percent below 2005 levels. To achieve this China launched seven regional pilot markets in 2011 to prepare for a nationwide emissions trading system (ETS). These are found in the cities of Beijing, Tianjin, Shanghai and Shenzhen and in the Chongqing, Guangdong, and Hubei provinces. The schemes altogether include a billion tonnes of carbon dioxide (Swartz, 2013). Each pilot market deals with different sectors. In Guangdong, which has the highest carbon emissions among the Chinese provinces (500 million tonnes of CO_2 annually), the sectors covered are power, cement, iron and steel, ceramic, petrochemical, textile, non-ferrous metals, plastics and paper. Meanwhile Hubei province has set up a carbon exchange for the industry sector only. Shanghai, as China's financial center, has included the financial and commercial sectors in the ETS (Hope, 2014). China's nationwide ETS will start during the 13th Five Year Plan (2016–2020). The unified emission market is still being studied. In terms of cap setting, one option being considered is for the national government to set the ETS inclusion criteria and methodology for distribution while allowing local governments some leeway. Another option is to divide the national target into an ETS part and a non-ETS part and provide enterprises emission allowances. Otherwise, the local governments will handle its distribution (IETA 2013a).

Korea launched its national ETS (KETS) on January 1 2015. It is the first emissions trading applied nationwide in Asia. The KETS is the world's second largest ETS following the European Union ETS imposing a cap of 573 Mt CO_2 in 2015 on 525 companies. The KETS covers power generators, petrochemical firms, steel producers, car makers, electro-mechanical firms and airlines (International Carbon Action Partnership, 2015). Due to its non-Annex I category, Korea is not obligated to reduce its emissions. However, the KETS targets the reduction of GHG emissions by 30% against business-as-usual by 2020. There are three phases in the KETS: Phase I: three years (2015-2017); Phase II: three years (2018-2020); Phase III: five years (2021-2025). For its first phase (2015-2017) the total allowed emissions would reach 1.686 million tonnes of carbon dioxide equivalent. In the initial phase there will be 100% free allowances and no auctioning (International Carbon Action Partnership, 2015).

Japan has also experimented with various carbon trading schemes. As part of the Copenhagen Accord, Japan pledged to reduce GHG emissions to 25% below 1990 levels by 2020. Emissions trading is conducted in Tokyo, Saitama and Kyoto. The Tokyo and Saitama schemes are compulsory while the latter is voluntary. At the national level, the J-Credit Scheme launched in 2013 is composed of the two national domestic voluntary crediting schemes: the Japan Domestic Credit Scheme (J-CDM) 151 and the Offset Credit (J-VER) Scheme. The J-Credit Scheme scheme will expire on 31 March 2021 (IETA 2013b). On the international front, Japan set up the Joint Crediting Mechanism (JCM). This scheme provides technologies, products and services which limit carbon emissions to Japan's partner countries to lower their carbon emissions. Bilateral agreements have been signed between Japan and 11 countries, namely Mongolia, Bangladesh, Ethiopia, Kenya, Maldives,Vietnam, Lao People's Democratic Republic, Indonesia, Costa Rica, Palau and Cambodia. Services that Japanese companies perform for these countries include installation of renewable energy or plant trees which also allows the companies to offset their own emission obligations (IETA, 2013b).

2.3.2 Clean Development Mechanism

Under the Kyoto Protocol Annex 1, countries are obliged to limit their greenhouse gas emissions. The Clean Development Mechanism (CDM) was created to assist adhering countries in meeting their targets. In the CDM, industrialised countries can support emission reduction projects in developing countries which will earn them certified emission reduction credits to meet their targets. Each of the credits is equivalent to one tonne of CO2 and can be traded and sold (UNFCCC (United Nations Framework Convention on Climate Change), 2015). The benefit of the CDM is that it promotes emission reduction while stimulating sustainable development in developing countries. The latter receive new investments, environmentally friendly technologies, information and employment.

CDM projects include renewable energy projects on biomass power generation, biogas power generation, solar water heating and photovoltaic systems and hydropower; energy efficiency projects include improving combined heat and electricity production, improved boilers and more efficient processing of heat and steam. In the transport sector, the projects include efficiency improvement for vehicles and switching to fuels with lower emissions. Other sectors included are forestry, waste management and agriculture.

While the primary objective of the CDM is to drive emissions reduction in developing countries, this is also achieved indirectly by another objective which is the transfer of clean technologies to developing countries. Seres, Haites, and Murphy (2009) evaluate the technology transfer in the CDM of industrial countries to developing countries. Out of 3,296 projects, 36% of projects involve technology transfers. These projects contribute 59% of reductions in emissions yearly. Technology transfer is also more observable for large projects as well as those involving foreign participants. Moreover, the technology is in the form of knowledge and equipment, from Japan, Germany, USA and Great Britain. It is noted that the host country can affect the degree of technology transfer through its criteria for approval of CDM projects and other factors such as import tariffs on equipment. It is observed that technology transfer claims have declined particularly in China and Brazil. This is because the technology transferred to a certain type of project is leaked out, enhancing the local's knowledge and equipment.

2.3.3 Fuel Substitution

2.3.3.1 China

China's 13th Five-Year Plan increase the targets for carbon dioxide intensity by 18 percent and decreased the energy intensity by 15 percent by 2020. Moreover, the total energy cap for all energy sources is set at less than the equivalent of five billion tons of coal, a first for the nation.

The government has targeted clean energy use to 15 percent by 2020. In 2016, China announced $373.1 billion (RMB 2.5 trillion) in total investment for new installed capacity of renewable energy by 2020: $74.6 billion (RMB 500 billion) for hydropower, $104.5 billion (RMB 700 billion) in wind, $149.3 billion (RMB 1 trillion) in solar, and other investments in biomass, power generation, biogas, and geothermal energy utilization.

The share of coal in primary energy consumption is reduced to 58% in 2020 and capping its consumption at 4.1 Gt. In spite of this new coal-fired power plants were built in the central and western provinces. By January 2017, the National Energy Administration suspended 101 coal power projects as oversupply looms (US-China Economic and Security Review Commission, 2017).

The 13th FYP will strictly control the approval of coal mines and fast track the elimination of backward production and production capacity that is not supporting industrial policy. The government will abolish coal production that does not uphold safety standards, heavily pollutes the environment and has incurred losses for a long time. The plan also supports integrated management of coal, power generation, chemical industry and other upstream and downstream industries.

The 13th FYP targets natural gas consumption at 10% of total energy consumption. To expand the natural gas consumption market, measures include natural gas pricing reform, establishment of a natural gas market and a price linkage mechanism between gas and electricity. The plan also stipulates for opening up of natural gas receiving and storage facilities, layout the natural gas distribution network and service facilities, focusing on residential users, power generation, transportation and industry and promote "coal to gas" projects in key cities. It is expected that by 2020, the installed gas-fired power generation capacity will reach 110 GW.

The quality of refined oil products will be raised. The national standard level six for gasoline and diesel will be implemented while promotion of quality upgrades of ordinary diesel and marine fuel oil will be promoted (Chinaenergyportal.org, 2016).

Since 2016 China has driven 13 million households in Northern China to switch from coal burning to electric or gas heating. In particular, the central province of Henan is one of the most polluted and plans to ban coal burning before the 2020 winter (compuserve.com, 2019).

2.3.3.2 Japan

The 2011 Fukushima Daiichi nuclear accident has shifted Japan’s focus from nuclear energy to natural gas and renewables. Liquefied Natural Gas (LNG) was favored to replace nuclear energy due to its low carbon emissions and lower price compared to the oil price. Amendments in the Gas Business Act liberalized the gas retail market in 2017 and legalized by 2022 the unbundling of gas pipes owned by three city gas utilities, Tokyo Gas, Osaka Gas and Toho Gas. The government intends to reform the electricity and gas systems into a more liberalized and competitive energy market (METI, 2015).

The government pushed for an energy mix where nuclear accounts for 20% to 22% of total generated electricity, renewables for 22% to 24%, liquefied natural gas (LNG) for 27%, coal for 26% and oil for 3%. Nuclear independence was reduced since the share of nuclear before the earthquake was around 30%. For renewables, hydro and solar are the two largest sources which accounts for 9.2%, and 7%, respectively (APERC, 2017a).

2.3.3.3 Korea

The Energy Transition Roadmap released by the government in 2017 aims to lessen the use of nuclear and coal and increase use of renewable energy and natural gas. The government will no longer construct new nuclear reactors and prohibits the extensions of existing ones. In the generation mix, renewable energy sources will generate 20% of electricity by 2030 while the share of natural gas will be 19%. The contribution of coal and nuclear energy will be 36% and 24%, respectively (APERC, 2016).

2.3.3.4 Malaysia

The Four-Fuel Diversification Policy established in 1981 aims to wean the economy from its dependence on oil and diversify the energy mix in generating electricity. It aims to optimize supply security by mixing oil, gas, hydro and coal. In the transportation sector, the National Biofuel Policy was established in 2006 to push for the production of biofuel by mixing processed palm oil (5%) with petroleum diesel (95%) as well as supporting biofuel consumption through setting up biodiesel pumps at certain stations (APEC, 2014).

The National Renewable Energy Policy and Action Plan was introduced in 2010 to increase the use of Malaysia’s renewable energy sources. The target is to make renewable energy comprise 9% of the total energy mix in 2020 and 24% by 2050. This will enable more than 30 million tonnes of CO2 emissions to be avoided. To reach this objective the government enforced a feed-in tariff system in 2011 that encourages the development of renewable energy business, lower financing costs and build up the skills of renewable energy workers (IEA, 2015).

Malaysia continues to diversify its LNG imports. There is a gap in the natural gas supply and demand among its regions. Peninsular Malaysia needs more natural gas supply for power and industrial use, while Sarawak and Sabah produce natural gas without strong local demand. To address this problem LNG RGTs are being constructed to increase the supply of LNG imports from the global gas market. To date, a second LNG was constructed at the southern part of Peninsular Malaysia which received its first commercial LNG cargo in 2017 (APERC, 2017a).

2.3.3.5 Philippines

The Philippines aspires to be a low carbon country, according to the 2012-2030 Philippine Energy Plan. Over the planning horizon, oil will remain the major fuel accounting for 43.5% of the total energy demand compared to the 50% share of oil in 2011. This share is lower due to the use of alternative fuels. A 20% increase is targeted for biodiesel and bioethanol by 2025 and 2020, respectively. It is also expected that the number of buses and taxis using compressed natural gas (CNG) will increase and electric vehicles are being introduced. By the end of the planning period the target for CNG buses is 15,000 units, for CNG taxis 16,000 units and for e-vehicles 230,000 units. Under the Natural Gas Vehicle Program, operators using liquefied petroleum gas (LPG) and CNG fuel are prioritized in obtaining a franchise to run a public bus service. Moreover, they are given two additional years to operate compared to other vehicles (APEC, 2014).

The Renewable Energy Act passed in 2008 aims for the development of renewable energy in the country. The law provides for fiscal incentives for the renewable energy sector such as income tax holidays, tax exemptions for the carbon credits produced from renewable energy sources and a tax cap on equipment and facilities used in the renewable energy industry. In addition, value added tax exemptions are granted on power produced from renewable energy sources (IEA, 2015).

The Philippines is now preparing to import LNG as domestic natural gas resources are depleting. An LNG terminal and a merchant gas-fired power is being constructed which will have two storage tank units with a capacity of 130,000 cubic meters (Cm) each, a regasification plant, and an on-site 600 MW merchant gas-fired power plant to serve as an anchor load for the project. (APERC 2017).

2.3.3.6 Singapore

Singapore is an energy disadvantaged city state due its inadequate supply of low emission energy sources. To diversify its energy mix and ensure Singapore's energy security, an LNG terminal started operating in May 2013 to allow the country to import LNG. Singapore is also looking into renewables with the formation of the Energy Innovation Program Office in 2007 (APEC 2014). In 2014, the by government announced its plan to increase the adoption of solar energy to 350 MegaWatt peak (MWp) by 2020. After 2020 solar power will be increased to 1 GigaWatt peak (GWp) which would enable Singapore to reach its climate change pledge of 36 percent emissions reduction from 2005 levels by 2030 (Energy Market Authority, 2016).

2.3.3.7 Thailand

Thailand integrated all energy plans under the Thailand Integrated Energy Blueprint (TIEB) in 2015 which covers the period 2015-2036. It aims to diversify the fuel mix by raising the share of coal to 23%, of which 17 % are advanced and clean coal technologies, like as the ultra-supercritical (USC) technology. The share of renewables will also be increased to 20% of power generation.

The pillars of energy policy related to fuel substitution promotes both development of renewables and fossil fuel exploration. These are: exploration and production for onshore and offshore oil and gas; construction of new power plants which will use both renewable energy and fossil fuels; and boosting international cooperation specially with the neighboring countries of Myanmar, Lao PDR, Cambodia and Malaysia to find new energy sources (APEC, 2016).

2.3.3.8 Indonesia

The National Energy Plan which was signed October 2014 revised the energy mix to utilize more of the country's indigenous energy supplies. The means that oil consumption will be minimized while gas production and consumption will be optimized, and consumption of renewables and coal will rise. Thus, the energy mix by 2025 will be composed of 30% coal, 22%oil, 23% renewable resources and 25% natural gas. Compared to current consumption, renewables are expected to increase by more than 11 times and gas use will more than double. However, coal is also expected to triple over the present coal consumption (IEA, 2015).

2.3.4 Energy Efficiency

2.3.4.1 China

In The 13th FYP China's goal is to reduce energy intensity from by 15% in five years since 2015 to improve energy efficiency. The government has imposed an energy cap covering all energy sources at less than the equivalent of five billion tons of coal. In addition, China has decided to shift from heavy industry to less energy-intensive industries. The companies which will receive support are engaged in the manufacture of new energy vehicles and advanced energy- saving technologies (Koleski, 2017). In particular the measures include the development of highly efficient boilers, electric motors, internal combustion engines and energy efficient equipment and lighting. Moreover, the government will enhance energy efficiency standards in buildings and increase the share of green vehicles in the transport sector (APERC, 2016). The latter initiative is important as China has seen higher vehicle purchases which raised energy intensity in the transport sector (APERC, 2017b).

Energy intensity is also high in China due to energy pricing which is strictly regulated by the government and the monopoly of state-owned enterprise (SOEs). To correct these, China works to create a market-oriented pricing stategy. The government also invites private companies to participate in the bidding process for power transmission, distribution and sales. This is intended to reduce the power of SOEs. In addition, the State Council has pending projects on renewable energy such as hydropower, wind and PV power as well as oil and gas pipelines, and energy storage buildings. These projects are open to the private sector through joint ventures, sole proprietorships or franchise agreements (APERC, 2017b).

2.3.4.2 Japan

The 2015 Long-Term Energy Supply and Demand Outlook which was based on the Strategic Energy Plan (2014) shows the role of energy efficiency to realize the targets for energy supply and demand in 2030. The objectives of energy policy are to have energy security, economic efficiency, environmental protection and safety. By 2030, it is expected that energy efficiency will lower energy demand by as much as 50.3 billion liters (crude oil equivalent). On a sectoral basis, transport will realize savings of 16,070 thousand kilo liters; commercial will save 12,260 thousand kilo liters; the residential sector will lower energy demand by 11,600 thousand kilo liters; and industry will save 10,420 thousand kilo liters of energy. Hence, energy intensity needs to improve by 35% from 2012 to 2030 (MITI, 2015). On electricity generation, energy efficiency is expected to save 196 TWh or 17% from 2013 baseline of 967 TWh (IEA, 2016).

2.3.4.3 Korea

Korea undertakes three major efficiency programs: the Energy Efficiency Label and Standard Program, High-efficiency Appliance Certification Program and e-Standby Program. The Energy Efficiency Label and Standard Program requires a product to indicate an energy efficiency grade from 1st to 5th grade. Products which are classified as 5th grade are not allowed to be sold and manufactured. Products under this program include household appliances, lighting equipment, and automobiles. The High-efficiency Appliance Certification Program issues high-efficiency equipment labels and certificates to products which perform above standards. This concerns products such as pumps, boilers and LED lighting equipment. The e-Standby Program aims to reduce standby power to enhance energy efficiency in products. Products which satisfy standby power reduction standards established by the government are attached with an energy boy label. Products which fall under this program are household appliances and office equipment (Korea Energy Management Corporation, 2015).

In the long-term, one of Korea's energy strategies is to raise energy efficiency. The target for 2030 is to decrease energy intensity by 46% to 185 toe/million US dollar from 341 toe/million US dollar. The energy savings from this would reach 42 Mtoe. Moreover, Korea intends to develop its technology in green energy which will increase energy efficiency by 12%

and reduce by half the country's target for emission reduction in 2020 which is 30% lower than the business-as-usual level (APEC, 2014).

2.3.4.4 Thailand

The Energy Efficiency Development Plan aims to reduce energy intensity by 25% in 2030 and achieve a 20% decline in final energy consumption by 2030, from 2005 levels. The sectors to be prioritized in energy conservation are the transportation and the industrial sectors. In addition, the Plan targets lowering the energy elasticity (the percentage change in energy consumption to achieve 1% change in national GDP) to 0.7 in 20 years' time from 0.98. The expected benefits from energy conservation are a cumulative final energy saving of 289,000 ktoe up to 2030 and avoided CO2 emissions of 976 million tons. Some strategies to achieve these targets are mandatory energy efficiency labeling and minimum energy performance standards for appliances, buildings and vehicles; advocating mass transit systems and other energy efficient transport; providing subsidies for verified amounts of energy saved by businesses; making energy prices show the actual costs; and promotion of technology development and innovations, particularly those which have not been commercialized in the local market (Thailand Ministry of Energy, 2011). Policies which promote fuel economy and high-efficiency vehicles will curtail energy demand in the transport sector. The comprehensive policy package will incur greater energy savings if properly monitored and evaluated. (APERC, 2016).

2.3.4.5 Indonesia

An updated draft of the National Master Plan for Energy Conservation aims to achieve a 17% energy savings in final energy consumption with an average annual growth of energy demand of 7.1%. Another target is to reduce energy intensity by 1% annually. In order to achieve these objectives, energy savings for the following sectors are: industrial sector 17%, transport sector 20%, commercial sector and households, 15%, electricity production 0.5% and transmission, distribution and refineries, 0.25% (IEA, 2015b).

The Indonesian government also issued the regulation on Energy Management which requires that energy users of 6,000 toe of energy per year must create an energy management team. An energy audit will be held every three years on the main energy consuming appliances and equipment. Reports on the implementation of energy management are provided by energy users to ministers and governors. Energy users who have successfully lowered their energy consumption by a minimum of 2% annually for three years will be granted these incentives: an energy audit partnership sponsored by the government and/or access to energy supplies (APEC, 2014).

2.3.4.6 Philippines

Mandatory energy standards and labelling were started in the Philippines in 1999. Manufacturers and importers of consumer electrical and electronic products have to apply the minimum energy performance standard (MEPS) and energy-labelling requirement on all their products. This includes air conditioners; refrigerators (5 to 8 cubic feet); compact, linear and circular fluorescent lamps; and ballasts for fluorescent lamps (DOE, 2014a). The Philippine Energy Plan states that the program would include other household appliances, industrial equipment such as fans and blowers, and vehicles in the future (DOE, 2014b).

According to the Philippine Energy Plan (2012-2030) the government's goal is to save 10% of energy demand in all sectors by 2030. The Energy Efficiency Roadmap targets in 2030 a reduction in energy intensity of 40% from the 2010 benchmark.

2.3.4.7 Malaysia

The National Energy Efficiency Action Plan (NEEAP) 2016-25 identifies the policies to implement energy efficiency for electricity use in the industry and buildings sectors. These sectors targets a reduction of electricity demand by 52,233 gigawatt-hours (GWh) over 10 years (equivalent to 8% of total electricity demand or 38 million tonnes of carbon dioxide [MtCO2] compared to business-as-usual levels). A registered electrical energy manager is required for units which consume electricity of at least 3000 GWh for six months. The manager produces a report of energy consumption every six months and adopt measures to lower the demand. In 2017 an Energy Performance Contracting (EPC) Fund was created. Its purpose is to raise the credibility and financial ratings of energy service companies (ESCOs) to enable them to conduct energy efficiency and conservation projects. Malaysia also finished a demand-side management study of electrical and thermal energy demand trends and energy use in the transport sector. This study is the basis for the Energy Efficiency and Conservation Act which is expected to be become effective in 2020 (APERC, 2019).

2.3.4.8 Singapore

The Energy Efficiency Program Office is responsible for supervising the implementation of energy efficiency programs in Singapore. The Office's objectives are to promote energy efficiency through regulation, standards and incentives; encourage technologies and innovation in energy efficiency; develop skills in implementing energy efficiency and make energy efficiency efforts international. The sectors served are the power generation, industry, transport, buildings and households. Singapore's Energy Conservation Act 2013 requires large energy users to maintain an energy management system that will appoint energy managers, report their energy consumption and develop energy improvement plans. Another program, the Energy Efficiency National Partnership, conducts courses and workshops on energy efficiency as well as granting energy efficiency awards. Singapore has also invested in equipment and new processes to achieve its long-term goals (Singapore-German Chamber of Industry and Commerce, 2014).

2.4 Research Focus on Interfuel Substitution and Energy Efficiency

This thesis focuses on fuel substitution and energy efficiency for several reasons. The three top reasons which are mentioned in the introduction and will be reiterated here are: (1) A comprehensive review of literature reveals that studies of fuel substitution and energy efficiency in Asia are limited. Hence, this research can aid in understanding these issues more within the Asian context; (2) The CDM already includes energy efficiency and fuel substitution in its portfolio which will make the analysis redundant if included in the research and (3) carbon pricing instruments aim to drive energy consumption towards less polluting energy sources. Moreover, carbon pricing also provides an incentive for energy efficiency improvements.

Table 2.2 shows the reductions in CO2 emissions through fuels switching in electricity generation. In the first example substituting a 35% efficient coal-fired steam turbine with a 48% efficient plant using advanced steam, pulverized-coal technology leads to a reduction in emissions by 27%. In the last example, replacing a natural gas single-cycle turbine with a natural gas combined cycle should lower carbon emissions by 36%. The examples illustrate that replacing coal with gas raises the efficiency of the power plant due to higher operating temperatures.

Energy efficiency is a cost-effective way to address the rising energy demand in Asia which can prevent the increase in anthropogenic emissions. There are two ways to reduce the need for energy: (1) by avoiding energy losses in the supply chain, which is known as supply side energy efficiency (SSEE) and (2) by generating the same level of service with less energy such as in running buildings, machinery and tools. The latter approach is called demand-side energy efficiency (DSEE). Investments in energy efficiency in the range of 1%-4% as a share of overall energy sector investment can cover 25% of the projected increase in primary energy consumption in developing Asian countries by 2030 (ADB, 2013).

The IEA (2013) generates projections of energy demand and supply for Southeast Asia countries from 2011 to 2035 under two scenarios. These scenarios are the New policies Scenario and the Efficient ASEAN scenario. The New Policies Scenario includes policies and measures for the energy markets which are already being implemented as well as commitments that were just announced such as initiatives to support renewable energy and energy efficiency and to reform fossil-fuel subsidies. In contrast, the Efficient ASEAN Scenario looks at the results when the best available technologies for improving energy efficiency are adopted and implemented in Southeast Asia. The projections for the two scenarios are generated by the IEA's World Energy Model. The simulation showed that CO2 emissions in Southeast Asia rose by an average of 2% annually compared to the emissions in the New Policies Scenario which increased by 2.8% per year. By 2035 CO2 emissions in the Efficient ASEAN Scenario are reduced by 19% or more than 400 (MT) compared with the New Policies Scenario. The emissions saving mostly come from decreased consumption of coal, especially in the power generation sector. In terms of sector, 42% of energy savings come from industry while transport and buildings account for 38% and 20% respectively.

On the macroeconomic effects of energy efficiency, regional GDP rises by 2% by 2035 to $1.7 trillion compared with the New Policies Scenario. The fall in oil imports by 700 thousand barrels per day lowers oil import bills by $31 billion by 2035. At the same time coal and natural gas exports amount to $29 billion.

2.5 Concluding Remarks

The economic development of Asian countries has been accompanied by rising carbon emissions. The resulting expansion in power generation, industry and transport has increased energy consumption along with the carbon emissions. The rise of carbon emissions is exacerbated by the propensity of Asian countries to use coal and oil as their main energy source. Use of gas as fuel has been rising over time but it is still low as a share in the energy mix. All of the countries studied have made a conscious effort to shift towards clean fuel like gas and renewable energy. However, these are still at an initial level. As countries move toward consumption of clean energy there is a need to assess whether these initiatives will result in environmental benefits.

Table 2.2 CO2 Emission Reductions with Fuel Switching in Electricity

Existing generation technology			Mitigation substitution option			Emission reduction per unit of output
Energy source	Efficiency (%)	Emission coefficient (gCO_2/kWh)	Switching option	Efficiency (%)	Emission coefficient (gCO_2/kWh)	(gCO_2/kWh)
Coal, steam turbine	35	973	Pulverised coal, advanced steam	48	710	-263
Coal, steam turbine	35	973	Natural gas, combined cycle	50	404	-569
Fuel oil, steam turbine	35	796	Natural gas, combined cycle	50	404	-392
Diesel oil, generator set	33	808	Natural gas, combined cycle	50	404	-404
Natural gas, single cycle	32	631	Natural gas, combined cycle	50		404

Source: IPCC (2014).

Chapter 3 : Evaluating Interfuel Substitution for Reduction of Carbon Emissions

3.1 Introduction

This chapter examines the potential of interfuel substitution to reduce carbon dioxide emissions in Asia. Interfuel substitution refers to the replacement of inefficient and polluting fuel with a cleaner alternative. The three fossil fuels mostly commonly used are oil, gas and coal. Due to its low extraction cost, coal is the most widely used fossil fuel but emits higher levels of GHG compared to oil or natural gas. Burning coal produces 75% more CO2 over natural gas per unit of energy and 34% more CO2 over oil (IEA, 2014). In 2011 for instance, coal consumption for the countries covered in this study reached 2203.3 Mtoe while oil consumption is 1145.0 Mt and gas consumption is 461.2 Mtoe.

The assessment is conducted based on cross-substitution elasticities for input factors that are calculated from translog production function that incorporates oil, gas, coal, capital and labor for each Asian economy. The production functions are estimated via ridge regression to avoid bias-induced multicollinearity. Based on the elasticities and additional data, scenarios with interfuel substitution are prepared to quantify the amounts of CO2 reductions that could be achieved whilst helding output constant. It should be noted that CO2 emissions computed are from energy consumption and not total anthropogenic CO2 emissions.

Interfuel substitution as a climate change mitigation strategy has been proven in the literature to be a feasible approach. In general, the estimated elasticities of substitution show that coal can be replaced with oil or gas. The findings are true from an economy wide analysis and at the sectoral level. In the power sector for instance, interfuel substitution is conducted in two ways. Firstly, single fuel fired plants can supply power by alternating between peak and base load. Base load is the minimum amount of electrical power that is supplied over a particular period of time while peak load refers to the time when electrical power is delivered by more than the average supply level. Secondly, power plants can be converted to burn different types of fuel. While fuel substitution can be taken automatically, it can be very expensive to switch fuels. For instance, modifying industrial coal boilers to burn natural gas substantially increases production costs. One option for utilities is to build new power plants that burn gas which will entail high capital expenditures but it takes around four years to build such plants (Williams, 2012). Thus, often government must intercede and drive reforms. In

2017 for instance, the Chinese government has ordered industries and households to replace coal with cleaner fuel in the Beijing-Tianjin-Hebei region during the heating season. The target is to lower by 25-percent smog-causing particles known as PM2.5 for the region by the end of 2017 as compared to 2012 (Lelyveld, 2017).

There is a gap in the literature looking at energy demand and interfuel substitution in developing countries. Existing literature is limited to studies estimating elasticity parameters of interfuel substitution among coal, oil, natural gas and electricity. Most of the research has concentrated in China (Ma, Oxley, Gibson, and Kim, 2008; Ma and Stern, 2008; Smyth, Kumar Narayan, and Shi, 2012) while in other Asian countries interfuel substitution has not been studied adequately. Moreover, even though most of the empirical results point to possible interfuel substitution, the literature falls short of examining the potential of interfuel substitution to reduce carbon dioxide emissions. In this chapter, the estimated elasticities of substitution are used to compute the reduction of carbon dioxide if a dirty fuel is substituted with a clean fuel. It is hypothesised that interfuel substitution can reduce carbon dioxide emissions in Asia. Energy demand in Asia is set to increase due to rising population, income and changing lifestyles. By switching from coal, which is a dirty fuel, to oil or gas, which have lower carbon emissions, the environment will not be sacrificed for development. The methodology employs a transcendental logarithmic (translog) cost function which is well suited for this analysis due to its flexible specification, tractability, insights into the properties of production and cost functions (Wesseh Jr, Lin, and Appiah, 2013).

The main finding is that all the energy fuels are close substitutes in production. Their estimated elasticities of substitution are high and positive. However, the effectiveness of interfuel substitution in reducing carbon emissions are not the same for all countries. For China, Japan and Korea there is a notable decline in emissions as a result of fuel switching. But for the ASEAN countries, it is found that switching to a country's dominant energy source exacerbates pollution.

The chapter is divided into these sections: introduction, review of literature, methodology, data, discussion of estimation output and conclusions.

3.2 Review of Related Literature

Interfuel substitution studies in Asia has mostly concentrated in China. Ma, Oxley, Gibson, and Kim (2008) investigate interfactor and interfuel substitutability among coal, electricity, gasoline and diesel in China. Their study also examines the factors which affect China's energy intensity. Its objective is to determine the changes in the energy use of China as its energy demand exerts an effect on world energy markets. A two-stage translog function approach is used to compute for the Allen partial elasticities of input factor and energy substitution as well as the price elasticities of demand. An energy price index is set up for each of seven regions which group the 31 provinces in China. Examining interfactor substitution possibilities, the results obtained show that labor and energy as well as capital and energy are substitutes while capital and labor are only slightly substitutable. The evidence on interfuel substitution shows that coal and electricity; gasoline and electricity and electricity and diesel are substitutes while coal and diesel are complementary.

Ma and Stern (2008) analyze the decline in energy intensity in China from 1994 to 2000 using index decomposition analysis. The latter is a decomposition technique which uses historical data to determine the factors that cause an indicator to change. The authors find that interfuel substitution partly explains the fall in energy intensity from 196.31 GSCE/RMB in 1994 to120.1 GSCE/RMB in 2000. This is accompanied by a shift from coal to other energy sources such as oil, natural gas and renewable energy. It is suggested that the change from the low energy quality of coal to a higher quality fuel has significantly improved energy efficiency contributing to a reduction in energy intensity.

Smyth, Kumar Narayan, and Shi (2012) applies a translog production function to estimate the inter-fuel substitution elasticities between coal, petroleum, natural gas and electricity in the iron and steel sector of China. The study covers the period 1978-2007. China's iron and steel industry is the largest in the world and also a major source of CO2 emissions due to its heavy reliance on coal. The results show that electricity, natural gas and oil can be substitutes for coal. This suggests that China can use other sources of energy which are cleaner than coal without hurting its iron and steel industry. However, there are obstacles to achieving this. Substituting oil for coal is actually discouraged by the government because oil is imported. Likewise, the potential of gas to replace coal is hampered by low production and limited transmission and trade infrastructure.

Wesseh Jr et al. (2013) studies how Liberia could break away from the economy's total reliance on petroleum to run its industries. Translog production and cost functions are employed to determine the possibility of interfactor substitution between capital, labor, petroleum and electricity for the period 1980-2010. The study finds that: (i) output is positively correlated with capital, labor, petroleum and electricity; and (ii) all inputs can be substituted for one another. However, in practice it is not so easy to substitute petroleum for electricity as the infrastructure for electricity has been considerably damaged by the civil war. It is suggested that the Liberian government promotes greater electricity use through taxes or pricing policies and also assists companies in minimizing the cost of fuel switching by providing subsidies. The study claims that Liberian authorities should facilitate the transmission mechanism by constructing the necessary infrastructure. Electricity generation from renewable sources should be encouraged to ensure that CO2 emissions do not continue through the use of petroleum in producing electricity.

Pereira and Pereira (2014) use a dynamic general equilibrium model to determine the role of fuel prices on climate policy and energy demand. Three fuel price scenarios are generated with different data sources: the US Department of Energy, (DOE-US), the International Energy Agency (IEA-OECD) and IHS Global Insight, Inc. (IHS). Under the DOE-US scenario a reduction in natural gas prices leads to a decline in the demand for coal and wind energy investments. The substitution is possible due to the flexibility in the industry and electric power generation. On the other hand, in the IEA-OECD scenario, lower coal prices induce an increase in the demand for coal and reduction in the demand for natural gas and infrastructures for wind energy. The IHS scenario, which forecasts all fuel prices to fall, resulted in higher demand for coal than oil, natural gas or wind energy infrastructure. In terms of impact on emissions, the DOE-US fuel price increases which lead to greater consumption of natural gas result in a decline in emissions of 1.3% in 2020. The IEA-OECD scenario with greater coal usage leads to a 2.4% increase in emissions by 2020. Lastly, the IHS scenario, which encourages coal and oil consumption, raises emissions by 12.2% in 2020.

Pettersson, Söderholm, and Lundmark (2012) investigates the short-run fuel switching choices between fossil fuels (i.e. coal, oil and gas) in the power sector in Western Europe. The study uses a generalized Leontief cost function and covers the period 1978-2004. The results show that there are two ways that interfuel substitution occurs in dual or multi fired plants in the power sector: single fuel fired plants can be used to supply power alternately between peak and base load, and power plants can be converted to burn different types of fuel. In addition, the research finds that policies to promote fuel switching from coal to gas, such as tax rebates, subsidies and subsidised loans to electric companies, as well as the market liberalization in the power sector were successful. Simulation to estimate the impact of different carbon prices in the European Union ETS shows that the higher the carbon dioxide price, the greater is the switch from oil to gas.

Serletis, Timilsina, and Vasetsky (2010) investigates interfuel substitution among oil, gas, coal and electricity in the US. The methodology used is the translog functional form subject to the theoretical regularity conditions of neoclassical microeconomic theory such as positivity, monotonicity, and curvature. The conditions require that the cost function be positive, have non- negative first order derivatives and be a concave function of prices respectively. The interfuel substitution is investigated not only in US total energy demand but in energy demand in sectors such as the industrial, commercial, residential and electricity-generation sectors. Empirical evidence shows that the interfuel elasticities of substitution are below unity consistently and in general. This indicates that interfuel substitution among fossil fuels is limited and they will remain the major source of energy. Nevertheless, the research finds strong substitutability in the industrial sector between (1) coal and electricity and (2) natural gas and electricity as the electricity price changes.

Steinbuks and Narayanan (2015) studies interfuel substitution of industrial energy demand among fossil fuel and non-fossil fuel producing countries. Elasticities of fuel demand in oil, gas, coal and electricity are estimated from 63 countries using a linear logit model. The results show that all fuels are substitutes as evidenced by their positive cross price elasticities. The highest estimated substitution elasticities are those for coal and natural gas with respect to electricity prices and oil prices. However, oil and electricity are poor substitutes. Based on country groups, the short-run substitution elasticities between coal and other fuels are higher for countries which can produce at least one fossil fuel or all fossil fuels. The case is also true for natural gas. The cross price elasticity of coal with respect to electricity is four times higher compared to countries which cannot produce any fossil fuels. In the long-run, the difference in the substitution elasticities between fossil fuel producing and non-producing countries become more pronounced. The reason is that countries which can produce fossil fuels can adjust their fuel- using capital stocks longer.

In light of the discussion above, it can be observed that studies on interfuel substitution have not gone beyond the estimation of elasticities to test the potential of interfuel substitution to reduce carbon dioxide emissions. This chapter extends the analysis by using the elasticities to estimate interfuel substitution effects on changes in fuel quantities and the resulting changes in carbon emissions. The review of literature also highlights the lack of interfuel substitution research for Asian economies other than China. This also allows regional comparison to elucidate significant patterns and generalizations. The research follows the normally adopted methodology in energy demand studies which is the translog production function. However, to achieve the objective of linking interfuel substitution with climate change mitigation, further steps are taken. Carbon dioxide emissions factors for each fuel are computed to calculate the reduction in carbon dioxide emissions when one fuel is substituted for another.

3.3 Methodology

3.3.1 Theoretical Framework

The neoclassical growth model, also known as the Solow-Swan growth model, explains long-run economic growth as dependent on capital accumulation, labor and technological progress. Central to this model is the concept of productivity growth which is determined by technological innovation. Discounting the effects of technology and assuming perfect competition, the production factors labor and capital are set in this model to exhibit diminishing returns each and constant returns to scale when combined. In the short-run, the rate of growth is determined by the rate of capital accumulation. However, in the long-run, the economy converges to a steady state rate of growth which is determined by the rate of growth of the labor force and the rate of technological progress.

The central equation in this model can be written as a Cobb-Douglas production function:

$$Y_t = f(K_t, L_t)$$

$$Y_t = A_t K_t^{\psi} L_t^{\phi} \qquad (3.1)$$

Where Y represents real output, K the capital stock, L employment and A total factor productivity or technological progress. The parameters ψ and φ denote the elasticity of capital and labor, respectively while the subscript t refers to time.

Definitions of factors determining output growth have undergone considerable change over time. The neoclassical growth model equates output with manufactured capital and labor force. With diminishing returns to capital, the model relies on exogenous technological progress to drive growth. This theory was further modified to endogenize technological change (Helpman, 1992). According to the endogenous growth theory, technological knowledge is the result of decisions undertaken by agents and can be categorized as another form of capital. Thus, growth can be sustained with the accumulation of capital, in its various forms. In the latest development on this evolving theory, energy has been added as an important factor of production (Beaudreau, 2005; Pokrovski, 2003; Stern, 2010). Stern (2010) notes that the generation of output involves changing matter from one form to another which require the use of energy.

Pokrovski (2003) classifies energy into two types – as an intermediate product that is included in the cost of the final product and as a substitute for labor in the form of energy-driven equipment. It is the latter form of energy which has the property to produce value and can therefore be considered a factor of production. Examples of energy as a substitute for labor are: transportation vehicles, machines used to manufacture goods and information technology tools. In short, the three production factors according to Pokrovski (2003) are capital stock, labor services and productive energy.

Similarly, Beaudreau (2005) argues that, from an engineering perspective and based on the principles of classical mechanics, the growth of output is not only determined by labor and capital, but also an increasing function of energy consumption and the information which enhances the productivity of energy. By testing his production theory against manufacturing data of the United States, Germany and Japan, he proves that the "Solow residual" (unaccounted growth) is almost minimized and that value added in the manufacturing sector is primarily due to electric power consumption.

Stern (2000) notes that energy constrains output growth when it is scarce but its marginal effect on economic growth declines once it becomes abundant. The author argues that in the industrial revolution, as more energy was obtained, long-run economic growth approaches the Solow model which points to the increase in labor as the source of growth. Energy used per unit of output has been on a downtrend due to technological change and the substitution of higher quality fuels, electricity in particular, for lower quality fuels like coal. Nevertheless, energy remains an important component of growth since there are limits to the substitutability of energy with other inputs of production.

Considering these views, this chapter adds energy consumption into the neo-classical one-sector aggregate production function modifying equation (3.1) into:

$$Y_t = A_t K_t^{\psi} L_t^{\phi} E_t^{\rho} \tag{3.2}$$

Where E_t denotes aggregate energy at time t and ρ is the elasticity of output with respect to energy.

3.3.2 Model

The model presented here follows Wesseh Jr et al. (2013) and Smyth et al. (2012), who propose a translog production function is used to illustrate the relationship between output and inputs of various productive factors of the following general functional form:

$$lnY_t = ln\alpha_0 + \sum_i \alpha_i \, lnX_{it} + \frac{1}{2}\sum_i \sum_j \alpha_{ij} \, lnX_{it} lnX_{jt} \tag{3.3}$$

Where Y_t refers to output at time t, α_0 denotes technical knowledge, X_{it} and X_{jt} denote the levels of inputs i and j at time t, and α_i and α_{ij} are parameters.

A twice differentiable production function relating output to capital, labor, coal, gas and oil inputs can then be specified as:

$$\begin{aligned} lnY_t = {} & \alpha_0 + \alpha_K lnK_t + \alpha_L lnL_t + \alpha_C lnC_t + \alpha_O lnO_t + \\ & \alpha_G lnG_t + \alpha_{Kl} lnK_t lnL_t + \alpha_{KC} lnK_t lnC_t + \alpha_{KO} lnK_t lnO_t + \\ & \alpha_{KG} lnK_t lnG_t + \alpha_{LC} lnL_t lnC_t + \alpha_{LO} lnL_t lnO_t + \alpha_{LG} lnL_t lnG_t + \\ & \alpha_{CO} lnC_t lnO_t + \alpha_{CG} lnC_t lnG_t + \alpha_{OG} lnO lnG_t + \alpha_{KK}(lnK_t)^2 + \\ & \alpha_{LL}(lnL_t)^2 + \alpha_{CC}(lnC_t)^2 + \alpha_{OO}(lnO_t)^2 + \alpha_{GG}(lnG_t)^2 \end{aligned} \tag{3.4}$$

Where Y_t denotes output at time t, and K_t, L_t, C_t, G_t and O_t refer to inputs of capital, labor, coal, gas and oil at time *t* while α is the estimated contribution of the inputs to output.

This homogeneous production function define strictly positive marginal productivities for each region that are estimated as:

$$\delta_{it} = \frac{\partial lnY_t}{\partial lnX_{it}} = \alpha_i + \sum_j \alpha_{ij} \, lnX_{jt} > 0 \tag{3.5}$$

Following this, the output elasticity for capital is computed as:

$$\delta_{Kt} = \frac{dlnY_t}{dlnK_t} = \alpha_K + \alpha_{KL} lnL_t + \alpha_{KC} lnC_t + \alpha_{KO} lnO_t + \alpha_{KG} lnG_t + 2\alpha_{KK} lnK_t > 0 \tag{3.6}$$

The output elasticity for labor is:

$$\delta_{Lt} = \frac{dlnY_t}{dlnL_t} = \alpha_L + \alpha_{LK} lnK_t + \alpha_{LC} lnC_t + \alpha_{LO} lnO_t + \alpha_{LG} lnG_t + 2\alpha_{LL} lnL_t > 0 \tag{3.7}$$

The output elasticity for coal is:

$$\delta_{Ct} = \frac{dlnY_t}{dlnC_t} = \alpha_C + \alpha_{CK} lnK_t + \alpha_{CL} lnL_t + \alpha_{CO} lnO_t + \alpha_{CG} lnG_t + 2\alpha_{CC} lnC_t > 0 \tag{3.8}$$

The output elasticity for oil is:

$$\delta_{Ot} = \frac{dlnY_t}{dlnO_t} = \alpha_O + \alpha_{OK}lnK_t + \alpha_{OL}lnL_t + \alpha_{OC}lnC_t + \alpha_{OG}lnG_t + 2\alpha_{OO}lnO_t > 0 \quad (3.9)$$

And the output elasticity for natural gas is:

$$\delta_{Gt} = \frac{dlnY_t}{dlnG_t} = \alpha_G + \alpha_{GK}lnK_t + \alpha_{GL}lnL_t + \alpha_{GC}lnC_t + \alpha_{GO}lnO_t + 2\alpha_{GG}lnG_t > 0 \quad (3.10)$$

Note that the elasticities of substitution between two energy or factor inputs can be written as:

$$\varphi_{ij} = \frac{\Delta X_{it}/X_{jt}}{\Delta P_{jt}/P_{it}} \quad (3.11)$$

where P=price. Assuming cost minimizing agents in the economy, equation 3.11 can be expressed as:

$$\varphi_{ij} = \frac{\Delta X_{it}/X_{jt}}{\Delta MP_{jt}/MP_{it}} = \left(\frac{d(X_{it}/X_{jt})}{d(MP_{jt}/MP_{it})}\right)\left(\frac{(MP_{jt}/MP_{it})}{(X_{it}/X_{jt})}\right) \quad (3.12)$$

Where MP=marginal product. Finally, Equation 3.12 is converted into the following formula for computation of the elasticity of substitution between inputs:

$$\varphi_{ij} = [1 + \frac{-\alpha_{ij}+(\delta_i/\delta_j)\alpha_{jj}}{-\delta_i+\delta_j}]^{-1} \quad (3.13)$$

Specifically, the substitution elasticities between capital, labor, coal, oil and natural gas are computed as:

$$\varphi_{KL} = [1 + \frac{-\alpha_{KL}+(\delta_K/\delta_L)\alpha_{LL}}{-\delta_K+\delta_L}]^{-1} \quad (3.14)$$

$$\varphi_{KC} = [1 + \frac{-\alpha_{KC}+(\delta_K/\delta_C)\alpha_{CC}}{-\delta_K+\delta_C}]^{-1} \quad (3.15)$$

$$\varphi_{KO} = [1 + \frac{-\alpha_{KO}+(\delta_K/\delta_O)\alpha_{OO}}{-\delta_K+\delta_O}]^{-1} \quad (3.16)$$

$$\varphi_{KG} = [1 + \frac{-\alpha_{KG}+(\delta_K/\delta_G)\alpha_{GG}}{-\delta_K+\delta_G}]^{-1} \quad (3.17)$$

$$\varphi_{LC} = [1 + \frac{-\alpha_{LC}+(\delta_L/\delta_C)\alpha_{CC}}{-\delta_L+\delta_C}]^{-1} \quad (3.18)$$

$$\varphi_{LG} = [1 + \frac{-\alpha_{LG}+(\delta_L/\delta_G)\alpha_{GG}}{-\delta_L+\delta_G}]^{-1} \quad (3.19)$$

$$\varphi_{LO} = [1 + \frac{-\alpha_{LOil}+(\delta_L/\delta_O)\alpha_{OO}}{-\delta_L+\delta_O}]^{-1} \quad (3.20)$$

$$\varphi_{CO} = [1 + \frac{-\alpha_{CO}+(\delta_C/\delta_O)\alpha_{OO}}{-\delta_C+\delta_O}]^{-1} \quad (3.21)$$

$$\varphi_{CG} = [1 + \frac{-\alpha_{CG}+(\delta_C/\delta_G)\alpha_{GG}}{-\delta_C+\delta_G}]^{-1} \quad (3.22)$$

$$\varphi_{OG} = [1 + \frac{-\alpha_{OG}+(\delta_O/\delta_G)\alpha_{GG}}{-\delta_O+\delta_G}]^{-1} \qquad (3.23)$$

Where:

φ_{KL}, φ_{KC},φ_{KG}, φ_{KO} are the elasticity of substitution between capital-labor, capital-coal, capital-gas and capital-oil, respectively.

φ_{LC}, $\varphi_{LG}$and φ_{LO} refer to the elasticity of substitution between labor-capital, labor-gas and labor-oil, respectively.

φ_{CO}andφ_{CG} denote the elasticity of substitution between coal-gas and coal-oil.

$\varphi_{OG}$is the elasticity of substitution between oil-gas.

3.3.3 Hypothesis

Interfuel substitution refers to the substitution of a clean fuel for a polluting fuel. The production function above is used to show the feasibility of substitution among fossil fuels as well as the output elasticity of each fuel. By definition output elasticity refers to the percentage change of output (GDP) divided by the percentage change of input. Hence, it measures the productivity of each fuel. It also indicates the degree of return to scale. When the coefficient of output elasticity is greater than 1, there are increasing returns to scale in production. When the coefficient is less than 1, production exhibits decreasing returns to scale. Lastly, when the coefficient is 1 then production is at a constant returns to scale (Perloff, 2008). Relating this to fuel usage, a low output elasticity shows that changes in fuel usage will have a low impact on a country's GDP. On the other hand, a high output elasticity indicates that changing the consumption of a particular fuel will substantially affect GDP. Asian countries which are already dependent on a particular fuel such as oil for Southeast Asian countries and coal for China are expected to have a high output elasticity on it because most of the infrastructure accommodates them. Thus, fuel switching may be detrimental to these economies. This analysis is also applicable for other factors of production such as labor and capital.

In terms of the elasticity of substitution between two fuels, a high number indicates that switching of fuels is possible. It is expected that substitution will be feasible between oil and coal as these are the widely used fuels in Asia. Natural gas consumption however, is still limited in the Philippines, Singapore and Korea and is expected to have a low substitution elasticity with other fuels. In Malaysia, Thailand and Japan, where natural gas and oil play a prominent role, it is hypothesised that the elasticity of substitution between these fuels will be high.

3.4 Estimation Procedure

3.4.1 Ridge Regression

In the Ordinary Least Squares (OLS) regression the interaction and squared terms of the independent variables of a translog production function may cause multicollinearity problems. Multicollinearity occurs when the regressors have nearly-linear relationships. In the presence of multicollinearity, OLS regression can produce biased estimates of the regression coefficients, inflate the standard errors of the regression coefficients and show wrong, non-significant p-values. To avoid these problems, a ridge regression approach is adopted.

A ridge regression is an econometric technique for estimating parameters in specific way. It penalizes not only large deviations of residuals but also large deviations of coefficient estimates. In a ridge regression, the vector of parameter estimates $\hat{\beta}$ arise from the following minimisation problem:

$$Min_{\beta} \underbrace{\underbrace{\sum(y_i - \beta x_{it})^2}_{\text{OLS}} + k\beta^2}_{\text{Ridge regression}} \qquad (3.24)$$

As $k \to 0$, $\beta^{ridge} \to \beta^{OLS}$, and

As $k \to \infty$, $\beta^{ridge} \to 0$.

Following Hoerl and Kennard (1970) the ridge estimator is calculated by solving

$$(X'X + kI)\beta = h \qquad (3.25)$$

Thus, $\hat{\beta} = (X'X + kI)^{-1}h$ (3.26)

Where $h = X'Y$ (3.27)

k is the ridge parameter ($k \geq 0$) and I is an identity matrix.

Although there is an optimum value of k in this procedure, a range of values of k may be acceptable. Small and positive k values lower the variance of the estimates which in turn, produces a smaller mean square error relative to least squares estimates. The limitation of the ridge regression is that it imposes some bias to reduce the variance and the multicollinearity in the equation.

In this methodology and the rest of the chapter the data used are historical data. Consequently, the results may not be reflective of future events specially if certain policies such as a carbon tax are implemented as they can alter the energy-sector relationships.

3.4.2 Calculation of Carbon Dioxide Emissions

Fossil fuels contain carbon which can generate energy but also produces carbon dioxide. Table 3.1 shows the conversion factors to obtain the quantity of carbon dioxide emitted by each fuel. In the first column the million tons of oil equivalent units are converted to a common energy unit: terajoules (TJ). The amount of fuel consumed is then multiplied by the carbon emission factor to derive the carbon content in tonnes of carbon. Upon combustion, carbon is emitted from the fuel and oxidises to form carbon dioxide. The carbon released from the combustion of fuel depends on the kind of fuel used. For oil, 99% of the carbon is released on combustion. The carbon content released by natural gas and coal is 99.5% and 98%, respectively. To determine the amount of carbon dioxide emitted into the atmosphere, the quantity of carbon is multiplied by the ratio of the molecular weight of carbon dioxide to carbon which is 44/12.

Table 3.1 Carbon Dioxide Emission Factors for Fossil Fuels

Fuel	Conversion factor (TJ/unit)	Carbon emission factor (tC/TJ)	Oxidation factor	CO_2/C ratio: 44/12
Oil	41868 TJ/10^6 toe	20	0.99	3.667
Coal	41868 TJ/10^6 toe	26.8	0.98	3.667
Natural Gas	41868 TJ/10^6 toe	15.3	0.995	3.667

Source: IEA (2014).

3.4.3 Substitution Process and Calculation of Net Carbon Emissions

After computing the substitution elasticities from the ride regression results, they are multiplied to a pair of fuels to be switched. For instance, 10% of coal consumption is multiplied to the substitution elasticity between coal and gas in order to obtain the amount of gas percentage increase that will replace coal while keeping output constant. Table 3.1 is used to compute for the emissions of the 10% coal consumption and the emissions of the additional gas consumption that are substituted. The net carbon emissions are computed by obtaining the difference between the foregone emissions of using 10% coal and the emissions of the new gas consumption.

3.5 Data Sources

The dataset for annual GDP and gross capital formation are sourced from the World Development Indicators, World Bank. Both output and gross capital formation are stated in constant prices (2005=100) that take out the effects of inflation. The World Bank defines gross capital formation as consisting of outlays on additions to the fixed assets of an economy plus net changes in the level of inventories. Fixed assets include land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, including schools, offices, hospitals, private residential dwellings, and commercial and industrial buildings. Inventories are stocks of goods held by firms to meet temporary or unexpected fluctuations in production or sales, and “work in progress".

With capital formation flow data, the capital stock is computed as:

$$K_t = K_{t-1}(1 - \vartheta) + I_t \tag{3.28}$$

Where K_t denotes the current capital stock, K_{t-1} stands for the capital stock of the past year, ϑ represents the capital depreciation rate and I_t denotes the current year capital investment.

The World Bank estimates the depreciation rate of capital for 124 countries at 5%, which allows to calculate:

$$K_0 = \frac{I_0}{g+\vartheta} \tag{3.29}$$

Where K_0 is the initial level of capital stock, I_0 is the initial level of capital investment, denotes the capital depreciation rate and g is the average growth rate of the capital investment in the sample.

Labor is represented by the employment ratio which is taken from the International Labor Organization’s statistics and the Asian Development Bank’s 2013 Key Indicators publication.

Data for oil, gas and coal consumption were derived from the BP Statistical Review of World Energy June 2017 database. The energy variables are quoted in million tonnes of oil equivalent (Mtoe). All values were transformed into log-levels before estimation of the model. See Appendix A for sample computation of the environmental impact.

3.6 Results and Discussion

3.6.1 China Analysis

3.6.1.1 Ridge Regression Result

The results of the ridge regression and Ordinary Least Square (OLS) regression are shown in Table 3.2. The dependent variable is lnY (GDP). The ridge regression result shows that the coefficient estimates of lnK, lnL, lnklnl, lnklnC, lnklnO, lnklnG, lnOlnG, lnK2, lnL2, lnG2 are significantly different than zero at nearly 0.001 level of significance; lnO2 at the 0.05 level of significance and lnO and lnLlnO at the 0.1 level of significance. The ridge parameter is estimated at 0.001638307. On the other hand, in the OLS regression lnL is significant at the 0.01 level of significance; lnK, lnL at the 0.05 level of significance, lnLlnO, lnOlnG at the 0.01 level of significance; lnKlnC, lnKlnO, lnClnG at the 0.1 level of significance.

3.6.1.2 Output Elasticity

The output elasticities of all the factor inputs are provided in Table 3.3. Among the fossil fuels, Coal has the lowest output elasticity at 0.061. Gas and oil consumption also have low levels of output elasticity at 0.336 and 0.324, respectively. This means that a 1% change in coal ,oil or gas consumption will not significantly affect output. Oil is imported while coal is an inexpensive and abundant resource in China. This result is favorable for reducing carbon emissions as large reductions in these fuels' consumption will not undermine output. Overall, Labor's output elasticity is relatively elastic compared to the other inputs. This suggests that the driver of growth in China is labor.

3.6.1.3 Substitution Elasticity

Table 3.4 shows the substitution elasticity of the different factor inputs. Substitution elasticities among fossil fuels are possible however, the natural gas market is still very limited in China and contributes little to the energy requirements of the industrial sector (i.e. chemical industry). The substitution between capital and coal, and between labor and coal have the highest substitution elasticity. These suggest that coal is an important energy source in China.

Table 3.2 Results of Ridge Regression vs OLS, China

	OLS					**Ridge Regression**				
	Estimate	Std. Err.	t	P>t		Estimate	Std. Err.	t	P>t	
Intercept	12790.4					-41.78				
lnk	72.06	45.18	1.6	0.13		0.078	0.135	5.656	0	***
lnl	-1293.3	415.24	-3.11	0.01	**	1.846	0.051	15.325	< 2e-16	***
lnc	-64.23	54.83	-1.17	0.26		0.012	0.099	0.448	0.654	
lno	(dropped)					0.049	0.115	1.686	0.092	.
lng	8.3	52.82	0.16	0.88		-0.045	0.171	1.495	0.135	
lnklnl	-3.61	2.37	-1.52	0.15		0.004	0.13	5.849	0	***
lnklnc	0.7	0.38	1.84	0.08	.	0.002	0.059	4.799	0	***
lnklno	-1.16	0.64	-1.81	0.09	.	0.003	0.054	7.884	0	***
lnklng	-0.31	0.49	-0.63	0.54		0.002	0.056	4.498	0	***
lnllnc	3.03	2.72	1.11	0.28		0.001	5. 9.075e-02	0.607	0.544	
lnllno	1.19	0.37	3.26	0.01	**	0.003	0.111	1.91	0.056	.
lnllng	-0.55	2.85	-0.19	0.85		0.001	0.093	0.684	0.494	
lnclno	-1.75	0.97	-1.8	0.09		-0.002	0.167	1.439	0.15	
lnclng	-0.08	0.39	-0.2	0.85		0.002	0.089	1.237	0.216	
lnolng	2.1	0.57	3.71	0.002	***	0.008	0.092	4.1	0	***
lnk2	0.13	0.21	0.59	0.57		0.002	0.129	5.652	0	***
lnl2	32.6	10.97	2.97	0.01	**	0.045	0.052	15.015	< 2e-16	***
lnc2	-0.29	0.55	-0.52	0.61		-0.002	0.102	1.158	0.247	
lno2	0.53	0.7	0.76	0.46		0.008	0.135	2.536	0.011	*
lng2	-0.14	0.3	-0.47	0.64		0.023	0.219	4.59	0	***

Signif. codes: ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Dependent Variable is lnY (GDP)
Ridge parameter: 0.001638307
Ridge Degrees of freedom: model 5.085 , variance 4.664 , residual 5.506
R-squared: 0.9991316
OLS R-squared: 1
No. of observations: 37

Table 3.3 Output Elasticity of Alternative Inputs in the Chinese Economy

Year	K	L	Coal	Oil	Gas
1980	0.248	3.755	0.052	0.256	0.188
1981	0.248	3.757	0.052	0.254	0.183
1982	0.248	3.759	0.052	0.254	0.18
1983	0.249	3.76	0.052	0.255	0.181
1984	0.25	3.762	0.053	0.256	0.183
1985	0.25	3.764	0.053	0.258	0.185
1986	0.251	3.766	0.053	0.259	0.189
1987	0.252	3.768	0.053	0.261	0.19
1988	0.253	3.77	0.054	0.263	0.192
1989	0.253	3.771	0.054	0.264	0.195
1990	0.254	3.773	0.054	0.264	0.195
1991	0.254	3.775	0.054	0.266	0.198
1992	0.255	3.776	0.054	0.268	0.199
1993	0.256	3.778	0.054	0.27	0.202
1994	0.257	3.779	0.055	0.271	0.204
1995	0.257	3.781	0.055	0.273	0.206
1996	0.258	3.782	0.055	0.275	0.209
1997	0.259	3.784	0.055	0.278	0.213
1998	0.26	3.785	0.056	0.279	0.215
1999	0.261	3.786	0.056	0.281	0.218
2000	0.262	3.787	0.057	0.284	0.225
2001	0.263	3.788	0.057	0.286	0.231
2002	0.264	3.789	0.057	0.288	0.235
2003	0.266	3.789	0.058	0.292	0.243
2004	0.268	3.79	0.058	0.296	0.252
2005	0.269	3.79	0.059	0.299	0.26
2006	0.27	3.791	0.059	0.302	0.271
2007	0.272	3.792	0.059	0.305	0.281
2008	0.273	3.793	0.06	0.307	0.288
2009	0.274	3.793	0.06	0.309	0.293
2010	0.275	3.794	0.06	0.313	0.303
2011	0.276	3.795	0.061	0.316	0.314
2012	0.277	3.796	0.061	0.318	0.319
2013	0.277	3.796	0.061	0.32	0.325
2014	0.278	3.796	0.061	0.322	0.33
2015	0.278	3.797	0.061	0.323	0.332
2016	0.279	3.797	0.061	0.324	0.336
Average	0.262	3.781	0.056	0.284	0.237

Table 3.4 Substitution Elasticity of Alternative Inputs in the Chinese Economy

Year	KL	KC	KO	KG	LC	LO	LG	CO	CG	OG
1980	0.21	0.905	0.809	0.934	0.911	0.817	0.94	0.787	0.919	0.912
1981	0.21	0.905	0.81	0.942	0.911	0.818	0.949	0.788	0.928	0.919
1982	0.21	0.905	0.81	0.947	0.911	0.818	0.953	0.789	0.932	0.924
1983	0.21	0.905	0.809	0.945	0.911	0.817	0.951	0.788	0.93	0.922
1984	0.21	0.905	0.809	0.943	0.911	0.816	0.949	0.788	0.928	0.92
1985	0.21	0.905	0.807	0.939	0.911	0.815	0.945	0.787	0.925	0.917
1986	0.21	0.905	0.806	0.934	0.911	0.814	0.94	0.785	0.92	0.912
1987	0.21	0.905	0.805	0.932	0.911	0.813	0.938	0.785	0.918	0.91
1988	0.21	0.905	0.804	0.929	0.911	0.811	0.935	0.783	0.915	0.908
1989	0.209	0.905	0.803	0.926	0.911	0.81	0.931	0.783	0.912	0.904
1990	0.209	0.905	0.803	0.925	0.911	0.81	0.93	0.783	0.911	0.903
1991	0.209	0.905	0.801	0.921	0.911	0.809	0.927	0.781	0.907	0.9
1992	0.209	0.905	0.8	0.92	0.911	0.808	0.925	0.78	0.906	0.899
1993	0.209	0.905	0.799	0.915	0.911	0.806	0.921	0.779	0.902	0.895
1994	0.209	0.905	0.798	0.913	0.911	0.805	0.918	0.778	0.899	0.893
1995	0.209	0.905	0.797	0.91	0.911	0.804	0.916	0.777	0.897	0.89
1996	0.209	0.905	0.795	0.907	0.911	0.802	0.912	0.776	0.894	0.887
1997	0.209	0.905	0.793	0.902	0.911	0.801	0.907	0.774	0.889	0.883
1998	0.209	0.905	0.793	0.9	0.911	0.8	0.905	0.774	0.887	0.881
1999	0.209	0.905	0.791	0.895	0.911	0.798	0.9	0.772	0.883	0.877
2000	0.209	0.905	0.789	0.887	0.91	0.796	0.892	0.771	0.875	0.869
2001	0.209	0.904	0.788	0.88	0.91	0.795	0.885	0.77	0.869	0.863
2002	0.209	0.904	0.786	0.876	0.91	0.793	0.881	0.768	0.865	0.859
2003	0.209	0.904	0.784	0.867	0.91	0.791	0.872	0.766	0.856	0.851
2004	0.209	0.904	0.781	0.858	0.91	0.788	0.863	0.763	0.847	0.842
2005	0.209	0.904	0.779	0.85	0.91	0.786	0.855	0.762	0.84	0.834
2006	0.209	0.904	0.777	0.84	0.91	0.784	0.845	0.76	0.83	0.825
2007	0.209	0.904	0.775	0.831	0.91	0.782	0.835	0.758	0.821	0.816
2008	0.209	0.904	0.774	0.824	0.91	0.78	0.829	0.757	0.815	0.81
2009	0.209	0.904	0.773	0.82	0.91	0.779	0.824	0.756	0.81	0.806
2010	0.209	0.904	0.77	0.812	0.909	0.776	0.816	0.753	0.802	0.798
2011	0.208	0.904	0.768	0.803	0.909	0.774	0.807	0.752	0.794	0.79
2012	0.208	0.904	0.767	0.799	0.909	0.773	0.803	0.751	0.79	0.786
2013	0.208	0.904	0.766	0.794	0.909	0.772	0.798	0.75	0.785	0.782
2014	0.208	0.904	0.765	0.791	0.909	0.771	0.795	0.749	0.782	0.778
2015	0.208	0.904	0.764	0.789	0.909	0.77	0.793	0.748	0.78	0.777
2016	0.208	0.904	0.763	0.786	0.909	0.769	0.79	0.747	0.777	0.774
Average	0.209	0.904	0.789	0.881	0.91	0.797	0.886	0.771	0.869	0.863

3.6.1.4 Environmental Impact

In 2016, a 10% reduction in coal consumption or 188.76 Mtoe translates to a rise in oil consumption of 141.02 Mtoe (Table 3.5). This change drives CO2 emissions to fall from 761,069,791.72 tCO2 to 428,652,046.27 tCO2 or net reductions of 332,417,745.46 tCO2. Decrease in carbon emissions were also realized with other fuel substitutions in 2016. As 188.76 Mtoe of coal consumption was replaced by 146.75 Mtoe of gas (Table 3.6) carbon emissions fall by 121,898,018.74 tCO2. Likewise, a 10% reduction in oil consumption substituted by 44.8 gas consumption (Table 3.7) led to a decline of carbon emissions reaching 97,207,338.31 tCO2.

Table 3.5 Scenario Analysis of Fuel Switching, China, 2016

Year	10% Change in Coal Consumption (in MTOE)	Change in Oil Consumption (in MTOE)	Change in Coal Emissions (tCO2)	Change in Oil Emissions (tCO2)	Net change in Total Emissions (tCO2)
2016	188.76	141.02	761,069,791.72	428,652,046.27	-332,417,745.46

Table 3.6 Scenario Analysis of Fuel Switching, China, 2016

Year	10% Change in Coal Consumption (in MTOE)	Change in Gas Consumption	Change in Coal Emissions (tCO2)	Change in Gas Emissions (tCO2)	Net change in Total Emissions (tCO2)
2016	188.76	146.75	567,962,531.14	446,064,512.39	-121,898,018.74

Table 3.7 Scenario Analysis of Fuel Switching, China, 2016

Year	10% Change in Oil Consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in Oil Emissions (tCO2)	Change in Gas Emissions (tCO2)	Net reductions in Total Emissions (tCO2)
2016	57.87	44.78	233,328,612.24	136,121,273.93	-97,207,338.31

3.6.2 Japan Analysis

3.6.2.1 Ridge Regression Result

The results of the ridge regression vs. OLS for Japan are shown in Table 3.8. In the ridge regression, the variables lnL, lnC lnG lnKlnC lnKlnG lnLlnC lnLlnG lnClnG lnOlnG lnL2 are significant at nearly 0.001 level of significance. lnC2 and lnG2 are significant at the 0.01 level of significance. lnKlnL and lnClnO at the 0.1 level of significance. The ridge parameter is estimated at 0.0219. In contrast, in the OLS regression estimates only lnK is significant at the 0.1 level of significance.

3.6.2.2 Output Elasticity

The output elasticities of the different factor inputs are shown in Table 3.9. Oil consumption is inelastic as indicated by low average output elasticity. Coal and gas consumption have low levels of output elasticity as well. This means that a unit change energy inputs will not alter the output of the Japanese economy significantly. In contrast, the output elasticity of labor is more than unity demonstrating that labor is an important component of GDP. Labor has a higher elasticity than capital because Japan has a capital-intensive economy, but the driver has been capital accumulation rather than labor accumulation.

3.6.2.3 Substitution Elasticity

Table 3.10 shows the substitution elasticity of the various factors of production. The substitution elasticity between coal and oil is the highest among the fossil fuels which are all substitutable. The high substitution elasticities between the energy inputs show that there is potential in Japan to minimise carbon dioxide emissions by redirecting energy use towards cleaner fuels. The substitution between capital and oil and labor and oil are very high as well, approaching unity.

Table 3.8 Results of Ridge Regression vs OLS, Japan

	OLS					Ridge Regression				
	Estimate	Std. Err.	t	P>t		Estimate	Std. Err.	t	P>t	
Intercept	-1171.05					5.308				
lnk	128.792	69.733	1.85	0.083	.	0.017	0.04	0.537	0.592	
lnl	47.116	235.4	0.2	0.844		1.136	0.026	5.815	0	***
lnc	0.534	43.176	0.01	0.99		0.063	0.026	3.345	0.001	***
lno	15.506	36.229	0.43	0.674		-0.025	0.017	0.985	0.325	
lng	-22.898	37.975	-0.6	0.555		0.051	0.025	5.725	0	***
lnklnl	-18.496	15.886	-1.16	0.261		0.009	0.033	1.844	0.065	.
lnklnc	-1.856	2.991	-0.62	0.544		0.002	0.018	3.759	0	***
lnklno	0.575	2.379	0.24	0.812		-0.002	0.022	1.102	0.271	
lnklng	0.09	2.351	0.04	0.97		0.002	0.02	6.021	0	***
lnllnc	3.666	12.2	0.3	0.768		0.015	0.027	3.431	0.001	***
lnllno	-8.316	7.752	-1.07	0.299		0.004	0.011	1.37	0.171	
lnllng	5.683	5.985	0.95	0.356		0.011	0.024	5.802	0	***
lnclno	1.221	1.918	0.64	0.534		0.007	0.029	1.741	0.082	.
lnclng	0.134	1.571	0.09	0.933		0.006	0.017	6.268	0	***
lnolng	-0.701	0.893	-0.79	0.444		0.007	0.029	3.788	0	***
lnk2	-1.296	2.794	-0.46	0.649		0	0.041	0.331	0.741	
lnl2	31.231	27.056	1.15	0.265		0.127	0.026	5.726	0	***
lnc2	0.891	2.11	0.42	0.678		0.006	0.027	2.943	0.003	**
lno2	0.745	0.889	0.84	0.415		-0.002	0.018	0.956	0.339	
lng2	0.004	0.685	0.01	0.996		0.004	0.034	2.774	0.006	**

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'
Dependent Variable is lnY (GDP)
Ridge parameter: 0.02191876
Degrees of freedom: model 4.547 , variance 4.105 , residual 4.988
R-squared: 0.9857053
OLS R-squared: 0.9981
No. of Observations: 37

Table 3.9 Output Elasticity of Alternative Inputs in the Japanese Economy

Year	K	L	Coal	Oil	Gas
1980	0.074	2.509	0.276	0.050	0.228
1981	0.075	2.512	0.278	0.051	0.228
1982	0.075	2.514	0.277	0.051	0.228
1983	0.075	2.518	0.277	0.051	0.229
1984	0.076	2.523	0.281	0.054	0.232
1985	0.076	2.525	0.281	0.055	0.233
1986	0.076	2.525	0.281	0.055	0.233
1987	0.076	2.526	0.282	0.055	0.233
1988	0.077	2.530	0.284	0.056	0.235
1989	0.077	2.533	0.284	0.056	0.236
1990	0.077	2.538	0.286	0.057	0.237
1991	0.077	2.541	0.286	0.057	0.238
1992	0.077	2.543	0.287	0.058	0.238
1993	0.077	2.544	0.287	0.058	0.239
1994	0.078	2.546	0.288	0.059	0.240
1995	0.078	2.547	0.289	0.059	0.240
1996	0.078	2.550	0.290	0.060	0.241
1997	0.078	2.552	0.291	0.060	0.242
1998	0.078	2.551	0.290	0.060	0.241
1999	0.078	2.551	0.291	0.061	0.242
2000	0.079	2.552	0.292	0.061	0.243
2001	0.079	2.551	0.292	0.062	0.243
2002	0.079	2.549	0.293	0.062	0.243
2003	0.079	2.550	0.294	0.063	0.244
2004	0.079	2.548	0.294	0.063	0.244
2005	0.079	2.549	0.294	0.063	0.244
2006	0.079	2.550	0.294	0.064	0.244
2007	0.080	2.551	0.295	0.064	0.245
2008	0.080	2.551	0.295	0.065	0.245
2009	0.079	2.546	0.292	0.063	0.243
2010	0.080	2.548	0.294	0.065	0.244
2011	0.080	2.547	0.294	0.065	0.245
2012	0.080	2.547	0.296	0.066	0.247
2013	0.080	2.549	0.296	0.067	0.247
2014	0.080	2.549	0.296	0.067	0.246
2015	0.080	2.548	0.295	0.066	0.246
2016	0.080	2.550	0.295	0.066	0.245
Average	0.078	2.541	0.289	0.060	0.240

Table 3.10 Substitution Elasticity of Alternative Inputs in the Japanese Economy

Year	KL	KC	KO	KG	LC	LO	LG	CO	CG	OG
1980	0.279	0.778	0.931	0.806	0.794	0.908	0.824	0.89	0.812	0.738
1981	0.279	0.778	0.931	0.806	0.793	0.908	0.824	0.89	0.812	0.739
1982	0.279	0.778	0.931	0.806	0.794	0.908	0.824	0.89	0.812	0.739
1983	0.278	0.778	0.931	0.806	0.794	0.908	0.823	0.89	0.812	0.739
1984	0.278	0.776	0.93	0.804	0.791	0.908	0.821	0.89	0.81	0.741
1985	0.278	0.776	0.93	0.803	0.791	0.908	0.82	0.89	0.809	0.742
1986	0.278	0.776	0.93	0.803	0.791	0.908	0.82	0.89	0.809	0.742
1987	0.278	0.775	0.93	0.803	0.791	0.908	0.82	0.89	0.809	0.742
1988	0.278	0.774	0.93	0.802	0.789	0.908	0.819	0.89	0.808	0.742
1989	0.277	0.774	0.93	0.802	0.789	0.908	0.818	0.89	0.807	0.742
1990	0.277	0.773	0.929	0.801	0.788	0.908	0.817	0.89	0.806	0.742
1991	0.277	0.773	0.929	0.8	0.787	0.907	0.817	0.89	0.806	0.742
1992	0.277	0.772	0.929	0.8	0.787	0.907	0.816	0.89	0.806	0.742
1993	0.277	0.772	0.929	0.8	0.787	0.907	0.816	0.89	0.805	0.742
1994	0.276	0.771	0.929	0.799	0.786	0.907	0.815	0.89	0.805	0.742
1995	0.276	0.771	0.929	0.799	0.786	0.907	0.815	0.89	0.804	0.742
1996	0.276	0.77	0.928	0.798	0.785	0.907	0.814	0.89	0.804	0.743
1997	0.276	0.77	0.928	0.798	0.785	0.907	0.814	0.889	0.803	0.743
1998	0.276	0.771	0.928	0.798	0.785	0.907	0.814	0.889	0.804	0.743
1999	0.276	0.77	0.928	0.797	0.784	0.907	0.814	0.889	0.803	0.743
2000	0.276	0.769	0.928	0.797	0.784	0.906	0.813	0.889	0.803	0.744
2001	0.276	0.769	0.928	0.797	0.784	0.906	0.813	0.889	0.803	0.744
2002	0.276	0.769	0.928	0.797	0.783	0.906	0.813	0.889	0.803	0.744
2003	0.276	0.768	0.927	0.796	0.783	0.906	0.812	0.889	0.802	0.745
2004	0.276	0.768	0.927	0.797	0.783	0.906	0.813	0.889	0.802	0.745
2005	0.276	0.768	0.927	0.796	0.782	0.906	0.812	0.889	0.802	0.745
2006	0.276	0.768	0.927	0.796	0.782	0.906	0.812	0.889	0.802	0.745
2007	0.276	0.768	0.927	0.796	0.782	0.906	0.812	0.888	0.801	0.746
2008	0.276	0.767	0.926	0.796	0.782	0.905	0.811	0.888	0.801	0.746
2009	0.277	0.769	0.927	0.797	0.784	0.906	0.813	0.889	0.803	0.746
2010	0.277	0.768	0.926	0.796	0.782	0.905	0.812	0.888	0.802	0.746
2011	0.277	0.768	0.926	0.796	0.782	0.905	0.812	0.888	0.801	0.746
2012	0.277	0.767	0.926	0.795	0.781	0.905	0.811	0.888	0.8	0.746
2013	0.277	0.767	0.926	0.795	0.781	0.905	0.811	0.888	0.8	0.747
2014	0.277	0.767	0.926	0.795	0.781	0.905	0.811	0.888	0.801	0.747
2015	0.277	0.768	0.926	0.796	0.782	0.905	0.811	0.888	0.801	0.747
2016	0.277	0.768	0.926	0.796	0.782	0.905	0.811	0.888	0.801	0.747
Average	0.277	0.771	0.928	0.799	0.786	0.907	0.815	0.889	0.805	0.743

3.6.2.4 Environmental Impact

In a 2016 scenario where there is a reduction of 10% in coal consumption (Table 3.11), 11.99 Mtoe of coal will be replaced by 10.65 Mtoe of oil. This will lower total CO2 emissions by 15,988,172.12 tCO2 which is derived from the lower emissions in oil consumption of 32,370,537.85 tCO2 compared to coal consumption emissions of 48,358,709.98 tCO2. In the same year, when coal is replaced by 9.61 Mtoe of gas (Table 3.12) the net reductions in carbon emissions reached 6,881,620.56 tCO2 as the change in coal emissions of 36,088,589.53 tCO2 is offset by only 29,206,968.98 tCO2 of gas emissions. Similarly, in Table 3.13 the switch from oil (18.43 mtoe) to gas (13.77 mtoe) produces less emissions amounting to 32,460,708.84 tCO2 in 2016. This is the difference of the change in oil emissions of 74,309,296.46 tCO2 and the new gas emissions of 41,848,587.61 tCO2.

Table 3.11 Scenario Analysis of Fuel Switching, 2016

Year	10% Change in Coal Consumption (in MTOE)	Change in Oil Consumption (in MT)	Change in Coal Emissions	Change in Oil Emissions	Net Change in Total Emissions (tCO2)
2016	11.99	10.65	48,358,709.98	32,370,537.85	-15,988,172.12

Table 3.12 Scenario Analysis of Fuel Switching, 2016

Year	10% Change in Coal Consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in Coal Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	11.99	9.61	36,088,589.53	29,206,968.98	-6,881,620.56

Table 3.13 Scenario Analysis of Fuel Switching, 2016

Year	10% Change in Oil Consumption (in MTOE)	Change in Gas consumption (in MTOE)	Change in Coal Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	18.43	13.77	74,309,296.46	41,848,587.61	-32,460,708.84

3.6.3 *Korea Analysis*

3.6.3.1 Ridge Regression Results

The ridge regression estimates show that these variables are significant at the 0.001 level of significance: lnK, lnL, lnC, lnKlnL, lnKlnC, lnKlnO, lnLlnC, lnClnO, lnClnG, lnK2, lnL2, lnC2 (Table 3.14). The variables which are significant at the 0.01 level of significance are lnLlnO and lnClnG. lnO is significant at the 0.05 level of significance while lnklnG and lnG2 are significant at the 0.1 level of significance. Under OLS LNG is significant at 0.05 level of significance. However, the rest of the variables are not significant.

3.6.3.2 Output Elasticity

Labor has the highest output elasticity estimate among the production inputs. It is valued at 1.12 on average (Table 3.15). On the other hand, capital is inelastic with an average output elasticity of 0.25. Among the fossil fuels oil is the most elastic with the average output elasticity at 2.13. In contrast, coal and gas are inelastic with their average output elasticities estimated at 0.216 and 0.016, respectively. Having few indigenous energy resources, Korea imports most of its energy supply.

3.6.3.3 Substitution Elasticity

All fuels are substitutable although the substitution elasticity between oil and gas is the highest on average (Table 3.16). The substitution elasticities of gas with respect to the other inputs such as capital, labor, coal and oil have consistently surpassed unity. In contrast, the elasticity of substitution between coal and oil is low at 0.32. The elasticity of substitution of capital and labor with oil are also down. The elasticity of substitution between capital and labor is also low at 0.47.

Table 3.14 Results of Ridge Regression vs OLS, Korea

	OLS				Ridge Regression					
	Estimate	Std. Err.	t	P>t	Estimate	Std. Err.	t	P>t		
Intercept	9160.542				3.323					
lnk	-439.215	344.268	-1.28	0.22	0.084	0.291	0.06	4.849	0	***
lnl	-439.997	485.31	-0.91	0.378	0.66	0.309	0.064	4.832	0	***
lnc	226.454	258.36	0.88	0.394	0.049	0.128	0.037	3.423	0.001	***
lno	90.826	233.196	0.39	0.702	0.034	0.076	0.033	2.336	0.019	*
lng	167.983	76.392	2.2	0.043	0.002	0.017	0.021	0.791	0.429	
lnklnl	18.38	19.857	0.93	0.368	0.004	0.294	0.048	6.19	0	***
lnklnc	-4.08	3.305	-1.23	0.235	0.002	0.171	0.026	6.634	0	***
lnklno	-5.052	3.146	-1.61	0.128	0.001	0.102	0.019	5.382	0	***
lnklng	-1.37	1.85	-0.74	0.47	0	0.037	0.02	1.868	0.062	.
lnllnc	-7.288	14.553	-0.5	0.623	0.003	0.136	0.034	3.968	0	***
lnllno	2.125	11.419	0.19	0.855	0.002	0.082	0.028	2.958	0.003	**
lnllng	-8.361	4.98	-1.68	0.113	0	0.019	0.021	0.914	0.361	
lnclno	1.321	2.622	0.5	0.621	0.006	0.113	0.032	3.563	0	***
lnclng	1.888	1.356	1.39	0.183	0.004	0.145	0.044	3.276	0.001	**
lnolng	1.52	1.123	1.35	0.195	-0.001	-0.047	0.042	1.123	0.262	
lnk2	2.921	2.427	1.2	0.246	0.002	0.296	0.06	4.965	0	***
lnl2	-1.153	5.913	-0.2	0.848	0.019	0.308	0.065	4.763	0	***
lnc2	0.488	1.527	0.32	0.754	0.01	0.205	0.054	3.783	0	***
lno2	0.754	1.278	0.59	0.563	-0.003	-0.064	0.043	1.496	0.135	
lng2	0.101	0.064	1.57	0.137	0.006	0.154	0.088	1.759	0.078	.

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’
Dependent Variable is lnY (GDP)
Ridge parameter: 0.008871387; Degrees of freedom: model 4.812 , variance 3.999 , residual 5.625;
R-squared: 0.9984261
OLS R-squared: 0.9996
No. of Observations: 37

Table 3.15 Output Elasticity of Alternative Inputs in the Korean Economy

Year	K	L	Coal	Oil	Gas
1980	0.242	1.099	0.175	2.119	0.011
1981	0.244	1.108	0.178	2.121	0.012
1982	0.244	1.108	0.179	2.121	0.012
1983	0.245	1.109	0.18	2.121	0.012
1984	0.245	1.109	0.184	2.123	0.013
1985	0.246	1.11	0.187	2.123	0.014
1986	0.246	1.111	0.177	2.124	0.014
1987	0.247	1.113	0.193	2.124	0.014
1988	0.248	1.114	0.196	2.125	0.014
1989	0.248	1.115	0.197	2.125	0.014
1990	0.249	1.117	0.199	2.125	0.014
1991	0.25	1.118	0.201	2.125	0.014
1992	0.25	1.119	0.203	2.125	0.014
1993	0.251	1.12	0.206	2.126	0.014
1994	0.251	1.121	0.209	2.126	0.015
1995	0.252	1.122	0.212	2.127	0.015
1996	0.253	1.123	0.216	2.128	0.015
1997	0.253	1.125	0.22	2.128	0.016
1998	0.253	1.124	0.219	2.129	0.016
1999	0.254	1.125	0.222	2.129	0.016
2000	0.254	1.126	0.225	2.13	0.017
2001	0.255	1.126	0.227	2.13	0.017
2002	0.255	1.127	0.229	2.131	0.017
2003	0.255	1.127	0.23	2.131	0.017
2004	0.256	1.128	0.232	2.132	0.018
2005	0.256	1.128	0.233	2.132	0.018
2006	0.256	1.129	0.233	2.132	0.018
2007	0.256	1.129	0.235	2.133	0.018
2008	0.257	1.13	0.237	2.133	0.019
2009	0.257	1.13	0.238	2.134	0.019
2010	0.257	1.13	0.241	2.134	0.019
2011	0.257	1.131	0.244	2.135	0.02
2012	0.258	1.131	0.244	2.135	0.019
2013	0.258	1.132	0.244	2.135	0.019
2014	0.258	1.132	0.245	2.135	0.02
2015	0.258	1.133	0.245	2.135	0.02
2016	0.258	1.133	0.245	2.135	0.019
Average	0.252	1.122	0.216	2.129	0.016

Table 3.16 Substitution Elasticity of Alternative Inputs in the Korean Economy

Year	KL	KC	KO	KG	LC	LO	LG	CO	CG	OG
1980	0.477	0.89	0.32	2.01	0.894	0.32	2.012	0.317	1.916	2.016
1981	0.475	0.886	0.32	1.904	0.891	0.32	1.906	0.317	1.82	1.908
1982	0.474	0.886	0.32	1.895	0.89	0.32	1.897	0.317	1.812	1.9
1983	0.474	0.884	0.32	1.854	0.888	0.32	1.856	0.317	1.776	1.859
1984	0.474	0.88	0.32	1.755	0.884	0.32	1.757	0.317	1.686	1.759
1985	0.474	0.878	0.319	1.71	0.882	0.32	1.711	0.317	1.645	1.713
1986	0.474	0.888	0.319	1.686	0.893	0.32	1.688	0.316	1.62	1.69
1987	0.473	0.872	0.319	1.681	0.876	0.32	1.683	0.317	1.62	1.685
1988	0.473	0.869	0.319	1.658	0.873	0.32	1.659	0.317	1.6	1.661
1989	0.473	0.868	0.319	1.668	0.872	0.32	1.669	0.317	1.609	1.671
1990	0.473	0.866	0.319	1.669	0.87	0.32	1.671	0.317	1.611	1.673
1991	0.472	0.864	0.319	1.667	0.868	0.32	1.668	0.317	1.61	1.671
1992	0.472	0.863	0.319	1.681	0.867	0.32	1.683	0.317	1.624	1.685
1993	0.472	0.859	0.319	1.648	0.863	0.32	1.649	0.317	1.593	1.651
1994	0.472	0.857	0.319	1.637	0.861	0.32	1.638	0.317	1.584	1.64
1995	0.471	0.854	0.319	1.62	0.858	0.319	1.621	0.317	1.568	1.623
1996	0.471	0.85	0.319	1.578	0.854	0.319	1.579	0.317	1.53	1.581
1997	0.471	0.847	0.319	1.557	0.851	0.319	1.559	0.317	1.511	1.56
1998	0.471	0.848	0.319	1.547	0.852	0.319	1.549	0.317	1.502	1.551
1999	0.471	0.846	0.319	1.533	0.849	0.319	1.534	0.317	1.489	1.536
2000	0.471	0.843	0.319	1.505	0.846	0.319	1.506	0.317	1.463	1.508
2001	0.471	0.841	0.319	1.492	0.845	0.319	1.493	0.316	1.451	1.495
2002	0.47	0.839	0.319	1.477	0.843	0.319	1.479	0.316	1.438	1.48
2003	0.47	0.838	0.319	1.469	0.842	0.319	1.471	0.316	1.43	1.472
2004	0.47	0.837	0.319	1.462	0.841	0.319	1.463	0.316	1.424	1.465
2005	0.47	0.836	0.319	1.456	0.84	0.319	1.457	0.316	1.418	1.459
2006	0.47	0.836	0.319	1.456	0.84	0.319	1.457	0.316	1.418	1.459
2007	0.47	0.834	0.319	1.441	0.838	0.319	1.442	0.316	1.404	1.444
2008	0.47	0.832	0.318	1.424	0.836	0.319	1.425	0.316	1.388	1.426
2009	0.47	0.832	0.318	1.418	0.835	0.319	1.419	0.316	1.383	1.42
2010	0.47	0.829	0.318	1.402	0.833	0.319	1.403	0.316	1.368	1.405
2011	0.469	0.827	0.318	1.388	0.831	0.319	1.389	0.316	1.355	1.391
2012	0.469	0.827	0.318	1.393	0.831	0.319	1.394	0.316	1.36	1.395
2013	0.469	0.827	0.318	1.391	0.83	0.319	1.392	0.316	1.358	1.394
2014	0.469	0.827	0.318	1.387	0.83	0.319	1.388	0.316	1.354	1.389
2015	0.469	0.826	0.318	1.385	0.83	0.319	1.386	0.316	1.353	1.388
2016	0.469	0.827	0.318	1.392	0.83	0.319	1.393	0.316	1.359	1.394
Average	0.471	0.852	0.319	1.576	0.856	0.319	1.577	0.317	1.526	1.579

3.6.3.4 Environmental Impact

As 10% of coal consumption (8.16 MToe) is replaced by 2.58 Mtoe of oil (Table 3.17) it drives total carbon emissions to fall by 25,052,416.46 tCO2 in 2016. Coal consumption generates 32,894,213.76 tCO2 however, oil consumption emits only 7,841,797.30 tCO2. At the same time when coal is replaced by gas consumption of 11.09 MToe (Table 3.18) the resulting net carbon emissions turn positive at 803,835.53 tCO2. Likewise, substituting gas for 10% oil consumption (Table 3.19) yields more carbon emissions reaching 2,521,060.33 tCO2 in 2016. Interestingly, the shift from coal and oil to gas have produced more carbon emissions. The data shows that Korea has a very high elasticity of substitution between coal and gas and oil and gas which are 1.526 and 1.579, respectively. This is possibly due to the government's aggressive promotion of gas for electricity and residential use in an effort to stem dependence on imported oil. State -owned Korea Gas Corporation (KOGAS) is the world's second largest LNG importer. On October 2017 Korea also announced the country's energy transition which will substitute renewables and natural gas for coal and nuclear generation (APEC, 2017).

Table 3.17 Scenario Analysis of Fuel Switching, Korea

Year	10% Change in Coal Consumption (in MTOE)	Change in Oil Consumption (in MTOE)	Change in Coal Emissions	Change in Oil Emissions	Net Change in Total Emissions (tCO2)
2016	8.16	2.58	32,894,213.76	7,841,797.30	-25,052,416.46

Table 3.18 Scenario Analysis of Fuel Switching, Korea

Year	10% Change in coal Consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in Coal Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	8.16	11.09	32,894,213.76	33,698,049.29	803,835.53

Table 3.19 Scenario Analysis of Fuel Switching, Korea

Year	10% Change in Oil consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in Coal Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	12.22	17.03	49,250,182.61	51,771,242.95	2,521,060.33

3.6.4 ASEAN Countries Analysis

3.6.4.1 Ridge Regression Results

The ridge regression estimates for the ASEAN countries are presented in Table 3.20. In general, the parameter estimates that are significant at the 0.001% level of significance are those of lnK, lnC, lnO, lnKlnL, lnKlnC, lnKlnO, lnLlnC, lnLlnO and lnK2. The ridge parameters are chosen automatically, computed using 2 PCs.

Table 3.20 Summary of Ridge Regression Estimates, ASEAN

	Malaysia		Philippines		Thailand		Singapore		Indonesia	
Intercept	16.217		16.63		29.364		18.91		13.603	
lnK	0.134	***	0.218	***	-0.07	.	0.135	***	0.386	***
lnL	0.048		-0.038	*	-0.047		-0.055		-0.241	*
lnC	0.021	***	0.025	***	0.063	***	0.009	**	0.003	
lnO	0.126	***	0.076	***	0.085	**	0.134	***	-0.08	
lnG	0.018		0.006	***	0.006		0.011		0.035	
lnKlnL	0.004	***	0.001	***	-0.002	.	0.002	***	0.007	***
lnKlnC	0.001	***	0.001	***	0.002	***	0	*	0.001	.
lnKlnO	0.004	***	0.003	***	0.002	***	0.004	***	0.002	
lnKlnG	0.001	.	0	***	0		0	***	0.003	*
lnLlnC	0.001	***	0.002	***	0.004	***	0.001	**	0	
lnLlnO	0.007	***	0.003	***	0.004	**	0.007	***	-0.004	.
lnLlnG	0.001		0	***	0		0	***	0.001	
lnClnO	0.001		0.007	***	0.022	***	0		0.002	
lnClnG	0		0.018	***	0.011	***	-0.001	**	-0.012	
lnOlnG	-0.003		0.001	*	0.008	*	0.001	***	-0.01	
lnK2	0.003	***	0.004	***	-0.001	.	0.002	***	0.007	***
lnL2	0.002		-0.001	*	-0.001		-0.002	.	-0.007	*
lnC2	0.012	**	0.048	***	0.024	*	0.002		0.013	*
lnO2	0.011	*	0.001		0.014	*	0.016	***	-0.008	
lnG2	-0.008		0.004	***	0.007		0		-0.016	

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'
Dependent Variable is lnY (GDP)
Malaysia: Ridge parameter: 0.004449414; Degrees of freedom: model 6.225 , variance 5.489 , residual 6.961; R-squared = 0.998055
Philippines: Ridge parameter: 0.04955707, chosen automatically, computed using 2 PCs; Degrees of freedom: model 5.49 , variance 4.625 , residual 6.354; R-squared = 0.9927752
Thailand: Ridge parameter: 0.003981344; Degrees of freedom: model 6.367 , variance 5.61 , residual 7.125; R-squared = 0.9963622
Singapore: Ridge parameter: 0.01946037; Degrees of freedom: model 6.058 , variance 4.975 , residual 7.141; R-squared = 0.997352
Indonesia: Ridge parameter: 0.003584371; Degrees of freedom: model 5.948 , variance 5.295 , residual 6.601; R-squared = 0.9899138

3.6.4.2 Output Elasticity

The following analysis on ASEAN comes with these caveats: Singapore does not use coal for fuel and gas consumption only began in 1992 while the Philippines' gas consumption only started in 2001. Except for Thailand, in the rest of ASEAN capital is more elastic than labor (Table 3.21). Indonesia has the highest capital elasticity and the widest gap relative to labor. The output elasticity of oil is greater than coal and gas for Malaysia, Philippines and Singapore. In contrast oil consumption in Indonesia is very inelastic with a negative output elasticity. Coal has a positive albeit low output elasticity in Indonesia compared to oil or gas. In Thailand the output elasticity of coal and oil are almost the same while gas lags behind. In general, the output elasticities for fossil fuels in the ASEAN countries are relatively low.

Table 3.21 Output Elasticity of ASEAN Countries, 2016 (Average)

	K	L	C	O	G
Indonesia	0.805	-0.281	0.216	-0.047	0.057
Malaysia	0.341	0.114	0.081	0.405	0.018
Thailand	-0.168	-0.035	0.364	0.377	0.045
Philippines	0.245	0.036	0.097	0.221	0.013
Singapore	0.278	0	0.009	0.426	0.016

3.6.4.3 Substitution Elasticity

In Table 3.22 all elasticity estimates which are close to unity shows that the input pairs are substitutes. The ASEAN countries exhibit high substitution elasticities among fossil fuels suggesting that these inputs can be interchanged easily. In particular, Indonesia has substitution elasticity greater than unity between coal and oil; For Thailand, substitution elasticity is greater than one between coal and gas, oil and gas; in the Philippines it is between oil and gas; for Singapore coal and gas are proven to be substitutes.

In terms of the substitution elasticities between labor and capital Singapore is negative which indicates that it is not possible to substitute labor for capital. However, for other countries capital and labor are substitutes. In addition most countries show that capital and labor can be substituted for all fossil fuels.

Table 3.22 Substitution Elasticity, 2016 (Average)

	KL	KC	KO	KG	LC	LO	LG	CO	CG	OG
Indonesia	1.418	0.872	1.282	0.746	0.873	1.261	0.75	1.268	0.782	0.647
Malaysia	0.902	1.011	0.719	0.677	0.999	0.696	0.674	0.714	0.683	0.681
Thailand	1.065	0.786	0.757	1.243	0.846	0.829	1.257	0.713	1.183	1.204
Philippines	0.937	0.429	0.814	1.103	0.297	0.775	1.093	0.83	0.864	1.098
Singapore	-9.846	1.373	0.713	0.984	1.235	0.655	0.816	0.756	1.025	0.982

3.6.4.4 Environmental Impact

3.6.4.4.1 Indonesia

The total reductions in CO2 emissions will reach 177,590,135.85 tCO2 in 2016 when a 10% reduction in coal consumption (959.99 MToe) is replaced by 1214.96 MToe of oil consumption (Table 3.23). The loss of CO2 emissions in coal usage amounts to 3,870,610,411.02 while the gain of CO2 emissions by substituting to oil is 3,693,020,275.17 tCO2. For Indonesia this fuel switch produces the greatest benefit in terms of net reductions in CO2 emissions. Switching from coal to gas (Table 3.24) produces 1,593,299,815.58 tCO2 in 2016 while the substitution of gas for oil (Table 3.25) takes 12,907,039,017.48 tCO2 out of the atmosphere in the same year.

Table 3.23 Scenario Analysis of Fuel Switching, Indonesia

Year	10% Change in Coal Consumption (in MTOE)	Change in Oil Consumption (in MTOE)	Change in Coal Emissions	Change in Oil Emissions	Net Change in Total Emissions (tCO2)
2016	959.99	1214.96	3,870,610,411.02	3,693,020,275.17	-177,590,135.85

Table 3.24 Scenario Analysis of Fuel Switching, Indonesia

Year	10% Change in Coal Consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in Coal Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	959.99	749.21	3,870,610,411.02	2,277,310,595.43	-1,593,299,815.58

Table 3.25 Scenario Analysis of Fuel Switching, Indonesia

Year	10% Change in Oil Consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in oil Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	6316.81	4132.76	25,469,032,044.72	12,561,993,027.24	-12,907,039,017.48

3.6.4.4.2 Malaysia

For Malaysia in 2016, 1.99 Mtoe of coal can be replaced by 1.41 Mt of oil which would successfully lower carbon emissions by 3,729,219.54 tCO2 (Table 3.26). The loss of CO2 emissions from coal reaching 8,023,062.69 tCO2 can partially be offset by oil CO2 emissions of 4,293,843.15. In the case of gas substituting for coal (Table 3.27), net reductions in emissions are 3,864,639.44 tCO2 in 2016. However, the substitution of gas for oil in 2016 has the highest drop in CO2 emissions reaching 7,030,707.43 tCO2 (Table 3.28). Oil and gas are consumed more in Malaysia. 10% oil consumption or 3. 63 MT can be replaced by 2.50 Mtoe of gas.

Table 3.26 Scenario Analysis of Fuel Switching, Malaysia

Year	10% Change in Coal Consumption (in MTOE)	Change in Oil Consumption (in MTOE)	Change in Coal Emissions	Change in Oil Emissions	Net Change in Total Emissions (tCO2)
2016	1.99	1.41	8,023,062.69	4,293,843.15	-3,729,219.54

Table 3.27 Scenario Analysis of Fuel Switching, Malaysia

Year	10% Change in Coal Consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in Coal Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	1.99	1.37	8,023,062.69	4,158,423.25	-3,864,639.44

Table 3.28 Scenario Analysis of Fuel Switching, Malaysia

Year	10% Change in Oil Consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in oil Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	3.63	2.5	14,631,822.16	7,601,114.73	-7,030,707.43

3.6.4.4.3 Philippines

A 10% reduction in coal consumption or 1.35 Mtoe will increase oil consumption by 1.07 Mt. (Table 3.29) in 2016. This will result in lowering overall emissions by 2,183,597.70 tCO2 in that year. The amount of coal CO2 emissions eliminated at 5,443,764.35 tCO2 is greater than the additional CO2 emissions of consuming oil 3,260,166.65 tCO2. Reductions in emissions in is also exhibited when gas is substituted for coal and when gas is substituted for oil in 2016. 1.42 Mtoe of gas is required to replace 1.35 Mtoe of coal which will reduce total CO2 emissions by 1,121,522.77 tCO2 (Table 3.30). 2.24 Mtoe of gas should be able to substitute 10% oil consumption or 2.24 Mt which will produce net reductions in total CO2 emissions of 1,207,814.80 (Table 3.31).

Table 3.29 Scenario Analysis of Fuel Switching, Philippines

Year	10% Change in Coal Consumption (in MTOE)	Change in Oil Consumption (in MTOE)	Change in Coal Emissions	Change in Oil Emissions	Net Change in Total Emissions (tCO2)
2016	1.35	1.07	5,443,764.35	3,260,166.65	-2,183,597.70

Table 3.30 Scenario Analysis of Fuel Switching, Philippines

Year	10% Change in Coal Consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in Coal Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	1.35	1.42	5,443,764.35	4,322,241.58	-1,121,522.77

Table 3.31 Scenario Analysis of Fuel switching, Philippines

Year	10% Change in Oil consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in Coal Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	1.99	2.24	8,029,981.62	6,822,166.82	-1,207,814.80

3.6.4.4.4 Singapore

In 2016, 0.03 Mt of oil can replaced 0.04 Mtoe of coal consumption (10% of total coal consumption) in Singapore (Table 3.32). This will lower carbon emissions from 153,563.46 tCO2 to 81,957.83 tCO2 which reduce 71,605.63 tCO2 from the atmosphere. The change from coal to gas (Table 3.33) produces the lowest level of reductions in carbon emissions in 2016 reaching to 34,444.65 tCO2. However, the greatest reductions in carbon emissions occurred when gas is substituted for oil (Table 3.34). This reached to 7,521,023.07 tCO2 in 2016 which is the difference of CO2 emissions from oil of 29,103,286.89 tCO2 and carbon emissions from gas of 21,582,263.82 tCO2.

Table 3.32 Scenario Analysis of Fuel Switching, Singapore

Year	10% Change in Coal Consumption (in MTOE)	Change in Oil Consumption (in MTOE)	Change in Coal Emissions	Change in Oil Emissions	Net Change in Total Emissions (tCO2)
2016	0.04	0.03	153,563.46	81,957.83	-71,605.63

Table 3.33 Scenario Analysis of Fuel Switching, Singapore

Year	10% Change in Coal Consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in Coal Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	0.04	0.04	153,563.46	119,118.80	-34,444.65

Table 3.34 Scenario Analysis of Fuel Switching, Singapore

Year	10% Change in Oil Consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in Oil Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	7.22	7.1	29,103,286.89	21,582,263.82	-7,521,023.07

3.6.4.4.5 Thailand

A 10% reduction in coal consumption or 1.77 Mtoe can be replaced by 1.22 Mt of oil and this will reduce carbon emission in Thailand by 3,442,903.70 tCO2 (Table 3.35) in 2016. Carbon emission from fossil fuels were halved from 7,152,521.15 tCO2 to 3,709,617.45 tCO2 with a shift from coal to oil. In the same year, carbon emissions when coal consumption is replaced by gas is also substantial at 1,645,754.41 tCO2 (Table 3.36). As with all ASEAN countries Thailand benefits most in reduced carbon emissions when oil is replaced by gas (Table 3.37). The net reductions in carbon emissions reached 5,365,910.58 tCO2 in 2016. From 23,771,383.11 tCO2 carbon emissions fell to 18,405,472.53 tCO2 as gas is substituted for oil.

Table 3.35 Scenario Analysis of Fuel Switching, Thailand

Year	10% Change in Coal Consumption (in MTOE)	Change in Oil Consumption (in MTOE)	Change in Coal Emissions	Change in Oil Emissions	Net Change in Total Emissions (tCO2)
2016	1.77	1.22	7,152,521.15	3,709,617.45	-3,442,903.70

Table 3.36 Scenario Analysis of Fuel Switching, Thailand

Year	10% Change in Coal Consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in Coal Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	1.77	1.81	7,152,521.15	5,506,766.74	-1,645,754.41

Table 3.37 Scenario Analysis of Fuel Switching, Thailand

Year	10% Change in Oil Consumption (in MTOE)	Change in Gas Consumption (in MTOE)	Change in oil Emissions	Change in Gas Emissions	Net Change in Total Emissions (tCO2)
2016	5.9	6.06	23,771,383.11	18,405,472.53	-5,365,910.58

3.7 Conclusion and Policy Implications

This chapter investigated inter-factor and inter-fuel substitution as a potential solution to reducing the amount of carbon dioxide emissions released to the atmosphere. A translog production function was adopted to analyse the relationships between capital, labor, oil consumption, gas consumption and coal consumption among the selected Asian countries. The estimation technique was a ridge regression which gives more robust results compared to OLS regression in light of multicollinearity problems in the model.

In general, the output elasticity of the energy sources across the selected Asian countries was found to be low. This shows that the output responsiveness to changes in fossil fuels is inelastic. The countries are also either elastic in capital or labor but not both. This implies that there is a tradeoff between labor and capital. As a country develops capital, the latter becomes less a determinant of output than labor. In the study, labor is more elastic than capital in Japan, China and Korea. In contrast, ASEAN countries exhibit higher output elasticities in capital than labor.

All fossil fuels are found to be substitutes. It is notable that the elasticity of substitution of gas for coal and oil is high, even surpassing unity in some countries (an indication of overall technologies in place). This result is favorable in the countries' desire to limit carbon dioxide emissions by replacing a highly polluting energy source with a cleaner fuel.

The highest elasticity of substitution between coal and oil is achieved by Indonesia. Despite having the lowest substitution elasticity between coal and oil among the eight countries Korea lowered its carbon emissions to what it would be otherwise without the fuel substitution. Among ASEAN countries the highest potential for gas for coal substitution are Thailand and Singapore with substitution elasticity between coal and gas exceeding unity. Korea also has a high elasticity of substitution but unlike other countries, the net carbon emissions of shifting to gas from coal is positive. While the substitution elasticity of other countries are below 1, it is still high which suggest that it is possible for the region to decarbonize its fuel consumption. The highest potential for gas for oil substitution are Thailand, the Philippines and Korea. However, unlike the Philippines and Thailand which saw lower carbon emissions, Korea's carbon emission rose after the fuel switch.

Shifting from coal to oil usage in all instances lead to carbon reductions. When China substituted oil for its coal usage, the reduction in carbon emissions reached 332.4 MtCO2. Japan's carbon reductions reached to almost 16 MtCO2 while Korea reduced CO2 by 25MtCO2. ASEAN countries also recorded smaller CO2 reductions. The same pattern is also exhibited in coal to gas substitution where CO2 reductions for China and Japan reached 122 MtCO2 and 6.9 MtCO2, respectively. The only exception is Korea which recorded increased CO2 emissions by 803,835.53 after the switch.

The substitution from oil to gas also proves to have high potential for reduction of carbon emissions released into the atmosphere. In Japan and Malaysia for instance, the switch from oil to gas shows that the carbon emissions reduction is twice that when the substitution occurs from coal to oil. The difference is more pronounced in Singapore and Indonesia. In Singapore switching from oil to gas reduces 7.5 MtCO2 from the atmosphere compared to only 71,605.63 tCO2 between coal and oil. Likewise, the reduction in CO2 emissions in Indonesia reached 12.9 BtCO2 when gas is substituted for oil, up from 177.6 MtCO2 reduction between coal and oil. The advent of electric vehicles, which can indirectly consume gas, should make the gas for oil substitution more and more implementable in upcoming years.

A major obstacle to fuel switching in Asia is government subsidies. Table 3.38 shows the total government subsidies and the breakdown by fuel in 2017. Overall, China has the highest absolute total subsidy amounting to $40B in 2017 as well as the largest subsidy for oil and gas costing $17.4B and $22.6 B, respectively. In terms of GDP percentage, Indonesia leads with 1.7% total fossil fuel subsidy, 1.2% oil subsidy and 0.5% electricity subsidy. The largest coal subsidy is given by Korea $127.6 M and reaching 0.009% of GDP.

Table 3.38 Fuel Subsidies by Country & Fuel Type, 2017

Country	Fuel	2017 (in Millions USD)	as % of GDP
China	Oil	17,423.86	0.171
	Electricity	22,623.62	0.223
	Gas	-	
	Coal	-	
	Total	40,047.48	0.394
Indonesia	Oil	13,449.53	1.233
	Electricity	5,386.91	0.494
	Gas	-	
	Coal	-	
	Total	18,836.43	1.727
Korea	Oil	-	
	Electricity	-	
	Gas	-	
	Coal	127.57	0.009
	Total	127.57	0.009
Malaysia	Oil	2,085.00	0.572
	Electricity	-	
	Gas	-	
	Coal	-	
	Total	2,085.00	0.572
Thailand	Oil	863.89	0.204
	Electricity	-	
	Gas	-	
	Coal	-	
	Total	863.89	0.204

Source: IEA Fossil Fuel Subsidies (2019)

The IMF (Coady, Parry, et. Al, 2019) estimates that without subsidies in 2015 global CO_2 emissions could have fallen 28% lower, tax revenues would have risen by 3.8% of global GDP more and air pollution deaths due to fossil fuel emissions would have been 46 percent lower than the actual rate.

Climate change is caused by the accumulation of carbon emissions in the atmosphere over time. Government energy subsidies distort prices and encourage excessive use of energy leading to greater emissions. Therefore to reduce emissions, subsidies must be removed so prices can reflect the true demand for energy and promote the right usage of fossil fuel.

The low energy prices provided by subsidies discourages consumers and industry from using appliances and equipment which are more energy efficient. On the production side, the bias toward fossil fuels dampened investments in energy efficient technologies and the deployment of renewable energy. Despite these disadvantages, subsidies in the region are hard to eliminate because of their political nature. Energy prices are sensitive issues with the electorate.

Chapter 4 : Energy Use, Intensity, and Carbon Emissions: Characterization of Asian Economies

4.1 Introduction

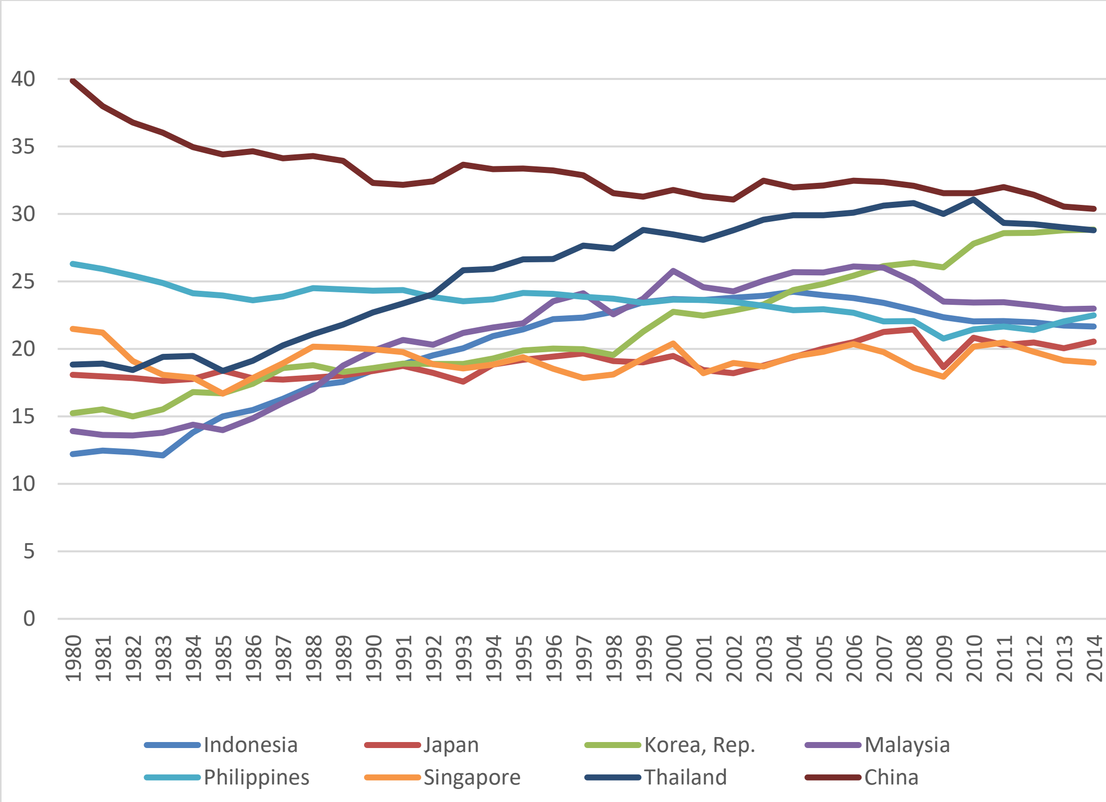
Asian countries are set to become the largest consumers of fossil fuels in the next decade due to the fast pace of development in the region. However, environmental effects of higher energy consumption will have repercussions on the sustainability of economic growth in these countries through policies. One of the highly debated aspects of the environment-income relationship has been examined using the Environmental Kuznets Curve (EKC). This theory posits that at the initial phase of economic development, some measures of environmental standards such as emissions of carbon dioxide or other pollutant emissions may increase, but at a later stage these environmental factors may improve along with income. However, there are many other macro-factors that affect CO2 emissions across Asian economies bringing an element of heterogeneity. This include: carbon and energy efficiency (i.e. state of technology), energy consumption mix, size of the country, share of manufacturing or industrial sectors in GDP, and trade openness.

This chapter contributes with two distinct approaches to the investigation of how energy consumption affects CO2 emissions in Asian economies. Firstly, an EKC panel regression augmented to account for the effects of industry share of GDP, energy intensity and trade openness. Secondly, it utilizes the Logarithmic Mean Divisia Index (LMDI) approach to investigate how CO2 emissions decompose at country level according to carbon intensity, energy intensity, share of fossil fuels over total energy consumed, share of the manufacturing sector, and a scale effect. Energy intensity in the textile and machinery sectors are also discussed. The resulting characterization of Asian economies from these two methods helps better identify policy spaces for implementing fuel substitution and efficiency measures.

The hypothetical EKC relationship between income and emissions is characterized by an inverted U shape. Rapid growth at the start of a development phase leads to higher pollution as more natural resources are used while people cannot afford or are unwilling to pay for abatement. However, with higher incomes, people expect a cleaner environment. Regulatory institutions have also become more effective in implementing stricter environmental policies. Furthermore, technology over time will have developed to enable continuing the same level of production with lower pollution. This could be achieved through sophisticated machines which require less fuel or the conversion of machines to burn a cleaner type of fuel.

One of the objectives of this chapter is to determine whether EKCs exist in Asian countries. While several studies have investigated the existence of EKC relationships in general, there is no definitive conclusion that applies to Asian economies. It is relevant to determine the nature of the environment and income linkage to ascertain the role of policymaking. The existence of an EKC shows that economic growth and a clean environment can be complementary as long as effective policies are put in place. Following the EKC a prerequisite for environmental policy to enter as a factor in decision-making is that incomes should be sufficiently high. However, the level of awareness of policy makers on the long-term environmental effects of projects will also influence whether the threshold point (when environmental degradation reverses) is achieved early or late. Guided by these ideas, this chapter will evaluate whether the countries of interest have achieved such threshold levels. Energy efficiency is one of the independent variables tested in the EKC equation to determine whether carbon emissions are affected negatively by improvements in energy efficiency. It is hypothesized that energy efficiency is inversely proportional to carbon emissions –other factors being held constant. Furthermore, a decomposition approach is also employed to determine the impact of energy efficiency on the manufacturing sector of each Asian country. It is expected that carbon emissions will decline as manufacturing energy intensity falls.

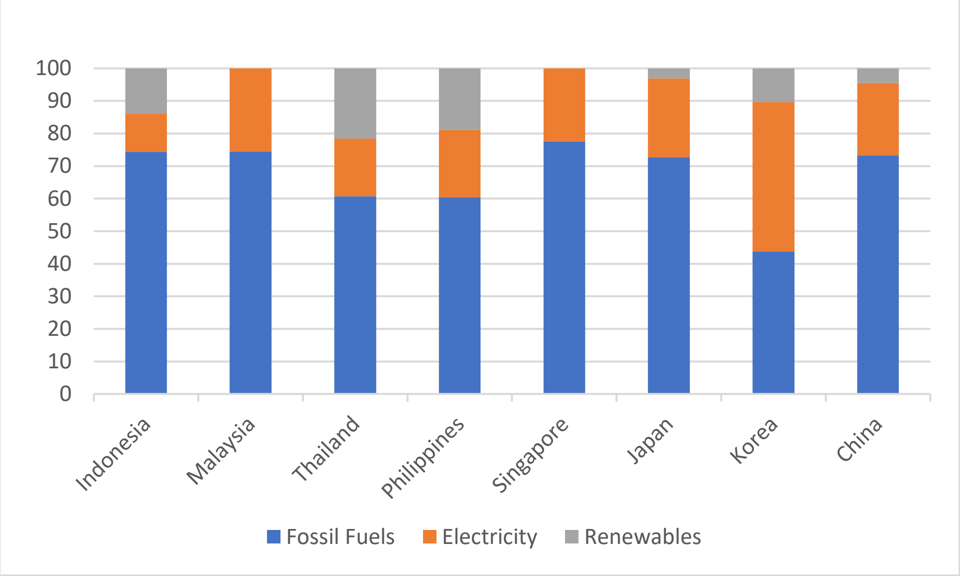
The manufacturing sector in Asia has been rising over the past two decades (Figure 4.1). This is mainly due to the shift in manufacturing output to more technologically advanced product and scale intensive sub-sectors (ADB, 2007). For the eight countries the average value added in manufacturing as % GDP in 2015 reached 24%. China is the highest with 29.4% in 2015 and Singapore is the lowest with 17.7%. Excluding China, the machinery and textile sectors comprised 36.23% and 3.94%, respectively of total manufacturing in the selected Asian in 2011 (year with latest data available for all countries).



Source: World Development Indicators, World Bank (2018)

Figure 4.1 Manufacturing Sector as % of GDP

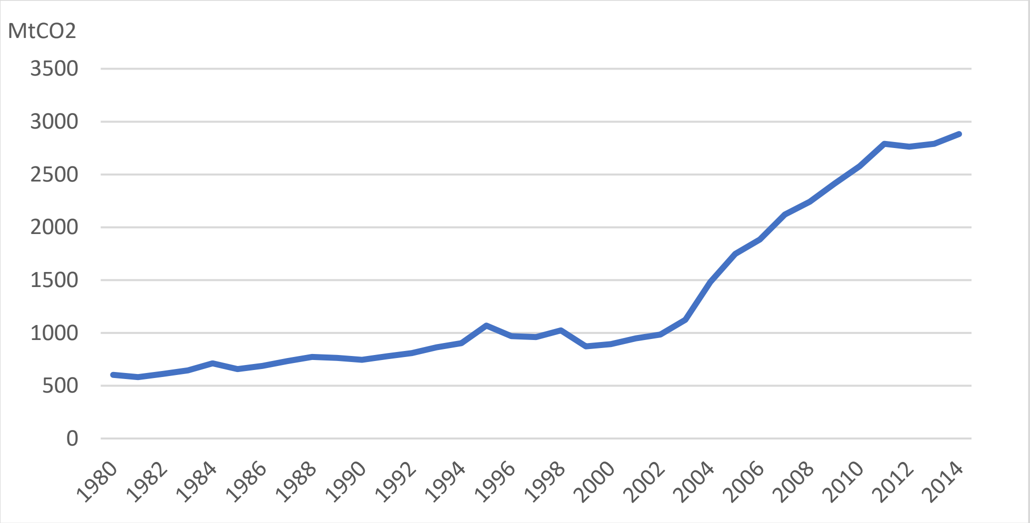
The manufacturing sector in Asian countries is still highly dependent on fossil fuels. On average, 67% of energy consumed by the sector in 2015 were fossil fuels, while the electricity and renewables accounted for 24 and 9%, respectively. On a percentage basis Singapore has the highest consumption of fossil fuels at 77.5% (Figure 4.2). However, on absolute terms China leads with 910,199.51 ktoe followed by Japan with 78,768.40 ktoe. The country with the lowest consumption of fossil fuels on a percentage basis is Korea at 43% but Singapore still consumes the lowest at 5,585.82 ktoe.



Source: OECD (2018)

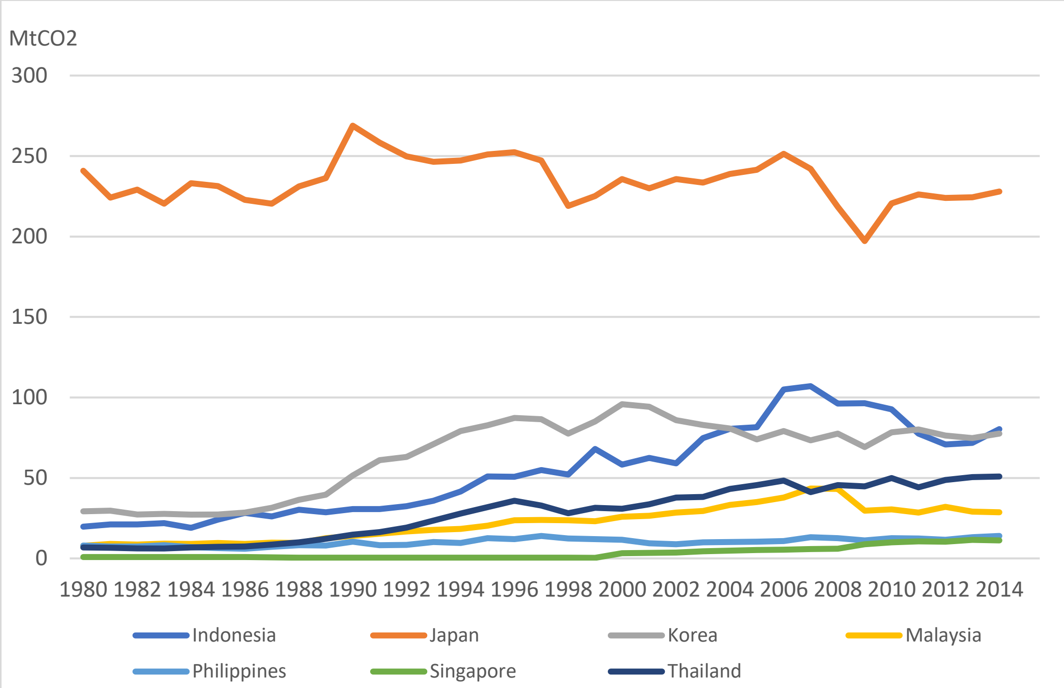
Figure 4.2 Sources of Energy of the Manufacturing Sector, 2015

China is the country with the highest carbon emissions (Figure 4.3). Total carbon emissions reached 2881.95 MtCO2 in 2014 from 745.2 MtCO2 in 1980. It started climbing steeply in 2002. In Figure 4.4 all other countries' carbon emissions are rising except for Japan which has remained the same on average. Singapore has the lowest carbon emissions.



Source: OECD (2018)

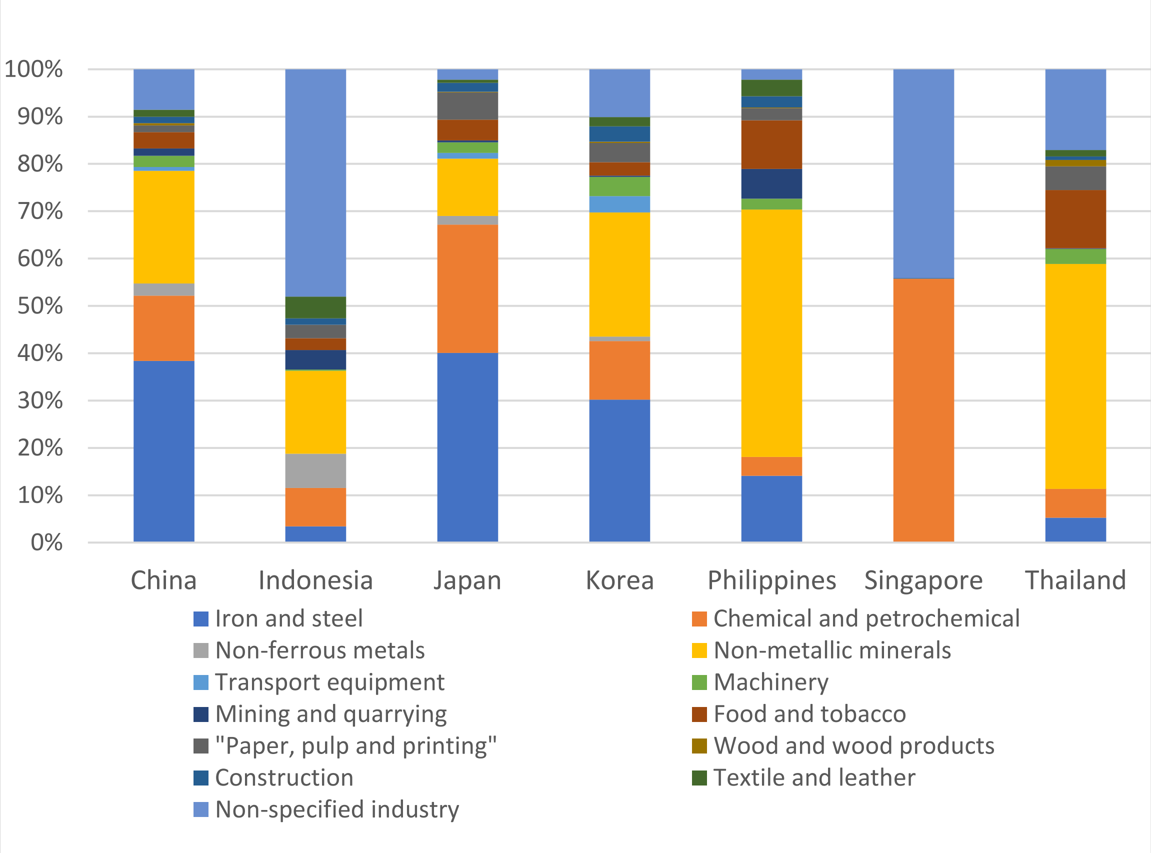
Figure 4.3 CO2 Emissions Trend of the Manufacturing Sector, China



Source: OECD (2018)

Figure 4.4 CO_2 Emissions Trend of the Manufacturing Sector, Asia (except China)

The 2014 CO_2 emissions in China is highest for the iron and steel industry which reached 38% of the total (Figure 4.5). This is followed by non-metallic minerals at 24% and chemical and petrochemical at 14%. For Japan, 40% of the total manufacturing emissions is produced by the iron and steel industry as well. The chemical and petrochemical industry comes second attributed with 27% of total manufacturing emissions. Korea's top carbon polluters are the iron and steel industry and non-metallic minerals industry registering 30% and 26% of the total manufacturing emissions, respectively. Singapore's carbon emissions are concentrated on the chemical and petrochemical sector comprising 56% of total carbon dioxide emissions in the manufacturing industry. On the other hand, almost half of Thailand's manufacturing carbon emissions are generated in the non-metallic minerals sector. The Philippines' highest emitter is also the non-metallic minerals industry at 52% of total while 48% of carbon emissions in Indonesia comes from non-specified industry.



Source: OECD (2020)

Figure 4.5 CO2 Emissions by Industry and Country, 2014

Energy efficiency can be a tool to mitigate carbon emissions in the manufacturing sector and consequently, the effects of climate change. This section looks into its effectiveness to achieve this goal. The chapter is organised as follows: the second section presents a discussion about the manufacturing sector based on the existing literature; the third section will expound on the conceptual framework of the model adopted to investigate the EKC; the fourth section will explain the econometric methodology implemented and the fifth section will elaborate on the data used; the sixth section will present the results and the last section will discuss the policy implications.

4.2 Review of Literature

4.2.1 Environmental Kuznets Curve (EKC)

The seminal study on the EKC was Grossman and Krueger (1995), who regressed air and water indicators collected from different cities in the world as a quadratic or cubic function of GDP per capita among other explanatory variables. The study, however, did not include carbon dioxide, which is one of the gases that cause the greenhouse effect. Using their regression results, the authors produced figures which show an inverted U shape relationship between the pollutants and GDP per capita. In general, the turning point was achieved even before a country's income reached $8,000. The results in this paper confirm previous works on the EKC (Holtz-Eakin & Selden, 1995; Selden & Song, 1994; Shafik & Bandyopadhyay, 1992).

Empirical studies using carbon dioxide (CO2) as the dependent variable provide mixed results, as is shown in Table 4.1. Several studies have gained a reputation in the literature by providing evidence for the EKC hypothesis (Agras, 1999; Cole, Rayner, & Bates, 1997; Galeotti & Lanza, 1999; Heil & Selden, 2001). On the other hand, there is also research which finds an N-shape cubic curve such that the increase in income levels coincides with a decrease in CO2 emissions up to a point, after which pollution levels go up along with rising incomes (Martínez-Zarzoso & Bengochea-Morancho, 2004; Sengupta, 1996).

Recent literature continues to produce contradicting results. Pao and Tsai (2011) investigates the relationships between emissions, energy consumption and output in Brazil covering the years 1980-2007. The cointegration test and error correction model in this study reveal an inverse U-shaped relationship between emission and real output. However, the emissions are monotonically rising for the entire time because the value of the turning point is higher than the maximum value of output in the data sample.

Saboori, Sulaiman, and Mohd (2012) investigates the presence of the EKC in Malaysia using real per capita carbon dioxide emissions and per capita real GDP data from 1980 to 2009. An AutoRegressive Distributed Lag methodology is employed to test for cointegration between the variables. Then, a Vector Error Correction Model is applied to determine the causality relationship. The empirical results confirms the EKC hypothesis in Malaysia. That is, an inverted-U shape relationship between CO2 emissions and GDP exists in both the short-run and the long-run. A Granger causality test also shows that in the long-run there is a uni-directional causality run from economic growth to CO2 emissions, whereas in the short-run there is no causality.

Song, Zhang, and Wang (2013) studies the relationship between per capita GDP and per capita pollution indices in China. Their EKC model adopts logarithmic quadratic or cubic function of per capita GDP for provincial data from 1985 to 2005. The econometric tools include panel unit root, panel cointegration and dynamic ordinary least squares. The results demonstrate inverted U-shaped relationships between per capita GDP and waste gas and solid wastes emissions.

Table 4.1 Selected Studies on the EKC for CO_2

Study	Data	Methodology	Conclusion
Grossman and Krueger (1995)	1977, 1982, 1988 (42 Countries)	Generalised Least Squares (GLS)	Inverted U Shape
He and Richard (2010)	1948-2004 (Canada)	Hamilton Model	Positive correlation bet. CO_2 and GDP
Müller-Fürstenberger and Wagner (2007)	1986-1998 (107 Countries)	Computable General Equilibrium (CGE) Model	
Fodha and Zaghdoud (2010)	1961-2004 (Tunisia)	Johansen Cointegration Vector Error Correction Model (VECM)	Inverted U Shape
Pao and Tsai (2011)	1980-2007 (Brazil)	Johansen Cointegration VECM	Inverted U Shape
Study	Data	Methodology	Conclusion
Nasir and Ur Rehman (2011)	1972-2008 (Pakistan)	Johansen Cointegration VECM	Inverted U Shape
Atici (2012)	1970-2006 (ASEAN-10)	Random Effects & Fixed Effects Panel Regression	Inverted S Shape
Saboori, Sulaiman, and Mohd (2012)	1980-2009 (Malaysia)	Auto Regressive Distributed Lag (ADL) VECM	Inverted U Shape
Esteve and Tamarit (2012)	1857-2007 (Spain)	Threshold Cointegration Test	Inverted U Shape
Liao and Cao (2013)	1971-2009 (132 Countries)	Feasible Generalised Least Square (FGLS)	first-rise-then-flat
Baek and Kim (2013)	1971-2007 (Korea)	ADL VECM	Inverted U Shape

Other studies however, have failed to produce the expected EKC result. Martínez-Zarzoso and Bengochea-Morancho (2004) tests the EKC hypothesis on the CO_2 emissions for 22 OECD countries and a sample from 1975 to 1998. They apply the pooled mean group estimator developed by Pesaran, Shin, and Smith (1998) on an EKC cubic function. The results confirm the existence of an N-shaped EKC suggesting that the delinking between CO_2 emissions and income is only temporary.

He and Richard (2010) tests the EKC hypothesis on Canada using parametric and non parametric econometric techniques. Results from both models find no evidence of the EKC on data covering a period of 57 years. According to the authors, the delinking of GDP and carbon dioxide emissions which occurred during the oil shock of the 1970s was explained by the development of less polluting technologies in response to higher oil prices. Thus, the turning point of carbon dioxide emissions as postulated in the EKC hypothesis was not observed in the case of Canada.

Atici (2012) finds an inverted S-shape relationship between CO2 emissions and GDP in a panel data of ASEAN countries from 1970-2006. As a country starts to develop, emission levels are still very low but once a threshold level of income is reached, emissions start to climb up. Eventually, higher levels of income prompt per capita emissions to go down. For some of the ASEAN countries which are still at the initial level of their development, emissions levels are predicted to increase further.

The threshold point at which income growth decouples from environmental degradation varies in the literature as well. Jayanthakumaran, Verma, and Liu (2012) estimates the turning point in a panel of 36 nations comprising OECD and non-OECD countries by including the effect of the fuel mix on carbon emissions. The model specifies fuel type as a percentage of total energy consumption. The turning point is found to be at $29,700. However, when only non-OECD nations are regressed, the relationship between income and emission is positive and there is no turning point. Liao and Cao (2013) examine 132 countries from 1971 to 2009 and found that per capita carbon dioxide emission first rises from a low income level and then flattens after reaching $22,000 dollars (2005 constant price) of per capita income. The flattening of the emission level is believed to be caused by trend saturation. For ASEAN countries, Atici (2012) finds that at an income of $14,106 emission levels begin to decline. In contrast, Martínez- Zarzoso and Bengochea-Morancho (2004) find that the N-shape curve of OECD countries has turning points at $4,914 and $18,364.

Aside from determining the effect of income on carbon emissions, several studies have incorporated other variables in the EKC model. Sari and Soytas (2009) employs the Toda and Yamamoto time series procedure to examine the link between carbon emissions, income, energy and total employment in several OPEC countries. The results show that energy use has no long-run effect on carbon emissions in Saudi Arabia. On the other hand, energy use and labor Granger cause emissions in Nigeria. Algeria and Venezuela do not exhibit any significant long-run relationship between the variables.

Nasir and Ur Rehman (2011) includes energy consumption and foreign trade in their model for per capita carbon emissions in Pakistan, which is based on a vector error correction method. The estimates for both variables are positive and significant in the long-run. The results suggest that energy consumption, in addition to stimulating economic activities, also raises carbon emissions through the domestic and transport sectors. Likewise, foreign trade may have contributed to pollution as a result of: (i) expansion of the economy through greater exports, (ii) a protected domestic industry that was not able to shift to environmentally friendly technologies, (iii) the importation of technologies which were not environmentally sustainable, and (iv) the composition of exports, which were mostly manufactured goods.

Liao and Cao (2013) finds that that population and urbanization are positive and statistically significant determinants of carbon emissions. According to this study, while developing countries increase their emissions as their trade balance or exports rise, developed countries experience a decline in emissions as they import more. Another finding suggests that greater economic freedom leads to lower per capita CO2 emissions. However, it is noted that for emission levels to come down, these factors combined must outweigh the income effect.

Atici (2012) adds export share, foreign direct investments, tariffs and regulation quality as explanatory variables for carbon emissions in the ASEAN. The trade flow is evaluated relative to Japan. The results show that total exports as a percentage of GDP tend to increase emissions, which is expected since economic growth in the region is export-led. However, pollution exports to Japan (iron and steel, chemicals, lime and cement) do not affect emission levels. The foreign direct investments has a significant but negative effect on carbon emissions. Interestingly, tariff levels show a deteriorating effect on pollution in this study, suggesting that heavy protection of industries may encourage the use of inefficient technologies that increase emissions. A possibly counterintuitive result from this study is that regulations have led to higher emission levels. This implies that policies do not hamper economic development.

Baek and Kim (2013) use the autoregressive distributed lag (ADL) approach to investigate the EKC in Korea. There are three advantages of using the ADL approach: (i) pre-testing for unit roots is not necessary as it can be employed regardless of whether the regressors are stationary or not; (ii) it estimates both the short and long-run coefficients; (iii) it is efficient with small sample sizes. This widely used approach can be found, for instance in the works of Saboori et al. (2012), Sari and Soytas (2009) and Jalil and Mahmud (2009).

On the other hand, Esteve and Tamarit (2012) applies the threshold cointegration vector error correction model in their investigation of the EKC relationship in Spain. Unlike the commonly applied linear, error correction modeling where the speed of adjustment toward the long-run equilibrium is constant for all time periods, this error correction model depends on a certain threshold. The speed of adjustment can vary in both regimes or the error correction may happen in one regime and be absent in the other. The paper divides the sample into two regimes with the threshold set at a per capita income of 8,266 euros. The first period covered is 1857 to 1985 while the second regime spans from 1986 to 2007. The results show that the EKC is evident in Spain and that the adjustment process toward the long run equilibrium is faster in the second regime.

Müller-Fürstenberger and Wagner (2007) use Computable General Equilibrium (CGE) analysis to determine the shape of the EKC in 107 OECD and Non-OECD countries. CGE models within the framework of an Integrated Assessment Model for climate change analysis can project future atmospheric carbon concentrations on business-as-usual assumptions. It can also point to the optimal carbon emission path by calculating avoided climate damages and abatement costs. Moreover, starting from the business-as-usual case, the cost and benefits of government policies can be measured. The findings show that there is an inverse U-shaped relationship between GDP and emissions. However, the inverted U-shape result of the model is not because of higher willingness to pay for a good environment as incomes rise but mainly due to exogenous technological progress. This underlines the risk of CGE analysis which is that it may be subject to misleading interpretations which do not adequately reflect the mechanisms of the model. The reason for this is the different assumptions of CGE models: the top down CGE is based on an aggregated macroeconomic production function while the bottom up CGE operates from a sectoral production structure which describes choices of adopted technologies.

4.2.2 Decomposition Analysis

The decomposition analysis approach used is the Logarithmic Mean Divisia Index (LMDI) which quantifies the impact of factors affecting the change of CO2 emissions. It is a robust method because the results are free of residuals and is based on robust theoretical foundations (Moubarak 2013).

The decomposition method has been used to monitor trends in country-wide energy efficiency. It has been adopted by national and international organizations such as the IEA, the European Commission and countries like Canada, Australia, the US and New Zealand.

The initial use of the decomposition analysis was for the study of electricity consumption in the 1980s. Hankinson and Rhys (1983) used this methodology to determine the impact on electricity consumption of changes in industrial output structure and industrial sector energy intensities Since then many methodological and empirical researches have been conducted.

Shen and Wang (2017) identify the emission factor in China's power sector and apply the index decomposition method to observe the variation trend of the emission. It was shown that east China reached the highest emissions factor while the central region reached the lowest. Three driving factors were included in the decomposition analysis: pollution control technology level, fuel mix and power structure. From 2005 to 2013 variation in the SO2 baseline emission factor was found to be mainly determined by the pollutant control technology improvement. Fuel mix in thermal power industry leads to lower emission reductions. The decline of the NOx emission can be attributed mainly to the technology level with substantial contributions from the fuel mix. However, the power structure has negligible effect on the Sox and NOx baseline emission factor.

Malla (2008) examines the increase in emissions from electricity generation of Australia, Canada, China, India, Japan, South Korea and the United States using the LMDI method of decomposition. The factors affecting CO2 emissions are electricity production, electricity generation structure and energy intensity of electricity generation affecting the evolution of CO2. The results show that during the 1990-2005 period the production factor is the dominant factor influencing the increase in CO2. The generation mix effect also supported the rise in C02. However, the energy intensity effect accounted for the decline in carbon emissions. During 2005-2030 the production structure is still the major factor in the rise of CO2. In contrast, the generation structure and the energy intensity effect are responsible for the decrease in emissions. This is due to the substitution of coal and oil by natural gas, the higher shares of nuclear and renewable energy sources in total electricity generation and the use of advance clean coal technologies.

Karmellos, Kopidou, and Diakoulaki (2015) decomposed the factors which affects CO2 emissions from electricity generation in all European Union countries (EU-28). The period studied is from 2000 -2012 subdivided into 2000-2007 and 2007-2012 periods to determine the effects of the economic crisis on carbon emissions. The methodology is the LMDI-I and considers five driving factors: level of activity, electricity intensity, electricity trade, efficiency of electricity generation and fuel mix. During 2000-2007, CO2 emissions from electricity generation in most EU countries have risen. The major reason for the increase was the activity effect. In contrast, electricity intensity is decreasing which suggests that the economy is decoupling from electricity use. Similarly the fuel mix effect drove CO2 emissions down while energy efficiency and the trade effect were negligible. During 2007 –2012, CO2 emissions in EU-28 registered a fall due mostly from the fuel mix effect with contributions from other factors. The economic crisis as evidenced by the negative activity effect pushed carbon emissions downward. The role of trade effect is greater in this second period suggesting growing trade in electricity between EU member states.

Mousavi et al. (2017) uses the LMDI approach to quantify the contributions of key drivers to Iran’s CO2 emissions from 2003 to 2014. In addition, the driving forces to changes in the carbon intensity of electricity generation (tCO2 per GWh) is also determined. The results show that consumption is the main driver of Iran's emissions. The effect of consumption outweighs technology-related effects such as the energy structure and emission factor effects. The rise in emissions due to the economic structure effect suggests that the country has favored energy intensive economic sectors over time. Meanwhile, the carbon intensity of electricity generation in Iran continues to increase yearly because of poor generation mixes in spite of improvements in generation efficiency. Iran relies on fuel oil and gas/diesel to address higher electricity demand.

Lou et al. (2017) uses a decomposition analysis to compare the urban transport sector between Tokyo and Shanghai. LMDI is used to study the driving factors of urban transport CO2 emissions. These are Population, trip generation rate, travel distance trip generation, mode shift, load factor or the number of people who use car/bus/transport equipment and emission efficiency. For Shanghai, the strongest positive effect on CO2 emissions is the mode shift. The trip generation rate and population also contributed to the rise in CO2 emissions. Fuel efficiency always affects CO2 emissions negatively. For Tokyo, the population effect has a constant positive effect on CO2 emissions. The trip rate, mode shift and distance effect have positive and negative effect depending on the sub periods. The load effect is always negative because of the rise in the occupancy rate. Fuel efficiency show positive and negative shifts due to energy technology improvements and consumers' car preferences.

In Asia most of the studies focused on China and Chinese industries while research on other Asian developing countries is wanting. This chapter contributes to bridge that gap by conducting a decomposition analysis of carbon dioxide emissions on these other countries.

4.2.3 Consideration on EKC Specification

In order to implement the U-shape EKC hypothesis, Grossman and Krueger (1995) decompose the sources of the EKC into different components:

$$E_{it} = \sum_{j=1}^{n} Y_{it}\, I_{ijt} S_{ijt} \qquad (4.2)$$

where Eit shows total emission of country *i* in year *t*; *Yt* represents GDP; *Iijt* is the emission intensity of sector *j* in country *i* and *Sijt* denotes the share of sector *j* in GDP.

Equation 4.2 can be further broken down into:

$$E_{it} = \sum_{j=1}^{n} Y_t\,(E_{jt}/Y_{jt})\,(Y_{jt}/Y_t) \qquad (4.3)$$

where *Ejt* is the emission of sector *j* and *Yjt* is the contribution of sector *j* to GDP.

Stern (2002) finds the above model insufficient and expands it to include technology and input mix effects. Hence, the four factors which affect emissions become:

- *The scale of production*, assumed to have a proportional increase with emissions such that a 1% rise in scale will lead to a 1% increase in emissions as well.
- *Changes in the output mix*– that lead to higher emissions as development moves from agriculture to industry. However, in the later part of development emissions may reduce as services increasingly become a significant portion of the economy.
- *Technological improvements*– that can produce less emissions per unit of output in two ways: (a) by using less heavily polluting inputs; (b) altering processes such that pollutant emissions are less per unit of output.
- *Changes in the input mix* that improve the environment as emission intensive inputs are replaced by less polluting inputs.

Stern (2002) proposes an emission function to show how these variables affect emissions:

$$S_{it} = f_i(y_{it}, x_{it}, A_{it}) \qquad (4.4)$$

Where *i* =country, *t*=time, *Sit* indicates total emissions; *yit* represents a vector of *j* outputs; *xit* is a vector of *K* inputs; and *Ait* shows the state of technology.

Under the assumption that *fi*(·) is homogenous of degree one in the inputs and homogenous of degree zero in the outputs, the function is decomposed into:

$$\frac{S_{it}}{P_{it}} = y_i \frac{Y_{it}}{P_{it}} \frac{A_t}{TFP_{it}} (y_{Jit}/Y_{it})^{(-\Sigma_{(j-1\ to\ J-1)} \propto_j)} \prod_{j=1}^{J-1} (y_{jit}/Y_{it})^{\propto_j} \sum_{k=1}^{K} \beta_k \frac{x_{kit}}{X_{it}} \varepsilon_{it} \qquad (4.5)$$

Where:

Y_{it}/P_{it} is the scale factor; Y = GDP, P= population

A_t is the technology-effects of emissions specific technical progress

I/TFP_{it} is overall technical progress; *TFP* refers to total factor productivity

$(y_{1it}|Y_{it}), \ldots\ldots, (y_{jit}|Y_{it})$ is output mix

$(x_{1it}|Y_{it}), \ldots\ldots, (x_{kit}|X_{it})$ is input mix

Following Stern (2002), Auci and Becchetti (2006) estimate an empirical EKC model on 173 countries which include scale, output and input mix and state of technology effects. The variables that can influence emissions are per capita GDP (scale effect); use of energy sources such as coal, oil, gas (input mix); and the value added of manufacturing, agriculture and service sectors (output mix). Their model is specified as:

$$CO_{2it} = b_0 + b_1 GDPPC_{it} + b_2 (GDPPC)^2_{it} + b_3 COAL_{it} + b_4 GAS_{it} + b_5 OIL_{it} + b_6 MANUF_{it} + b_7 AGR_{it} + b_8 SERV_{it} + \alpha_t + \mu_i + \varepsilon_{ijk.t} \quad (4.6)$$

Where coal, gas and oil are measured as the share in generating electricity and the value added of sectors are expressed as percentage of GDP.

A related study by Fujii and Managi (2013) examines the relationship between C02 emissions and economic growth at the industrial sector level. Each industry is identified by the fuel type in order to control for technological innovation. The overall objective is to observe the existence of the EKC through an industrial structure composition effect. This study is the first to look at the EKC on a sectoral level. The study tests the hypothesis that the EKC is absent for the industrial sector because industry uses fossil fuels as intermediate products which increase with greater production driving more carbon emissions. The panel regression model is specified as:

$$CO2PC_{ijkt} = b_1 GDPPC_{kt} + b_2 (GDPPC)^2_{kt} + Xb + \eta_k + \mu_t + \varepsilon_{ijkt} \quad (4.7)$$

Where *i*, *j*, *k* are energy type, industry and country, respectively; *GDPPC* is GDP per capita and t denotes time; and X represents the vector of control variables.

4.3 Methodology

4.3.1 Model and Hypothesis

Based on the above considerations, the model used proposed for the panel regression in this chapter is:

$$CO2PC_{it} = b_0 + b_1 GDPPC_{it} + b_2 (GDPPC)^2_{it} + b_3 (GDPPC)^3_{it} + b_4 INDSH_{it} + b_5 EEPC_{it} + b_6 TO_{it} + \varepsilon_{it} \quad (4.8)$$

where *i* denotes country, *t* is time, *CO2PC* is CO2 per capita, *GDPPC* is GDP per capita, *INDSH* is industry share, EEPC is energy efficiency per capita and *TO* is trade openness. *EEPC* is computed as *GDPPC/ Energy use per capita*; *TO* is computed as (*Exports + Imports*)/*GDP*. The model contemplates the possibility of N-shaped relationships by including a cubic term.

The hypothesis for this model follows. It is expected that GDPPC and INDSH are positively correlated to *CO2PC*. As GDP per capita rises economic activity rises which increases CO2 emissions. In the same way, higher *INDSH* contributes to greater emissions. In contrast, a higher *EEPC* means that it requires lesser energy to produce GDP and consequently lower carbon emissions. Therefore, *EEPC* is expected to be negatively correlated to *CO2PC*. For trade openness, the pollution haven hypothesis posits that companies tend to set up factories in developing countries with less stringent environmental regulations to save on costs. Except for Singapore, all Asian countries covered in the study are classified as developing countries. Therefore, it is expected that the trade openness indicator is positively correlated with carbon emissions.

4.3.2 Panel Regression

The econometric approach use to determine the existence of EKC in the Asian countries is panel data regression. Two basic estimation alternatives for this panel data regression include fixed effects and random effects. The fixed effect model assumes time invariant characteristics for each entity which creates the correlation between the independent variable and the error term. On the other hand, random effects model assumes that the individual effects are randomly distributed and that there is no correlation between the two. A Hausman test determines which is the appropriate model to use. The null hypothesis in that test is the constant term is not related to independent variables. If the null hypothesis is rejected the fixed effect model is selected. However, if the null hypothesis is not rejected the random effects model is chosen.

In the fixed effects specification, individual countries in the panel have a different intercept term (α_i) but the same slope parameters:

$$y_{it} = \alpha_i + x_{it}\beta + u_{it} \quad (4.9)$$

The individual specific effects after estimation is:

$$\hat{\alpha}_i = \bar{y}_i - \bar{x}_i\hat{\beta} \quad (4.10)$$

Hence, the individual-specific effects are the leftover variation in the dependent variable that cannot be explained by the regressors.

In the random effects model the individual specific effects α_i are included in the error term. Each individual has the same slope parameters and a composite error term. It assumes that individual-specific effects are distributed independently of the regressors.

$$\varepsilon_{it} = \alpha_i + e_{it} \quad (4.11)$$

$$y_{it} = x_{it}\beta + (\alpha_i + e_{it}) \quad (4.12)$$

The main advantage of using a panel data model is that it controls for omitted or unobserved variables. It can detect effects which can be easily missed in a pure cross section or time series specification. The time series of cross section observations provides more information, more variability, more degrees of freedom and more efficiency and less collinearity of the variables. A better analysis of the dynamics of change could be made through repeated study of cross section of observations in large samples.

According to Hsiao (2003), the main advantages of random effects (RE) model are (i) the number of parameters are constant even if the sample size increases; (ii) the efficient estimators use both within and between group variation and (iii) RE estimates the impact of time-invariant variables. However, the conditional density of $\alpha_i | \, x_i' = (x_{it,\ldots,}x_{iT}), f(\alpha_i|x_i)$, works under the common assumption that $f(\alpha_i|x_i)$ is identical to the marginal density of $f(\alpha_i)$.

The fixed effects model has the advantage that it enables the individual and/or time specific effects to be correlated with the explanatory variable x_{it}. The disadvantages of this specification are: (i) as the number of sample observations rise so does the number of unknown parameters; (ii) Time-invariant coefficients cannot be estimated by the FE estimator.

In the Hausman test, the null hypothesis is the random effect because the random effects estimator is more efficient. The null hypothesis also shows that the individual errors are not correlated with the regressors. If rejected, the fixed effects is chosen. The Hausman test statistic is:

$$H = (\hat{\beta}_{RE} - \hat{\beta}_{FE})' \left(V\left(\hat{\beta}_{RE}\right) - V\left(\hat{\beta}_{FE}\right)\right)(\hat{\beta}_{RE} - \hat{\beta}_{FE}) \quad (4.13)$$

4.3.3 Decomposition

The LMDI (logarithmic mean Divisia index) is a decomposition analysis approach which can be used to quantify the impact of factors affecting the change of CO2 emissions. It is a robust method because the results are free of residuals and has strong theoretical foundations (Moubarak 2013). According to Ang (2015), the choice of decomposition method depends on whether the indicator to be decomposed is a quantity indicator or an intensity indicator. For the former, an additive decomposition analysis is used and the results are given in a physical unit. On the other hand, a multiplicative decomposition analysis is employed when the ratio change (intensity) of an aggregate indicator is decomposed. This results in indexes. There is also the consideration on the type of data used in the application of the methodology. Both the additive and the multiplicative decomposition methodologies are applicable with time series data. Meanwhile, the additive approach is more useful for selected benchmark years only.

The additive decomposition procedure is followed in the CO2 analysis below based on Ang (2005) and Fuji and Managi (2012). CO2 emissions from fossil fuels (denoted by *i*) in the manufacturing industry (denoted by *j*) can be decomposed into:

$$CO2_j = \sum_{ij} \left(\frac{CO2_{ij}}{E_{ij}}\right)\left(\frac{E_{ij}}{E_j}\right)\left(\frac{E_j}{Value_j}\right)\left(\frac{Value_j}{GDP}\right) GDP \quad (4.14)$$

$$CO2_j = \sum_{ij} (CI)(ES)(EI)(GDPS)(SCALE) \quad (4.15)$$

Where *i* refers to the sum of fuel coal, oil, gas and electricity, *j* is industry, CO2 is CO2 emissions, *E* is the energy use, *Value* is the value added of Manufacturing Sector, and GDP is the gross domestic product.

Equation 4.15 shows that the Manufacturing sector CO2 can be decomposed into five factors: carbon intensity (*CI*), energy share (*ES*), energy intensity (*EI*), GDP share (*GDPS*), and the scale effect (*SCALE*). The carbon intensity measures the average emission factor of energy use. The energy share effect shows the use of fossil fuels to total energy consumption. The energy intensity effect reflects the ratio of energy consumption in manufacturing to the value added of manufacturing. This also measures energy efficiency in manufacturing. A high value of EI means that energy usage is high and energy efficiency is low. In contrast, lower values of EI show that energy use per unit in manufacturing is low and energy efficiency is high. The industry structure effect shows the share of manufacturing in GDP. Finally, the scale effect measures the effect of GDP on carbon emission of the manufacturing sector. The change of CO2 emissions between a base year *x* and a target year *t* can be further shown as follows:

$$\Delta CO2_j = CO2_j^t - CO2_j^x = \Delta CO2_{CI} + \Delta CO2_{ES} + \Delta CO2_{EI} + \Delta CO2_{GDPS} + \Delta CO2_{SCALE} \qquad (4.16)$$

When t = 2014 x=1980

$$\Delta CO2_J^{1980,2014} = CO2_J^{2014} - CO2_j^{1980}$$

$$= \varphi_j ln\left(\frac{CI_{ij}^{2014}}{CI_{ij}^{1980}}\right) + \varphi_j ln\left(\frac{ES_{ij}^{2014}}{ES_{ij}^{1980}}\right) + \varphi_j ln\left(\frac{EI_j^{2014}}{EI_j^{1980}}\right) + \varphi_j ln\left(\frac{GDPS_j^{2014}}{GDPS_j^{1980}}\right) + \varphi_j ln\left(\frac{SCALE^{2014}}{SCALE^{1980}}\right) \qquad (4.17)$$

$$\varphi_j = \frac{CO2_J^{2014} - CO2_j^{1980}}{lnCO2_J^{2014} - lnCO2_j^{1980}} \qquad (4.18)$$

Eq. 4.17 is an index decomposition analysis identity which shows that changes in the CO2 emissions of the manufacturing sector are contributed by the changes in carbon intensity (CI), energy share (ES), energy intensity (EI), GDP share (GDPS), and the scale effect (SCALE).

Eq. 4.18 is a logarithmic mean weight function developed in Ang, Zhang and Choi (1998) which gives perfect decomposition and solves problems when zero values are in the data set. This is an improvement from the arithmetic mean weight function used in previous decomposition methods namely the Laspeyres index method and the Divisia index method which yields large residual in the former method and create computational problems when zero values are present in the data set in the latter method.

The hypotheses for the decomposition model are as follows.

It is expected that CO_2 emissions in the manufacturing sector will have falling contributions from carbon intensity, energy share and energy intensity. Due to technological innovations and clean energy policies energy efficiency has improved considerably and the energy mix has favored clean fuel such as natural gas. In contrast, the industry structure effect and the scale effect are hypothesized to affect CO_2 emissions positively. In spite of the development of the services sector manufacturing remains a strong sector in these Asian countries. Moreover, as countries realized higher GDP growth demand for manufactured products is expected to rise as well leading to greater energy consumption. Hence, CO_2 emissions will increase accordingly. It is important to note however, that many changes in energy efficiency and carbon dioxide emissions are not related to policies.

4.4 Data Sources

The data on Annual GDP (constant 2010 US$), industry and manufacturing value added, Machinery and transport equipment (% of value added in manufacturing), Machinery and transport equipment (% of value added in manufacturing), Textiles and clothing (% of value added in manufacturing) are taken from the World Bank's World Development Indicators. Carbon emissions data sector and aggregate as well as energy consumption sectoral and aggregate are obtained from the OECD database. The period covered in the dataset is 1980 to 2014. 2014 is the latest year wherein all countries have complete data for all indicators. All data are converted to logs.

4.5 Results

4.5.1 Panel Analysis

The econometric approach used to determine the existence of EKC in the Asian countries is panel data regression. Fixed effects and random effects were considered. In order to determine the appropriate specification between these two, the Hausman test was executed. The null hypothesis is that a constant term is not related to independent variables or the random effects model. If the null hypothesis is rejected the fixed effect model is selected. The Hausman test result shows that the fixed effects model should be chosen. Furthermore, the result for Peasaran test for cross sectional dependence of the error terms cannot reject the null hypothesis of cross sectional independence.

Under the panel fixed effects model the relationship between the carbon emissions and GDP is an inverted N (Table 4.2). Initially, carbon emissions decline and then starts rising as the countries grow; then eventually falls as environmental measures are set up. Energy Efficiency has the right sign – negatively correlated with CO2. A 1% increase in energy efficiency will decrease carbon emissions by 0.7%. The trade openness indicator has a positive sign and is significant. A 1% increase in trade openness will increase carbon emissions by 0.28%. This result confirms the pollution haven hypothesis. In contrast, the correlation of the share of industry to CO2 emissions show the opposite of the expected sign. A 1% increase in the share of industry to GDP lowers carbon emissions by 0.26%. While this result is unexpected it confirms the result for energy efficiency. The higher share of industry in GDP contributes to lower carbon emissions by harnessing energy efficiency.

Table 4.2 Estimated Results for CO2 per capita

Variables	Coef.	Std. Err.	t	P>t
$GDPPC$	-11.57	1.71	-6.77	0
$(GDPPC)^2$	1.64	0.2	8.28	0
$(GDPPC)^3$	-0.07	0.01	-9.34	0
INDSH	-0.26	0.12	-2.23	0.03
EEPC	-0.7	0.08	-8.93	0
TO	0.28	0.05	6.3	0
Constant	25.76	4.85	5.31	0
R-sq	0.7			

Note: No. of groups: 8; Obs per group: 32; variables are in logs

There are two turning points. First, when GDPPC reaches US$319.9 (constant 2010 US$), CO2 emissions begins to rise, and when GDPPC reached US$15,593.1 (constant 2010 US$) CO2 starts to fall. The result conforms to the EKC theory that higher incomes drive greater demand for lower pollution. It is important to note however, that the EKC turning points are conditional on holding the other variables in the model. They are unlike the standard EKC case which does not include control variables. The variables that are being controlled for are key channels through which the EKC could operate, so one needs to be careful when interpreting the results for the log GDP per capita terms.

4.5.2 Decomposition Analysis

For each country the analysis was implemented in four subperiods, namely, 1980–1989, 1990–1999, 2000-2006, and 2007-2014. The variables which influence carbon dioxide emissions are *CI, ES, EL, GDPS* and *GDP*. For the machinery and textile sectors the effect of energy intensity on carbon dioxide emissions for the 1980-2015 period is also evaluated.

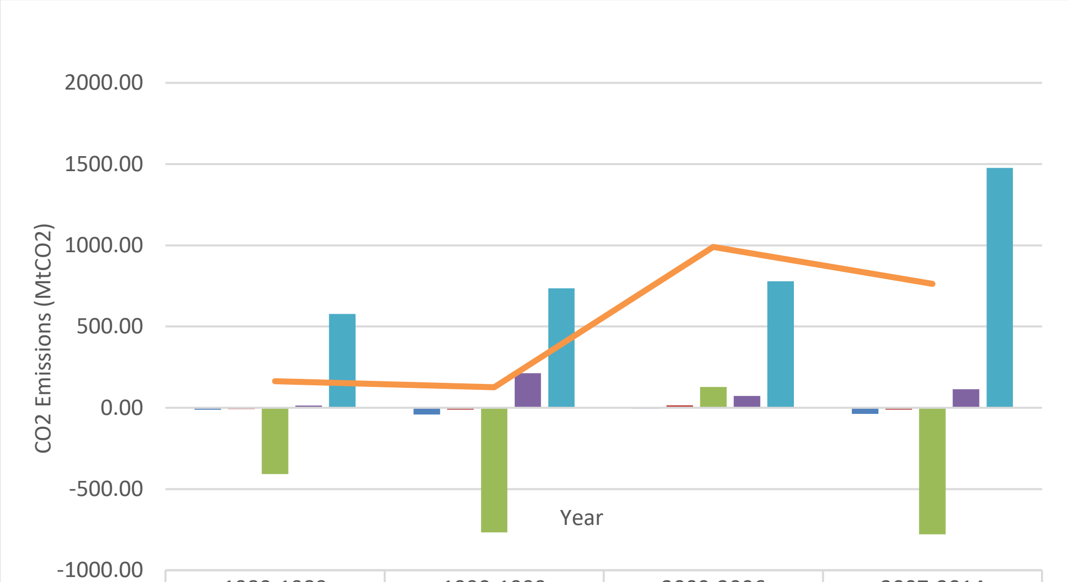
4.5.2.1 China

During 1980-1989 CO2 emissions rose by 163.45 from 601.03 MtCO2 in 1980 to 764.48 MtCO2 in 1989 (Figure 4.6). GDPS and Scale are responsible for the increase in CO2 emissions by 14.5 MtCO2 and 577.31 MtCO2, respectively. However, CO2 emissions would have been higher without the negative contributions of CI, ES and EI. EI accounts for most of the fall in CO2 of 408.18 MtCO2. CI and ES lowered emissions by 12.35 MtCO2 and 7.83 MtCO2, respectively. In the period 1990-1999 CO2 emissions increase by 126.23 MtCO2 from 745.2 MtCO2 in 1990 to 871.43 MtCO2 in 1999. The positive contribution of GDPS has increased substantially from period 1 (1980-1989) at 14.5 MtCO2 to period 2 (1990-1999) at 212.7 MtCO2 . Scale is mainly responsible for the increase in CO2 contributing 734.5 MtCO2. CI and ES reduced CO2 emissions by 42.34 MtCO2 and 11.29 MtCO2, respectively. However, the highest negative contribution is by EI with 767.31 MtCO2.

CO2 emissions increase by 989.94 MtCO2 from 893.04 MtCO2 in 2000 to 1882.98 MtCO2 in 2006, the largest rise in emission among the four periods studied. Except for CI, all indicators contributed positively to CO2 emissions. Compared to other periods CI has the lowest fall in 2000-2006 at -5.6 MtCO2. Highest contributors to the rise of CO2 emissions are EI and SCALE with 128.15 MtCO2 and 779.08 MtCO2, respectively. ES which previously registered falling emissions has turned positive this period increasing to 16.2 MtCO2. The contribution of GDPS has fallen from the previous period and stood at 72.13 MtCO2

During 2007-2014, CO2 emissions increase 762.12 MtCO2 from 2119.83 MtCO2 in 2007 to 2881.95 in 2014. This is attributed to higher GDPS and Scale while reductions in CO2 emissions are due to falling CI, ES and EI. GDPS and Scale lifted CO2 emissions by 114.99 MtCO2 and 1476.31 72.13 MtCO2, respectively. Compared to the previous periods CI and EI has pulled down emissions considerably at -37.4 MtCO2 and -779.6 MtCO2, respectively. ES also reduced emissions by 12.21 MtCO2.

In general, the greatest contributor to CO2 emissions is Scale. GDPS has also consistently supported emissions while carbon intensity has always contributed negatively to emissions. The highest contributor to falling emissions from 1980 to 2014 is the energy intensity effect. This suggests that energy efficiency measures are effective in China's industry sector.



	1980-1989	1990-1999	2000-2006	2007-2014
CI	-12.35	-42.34	-5.58	-37.35
ES	-7.83	-11.29	16.16	-12.21
EI	-408.18	-767.31	128.15	-779.56
GDPS	14.50	212.68	72.13	114.93
ScaleE	577.31	734.49	779.08	1476.31
CO2	163.45	126.23	989.94	762.12

Figure 4.6 Decomposition Analysis of CO2 Emissions, China

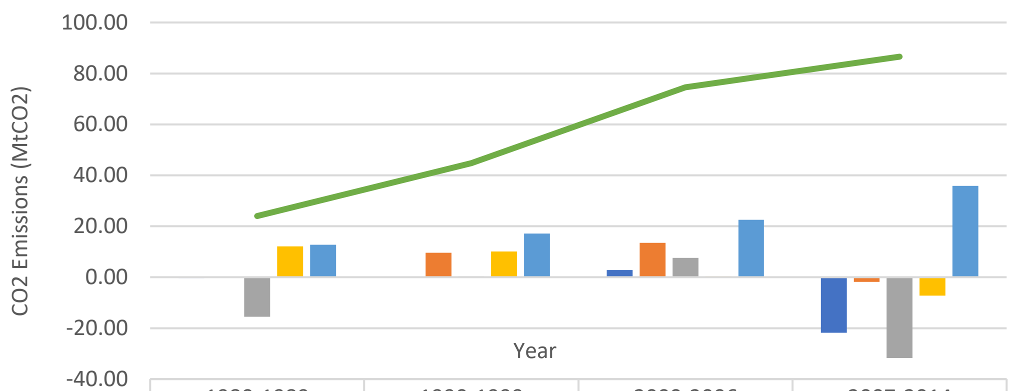
4.5.2.2 Indonesia

CO2 emissions increase by 8.95 MtCO2 from 19.73 MtCO2 in 1980 to 28.68 MtCO2 in 1989 (Figure 4.7). GDPS and Scale are responsible for the increase in CO2. Changes in CI, ES and EI have resulted to lower carbon emissions. The greatest contributor to changes in carbon emissions is the energy intensity effect which pulled down emissions by 15.5 MtCO2. During 1990-1999, carbon emissions rose 37.3 MtCO2 from 30.63 MtCO2 in 1990 to 68 MtCO2 in 1999. All indicators contributed to the rise in CO2. The highest contributors are ES, GDPS and SCALE recording 9.63 MtCO2, 10.09 MtCO2 and 17.22 MtCO2, respectively

In the period 2000-2007 carbon emissions added 46.63 MtCO2 and all indicators increased in CO2. The greatest source of emissions are the Scale effect and energy share which contributed 22.6 and 13.4, respectively.

The last period saw CO2 emissions fall by 26.72 MtCO2 from 107.02 MtCO2 in 2007 to 80.3 MtCO2 in 2014. Except for Scale all indicators reduced CO2. The largest decline was recorded for CI and EI with 21.8 MtCO2 and 31.7 MtCO2, respectively. In contrast, SCALE added 35.86 MtCO2 to total manufacturing emissions within 7 years.

Energy subsidies in Indonesia are detrimental to investments in energy efficiency measures, renewable energy and electricity infrastructure. It encourages wasteful energy consumption which adds to air pollution. Furthermore, it makes it difficult for Indonesia to lower the share of oil in the energy mix which has been the goal of the government in favor of gas, renewables, coal and nuclear energy.



	1980-1989	1990-1999	2000-2006	2007-2014
CI	-0.37	0.17	2.80	-21.79
ES	0.00	9.63	13.43	-1.78
EI	-15.51	0.31	7.57	-31.74
GDPS	12.10	10.09	0.25	-7.27
ScaleE	12.73	17.11	22.58	35.86
CO2	24.02	44.77	74.51	86.59

Figure 4.7 Decomposition Analysis of CO2 Emissions, Indonesia

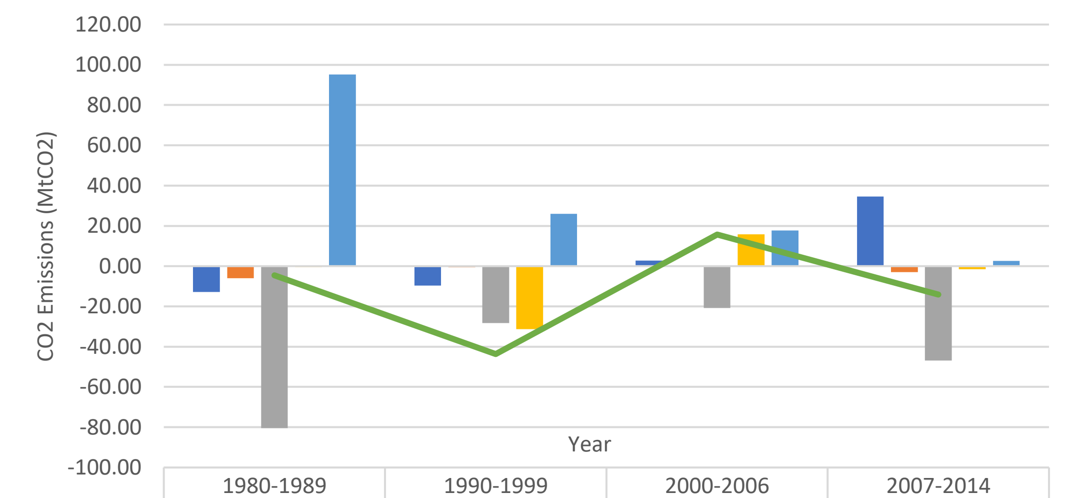
4.5.2.3 Japan

CO2 emissions decrease by -4.61 MtCO2 from 240.9 MtCO2 in 1980 to 236.29 MtCO2 in 1989 (Figure 4.8). CO2 emissions are reduced by CI, ES, EI and GDPS by 12.82 MtCO2, 6.07 MtCO2, 80.47 MtCO2 and 0.41 MtCO2, respectively. However, the scale effect put upward pressure on emissions by 95.16 MtCO2. During 1990-1999, CO2 emissions decreased further by 43.68 MtCO2 attributed also to CI, ES, EI and GDPS. EI and GDPS reduced carbon emissions substantially by 28.2 MtCO2 and 31.2 MtCO2, respectively. CI and ES also lowered emissions by 9.71 MtCO2 and 0.53 MtCO2. The scale effect continues to increase carbon emissions by 26.01 MtCO2. A reversal occurred in the period 2000-2006 in which carbon emissions increase by 15.7 MtCO2 spurred by all indicators except EI. CI, ES, GDPS and Scale raised CO2 emissions by 2.76 MtCO2, 0.27 MtCO2, 15.79 MtCO2 and 17.72

MtCO2. In contrast, EI lowered emissions by 20.8 MtCO2. The last period (2007-2014) saw CO2 emissions decrease by14.08 MtCO2 from 242.07 MtCO2 in 2007 to 227.99 in 2014. The main factor contributing to this is EI followed by ES and GDPS. EI lowered emissions by 46.83 MtCO2 while ES and GDPS reduced it by 3.01 MtCO2 and 1.51 MtCO2, respectively. Contrary to previous periods CI heavily contributed to raising CO2 emissions by 34.63 MtCO2 while the scale effect increased CO2 but at a much lower rate of 2.64 MtCO2.

Inspite of energy intensity effect pulling down carbon emissions, the carbon intensity effect in period 2007-2014 registered the highest positive contribution of 34.6 MtCO2. This is the result of 2011 Fukushima Daiichi nuclear disaster caused by Tohoku earthquake. This eventually led to the shutdown of all nuclear reactors and the increased use of gas and coal as substitute.

EI has constantly pulled down carbon emissions which attest to the success of energy efficiency initiatives in Japan. These energy efficiency measures started early in 1979 underpinned by the Act on the Rational Use of Energy. In 1998, the Top Runner Program was launched as part of amendments in the law and to implement the Kyoto Protocol. The program placed the most energy efficient products as the benchmark for energy efficiency performance targets of machinery and equipment, including vehicles. In April 2003, owners of large office buildings are required to submit reports to government energy efficiency measures implemented during the construction or renovation of their buildings.



	1980-1989	1990-1999	2000-2006	2007-2014
CI	-12.82	-9.71	2.76	34.63
ES	-6.07	-0.53	0.27	-3.01
EI	-80.47	-28.20	-20.85	-46.83
GDPS	-0.41	-31.25	15.79	-1.51
ScaleE	95.16	26.01	17.72	2.64
CO2	-4.61	-43.68	15.69	-14.08

Figure 4.8 Decomposition Analysis of CO2 Emissions, Japan

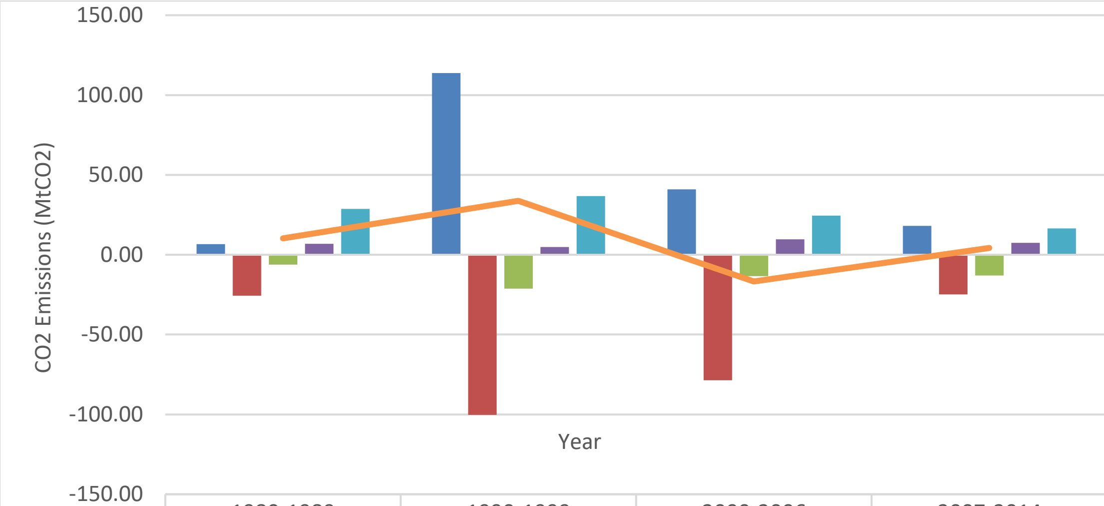
4.5.2.4 Korea

In Figure 4.9, CO2 rose by 10.31 MtCO2 from 29.3 MtCO2 in 1980 to 39.61 MtCO2 in 1989. CI, GDPS and Scale increase CO2 while ES and EI lower CO2 emissions. CI, GDPS and Scale raised carbon emissions by 6.56 MtCO2, 6.82 MtCO2 and 28.69 MtCO2, respectively. Meanwhile ES and EI substantially lowered carbon emissions by 25.6 MtCO2 and 6.14 MtCO2. During 1990-1999 CO2 emissions rose further by 33.75 MtCO2 reaching 85.17 MtCO2 in 1999. The CI effect mostly drove emissions upward with 113.74 MtCO2, surpassing the downward pull of ES. Both ES and EI contributed negatively to carbon emissions by 100.27 MtCO2 and 21.2 MtCO2, respectively. GDPS and Scale also increased CO2 by 4.82 MtCO2 and 36.67 MtCO2, respectively. In the period 2000-2006 carbon emissions fell by 16.74 MtCO2 due to falling ES and EI, ES registering a substantial decline of -78.64 MtCO2 and EI by 13.38 MtCO2. In contrast, CI leads the increase in carbon emissions by 41.01 MtCO2 followed by GDPS (9.73 MtCO2) and the Scale effect (24.55 MtCO2). Carbon emissions increased in 2007-2014 spurred by CI, GDPS and Scale effect which recorded increases by 18.16 MtCO2, 7.40 MtCO2 and 16.46 MtCO2 . On the other hand, ES and EI pulled down emissions by 24.74 MtCO2 and 13.1 MtCO2, respectively.

For Korea, decreasing energy share of fossil fuels to total energy consumption in industry has consistently lowered CO2. The reason is that the share of oil has fallen significantly and is replaced by electricity and by gas. In electricity CO2 free generation is mainly due to nuclear power. It should be noted however, carbon Intensity remains a significant factor in CO2 emissions. This because electricity use is powered mostly by coal and gas which has been rising in absolute terms. Moreover, Korea is also reliant on energy intensive industries.

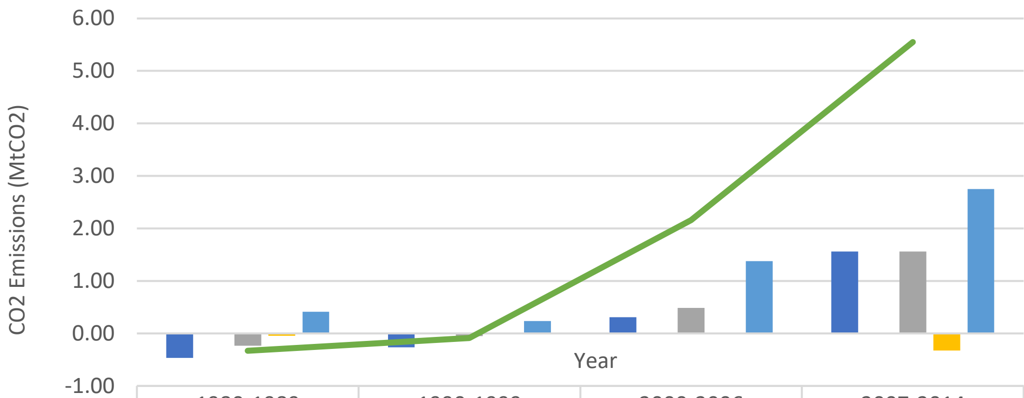
4.5.2.5 Singapore

Carbon emissions fell by 0.33 MtCO2 during 1980 to 1989 (Figure 4.10). Except for the scale effect, CI, EI and GDPS decreased carbon emissions by 0.47 MtCO2, 0.24 MtCO2 and 0.04 MtCO2, respectively. In 1990-1999, emissions fell by 0.09 due to CI, EI and GDPS which lowered emissions by 0.27 MtCO2, 0.05 MtCO2 and 0.01 MtCO2, respectively. However, the scale effect placed upward pressure on emissions raising it by 0.24 MtCO2. The period 2000-2006 saw a rise in carbon emissions of 2.16 MtCO2 from 3.27 MtCO2 to 5.43 MtCO2. Except for a small dip in GDPS all factors contributed positively to the rise in carbon emissions. GDPS lowered CO2 by 0.01 MtCO2 while CI, EI and Scale decreased CO2 by 0.31 MtCO2, 0.49 MtCO2 and 1.38 MtCO2, respectively. Carbon emissions climb further in 2007-2014 by 5.55 MtCO2 reaching 11.28 MtCO2. The negative push from GDPS (0.33 MtCO2) were outweighed by the increase in CI, EI and the scale effect of 1.56 MtCO2, 1.56 MtCO2 and 2.75 MtCO2, respectively. The uptick in the contribution of energy efficiency in carbon emissions in the last period shows that the various EE initiatives by the government have not been fully maximized. Businesses failed to execute and invest in EE measures due to low level of awareness and limited financing schemes. (APEC 2014).



	1980-1989	1990-1999	2000-2006	2007-2014
CI	6.56	113.74	41.01	18.16
ES	-25.61	-100.27	-78.64	-24.74
EI	-6.14	-21.20	-13.38	-13.10
GDPS	6.82	4.82	9.73	7.40
ScaleE	28.69	36.67	24.55	16.46
CO2	10.31	33.75	-16.74	4.17

Figure 4.9 Decomposition Analysis of CO2 Emissions, Korea



	1980-1989	1990-1999	2000-2006	2007-2014
CI	-0.47	-0.27	0.31	1.56
ES	0.00	0.00	0.00	0.00
EI	-0.24	-0.05	0.49	1.56
GDPS	-0.04	-0.01	-0.01	-0.33
ScaleE	0.42	0.24	1.38	2.75
CO2	-0.33	-0.09	2.16	5.55

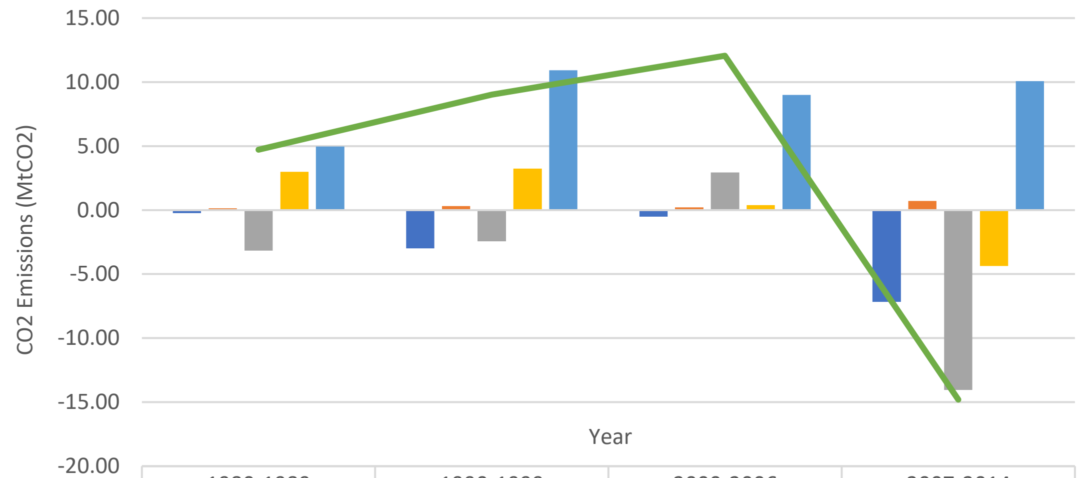
Figure 4.10 Decomposition Analysis of CO2 Emissions, Singapore

4.5.2.6 Malaysia

During 1980 to 1990, carbon emissions rose 4.72 MtCO2 from 7.86 MtCO2 in 1980 to 12.58 MtCO2 in 1989 (Figure 4.11). This can be attributed to the *ES*, *GDPS* and *Scale* effect which raised carbon emissions by 0.15 MtCO2, 3 MtCO2, 4.96 MtCO2, respectively.. *CI* and *EI* pulled down carbon emissions by 0.23 MtCO2 and 3.16 MtCO2. From 1990 to 1999 emissions expanded by 9.03 MtCO2 due to the same factors. Scale, GDPS and ES contributed positively with 10.92 MtCO2, 3.23 MtCO2 and 0.31 MtCO2, respectively. EI and CI decreased emissions again by 2.45 MtCO2 and 2.99 MtCO2. The period from 2000-2006 shows that except for the *CI* effect all other factors contributed to the rise of carbon emissions by 12.06 MtCO2. EI's effect on CO2 turned positive at 2.95 MtCO2. ES, GDPS and Scale increased carbon emissions by 0.23 MtCO2, 0.38 MtCO2 and 9 MtCO2. Only CI decreased CO2 by 0.5 MtCO2. In the last period (2007-2014) carbon emissions fell by 14.8 MtCO2 driven by *CI*, *EI* and *GDPS*. EI also has the highest negative contribution to CO2 compared to previous periods. *EI* in this period has fallen substantially by 14.04 MtCO2. Likewise, CI and GDPS lowered carbon emissions by 7.17 MtCO2 and 4.37 MtCO2, respectively. In contrast, *ES* and the *Scale* effect pushed emissions upwards by 0.71 MtCO2 and 10.07 MtCO2

The sudden fall of carbon emission in the last period is primarily due to energy intensity effect of energy efficiency improvements. The Malaysian government has initiated several reforms to promote the efficient utilization of energy. The National Green Technology Policy aims to attain energy independence and efficient energy use while minimizing environmental impacts. The Malaysia Green Labelling Program ensures the certification of eco-friendly locally manufactured products and energy-efficient home appliances. Under the Tenth Malaysian Plan 2011–2015, fuel subsidies were gradually rationalized.

It is important to note that the energy share effect has consistently been positive in raising carbon emissions even with fuel substitution. Fuel substitution initiatives since 1980 in the power sector has decreased oil consumption in favor of gas and coal. In 2001 the use of renewable energy was promoted as it was declared the fifth fuel after oil, gas, coal and hydro.



	1980-1989	1990-1999	2000-2006	2007-2014
CI	-0.23	-2.99	-0.50	-7.17
ES	0.15	0.31	0.23	0.71
EI	-3.16	-2.45	2.95	-14.04
GDPS	3.00	3.23	0.38	-4.37
ScaleE	4.96	10.92	9.00	10.07
CO2	4.72	9.03	12.06	-14.80

Figure 4.11 Decomposition Analysis of CO2 Emissions, Malaysia

4.5.2.7 Philippines

Carbon emissions fell by -0.15 MtCO2 in 1980 to 1989 due to negative contributions from CI, ES and GDPS (Figure 4.12). CI fell by 0.49 MtCO2 while ES and GDPS declined by 0.20 MtCO2 and 0.60 MtCO2, respectively. However, the Scale effect pushed up carbon emissions by 1.10 MtCO2. During 1990-1999 emissions increase by 1.66 MtCO2 as ES turned positive (0.3 MtCO2) and the Scale effect rose even more (2.68 MtCO2). In contrast, EI turned negative from its positive contribution in the previous period lowering carbon emissions by

0.51 MtCO2. 2000-2006 shows a decline in carbon emissions of 0.77 MtCO2 which is attributed to all factors except the scale effect. CI, ES, and GDPS reduced carbon emissions by 0.41, 0.55 and 0.47 MtCO2, respectively. The highest negative contribution is attributed to EI at 2.39 MtCO2. However, the reduction in carbon emissions was tempered by the positive contribution of scale effect of 3.05. In the final period (2007-2014) carbon emissions again rose by 0.81 MtCO2 due mainly to scale effect (4.77 MtCO2) and *GDPS* (0.28 MtCO2). Meanwhile, CI, ES and EI all declined by 0.38, 0.58 and 3.27 MtCO2, respectively.

Energy efficiency measures were set up in the 1990s in response to the power crisis in 1993. An information campaign was launched to promote efficient use of electricity and aims to reduce at least 10% of power demand in the household, commercial and industrial sectors. This include holding seminars on energy efficiency improvements in equipment operation and technologies for the industrial sector. A yearly award is also given to companies and energy managers who effectively implemented energy efficiency and conservation programs.

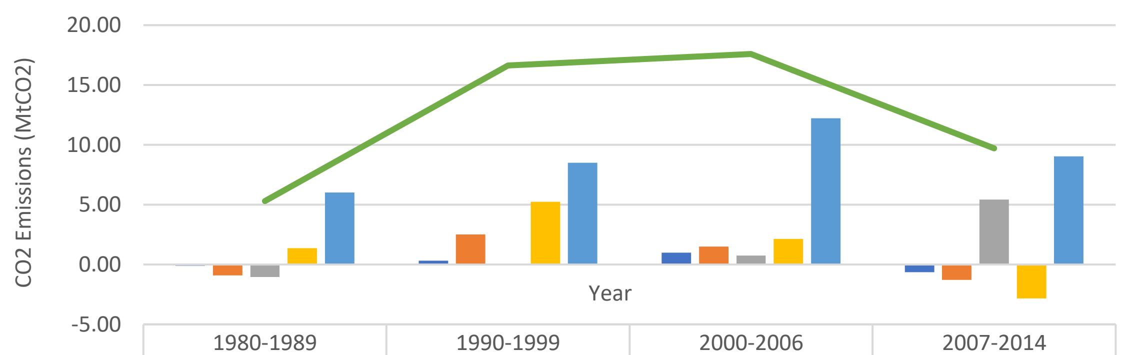
	1980-1989	1990-1999	2000-2006	2007-2014
CI	-0.49	-0.39	-0.41	-0.38
ES	-0.20	0.30	-0.55	-0.58
EI	0.04	-0.51	-2.39	-3.27
GDPS	-0.60	-0.43	-0.47	0.28
ScaleE	1.10	2.68	3.05	4.77
CO2	-0.15	1.66	-0.77	0.81

Figure 4.12 Decomposition Analysis of CO2 Emissions, Philippines

4.5.2.8 Thailand

Carbon emissions rose by 5.3 MtCO2 during 1980-1989 driven by the Scale effect and GDPS (Figure 4.13). CI, ES and EI recorded negative contributions. CI reduced carbon emissions by 0.11 while ES and EI also reduced emissions by 0.91 and 1.05, respectively. In contrast, GDPS added 1.35 MtCO2 to CO2 while Scale also contributed 6.0 MtCO2. In the period 1990-1999 carbon emissions further increase by 16.64 MtCO2 as all factors have positive and higher emissions. The highest contributors are Scale, GDPS and ES with 8.51 MtCO2, 5.25 MtCO2 and 2.51 MtCO2, respectively. From negative contributions in the previous period EI lifted CO2 by 0.05 MtCO2. For 2000-2006, emissions also climb by 17.59 MtCO2 as all indicators continue to contribute to emissions. CI raised CO2 emissions by 1 MtCO2, ES by 1.49 MtCO2, GDPS by 2.14 MtCO2 and Scale by 12.21 MtCO2. EI still increased emissions by 0.76 MtCO2. In the last period most of the 9.7 MtCO2 carbon emissions increase were due to EI and Scale effect which recorded 5.4 MtCO2 and 9 MtCO2 carbon emissions, respectively. In contrast, CI, ES and GDPS pulled down emissions by 0.65 MtCO2 1.29 MtCO2 and 2.83 MtCO2, respectively.

These results show that Thailand's efforts at energy efficiency has not been adequate. In 1992 Thailand approved the Energy Conservation and Promotion Act (ENCON Act) which established regulations on energy efficiency standards and promotes financing of energy efficiency projects. The government's latest effort is the Energy Efficiency Action Plan 2011–2030 (EEAP) which aims to increase the use of alternative energy sources (solar, wind, biomass, and mini hydropower) and garner energy efficiency savings of 25% by 2030.



	1980-1989	1990-1999	2000-2006	2007-2014
CI	-0.11	0.32	1.00	-0.65
ES	-0.91	2.51	1.49	-1.29
EI	-1.05	0.05	0.76	5.43
GDPS	1.35	5.25	2.14	-2.83
ScaleE	6.02	8.51	12.21	9.03
CO2	5.30	16.64	17.59	9.70

Figure 4.13 Decomposition Analysis of CO2 Emissions, Thailand

4.5.2.9 Sectoral Energy Intensity

4.5.2.9.1 Machinery

In terms of contribution to carbon emissions energy intensity in most countries reduced emissions (Table 4.3). As with the analysis above negative contributions indicate a decline in carbon emissions while positive contributions means an increase in carbon emissions. China has the highest negative contribution at -181.7 MtCO2. In contrast, Indonesia's contribution is the lowest at -0.1 MtCO2. This achievement is similar to Korea, Thailand and Philippines which recorded -0.6 MtCO2, -0.4 MtCO2 and -0.2 MtCO2, respectively. Japan on the other hand significantly improved its energy intensity and lowered carbon emissions by 4.1 MtCO2. The results show that the countries' energy efficiency reforms were effective in lowering carbon dioxide emissions.

4.5.2.9.2 Textile

In Table 4.3 China also posted the highest negative contributions to carbon dioxide emissions at -59.1 MtCO2. Other countries which lowered their carbon emissions through improvements in energy intensity are Korea, Indonesia and Thailand recording -1.5 MtCO2, -2.0 MtCO2 and -0.4 MtCO2, respectively. On the other hand, Japan and the Philippines increased their carbon emissions through energy intensity of 2.8 MtCO2 and 0.2 MtCO2, respectively.

Table 4.3 Sectoral Contribution of Energy Intensity to CO2 Emissions, 2014 (in MtCO2)

	Machinery	Textile
China	-181.66	-59.08
Indonesia	-0.13	-2.01
Japan	-4.07	2.76
Korea	-0.62	-1.49
Thailand	-0.41	-0.42
Philippines	-0.16	0.23

Note: computed from Logarithmic Mean Divisia Index (LMDI) using share of Machinery and Textiles in GDP.

4.6 CONCLUSION

Energy efficiency initiatives have been effective in bringing down carbon emissions in Asia. The EKC panel regressions shows that a 1% improvement in energy efficiency lowers carbon emissions by 0.7%. The decomposition analysis of carbon emissions for each country confirms the negative contribution of energy intensity/efficiency to carbon emissions. However, the results of the GDP factor shows that as Asia grows carbon emissions are to rise due to a higher share of fossil fuels in total energy consumed. Hence, there are still much to be done to improve energy efficiency.

The results also show that Singapore and Thailand's energy intensity raised carbon emissions in the manufacturing sector for the last subperiod (2007-2014). This indicates that the energy efficiency measures that had been set up were not effective. On the sectoral contribution of EI to CO2, Japan and Philippines need to improve industrial energy efficiency in textiles while Indonesia and the Philippines also need to work on its energy intensity in the machinery sector.

There are two turning points derived from the panel regression. At a per capita GDP of US$320 CO2 begins to fall. However, when per capita GDP reaches US$15,593.1 CO2 emissions decline. Only three countries have reached and surpassed the second turning point: Japan, Korea and Singapore. Japan's per capita GDP was already beyond the turning point in 1980 at U$25,490. Korea reached the turning point in 2001 with a per capita GDP of US$15672 while Singapore was able to achieve it in 1984 at a per capita GDP of US$16,472. China and ASEAN are still a long way before reaching the second tipping point and are still on the path of rising emissions. The per capita of GDP of China in 2013 (the end of the panel series) stood at US$5722. GDP per capita of other ASEAN countries in 2013 are as follows: Indonesia (US$3,571), Philippines (US$2,422), Malaysia (US$10,063) , and Thailand (US$5,613).

Policy measures to facilitate energy efficiency are the development of energy management systems, faster deployment of smart-grid and development of technologies such as CCS and batteries for electricity. However, this requires increasing energy investments from both public and private sectors and may need to deregulate policies on private investments (APEC 2014).

According to the IEA (2018) efficiency gains are highest in less energy-intensive manufacturing sectors such as textiles. In order to harness this potential measures that needs to be adopted are deploying electric heat pumps and improving efficiency of motor-driven systems. In China, regulations to impose mandatory efficiency improvement targets on industry sectors have contributed greatly to lowering energy use worldwide. However, mandatory energy efficiency policies for global industrial energy use still covers just a fraction of the total especially in global electric motor energy use.

Chapter 5 : Dynamic Interaction of Output and Input Factors and Role of Energy Substitution

5.1 Introduction

Chapter 3 has contributed with some estimates that demonstrate how fuels could be substituted in Asian economies, to reduce CO2 emissions while keeping the level of output constant. Chapter 4 has analyzed the role of development through a controlled EKC estimation, and provided an idiosyncratic characterization of Asian economies to identify areas where energy efficiency measures could be applied. The third important aspect that is considered in this thesis relates to how changes to fuel consumption induced by policies that provide fuel efficiency or fuel substitution affect the level of output of Asian economies. In particular, dynamic causality analysis that applies to production factors including oil, gas and coal provide insightful information for policy design. A panel vector error-correction econometric model is used to analyze causality.

Empirical analysis of energy consumption − GDP causality is critical in the evaluation of climate change policies. In response to potential environmental threats, many countries have been adopting environmental and energy policies such as partial switching from fossil fuels to renewable sources or from coal to less carbon intensive fuels and lowering energy intensity (that is, using energy more efficiently and developing emission markets). When this substitution process is not enough, reduction of domestic energy consumption becomes necessary for meeting environmental targets. However, if reducing the amount of energy consumed restricts economic growth, then climate change policies and economic growth are incompatible goals (Soytas & Sari, 2006).

There are four possible economic links between energy consumption and economic growth (Chiou-Wei, Chen, & Zhu, 2008; Glasure & Lee, 1997; Lee & Chang, 2008; Masih & Masih, 1996; Narayan & Smyth, 2005; Ozturk, 2010; Soytas & Sari, 2003; Squalli, 2007) with different implications for policy. These are:

1) unidirectional causality from energy consumption to economic growth, or the "growth hypothesis". This asserts that an increase in energy consumption induces an increase in real GDP so that policies to reduce energy consumption will adversely affect growth;
2) unidirectional causality from real GDP to energy consumption, or the "conservation hypothesis". This argues that an increase in real GDP causes energy consumption to

rise, hence, energy conservation policies will not have a negative effect on economic growth;

3) an absence of causality between energy consumption and GDP, or the "neutrality hypothesis". This implies that energy conservation policies will also not reduce growth; and

4) bi-directional causality between energy consumption and economic growth, or the "feedback hypothesis". In this instance, both GDP and energy consumption affect each other.

To date, there has been no consensus in the literature on the direction of causality. Different types of causality have been found for different countries and regions. Even studies on the same countries produce different and conflicting results. The varied outcomes arise from different data sets, time frame, methodologies and country characteristics (Ozturk, 2010). In regards to the questions that concern this chapter, three sources of discrepancy are identified. First, studies have considered different time frames and countries in their samples. Second, some studies are based on demand-side theoretical foundations, others are based on supply-side considerations and others lack a theoretical framework. Third, issues may be found in the use of econometric techniques. The Granger causality test, which is used in most studies in this area, does not necessarily imply economic causality. For instance, the apparent causality between two variables could be caused by a third variable. To overcome this problem, it is important to include all the relevant variables in the analysis. The empirical investigation in this chapter includes recent data for a set of relevant countries and variables on the production side are identified to avoid the invalidity of Granger causality results.

For Asian countries, the energy consumption - GDP causality has also been studied extensively. However, the literature on Asian economies as a group has not explored the causality when the energy variable is disaggregated into coal, oil, gas and others (renewable energy and nuclear energy). This chapter intends to fill this gap, to investigate how these sources of energy affect output, employment and private investment in selected Asian countries.

This chapter uses panel vector error correction (VEC) econometric techniques. Main macroeconomic variables as well as aggregate energy and its decompositions are included. Unit root and cointegration tests are undertaken following the literature. In addition, tests on the model's residuals for serial correlation, heteroscedasticity and normality of the error term are conducted. Once the model has been identified, short- and long-term causality tests are introduced. The sample includes selected Asian countries from 1980 to 2016.

The chapter is divided as follows. Section 3.2 describes the empirical literature and section 3.3 elaborates on the theoretical background. Section 3.4 and 3.5 explain the methodology and data, respectively. Section 3.6 discusses the empirical results while the last section provides the conclusion and policy implications.

5.2 Review of Literature

A seminal paper by Kraft and Kraft (1978) pioneered the research on the relationship between energy use and gross national product (GNP). In this article, regressions between energy inputs and GNP were estimated including their lagged values. The estimations were conducted on US energy data from 1947 through 1974. The authors found evidence of causality flowing unidirectionally from GNP to energy consumption and no causality from energy consumption to GNP. The authors concluded that because the level of energy consumption cannot significantly affect the level of economic activity, energy conservation programs can be implemented without hampering economic growth.

One criticism of the early studies on energy causality is that their results are only valid if time series are stationary (Mehrara, 2007). Under non-stationarity, results may be subject to spurious regression effects. It is also of interest to know if the causality occurs in the short run or the long run. Second generation and third generation studies have subsequently addressed the non-stationary properties of the variables by introducing cointegration techniques (Mehrara, 2007). This literature produced results that were in conflict with Kraft and Kraft (1978), as shown in Table 5.1.

For the US, studies supporting the growth hypothesis include Stern (2000), Soytas and Sari (2006) and Bowden and Payne (2009). Research affirming the conservation theory includes Erol and Yu (1987), Abosedra and Baghestani (1991) and Murray and Nan (1992). In contrast, Lee (2006) and Asafu-Adjaye (2007) find bi-directional causality between energy consumption and growth. A spate of literature also favours the neutrality hypothesis, such as Akarca and Long (1980), Yu and Choi (1985), Yu and Hwang (1984), Yu and Jin (1992), Cheng (1995), Soytas and Sari (2003), Chiou-Wei et al. (2008), and Payne (2009).

For Asia, country studies find mixed results. Ang (2008) tests the relationship between output growth, carbon dioxide emissions and energy consumption in Malaysia from 1971-1999. An error correction model is identified for causality testing after finding a long-run cointegration relationship among the variables using Johansen's cointegration test. Three intervention dummy variables are included in the regression to correct for shocks arising from the oil price crises which occurred in 1973 and 1979 and the Asian financial crisis during 1997-

1998. The empirical results indicate causality running from output growth to energy consumption growth in the short- run. However, evidence of long-run bi-directional causality between these variables is found, implying that Malaysia was an energy dependent country in that period. The study also finds weak causality running from carbon dioxide emissions growth to economic growth in the long- run. These findings are similar to those of Yoo (2006) but run counter to Masih and Masih (1996).

For India, Ghosh (2010) uses the autoregressive distributed lag bound testing methodology with the Johansen–Juselius maximum likelihood procedure to investigate the long-run relationship between output, energy supply and carbon emissions. The multivariate framework also includes investment and employment for the period 1971-2006. While the study fails to identify a long- run equilibrium relationship among the variables, it shows unidirectional causality in the short- run running from GDP growth to energy use, and from energy use to carbon emissions. Thus, for India, higher economic growth would induce greater energy demand in end-use sectors such as industry, transport and commercial sectors. The penetration of natural gas and oil in these sectors of the Indian economy is limited, so there is still high reliance on coal which drives up carbon emissions. The results in Ghosh (2010) contradict the findings in Masih and Masih (1996); Fatai, Oxley, and Scrimgeour (2004); Paul and Battacharya (2004); and Asafu-Adjaye (2000).

For South Korea, Glasure (2002) finds bidirectional causality between real income and energy consumption. A rather complex vector error correction model is used to analyse how GDP and energy consumption are affected by real money, real government expenditure, oil price and oil price shocks. The study covers the period from 1961 to 1990. Evidence of a bidirectional relationship between energy consumption and real income is found through the statistical significance of changes in energy consumption when the dependent variable is real income as well as in the significance of the error correction term when the dependent variable is energy consumption. The author's conclusion is supported in Oh and Lee (2004) and Glasure and Lee (1997). However, Yu and Choi (1985) and Soytas and Sari (2003) arrive at different results.

Bloch, Rafiq, and Salim (2012) analyze the direction of causality between coal consumption and income in China using a supply-side approach and a demand-side approach. On the supply-side the variables employed are the usual indicators, including labor force, capital stock, technology and coal consumption. On the demand-side, two estimations are conducted. Firstly, the relationship between coal consumption, output and coal price is investigated. Secondly, the relationship between coal consumption, carbon emissions and output is analyzed. Under the supply-side framework, unidirectional causality flows from coal consumption to output in both the short- and long-run. On the other hand, unidirectional causality runs from income to coal consumption in both the short-run and long-run using the demand-side framework. Other studies supporting the same unidirectional causality from energy consumption to economic growth using a production or supply-side approach include Wang, Wang, Zhou, Zhu, and Lu (2011) and Shiu and Lam (2004).

For Australia, Shahiduzzaman and Alam (2012) analyze the direction of causality between energy consumption and GDP from 1961-2009. This study was the first to employ a production function for Australia to study the link between energy consumption and output. It also adjusts for energy quality by constructing a Divisia index of total energy use for the country as opposed to thermal content. To determine causality, a Vector Error Correction Model and the Toda and Yamamoto procedure are used. In both cases, the results show bidirectional causality between GDP and the Divisia aggregation of energy use. Other studies such as Fatai, Oxley, and Scrimgeour (2004), however, contradict these findings for Australia.

Research conducted on regional groupings exhibit conflicting results as well. Joyeux and Ripple (2011) studies the relations between income and energy on a set of 30 OECD and 26 non-OECD countries from 1971 to 2007. Three measures of energy consumption are used: total electricity consumption, residential electricity consumption and total energy consumption. The authors perform panel data analysis to determine the short-run and long-run causality between energy and GDP. The tests reveal that in general, unidirectional causality runs from income to residential energy and total energy for both OECD countries and non-OECD countries.

In another study at regional level, Niu, Ding, Li and Luo (2011) studies the causality between energy consumption, GDP growth and carbon emissions for eight Asia-Pacific countries between 1971 to 2005. The countries are divided into two groups, four developed countries (Australia, New Zealand, Japan and South Korea) and four developing countries (China, Indonesia, Thailand and India). A panel method is employed to test for unit root, cointegration and Granger causality. The tests reveal that bidirectional causality exists between GDP and energy consumption for developed countries but only unidirectional causality from GDP to energy consumption is evident for Asian developing countries.

Table 5.1 Selected Studies of GDP-Energy Consumption Causality Test

Study	Model	Period	Subject	Causal Relationship
Kraft and Kraft (1998)	Bivariate	1947-1974	USA	Income → Energy
Yu and Jin (1992)	Bivariate	1974-1989	USA	Energy ---- Income
Stern (2000)	Production	1948-1994	USA	Energy → Income
Soytas and Sari (2003)	Bivariate	1950-1992	USA	Energy --- Income
Asafu-Adjaye (2000)	Demand	1973-1995	India & Indonesia, Thailand & Philippines	Energy → Income Energy ↔ Income
Masih and Masih (1996)	Production	1955-1990	Malaysia, Singapore & Philippines India Indonesia	Energy ---- Income Energy → Income Income → Energy
Masih and Masih (1998)	Demand	1955-1991	Thailand	Energy → Income
Paul and Bhattacharya (2004)	Production	1950-1996	India	Energy ↔ Income
Glasure and Lee (1998)	Production	1961-1990	South Korea & Singapore	Energy ↔ Income
Soytas and Sari (2003)	Production/ Demand	1950-1992	South Korea	Income → Energy
Oh and Lee (2004)	Production	1981-2000	South Korea	Income → Energy
Shiu and Lam (2004)	Production	1971-2000	China	Energy → Income
Yuan, Kang, Zhao, and Hu (2008)	Production	1963-2005	China	Income → Energy
Joyeux and Ripple (2001)	Bivariate	1973-2007	OECD & Non-OECD	Income → Energy
Mahadevan and Asafu-Adjaye (2007)	Demand	1971-2002	20 energy importers and exporters	Energy ↔ Income
Lee and Chang (2007)	Production	1971-2002	18 developing countries	Income → Energy

Notes: → means variable x Granger causes variable y; ↔ means bidirectional causality; --- means no causality in any direction.

Lee and Chang (2008) applies panel tests on 16 Asian countries in a multivariate production model which includes capital stock and labor force from 1971-2002. In the long-run energy consumption granger causes GDP. They do not find support for causality running from GDP to energy consumption in either the short-run or long-run. When the panel is broken down into APEC and ASEAN groups, unidirectional causality from energy consumption to GDP is established but not the converse.Mahadevan and Asafu-Adjaye (2007) studies the energy consumption – GDP growth relationship for a panel of 20 net energy importers and exporters. Each group is composed of seven developing and three developed countries. The net energy exporters include Australia, Indonesia and Malaysia, while among the net pertinent energy importers Japan, India, Korea, Thailand and Singapore are included. A trivariate model consisting of GDP, energy consumption and prices is estimated using a panel-based VECM. The time series data runs from 1971 to 2002. Among the energy exporters, the causality between energy consumption and GDP is bidirectional in the short-run and unidirectional in the long-run from GDP to energy consumption. For the energy importing countries, there is also bidirectional causality between GDP and energy consumption in the short-run. However, the causality is reversed in the long-run from energy consumption to GDP only.

It can be observed from the discussion above that the sources of the disparity in the estimation results stem from several sources: different time periods, sample sizes and econometric methodology. The models adopted are either bivariate or multivariate. Moreover, the energy- output nexus has been investigated from either a demand/consumption approach or a supply/production approach.

In regards to the methodology, it is worth emphasizing that time series analysis of energy consumption-income causality takes two forms: bivariate and multivariate with three or more variables. In a bivariate equation energy consumption and income are tested. Bivariate tests are usually criticized for failing to consider other channels of causality causing omitted variable biasedness (Asafu- Adjaye, 2000; Glasure, 2002; Stern, 2000). For the multivariate approach with three or more variables, analysis on energy consumption-output causality is derived from two perspectives: the demand side and the production side. There are only a handful of researches utilizing the demand side (Asafu-Adjaye, 2000; Fatai, Oxley, & Scrimgeour, 2004; Masih & Masih, 1996; Oh & Lee, 2004) while most of the literature uses the production side approach. Models on the demand side generally use three variables, namely: energy consumption, GDP and energy price proxied by the consumer price index. Variables in production-side models generally consist of energy consumption, GDP, capital stock and labor. Regardless of the framework adopted, the results from the multivariate analysis are also varied and inconclusive. On the demand side for instance, Asafu-Adjaye (2000) finds bi-directional causality for Thailand while Masih and Masih (1998) show that causality flows from energy to income. With the production side approach, Soytas and Sari (2003) find that in Korea causality runs from income to energy while Oh and Lee (2004) find bi-directional causality. Moreover, a comparison of results from both frameworks does not yield any consensus. For India, Paul and Bhattacharya (2004) use the production-side model to show bi-directional causality while

Fatai et al. (2004), employing the demand-side approach, find the direction of causality flowing from energy consumption to income.

Another reason for the conflicting results is the arbitrary use of variables without adequate explanations on the theoretical foundations. In a study of 66 countries, Sharma (2010) adopts inflation and trade in addition to the usual variables (capital, labor and energy consumption). Mishra, Smyth, and Sharma (2009) include urbanization in a panel of Pacific Island countries. Ghosh (2010) uses investment as one of the regressors in a production function model for India. Thus, one of the contributions of this chapter is some elaboration on the theoretical basis for the variables that will be included in the model.

In contrast to the literature on energy consumption and GDP growth, the literature on causality between income and the disaggregated energy sources such as oil, gas and coal have not been adequately explored, particularly in Asia. Following the trend in the previous literature, studies analyzing the relationship between GDP and particular energy sources like coal, oil and natural gas also fail to achieve consensus.

Chu (2012) studies the causality between oil consumption and economic growth for 49 countries from 1970 to 2010. A bootstrap panel causality approach is used which checks for cross- sectional dependence and cross-country heterogeneity. The empirical results show that the growth hypothesis is supported for five countries, the conservation hypothesis for 13 countries, the feedback hypothesis for seven countries, and the neutrality hypothesis for 24 countries. For Asian countries, the growth hypothesis is found valid only in Japan. The conservation hypothesis is supported by China, Singapore, South Korea and Taiwan. Meanwhile, the neutrality hypothesis is evident for Hong Kong, India, Indonesia, Malaysia, the Philippines and Vietnam. Overall, the study suggests that oil consumption has a significant role in the economic growth of most countries. This is in part due to heavy industries in these countries which use oil for producing energy. In other studies, Yoo (2006) shows that the causal relationship between oil consumption and income growth in Korea from 1968 to 2002 is bidirectional while Yang (2000) finds unidirectional causality between real GDP and oil consumption in Taiwan.

Apergis and Payne (2010a) finds bi-directional causality between coal consumption and output growth for 15 emerging market economies including China, Indonesia, Malaysia, Philippines and Thailand. The panel FMOLS test shows that in the long-run, a 1% increase in coal consumption reduces real GDP by 0.251%. This may be due to the environmental costs of carbon dioxide emissions from burning coal which offsets economic benefits of using coal. Moreover, the panel error correction model suggests that there is a slow adjustment towards long-run equilibrium.

Apergis and Payne (2010b) study the relationship between natural gas consumption and income growth in 67 countries using a production model approach. Asian countries included in the panel are China, Japan, South Korea, Malaysia, Indonesia and Thailand. The long-run relationship is estimated with a fully modified Ordinary Least Squares (FMOLS) regression while the causal relationship is estimated with a panel vector error correction model. Both the short- and long-run relationships show bi-directional causality exists between natural gas consumption and income confirming the feedback hypothesis. In contrast, Yang (2000) shows that results of the Granger causality tests in Taiwan prove unidirectional causality from natural gas consumption to income. Fatai et al. (2004) observe no causality between natural gas consumption and income for Australia and New Zealand.

In a study of coal-consuming countries, Wolde-Rufael (2010) applies the Toda-Yamamoto process to determine the causal relationship between coal consumption and real GDP during 1965-2005. The results indicate that unidirectional causality runs from coal consumption to output in India and Japan while the reverse is true in China and South Korea. Meanwhile, South Africa and United States data suggests bi-directional causality exists between output and coal consumption.

5.3 Theoretical Framework

In Chapter 3 the neo-classical aggregate production function equation (5.1) is written as

$$Y_t = A_t K_t^{\psi} L_t^{\phi} E_t^{\rho} \tag{5.1}$$

Where E_t denotes aggregate energy at time t and ρ is the elasticity of output with respect to energy.

In this chapter, the model adopted expounds on the different types of energy used as such:

Y_t = *f*(employment, investment, oil, natural gas, and coal)

The logarithmic form of this production function is expressed as follows:

$$ln\, Y_t = lnA + \psi\, lnK_t + \phi\, lnL_t + \Omega_C\, lnC_t + \Omega_G\, lnG_t + \Omega_O\, lnO_t \tag{5.2}$$

Where Y_t is real GDP at time t; K_t denotes capital; L_t refers to labor; C_t is coal consumption; G_t is gas consumption; O_t denotes oil consumption.

It is expected that there will be a unidirectional causality from labor to GDP as more employment translates into more income and production. Likewise, unidirectional causality also exists from capital to GDP because higher investments increases the productivity of the economy. In terms of fossil fuels, coal is believed to have a bidirectional causality with GDP since coal is a cheap energy source and is commonly used. It is also hypothesized that there will be a bi-directional causality between oil and GDP. Since all the countries in the study import oil, the impact of oil on GDP will be the net effect of increased production and lower GDP revenues through imports. It is expected that there will be no causality between gas and GDP because gas consumption in these countries is still small.

While the same production function was estimated earlier in Chapter 3, there is a difference in the analysis between these two chapters. Chapter 3 estimates the parameters of the production function to explain how output was produced in particular year using the stocks of capital and labor and energy input that were available that year. There are no lags included. It is a static scenario. The output provides estimates of elasticities that are in line with the proposed production function and describe the production process. On the other hand, this chapter analyses dynamic interactions between all the variables in the production function. The empirical approach adopted provides information on the dynamic relationship between output and input variables in terms of (i) short- and long-term components; (ii) short- and long-term causality and the persistence of reaction to shocks as measured by the impulse-response analysis.

This chapter uses a vector error correction model to relate output, employment and investment to the various types of energy namely oil, gas, and coal. This will capture the direct and indirect ways that energy consumption influence output. In addition to the direct effect, energy consumption can affect output indirectly by influencing labor/employment and capital/investments. In this regard it is expected that coal and oil will also affect output through labor and investments. Coal is attractive for investments because it is cheap while oil is widely used in industry and transport. Gas will affect output through investments as countries increase their capacity.

5.4 Methodology

The empirical procedure used in this chapter to test causal links between energy consumption and GDP is as follows. First, panel unit roots are tested to determine stationarity properties of the data. Second, the panel cointegration test developed by Pedroni (1999) is implemented. Third, the long-run relationship is formulated through the FMOLS technique for heterogeneous cointegrated panels (Pedroni, 2001). Fourth, a panel error correction model is set-up to study the short-run and long-run causality between energy consumption and GDP. Along these steps, standard diagnostic tests are conducted to determine the appropriateness of the model and the validity of tests. Lastly, an impulse response function analysis is also applied to study some relationships of interest among the variables.

5.4.1 *Panel Unit Root Testing*

The paper utilizes several panel unit root tests: Im, Pesaran and Shin (2003) (IPS); Levin, Lin and Chu (2002) (LLC); Phillips and Perron (1988); and a modified Dickey and Fuller (1979) test.

The IPS test uses an autoregressive model for unit roots testing:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \sum_{j=1}^{p_i} \rho_{ij}\, \Delta y_{i,t-j} + \mu_{it} \qquad (5.3)$$

Where i = 1……N for countries; t= 1…..T for time. The errors are independent across the cross-section units but the individual time series are autocorrelated with different serial correlation and variance properties.

The null hypothesis tests if individual series contain a unit root across the sample while the alternative tests if at least one of the series is stationary:

H_0: $\beta_i = 0$ for all i, H_1: $\beta_i < 0$, $i = 1,2, \dots, N_1$, $\beta_i = 0$, $i = N_1 + 1, N_1 + 2, \dots\dots, N$.

In the alternative hypothesis, β_i is allowed to vary across groups. Some of the individual series also have unit roots under the alternative hypothesis. For consistency purposes, the fraction of the individual processes that are stationary under the alternative hypothesis is non-zero.

Levin et al. (2002) unit root test allows for deterministic variables such as intercepts and time trends:

$$y_{it} = \beta y_{i,t-1} + \alpha_{mi} d_{mt} + \mu_{it}, \quad i = 1, \dots, N; \; t = 1, \dots, T; m = 1,2,3, \qquad (5.4)$$

Where d_m denotes the vector of deterministic variables such that $d_{1t} = 0$ (empty set); $d_{2t} = \{1\}$ and $d_{3t} = \{1, t\}$.; α_m shows the vector of coefficients corresponding to a particular model *m*=1,2,3. The individual time series in the panel also show serial correlation. Monte Carlo simulations by these authors prove that the model is robust for relatively small samples. Moreover, the panel framework is more useful for cross country data analysis as it has more power compared to unit root test of individual time series in the group.

Use is also made of the Philips Peron/Fisher test which is non-parametric in the treatment of nuisance parameters and includes Autoregressive Integrated Moving Average models with heterogeneously and identically distributed innovations. The test is useful when there are moving average components in the time series. It also allows for cases where there is a drift and a linear trend. Note that it is also possible to have a non-zero drift and a deterministic linear time trend.

Maddala and Wu (1999) compare the merits of the different unit root tests. In terms of test power the IPS test is superior to the LLC test because the LLC test requires panel estimation method which is invalid if pooling is not needed. The main difference between the two is that the LLC test is based on homogeneity of the autogregressive parameter while the IPS test is based on the heterogeneity of the autoregressive parameter. Thus, the LLC tests are implemented on pooled regressions while the IPS test does not require any pooling of data as the tests are a combination of several independent tests.

There are other significant differences between the Fisher test and the IPS test. The Fisher test combines the significance levels of the different tests, and the IPS test focuses on combining the test statistics. Both tests aim to combine independent tests. The Fisher test is non-parametric while the IPS test is parametric. On the length of the time series, if the length varies for the different samples, the tables of the IPS cannot be used. The Fisher test, however, allows any lag length for each sample and does not restrict the sample sizes.

5.4.2 Panel Cointegration Test

The cointegration test assesses if for variables which are individually integrated of order one, there is a linear combination which is stationary. The cointegrating vector refers to the slope coefficients which makes them stationary. In panel cointegration tests the different members have heterogeneous short-run and fixed effects even as information is gathered on their long-run relationships. The null hypothesis is that the each member of the panel is not cointegrated in the variables studied and the alternative hypothesis is that there is a cointegrating vector for each member of the panel.

With multiple variables, Pedroni (1999) derives the regression residual from this cointegrating regression model:

$$y_{i,t} = \alpha_i + \delta_i t + \beta_{1i} x_{1i,t} + \beta_{2i,t} + \cdots + \beta_{mi} x_{mi,t} + e_{i,t} \qquad (5.5)$$

$$for\ t = 1, \ldots\ldots, T; i = 1, \ldots.N; m = 1, \ldots..M$$

Where *N* shows the number of individual members in the panel, *T* denotes the number of observations over time, and *M* specifies the number of variables in the regression. The slope coefficients $\beta_{1i}, \beta_{2i}, \dots \dots \dots \beta_{mi}$and the fixed effects parameter α_i can vary along the different members the panel. The term $\delta_i t$ is the deterministic time trend of each panel members.

Pedroni (1999) explores seven test statistics which are grouped in two groups. The first group consists of four panel cointegration statistics and is based on pooling along the within-dimension. There are three test statistics in the second group. They are referred as the group-mean panel cointegration statistics and are based on pooling along the between-dimension.

For the within-dimension statistics, the test for the null of no cointegration is the test of the null hypothesis: $H_0 : y_i = 1$ for all *i*. The alternative hypothesis is $H_1 : y_i = y < 1$ for all *i*. For the between-dimension statistics, the null of no cointegration is: $H_0 : y_i = 1$ and the alternative hypothesis $H_1 : y_i < 1$ for all *i* and does not assume the same value for $y_i$and y. This means that for statistics based on between-dimension there is an additional source of potential heterogeneity across the different members of the panel.

Pedroni (1999) uses two non-parametric and one parametric test statistics in both groups which considers autocorrelation: (i) A Phillips-Perron (1988) (PP) type rho-statistics; (ii) A Phillips- Perron (1988) (PP) type *t*-statistics; (iii) A Dickey-Fuller (1979) (ADF) type *t*-statistics. In addition, Pedroni (1999) also proposes a non-parametric panel variance ratio test statistic under the simple panel cointegration statistics, claiming that these statistics to have a comparative advantage in terms of small sample size and power properties.

5.4.3 Panel Causality Test

The panel cointegration test shows the existence of causality between two variables. However, it does not point to the direction of the causal relationship. According to Engel and Granger (1987) cointegrated variables show that the changes in the dependent variable are a function of the changes in the independent variables as well as an error correction term which refers to the relationship among the cointegrating variables. The one-period lagged error correction term (ECT) generated is added to the traditional vector autoregressive (VAR) model. Without the ECT using a VAR with cointegrated variables will lead to misspecification. For our data, the vector error-correction model is given by the following equations:

$$\Delta LY_{it} = \theta_{1j} + \lambda_{1i}ECT_{it-1} + \sum_k \theta_{11ik} \Delta LY_{it-k} + \sum_k \theta_{12ik}\Delta LK_{it-k} + \sum_k \theta_{13ik}\Delta LL_{it-k} + \sum_k \theta_{14ik}\Delta LOIL_{it-k} + \sum_k \theta_{15ik}\Delta LGAS_{it-k} + \sum_k \theta_{16ik}\Delta LCOAL_{it-k} + \mu_{1it} \quad (5.6)$$

$$\Delta LL_{it} = \theta_{2j} + \lambda_{2i}ECT_{it-1} + \sum_k \theta_{21ik} \Delta LY_{it-k} + \sum_k \theta_{22ik}\Delta LK_{it-k} + \sum_k \theta_{23ik}\Delta LL_{it-k} + \sum_k \theta_{24ik}\Delta LOIL_{it-k} + \sum_k \theta_{25ik}\Delta LGAS_{it-k} + \sum_k \theta_{26ik}\Delta LCOAL_{it-k} + \mu_{1it} \quad (5.7)$$

$$\Delta LK_{it} = \theta_{3j} + \lambda_{3i}ECT_{it-1} + \sum_k \theta_{31ik} \Delta LY_{it-k} + \sum_k \theta_{32ik}\Delta LK_{it-k} + \sum_k \theta_{33ik}\Delta LL_{it-k} + \sum_k \theta_{34ik}\Delta LOIL_{it-k} + \sum_k \theta_{35ik}\Delta LGAS_{it-k} + \sum_k \theta_{36ik}\Delta LCOAL_{it-k} + \mu_{1it} \quad (5.8)$$

$$\Delta LOIL_{it} = \theta_{4j} + \lambda_{4i}ECT_{it-1} + \sum_k \theta_{41ik} \Delta LY_{it-k} + \sum_k \theta_{42ik}\Delta LK_{it-k} + \sum_k \theta_{43ik}\Delta LL_{it-k} + \sum_k \theta_{44ik}\Delta LOIL_{it-k} + \sum_k \theta_{45ik}\Delta LGAS_{it-k} + \sum_k \theta_{46ik}\Delta LCOAL_{it-k} + \mu_{1it} \quad (5.9)$$

$$\Delta LGAS_{it} = \theta_{5j} + \lambda_{5i}ECT_{it-1} + \sum_k \theta_{51ik} \Delta LY_{it-k} + \sum_k \theta_{52ik}\Delta LK_{it-k} + \sum_k \theta_{53ik}\Delta LL_{it-k} + \sum_k \theta_{54ik}\Delta LOIL_{it-k} + \sum_k \theta_{55ik}\Delta LGAS_{it-k} + \sum_k \theta_{56ik}\Delta LCOAL_{it-k} + \mu_{1it} \quad (5.10)$$

$$\Delta LCOAL_{it} = \theta_{6j} + \lambda_{6i}ECT_{it-1} + \sum_k \theta_{61ik} \Delta LY_{it-k} + \sum_k \theta_{62ik}\Delta LK_{it-k} + \sum_k \theta_{63ik}\Delta LL_{it-k} + \sum_k \theta_{64ik}\Delta LOIL_{it-k} + \sum_k \theta_{65ik}\Delta LGAS_{it-k} + \sum_k \theta_{66ik}\Delta LCOAL_{it-k} + \mu_{1it} \quad (5.11)$$

LY, LK, LL, LOIL, LGAS, and *LOTHER* refer to the logs of GDP, capital, labor, oil, gas and other energy sources. *ECT* is the error-correction term derived from long-run cointegrating relationship while the μ_{it} are the serially uncorrelated random error terms with mean zero. Both the long-run and short run effects of the model are analyzed through the short-run and long-run Granger non-causality test. For short-run causality, the null of H0: θij=0 $H_0: \theta_{ij} = 0$ is tested for all lagged dynamic terms using the Wald test. To test the significance of the speed of adjustment which is the coefficient of the error correction term, the null of $H_0: \lambda_{1j} = \lambda_{2j} = \lambda_{3j} = \lambda_{4j} = 0$for all *i* is tested. This is a test of long-run non-causality. The short-run effect is temporary while the long- run effect is permanent.

5.4.4 Impulse Response Function

An important technique to analyze the relationship among the economic variables is the impulse response analysis (Enders, 1995). The impulse response function shows the time path of shocks on the variables defining the VAR system. It is usually plotted to visually illustrate the behavior of economic variables in response to a particular shock. More formally, Hamilton (1994) defines an impulse response function as a function mapping a primitive impulses $\varepsilon_{i,t}$ into conditional forecasts of $y_{j,t+k}$. The VECM-based impulse response functions analyze the response of variables to shocks equal to the standard deviation of μ_{it} above.

The ordering of the Cholesky decomposition is as follows: GDP, Coal, Gas, Capital, Labor and Oil. GDP is evaluated first because a shock on any variables will directly affect it. Fossil Fuel variables follow as energy is important in the functioning of Asian economies particularly coal. Capital is evaluated next as this will also affect the previous two variables. However, the ordering between economic and energy variables is not strict as they are endogenous to each other and can be interchanged.

5.5 Data Sources

The model is estimated using annual data from 1980 to 2016. The countries studied are China, Japan, Korea, Philippines, Singapore, Thailand, Malaysia and Indonesia. Data on energy consumption was sourced from BP Statistical Review of World Energy June 2013 and covers primary energy consumption, coal, oil and natural gas consumption in million tons of oil equivalent (Mtoe). Data on other energy consumption was derived by subtracting the sum of coal, oil and gas consumption from primary energy consumption. Employment data was mostly taken from the International Labor Organization database while the data for the last year was taken from Key Indicators of the Asian Development Bank. Macroeconomic data on GDP and capital was sourced from the World Development Indicators of the World Bank. GDP and gross fixed capital formation are measured in constant 2010 US$. All variables were transformed into log levels before processing.

5.6 Discussion and Empirical Results

5.6.1 Panel Unit Root Test

Table 5.2 presents the results of the four unit root tests: Im, Pesaran and Shin (2003) (IPS), Levin et al (2002) (LLC), Phillips and Peron (1988) and a modified Dickey and Fuller test (1979). The unit root tests have the null hypothesis of non-stationarity or the presence of the unit root against the alternative hypothesis of no unit root test or stationarity. The tests in log-levels include an intercept and trend while the test in first difference has the intercept only. The results show that at log-levels not all variables rejected the null hypothesis. In particular, LNY and LNO (oil) have unit roots. In contrast, unit root tests on first difference confirm that all variables are stationary at the 1% significance level and are thus, integrated of order one.

Table 5.2 Panel Unit Root Test Results

	Determinants	LLC		IPS		ADF_FISHER		PP_FISHER	
Levels									
LNY	Intercept and Trend	-0.203		1.498		11.68		3.392	
LNL	Intercept and Trend	-5.117	***	-14.996	***	381.441	***	80.065	***
LNK	Intercept and Trend	-1.861	**	-0.405		17.1135		6.912	
LNC	Intercept and Trend	-2.614	***	-4.248	***	67.9219	***	67.922	
LNG	Intercept and Trend	-6.298	***	-5.211	***	149.21	***	57.7489	***
LNO	Intercept and Trend	0.763		1.426		22.906		12.806	
First Difference									
LNY	Intercept	-9.187	***	-8.042	***	91.6202	***	88.411	***
LNL	Intercept	-15.548	***	-17.99	***	121.466	***	184.559	***
LNK	Intercept	-5.891	***	-6.196	***	72.851	***	63.486	***
LNC	Intercept	-10.837	***	-12.072	***	146.184	***	149.461	***
LNG	Intercept	-29.539	***	-19.729	***	94.397	***	134.17	***
LNO	Intercept	-8.8	***	-9.921	***	120.011	***	127.284	***

5.6.2 Panel Cointegration Test

In order to determine the long-run relationship between the variables, the seven cointegration statistics proposed in Pedroni (1999) are calculated. The results in Table 5.3 show that the null hypothesis of no cointegration is rejected at the 1% significance level in the Panel ADF-Statistic and Group ADF-Statistic.

Table 5.3 Panel Cointegration Tests

Alternative hypothesis: common AR coefs. (within-dimension)				
	Statistic	Prob	Weighted Statistic	Prob
Panel v-Statistic	-0.714		-1.588	
Panel rho-Statistic	2.236		1.949	
Panel PP-Statistic	2.445		-1.076	
Panel ADF-Statistic	-3.064	***	-3.385	***

Alternative hypothesis: individual AR coefs. (between-dimension)		
	Statistic	Prob
Group rho-Statistic	2.950	
Group PP-Statistic	-0.380	
Group ADF-Statistic	-3.521	***

Note: ***, ** and * indicate that the test statistic is significant at 1%, 5% and 10% level respectively.

5.6.3 Lags

The optimal lag lengths for the cointegration test are presented at Table 5.4. The paper adopted the Final Prediction Error (FPE) criterion which indicates four lags.

Table 5.4 VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1562.23	NA	0.649085	16.59507	16.69798	16.63676
1	1540.669	5975.961	5.22E-15	-15.85893	-15.13854	-15.56708
2	1647.283	198.5622	2.48E-15	-16.60617	-15.26831*	-16.06417
3	1735.685	159.0293	1.43E-15	-17.16069	-15.20535	-16.36853*
4	1779.368	75.80996	1.32e-15*	-17.24199	-14.66917	-16.19968
5	1811.949	54.47444	1.38E-15	-17.20581	-14.01552	-15.91335
6	1848.967	59.54122	1.38E-15	-17.21658	-13.40881	-15.67396
7	1889.537	62.68067	1.34E-15	-17.26494	-12.8397	-15.47217
8	1929.106	58.62069*	1.33E-15	-17.30271*	-12.25999	-15.25979

* indicates lag order selected by the criterion

LR: sequential modified LR test statistic; FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion

5.6.4 Panel Granger Causality

In the *Y* equation the coefficient of oil is statistically significant at the 10% level while in the oil equation the coefficient of *Y* is significant at the 5% level (Table 5.5). Therefore, there is a short-run bi-directional relationship between GDP and oil. This confirms that oil is an important input in most productive activities in these economies. At the same time, increased income promotes more oil usage. A unidirectional causality from GDP to coal in the short run exists because the coefficient of GDP in the coal equation is significant at the 5% level. Coal is a major fuel in the selected countries and this shows that it is still the preferred choice of fuel when GDP rises. Furthermore, there is also a long-run bi-directional relationship between GDP and Coal since the coefficient of *ECT* of coal is significant at 5% while the coefficient of *ECT* in GDP is significant at the at 10%. This result indicates that coal will be a significant input in the future production and consumption of these economies. There is also a long-run bi-directional relationship between GDP and Gas because the coefficient of *ECT* in both equations are significant at the 10% and 1%, respectively. This suggests that the use of gas which has the lowest carbon dioxide emissions among the fossil fuels is promising in these Asian countries.

There is short-run bidirectional causality between oil and output, with output-to-oil causality being statistically stronger than the oil-to-output causality. There is also short-run unidirectional causality from oil to gas significant at the 1% level, which may be traced back to output transitively. We could say that output drives gas consumption with a delay compared to oil, which may be explained by the fact that natural gas requires substantial development of infrastructure in Asian economies. Output is also found to unidirectionally drive coal use in the short run at the 1% significance level. This altogether suggests that output is the main driver of oil, gas and coal consumption in the short run. The capital equation shows that oil is significant at the 10% level. The unidirectional causality from oil to capital shows that higher consumption of oil encourages more investments. There is a short-run unidirectional causality from coal to labor as shown by the significance of the coefficient of coal at the 1% level in the labor equation. Greater coal consumption translates to more demand for labor. It confirms that the coal industry employs substantial labor in its operations. The labor equation also shows that *K* is significant at the 10% level, *Y* is significant at the 5% and *ECT* is significant at 1%.

Table 5.5 Panel Causality Test Results

Dependent Variable	Source of Causation						
	Short-run						Long-run
	ΔLNY	ΔLNL	ΔLNK	ΔLNC	ΔLNG	ΔLNO	ECT
ΔLNY		1.35	0.705	1.197	0.146	2.036 *	2.889 *
ΔLNL	2.828 **		1.966 *	4.701 ***	4.054	1.502	30.373 ***
ΔLNK	1.487	0.283		0.182	0.17	2.222 *	0.851
ΔLNC	3.862 ***	1.471	2.434		0.28	0.246	7.787 ***
ΔLNG	0.892	1.204	0.792	0.195		4.624 ***	5.782 ***
ΔLNO	2.909 **	1.061	2.052	0.275	0.904		0.047

Note: all are F statistics. ***, ** and * indicate that the test statistic is significant at 1%, 5% and 10% level respectively.

The optimal lag length for the variables is one and determined by the Akaike Information Criteria. ECT indicates the estimated error correction term.

5.6.5 Impulse Response Function

There are two useful aspects of the impulse response function: it measures the impact of a one standard deviation shock to another variable, and the persistence of the change on the variable (Soytas & Sari, 2009). These analyses can be used to determine whether the climate change policies discussed in the thesis namely, energy efficiency and fuel substitution are feasible and realistic. It should be noted though that unlike vector autoregression (VAR), the impulse response function for VECM is permanent. This is because the dependence variable is nonstationary and has not been differenced. The results of the impulse response function should be treated with caution as this method is more suited for a VAR. Selected responses are reported and analyzed next.

The effect of a shock to energy consumption is a decrease in output. A one standard deviation shock in oil consumption causes GDP to fall by 0.0035% in the third year following the shock (Figure 5.1). GDP rises on the fourth year by 0.0005% before falling again to negative levels. A one time increase in oil consumption also leads to declining capital growth (Figure 5.2). On the second year after the shock, capital fell by 0.005% and continued its downward trend such that by the 10th year capital has fallen by 0.024%. The response of Labor to a one standard deviation shock in coal consumption is persistent decrease which reached 0.007% on the 10th year (Figure 5.3).

On the other hand the response of energy variables to economic disturbance is positive. A one standard deviation shock in GDP drives coal consumption to rise by 0.097% in the 4th year after the shock, the highest rate in 10 years (Figure 5.4). A 1% increase in GDP will lead to a perpetual rise in oil consumption which reached 0.089% in the 10th year (Figure 5.5). As for the effect of fossil fuels on each other, the initial response of gas consumption to a 1% increase in oil consumption is to fall by 0.066% on the fourth year after the shock but eventually increase by 0.015% in the 10th year (Figure 5.6).

The response of economic variables on each other is mixed. The impulse response shows that the relationship between GDP and labor is positive (Figure 5.3). A one standard deviation shock in GDP results in a rise in labor of 0.006% by the 10th year after the initial disturbance. In contrast, a 1% increase in capital leads to a consistent decline of labor (Figure 5.3). By the 5th year labor has fallen by 0.005% and by 0.008% by the 10th year.

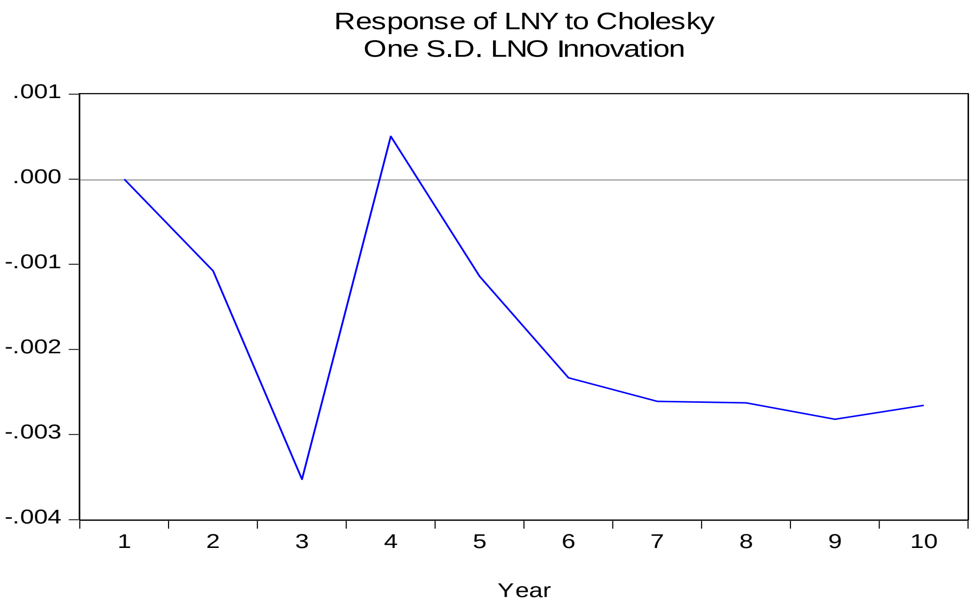


Figure 5.1 Response of GDP to a Shock in Oil Consumption

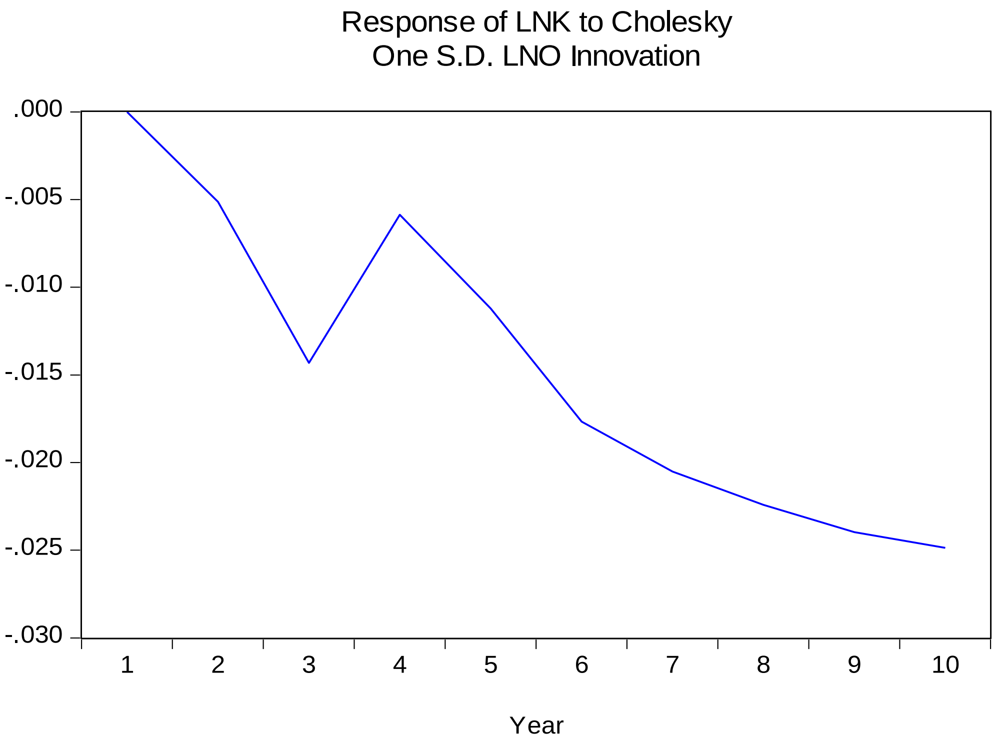


Figure 5.2 Response of Capital to a Shock in Oil Consumption

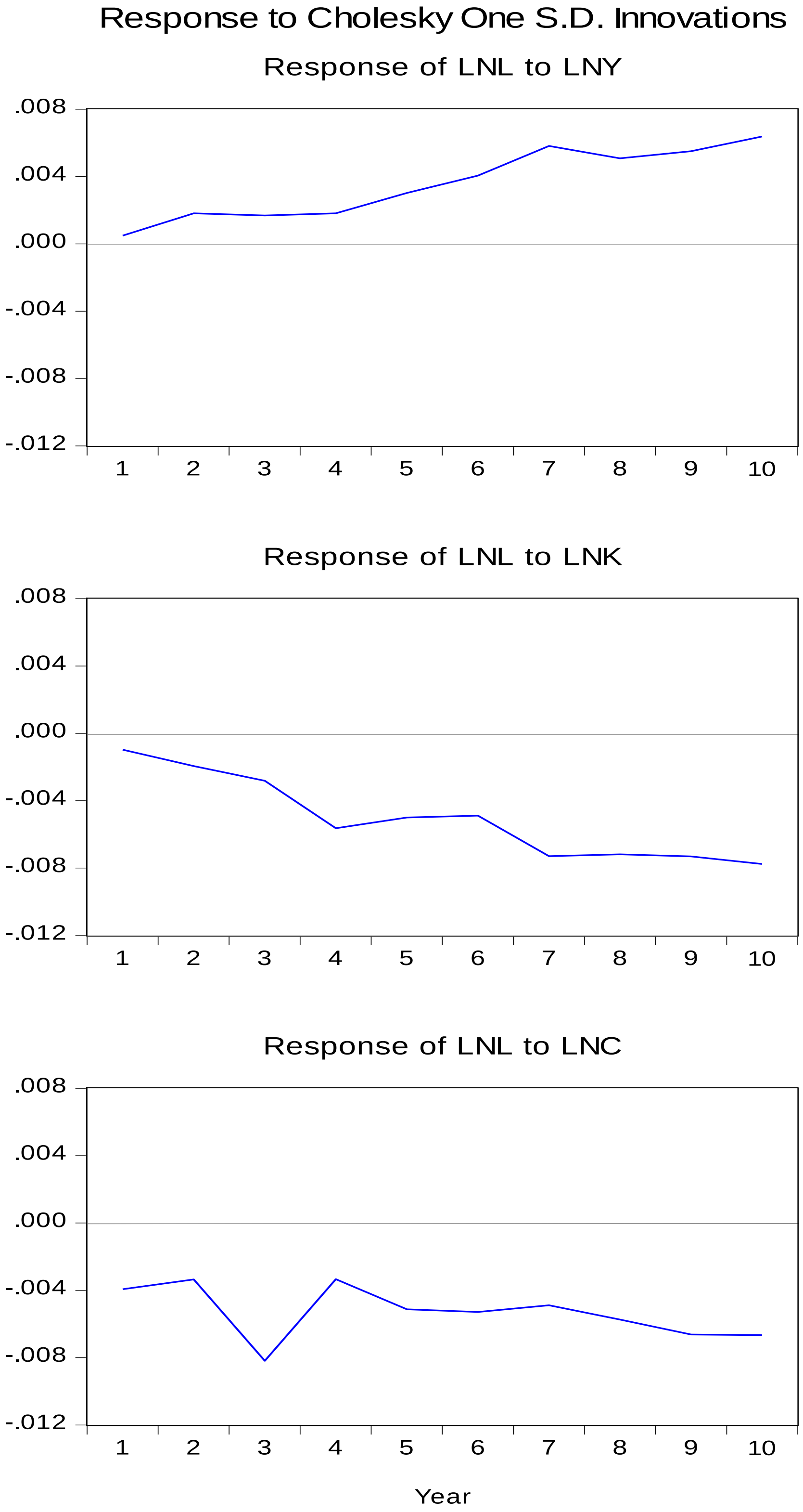


Figure 5.3 Responses of Labor to a Shock in GDP, Capital and Coal Consumption

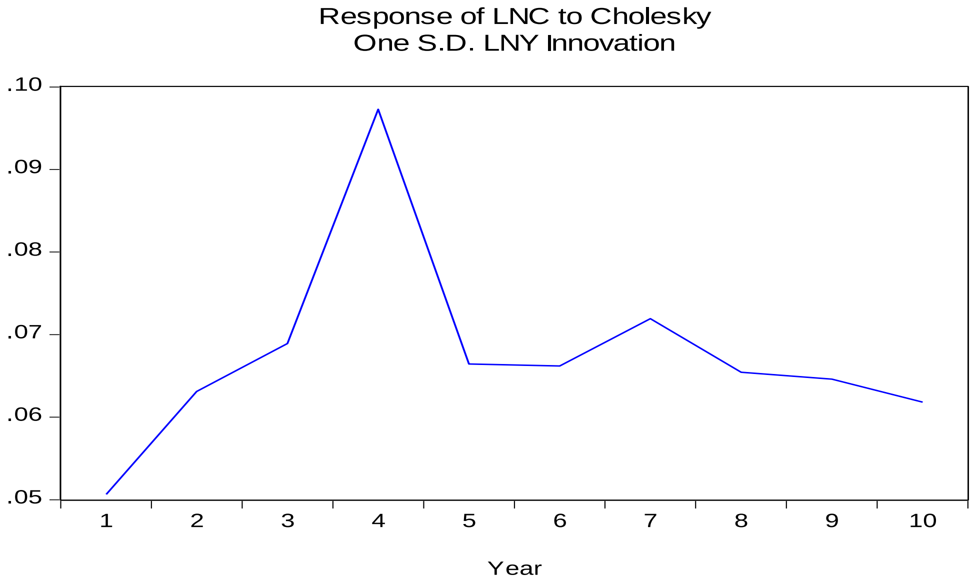


Figure 5.4 Response of Coal Consumption to a Shock in GDP

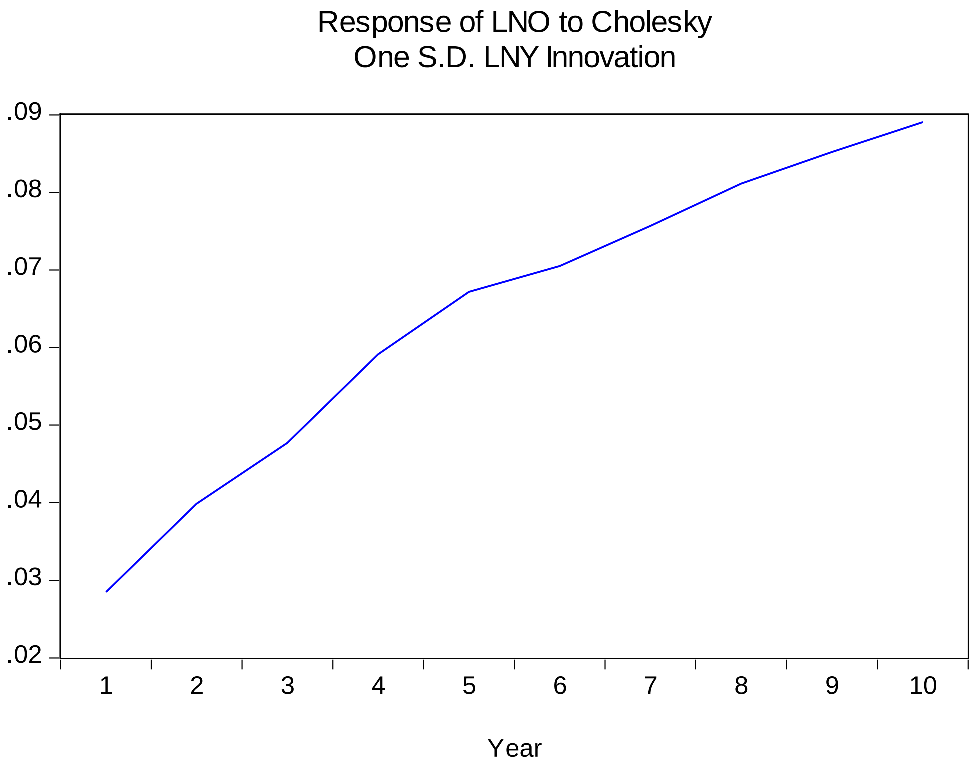


Figure 5.5 Response of Oil Consumption to a Shock in GDP

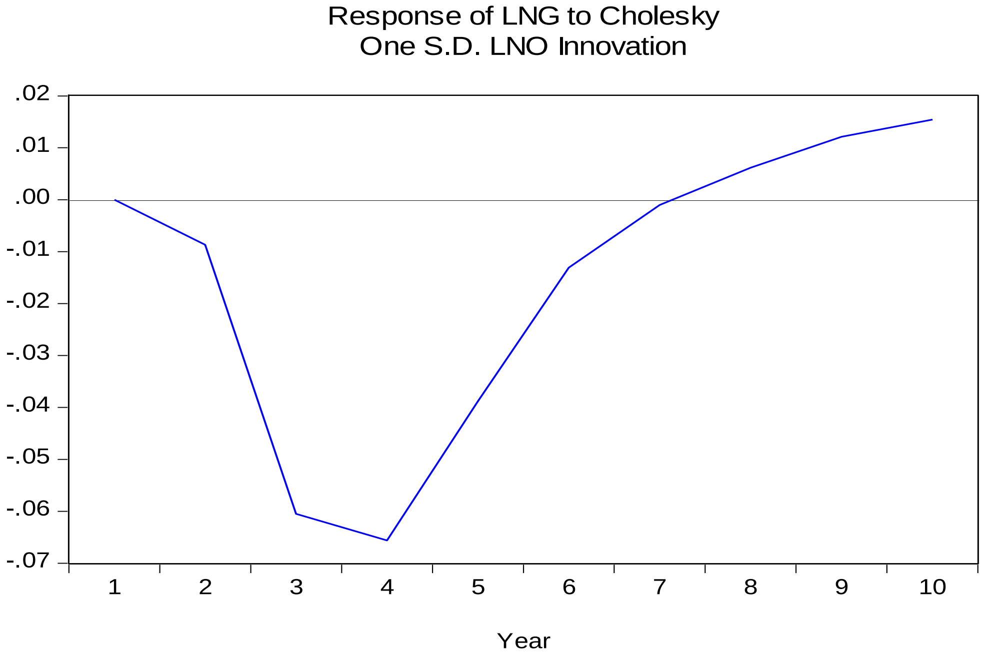


Figure 5.6 Response of Gas Consumption to a Shock in Oil Consumption.

5.7 Conclusion

This chapter has examined the relationship between real GDP, employment, investments, aggregate energy and its various forms (oil, gas and coal) in eight selected Asian countries. Tests proposed by Pedroni (1999) were employed to assess the cointegration among the variables and a VEC model was used to show the Granger causality.

In the short run output drives coal, oil and gas consumption . The causality generally runs from GDP to energy variables referred in the literature as the "conservation hypothesis". This means that as GDP rises coal, oil and gas consumption increase as well. The direction of causality allows governments to impose energy conservation policies like fuel substitution and energy efficiency without disrupting economic growth. A reversal , or if energy variables cause GDP to rise instead, should restrict economic growth when energy sources are conserved. One caveat is that oil exhibits short-run bidirectional causality to GDP so curtailing its use may negatively affect output also. The short-run causality from oil to gas consumption suggests that output causes increased gas consumption but with a lag due to heavy infrastructure requirements.

A positive unidirectional causality from GDP to coal consumption in the short-run confirms Asian countries' reliance on coal. However, the long-run bi-directional relationship between GDP and coal underscores the resilience of coal use in Asia. The long-run bilateral relationship between GDP and gas indicates that fuel substitution is a viable solution to lowering carbon emissions. With the right conditions, substituting gas for coal can lessen emissions since coal is the most polluting fossil fuel. Promoting energy efficiency can also significantly reduce the use of coal. Both these approaches improve environmental quality but do not affect productivity.

Chapter 6 : Conclusion and Policy Recommendations

6.1 Key Findings and Policy Recommendation

This thesis has endeavored to address the following primary question: Can climate change mitigation policies in Asia lower carbon emissions without significantly affecting countries' economies? Two climate change policies were investigated: fuel substitution and energy efficiency. To identify spaces for policy making, the thesis proceeded with macro-analysis of key aspects of the energy use-production-output-emissions process in Asian economies.

The results shows that GDP growth promotes environmental protection by facilitating the substitutability of fossil fuels. The empirical analysis in Chapter 3 proves that the substitution elasticity between the fossil fuels are high and positive. Moreover, the substitution leads to lower carbon emissions. Coal emits the most CO2 emissions compared with oil or natural gas. By substituting oil or natural gas for coal, it was hypothesized that CO2 emissions would be reduced. In the same manner, replacing oil consumption with gas consumption would also lower emissions.

With the exception of Korea, all countries show net losses in carbon emissions when energy consumption shifts from coal to oil, coal to gas and oil to gas. For Korea, only the shift from coal to oil resulted in lower emissions. In contrast the substitution from coal to gas and oil to gas led to higher emissions. Nevertheless, the general results conform with the hypothesis that in Asia substituting a cleaner fuel for a dirty one is possible and good for the environment. However, it is unlikely that Asia will decouple from coal energy consumption in the near future hence it is imperative to increase investments in clean coal technology.

On the macroeconomic effects of fuel substitution, the estimated output elasticity was low and inelastic. This means that the change in output in response to changes in fossil fuel consumption is not substantial. Thus, it is possible to implement fuel substitution without sacrificing productivity and output in Asia. This result is significant because fuel substitution policy is only feasible if the economic cost to a country is low. Developing countries in Asia confront a multitude of problems aside from climate change while resources are tight.

Chapter 4 analyzes the effects of energy efficiency on carbon emissions on the manufacturing sector. Energy efficiency can be utilized to lower carbon emissions by conserving energy. Two methodologies were used to evaluate this: the Environmental Kuznets

Curve (EKC) and the Decomposition approach. According to the EKC hypothesis, the economic growth of countries is initially accompanied by worsening pollution until a threshold is reached when pollution declines as incomes further rise. The reason for the decline in emissions is that as environmental quality becomes a concern, stricter environmental policies are enforced. This relationship between income and emissions follows an inverted U shape curve. The model also identified the turning points where carbon emissions fell or rose during the time period. The Decomposition Analysis method breaks down the sources of carbon emissions into different factors including energy intensity. Technically, energy intensity measures the ratio of energy consumption in manufacturing to the value added of manufacturing. Hence it shows the energy efficiency changes in the sector.

The panel regression yields two turning points. The first turning point is when GDP per capita reaches US$320 which is when CO2 emissions begins to rise. The second is when GDP per capita reached US$15,593 which is when CO2 starts to fall. Out of the 8 countries studied there are only three countries which have surpassed the second turning point. Japan's GDP per capita in 1980 stood at U$25,490 which is greater than the turning point. The threshold point when CO2 begins to decline was reached by Korea in 2001 and by Singapore in 1984. China and the ASEAN-5 countries are still far from reaching the second turning point of carbon emissions.

The results of the decomposition analysis show that the countries have lowered their carbon emissions using energy efficiency as policies. However, Thailand and Singapore estimates show that energy efficiency efforts need to be harnessed more to further reduce carbon emissions. On a sectoral level, most countries were able to lower carbon emissions through energy efficiency in the machinery and textile sectors. The contributions however, are not considerable and the potential for energy efficiency is large.

Overall, the results of the analysis confirmed energy efficiency measures are effective in lowering carbon dioxide emissions. To encourage the adoption of energy efficiency by firms, it is suggested that dissemination of information be conducted through workshops and seminars. It is also advisable to initiate energy audits and machine labelling. The government can also extend financial support to encourage the uptake of technology research and development to improve energy efficiency. It is also recommended that Asian countries further develop cooperation in the exchange of information on energy efficient methods and technologies.

The objective of Chapter 5 was to determine the dynamic relationship between output and energy in Asia. Specifically, the direction of causality running between them was tested. Four types of causality were observed: (1) unidirectional causality from energy consumption to economic growth; (2) unidirectional causality from GDP to energy consumption; (3) bi-directional causality between energy consumption and economic growth and (4) no causality between energy consumption and GDP. In this way, it can be determined whether energy conservation or energy efficiency measures adversely affect GDP or not. If GDP is negatively affected by the policy, it might not be feasible to implement it. In addition, it is also shown which fuel will affect GDP more and by how much. This has significant implications for policy.

Chapter 5 used a panel vector error correction model to investigate the short-run and long-run causality between GDP and the various types of fuel. The empirical test results show short-run relationships between energy and GDP is a favorable condition for fuel substitution and energy efficiency. The short-run unidirectional causality from GDP to coal consumption allows some room to institute energy efficiency measures as changes in coal consumption will not affect economic growth. An increase in GDP will affect coal consumption but the reverse is not applicable. This is a good outcome for Asia as the countries rely heavily on cheap and abundant coal to power their economies. The bi-directional relationship between GDP and oil consumption shows that GDP and oil consumption affects each other. When GDP rises, oil consumption also increases. In turn, the rise in oil consumption contributes to a very small dip in output. Thus, there is a feedback loop between GDP growth and oil consumption. Switching from coal to oil will successfully lower carbon emissions as evidenced by the results in Chapter 3 without affecting economic growth. Unidirectional causality from oil consumption to gas consumption shows that governments can work to gradually increase the later without disruption on the former.

In conclusion, the answer to the above question is affirmative. Climate change policies in the form of fuel substitution and energy efficiency can mitigate carbon emissions without undue damage to Asian economies. However, for this to take effect, the countries must reform their energy policies which currently encourage excessive use of fuel. Moreover, they need to continue innovating and upgrading technology and systems to improve energy usage.

6.2 Further Research

The research is important to assess the state of fuel substitution and energy efficiency policies in Asia and identify opportunities for policy implementation. The limitation of the study is it focuses on broad macro-aggregates to identify policy spaces for fuel substitution and fuel efficiency policies, but has not studied a sector or specific policy plan at a micro level. The latter can be a topic for future research. Moreover, this thesis can be extended by incorporating technological innovations in the analysis on fuel substitution. For instance, Carbon Capture and

Storage may have developed substantially to be viable and reduce the carbon emissions from burning coal. As the price of oil and gas decline due to improvements in shipping and extraction costs, countries may eliminate subsidies. It would be interesting to see how this development impacts the fuel substitution process. In terms of energy efficiency, future research should look into the influence of infrastructure (i.e. information technology), energy efficiency measures implemented outside the country and regional cooperation to promote energy efficiencies.

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Appendix A Chapter 3, Environmental Impact: Japan (Sample Computation)

A	B	C	D	E	F	G	H	I	J	K
Fuel	**Remarks**	**Qty: 10^6 toe**	**Conversion factor (TJ/unit)**	**TJ/unit**	**Carbon emission factor (tC/TJ)**	**Carbon content**	**Oxidation factor**	**CO2/C ratio: 44/12**	**Carbon dioxide emission factor (t CO2)**	**Change**
				(C X D)		(E X F)			(G X H X I)	
Coal vs Oil										
Oil_new	Substitution elasticity between Coal and Oil X Coal_new	10.65	41868	445875.18	20	8917503.541	0.99	3.67	32,370,537.85	32,370,537.85
Coal_new	10% of 2016 Coal Consumption	12	41868	502160.34	26.8	13457897.02	0.98	3.67	48,358,709.98	48,358,709.98
Total Change CO2										-15,988,172.12
Coal vs Gas										
gas_new	Substitution elasticity between Coal and Gas X Coal_new	9.61	41868	402299.85	20	8045996.96	0.99	3.67	29206968.98	29,206,968.98
Coal_new	10% of 2016 Coal Consumption	11.99	41868	502160.34	20	10043206.73	0.98	3.67	36088589.53	36,088,589.53
Total Change CO2										-6,881,620.56
Oil vs Gas										
gas_new	Substitution elasticity between Oil and Gas X Coal_new	13.77	41868	576426.83	20	11528536.53	0.99	3.67	41848587.61	41,848,587.61
oil_new	10% of 2016 Oil Consumption	18.43	41868	771633.10	26.8	20679767.10	0.98	3.67	74309296.46	74,309,296.46
Total Change CO2										-32,460,708.84

Appendix B

Chapter 4, Panel Regression Result

```
Fixed-effects (within) regression               Number of obs      =       270
Group variable: id                               Number of groups   =         8

R-sq:  within  = 0.8954                          Obs per group: min =        32
       between = 0.6654                                         avg =      33.8
       overall = 0.7016                                         max =        34

                                                 F(6,256)           =    365.40
corr(u_i, Xb)  = 0.1424                          Prob > F           =    0.0000

------------------------------------------------------------------------------
      lco2pc |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lgdppc |  -11.57119   1.710064    -6.77   0.000    -14.93877   -8.203604
     lgdppc2 |   1.638276   .1979329     8.28   0.000     1.248492     2.02806
     lgdppc3 |  -.0708168    .007584    -9.34   0.000    -.0857518   -.0558817
      lindsh |  -.2598442   .1166899    -2.23   0.027    -.4896385   -.0300498
       leepc |  -.6991959    .078286    -8.93   0.000    -.8533626   -.5450292
         lto |   .2842337   .0451462     6.30   0.000     .1953285    .3731389
       _cons |    25.7552   4.849663     5.31   0.000     16.20488    35.30551
-------------+----------------------------------------------------------------
     sigma_u |  .56580788
     sigma_e |  .13052434
         rho |  .94947254   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F test that all u_i=0:     F(7, 256) =    77.29              Prob > F = 0.0000
```

```
Random-effects GLS regression                   Number of obs      =       270
Group variable: id                              Number of groups   =         8

R-sq:  within  = 0.8704                         Obs per group: min =        32
       between = 0.9377                                        avg =      33.8
       overall = 0.9272                                        max =        34

Random effects u_i ~ Gaussian                   Wald chi2( 6)      =   2156.13
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0000
```

lco2pc	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lgdppc	-12.31704	1.906281	-6.46	0.000	-16.05328	-8.580796
lgdppc2	1.728525	.2201241	7.85	0.000	1.29709	2.159961
lgdppc3	-.0730735	.0084469	-8.65	0.000	-.0896291	-.0565179
lindsh	-.4435265	.120883	-3.67	0.000	-.6804529	-.2066002
leepc	-.8427151	.0789334	-10.68	0.000	-.9974218	-.6880084
lto	-.0319954	.0322575	-0.99	0.321	-.0952189	.031228
_cons	26.7154	5.472625	4.88	0.000	15.98925	37.44154
sigma_u	.06754687					
sigma_e	.13052434					
rho	.21123851	(fraction of variance due to u_i)				

. hausman fixed re

	Coefficients (b) fixed	Coefficients (B) re	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
lgdppc	-11.57119	-12.31704	.7458502	.
lgdppc2	1.638276	1.728525	-.0902492	.
lgdppc3	-.0708168	-.0730735	.0022567	.
lindsh	-.2598442	-.4435265	.1836824	.
leepc	-.6991959	-.8427151	.1435192	.
lto	.2842337	-.0319954	.3162291	.0315854

```
                 b = consistent under Ho and Ha; obtained from xtreg
  B = inconsistent under Ha, efficient under Ho; obtained from xtreg

 Test:  Ho:  difference in coefficients not systematic

               chi2(  6) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                         =        73.49
             Prob>chi2 =         0.0000
             (V_b-V_B is not positive definite)
```

Pesaran's test of cross sectional independence = **0.142**, Pr = **0.8871**

Average absolute value of the off-diagonal elements = **0.339**

Appendix C

Chapter 5, Impulse Response Tables

Response of LNY:						
Period	LNY	LNC	LNG	LNK	LNL	LNO
1	0.032563	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.046012	-0.001620	-0.001181	-0.000625	-0.000715	-0.001077
3	0.050423	-0.004858	-0.002251	-0.000883	0.000965	-0.003526
4	0.058611	-0.004186	-0.001022	-0.003019	0.003364	0.000505
5	0.064832	-0.002907	-0.001388	-0.006200	0.005887	-0.001142
6	0.069438	-0.002147	-0.001295	-0.007438	0.006686	-0.002335
7	0.074574	-0.001242	-0.001536	-0.010119	0.007966	-0.002611
8	0.078595	-0.000158	-0.001628	-0.012872	0.009523	-0.002628
9	0.081764	0.000117	-0.001321	-0.014189	0.010437	-0.002822
10	0.085165	0.000446	-0.001127	-0.015344	0.011355	-0.002658

Response of LNC:						
Period	LNY	LNC	LNG	LNK	LNL	LNO
1	0.050655	0.226204	0.000000	0.000000	0.000000	0.000000
2	0.063112	0.245870	0.003176	0.008909	0.028680	-0.005180
3	0.068920	0.260550	0.006642	-0.020351	0.022098	-0.014927
4	0.097285	0.238466	0.015447	-0.048327	0.025737	-0.021586
5	0.066452	0.189711	0.026103	-0.026744	0.016122	-0.008427
6	0.066192	0.171389	0.031944	-0.016182	0.023884	-0.014102
7	0.071923	0.170681	0.048189	-0.009026	0.028169	-0.005980
8	0.065433	0.169721	0.054132	-0.005525	0.029222	-0.013685
9	0.064599	0.173512	0.058464	-0.009776	0.027663	-0.015517
10	0.061811	0.172116	0.062517	-0.016297	0.029878	-0.018233

Response of LNG:						
Period	LNY	LNC	LNG	LNK	LNL	LNO
1	0.015042	-0.011705	0.202706	0.000000	0.000000	0.000000
2	0.019288	-0.003077	0.339135	0.011234	0.000746	-0.008662
3	0.027535	0.029130	0.363149	0.012049	0.015720	-0.060492
4	0.018596	0.043122	0.367387	-0.000224	0.045625	-0.065603
5	0.008368	0.045833	0.369333	-0.005218	0.063439	-0.038827
6	0.012553	0.046520	0.365168	0.004439	0.069469	-0.013079
7	0.020826	0.047840	0.359821	0.019520	0.075544	-0.001020
8	0.032519	0.052211	0.357185	0.028253	0.081369	0.006166
9	0.041468	0.056212	0.353039	0.028634	0.082532	0.012131
10	0.045010	0.058307	0.345760	0.025473	0.082806	0.015429

Response of LNK:						
Period	LNY	LNC	LNG	LNK	LNL	LNO
1	0.078060	-0.000374	-0.001327	0.054850	0.000000	0.000000
2	0.128689	-0.000724	-0.005883	0.073227	0.003681	-0.005140
3	0.138957	-0.003055	-0.009378	0.072162	0.005501	-0.014315
4	0.147199	-0.004540	-0.010597	0.071294	0.007930	-0.005870
5	0.153840	-0.004304	-0.015221	0.066160	0.008869	-0.011219
6	0.159615	-0.004376	-0.016969	0.064951	0.010841	-0.017668
7	0.165818	-0.003776	-0.016595	0.062806	0.010218	-0.020511
8	0.170098	-0.002386	-0.017498	0.058648	0.010990	-0.022419
9	0.172659	-0.000798	-0.017402	0.056419	0.011731	-0.023969
10	0.175731	-0.000163	-0.016748	0.055531	0.012522	-0.024865

Response of LNL:

Period	LNY	LNC	LNG	LNK	LNL	LNO
1	0.000493	-0.003939	-0.001892	-0.000979	0.019959	0.000000
2	0.001804	-0.003360	0.004410	-0.001941	0.010011	-0.001688
3	0.001685	-0.008187	0.001108	-0.002819	0.012539	0.000312
4	0.001809	-0.003352	0.001187	-0.005625	0.013520	-0.000107
5	0.003015	-0.005133	0.003998	-0.004995	0.015065	-0.001386
6	0.004054	-0.005289	0.005414	-0.004887	0.013698	-0.000622
7	0.005812	-0.004891	0.005258	-0.007295	0.014885	-0.002407
8	0.005072	-0.005740	0.006727	-0.007184	0.015119	-0.001790
9	0.005503	-0.006622	0.007558	-0.007305	0.015383	-0.002144
10	0.006368	-0.006671	0.008359	-0.007753	0.015709	-0.001973

Response of LNO:

Period	LNY	LNC	LNG	LNK	LNL	LNO
1	0.028486	-0.006374	0.001552	0.011192	0.006003	0.040359
2	0.039860	-0.006334	-0.003180	0.011550	0.006646	0.046392
3	0.047702	-0.010907	-0.003076	0.018883	0.012304	0.052796
4	0.059114	-0.010990	-0.002765	0.018408	0.013724	0.059685
5	0.067191	-0.010431	-0.006301	0.011419	0.016949	0.059886
6	0.070498	-0.011282	-0.007363	0.008145	0.017361	0.060881
7	0.075694	-0.012736	-0.007706	0.004649	0.018671	0.061533
8	0.081144	-0.012558	-0.007018	0.001004	0.020123	0.061672
9	0.085217	-0.013092	-0.005698	-0.001155	0.021262	0.060780
10	0.089041	-0.013343	-0.004341	-0.003160	0.022148	0.060669

Cholesky Ordering: LNY LNC LNG LNK LNL LNO

Appendix D

Chapter 5, Serial Correlation Tests

VEC Residual Serial Correlation LM Tests
Null Hypothesis: no serial correlation at lag order h
Date: 05/03/19 Time: 15:47
Sample: 1980 2016
Included observations: 240

Lags	LM-Stat	Prob
1	118.3598	0.0000
2	101.7718	0.0000
3	49.26084	0.4627
4	66.65074	0.0474
5	52.22312	0.3498
6	53.13767	0.3179
7	62.97357	0.0866
8	44.02270	0.6747
9	68.59216	0.0337
10	29.41937	0.9880
11	35.25930	0.9299
12	43.38133	0.6994

Probs from chi-square with 49 df.