CLIMATE POLICY AND ENERGY DEVELOPMENT IN THAILAND: AN ASSESSMENT

Ram M. Shrestha
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This book is dedicated to

Dr. Tsuneyuki Morita (1950-2003)

Founder of the Asia-Pacific Integrated Model (AIM) and AIM Network.

Without Dr. Morita's encouragement and support

the research leading to this book would not have been possible.

Preface

With growing global concern about climate change, it is now widely recognized that there is a need for serious efforts from both developed and developing countries to adopt a climate friendly and sustainable path for economic and social development. This is reflected in recent agreements of the Conferences of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC). The Paris Agreement 2015 in COP-21 has clearly formalized the requirement for countries to submit their Intended Nationally Determined Contributions (INDCs) to reduce emission of greenhouse gases (GHGs).

There are close interrelations between climate and energy policies. In many situations, energy policies are introduced with purely national considerations like energy security and local/regional environmental quality. Yet they can also contribute to the attainment of climate goals by reducing GHG emissions. On the other hand, climate policies like carbon tax or GHG emission permits and trading are primarily focused on achieving GHG abatement goals in an economically efficient manner; however, such policies can also help to achieve certain energy policy objectives, e.g., sustainable energy development, energy security and cleaner local environment through improved energy efficiency, wider use of cleaner and renewable energy resources and lower emissions of local/regional pollutants. Thus, in many ways, climate and energy policies can play complementary roles. However, the choice of a specific climate or energy policy would depend upon national priorities and various other considerations. It is therefore important for individual countries to conduct systematic assessments of the long term implications of energy and climate policies for technology choice, energy resource mix, as well as emissions of GHGs and other pollutants.

Systematic analyses of the long-term implications of climate and energy policies are lacking in many developing countries. Studies in this volume are mostly focused on the assessment of the energy and environmental implications of climate policy options like carbon emission reduction targets and GHG mitigation measures under emissions trading in Thailand, the second biggest economy and second largest emitter of carbon dioxide among ASEAN countries. The volume also includes an analysis of the effects of alternative biofuel promotion scenarios in road transport in Thailand, keeping in mind the rapidly growing role of the transport sector in the national oil consumption and GHG emissions. With economic growth and increasing energy demand, the emission of GHGs in the country is expected to increase further if the business as usual trends are to continue. It is important for a country like Thailand to have a systematic assessment of the long term implications of energy and climate friendly policies since such an assessment could be immensely useful to policy makers to develop sustainable development strategies.

Recognizing the dominant role of energy-consuming activities on GHG emissions in Thailand, the assessments in this volume mainly focuses on the effects of selected climate and energy policy options in energy system development and emissions of GHGs and local/regional pollutants. Most of the analyses are based on a particular energy system model of Thailand (i.e., the "Thailand AIM/Enduse model"), but two of the studies are based on different models – one uses a computational general equilibrium (CGE) model and the other uses a MARKAL- based energy system model of Thailand.

All of the studies in this volume, except Chapter 9, were carried out at the Asian Institute of Technology (AIT) during 2005-2007, but publication was delayed for various reasons. Although an attempt has been made to provide updated information on actual energy development and emissions in Thailand wherever possible, one can expect to observe differences between the results of the studies presented here and the way the energy use and environmental emissions of Thailand have actually evolved since the time the studies were carried out. We expect that the value of the present volume will lie more in the insights generated rather than the "accuracy" of the quantitative results reported in the studies.

The book is organized as follows: Chapter 1 presents an up to date overview of the socio-economic, energy and environmental trends of Thailand along with a brief account of the climate friendly policies of the country. Chapter 2 provides a detailed description of the Thailand AIM/Enduse model, which is a detailed energy system model of the country. Chapter 3 discusses the energy development and emissions of GHGs and other pollutants in Thailand during 2000-2035 under the reference (or base) case, in which no climate friendly policy intervention is considered. Chapter 4 presents analyses of energy system development and its environmental implications in Thailand during 2000-2050 under four different scenarios with widely varying assumptions on economic and demographic growth patterns, technological change as well as market and institutional regimes following the Special Report on Emission Scenarios (SRES) of the Intergovernmental Panel on Climate Change. The fifth chapter discusses the estimated trends of GHG and local air pollutant emissions from the country during 2000–2035 from both energy using activities and non-energy sources, which include energy combustion activities, industrial processes, agriculture, land use, forestry and waste. Chapter 6 examines the energy system development and its associated GHG and local/regional air pollutant emissions under the reference case and three different emissions reduction (ER) targets in Thailand during 2000-2035. Chapter 7 assesses the energy and environmental implications of liquid biofuels promotion and use in Thailand's road transport sector under four scenarios: These scenarios include a reference scenario and three biofuel scenarios that involve different biofuel resource limitations and prices, and future development of biofuels as a potential transportation fuel. In Chapter 8, the co-benefits of reducing CO_2 emissions in Thailand during 2005–2050 in terms of local pollutant emissions as well as the role of renewable, biomass and nuclear energy are analyzed using a MARKAL-based energy system model of Thailand. The chapter also examines the implications of CO_2 emissions reduction policy on the energy security of the country. The final chapter analyzes the economy-wide implications of GHG mitigation measures under emission trading and carbon capture and storage (CCS) technology in Thailand using a CGE model (i.e., AIM/CGE model).

One of the objectives of this book is to demonstrate model-based assessment of the implications of selected climate and energy policies on energy system development as well as emissions of GHGs and local pollutants in the case of Thailand. We hope that the book will promote a better understanding of the potential role of these policies in formulating national climate policies and programs in Thailand. Furthermore, we hope that the present set of studies will provide some useful insights to researchers and climate policy makers in other developing countries.

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Sunil Malla
Migara H. Liyanage

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We also benefitted both from the presentations made by the members of the AIM Network from China, India, Japan, South Korea and the USA in AIM international workshops, and individual discussions with them. We would like to thank them all for their help and cooperation.

We are pleased to acknowledge our coauthors for their contributions in several chapters of the book. Dr. Bundit Limmechokchai coauthored with us the overview of socio-economic, energy and environmental trends in Chapter 1 and multi-gas emissions in Chapter 5. Dr. Panida Thepkhun, Dr. Bundit Limmeechokchai, Dr. Shinichiro Fujimori, and Dr. Toshihiko Masui coauthored Chapter 9 on low carbon scenario analysis with Ram M. Shrestha. Mr. Shreekar Pradhan coauthored Chapter 8 on the co-benefits of CO_2 emission reduction with Ram M. Shrestha.

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R.M.S.
S.L.
M.H.L.

Abbreviations

AAGR	Average Annual Growth Rate
AEDP	Alternative Energy Development Plan
AEEI	Average Energy Efficiency Improvement
AIM	Asia-Pacific Integrated Model
AIT	Asian Institute of Technology
APEC	Asian-Pacific Economic Cooperation
ASEAN	Association of Southeast Asian Nations
BAU	Business-as-usual
BIGCC	Biomass Integrated Gasification Combined Cycle
CAGR	Compound Annual Growth Rate
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CER	Certified Emission Reductions
CES	Constant Elasticity of Substitution
CGE	Computable General Equilibrium
CNG	Compressed Natural Gas
CT	Carbon Tax
DEDE	Department of Alternative Energy Development and Efficiency
EDGAR	Emission Database for Global Atmospheric Research
EE	Energy Efficiency
EID	Energy Import Dependency
ER	Emission Reduction
FAME	Fatty Acid Methyl Ester
FCEV	Fuel Cell Electric Vehicle
FED	Final Energy Demand
FGD	Flue Gas Desulfurizers
GAMS	General Algebraic Modeling System
GGE	Gasoline Gallon Equivalent
GHG	Greenhouse Gas
GWh	Giga-Watt hour
HSD	High-speed Diesel
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IIASA	International Institute for Applied Systems Analysis
IMF	International Monetary Fund
IO	Input-Output
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producers
KP	Kyoto Protocol
LPG	Liquefied Petroleum Gas

MEA	Metropolitan Electricity Authority
MSW	Municipal Sewage Waste
Mt	Million tonne
MTBE	Methyl Tertiary Butyl Ether
Mtoe	Million ton of oil equivalent
MW	Mega Watt
NEC	National Ethanol Committee
NESDB	National Economic and Social Development Board
NGV	Natural Gas Vehicle
NIES	National Institute for Environmental Studies
NRE	New and Renewable Energy
OECD	Organization for Economic Co-operation and Development
PCD	Pollution Control Department
PEA	Provincial Electricity Authority
PES	Primary Energy Supply
PFBC	Pressurized Fluidized Bed Combustion
RPS	Renewable Portfolio Standard
SAM	Social Accounting Matrix
SC	Super Critical
SPP	Small Power Producers
SRES	Special Report on Emissions Scenarios
TDRI	Thailand Development Research Institute
TEI	Thailand Environment Institute
TFED	Total Final Energy Demand
TPES	Total Primary Energy Supply
toe	Ton of oil equivalent
ULG	Unleaded Gasoline
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US$	United States Dollar
WBCSD	World Business Council for Sustainable Development
WTO	World Trade Organization

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Chapter 1

Socio-economic, Energy and Environmental Emission Trends in Thailand: An Overview[1]

1.1. Introduction

This chapter presents the historical trends of socio-economic growth, energy consumption and emissions of greenhouse gases and local/environmental pollutants in Thailand. Section 1.2 discusses the historical trends of demographic and economic growth. Section 1.3 to Section 1.6 reviews the energy supply and energy consumption pattern, while section 1.7 describes the electricity generation trend. The availability of domestic energy resources are discussed in Section 1.8 while CO_2 emission trend is discussed in Section 1.9. The climate friendly policies in Thailand have been discussed in Section 1.10 followed by Section 1.11 which contains a summary of the chapter.

1.2. Demographic and economic trends

Thailand has undergone a remarkable economic transformation since the financial crisis in 1997. The country's economic growth trend improved from -10.2% in 1998 to 5.1% in 2006 and temporarily decelerated from 2006 to 2013 (2.9%), due to concerns over rising oil prices and devastated floods. The annual average economic growth is projected to remain strong at 3.8% in 2020 (IMF, 2015). The total gross domestic product (GDP) of Thailand , measured in Purchasing Power Parity (PPP), was about US$1,067 billion and the GDP per capita was US$15,929 in 2014 (ADB, 2015).

It is seen from Figure 1.1 that industry and service sectors has major contribution in Thailand's GDP in recent years. The population employed in agriculture decreased from 63.3% in 1990 to 38.2% in 2010, while that in the service sector increased from 26.7% in 1990 to 47.6% in 2010. Although more than one-third of the population is involved in agriculture, the contribution of agriculture in GDP was only 10.5% in 2014 (ADB, 2015).

Thai population more than tripled during 1950-2015. It reached the 66 million mark in 2010 and 67 million in 2013 (MICT, 2015; UN, 2013). Between 1950 and 2015, the average annual growth rate of population increase in Thailand was 1.9%. This figure is slightly higher when compared to the world average (1.7%). However, it is lower compared to Southeast Asia[2] average (i.e., 2.1%). It is expected that the increase in population will show a declining trend in the years to come (UN 2015). The forecasts suggest that it will increase up to 68 million by 2023 and steadily decline thereafter

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[1] Bundit Limmeechokchai is a co-author of this chapter.

[2] Southeast Asia includes Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Philippines, Singapore, Thailand, Timor-Leste and Vietnam.

(Figure 1.2). The demand for land area would be a matter of concern in the future. The population density follows a similar trend: 132 person per sq. km in 2015 to 81 person per sq. km in 2100.

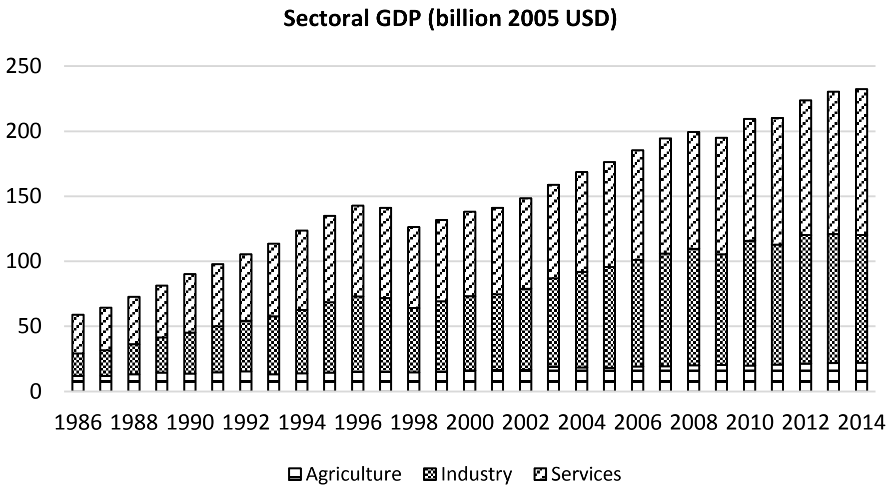

Figure 1.1: Sectoral GDP contribution during 1986-2014
(Source: WB, 2015)

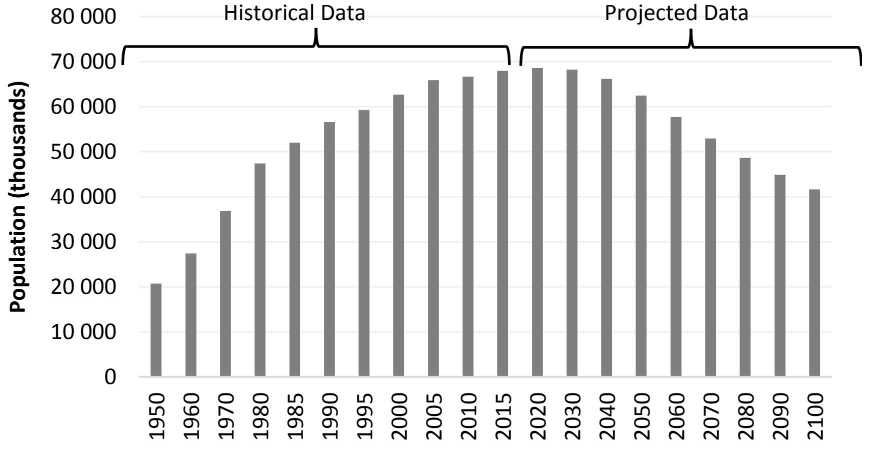

Figure 1.2: Historical and Projected Thai population during 1950 – 2100
Source: UN (2015)

One important demographic change in Thailand is the rising aging population. The number of people aged 65 and over in the country has continued to grow. Only 3.2% of the population were aged 65 and above in 1950. This figure reached 15.8% in 2015. According to the UN projections, this value would reach almost 40.4% in 2100 (UN, 2015). This would have greater implications on the working population (less than 65 years of age) in years to come.

Along with the increased economic activity, urbanization in Thailand is also projected to increase at a steady pace. The urban population is projected to increase from 49% in 2014 to 72% in 2050 (see Figure 1.3). As the country's economy expands, Thai people are likely to get increasing access to clean water, reliable electricity, roads and other infrastructures. It will result in extending the existing city limits. It is projected that the urban population will exceed the rural population by 2020 (UN 2015). Also, it is likely that more energy would be needed to satisfy the growing demand for energy-using household and energy services in the long-term.

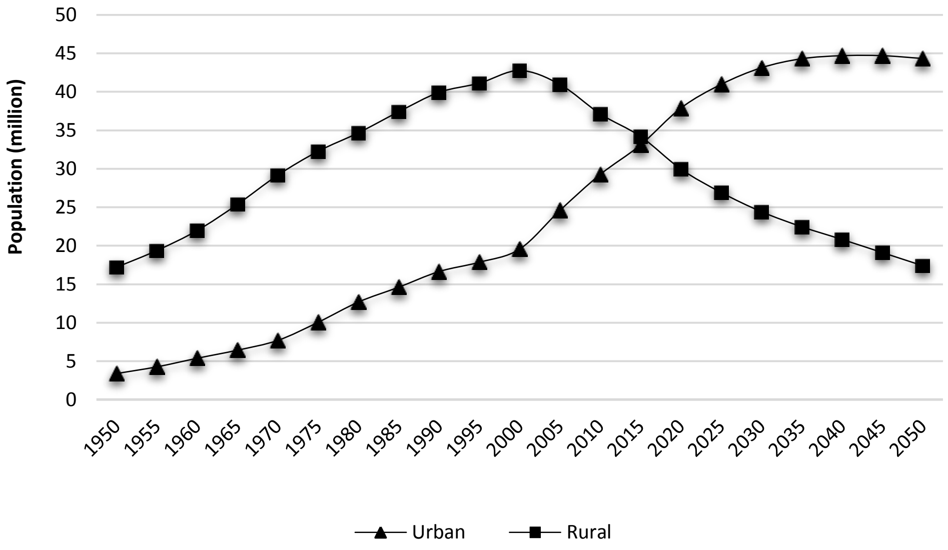

Figure 1.3: Rural and urban Thai population during 1950 – 2050
Source: UN (2015)

Based on social indicators, Thailand is ahead of most of the other developing countries of the world. The overall human development index (HDI) of Thailand was 0.722 in 2013. The country is ranked 89 out of 189 nations and fourth among the Southeast Asian nations (UNDP, 2014). The life expectancy of Thai people was about 74.4 years in 2013. This figure is higher compared to East Asia and the Pacific (74 years) and the world average (70.8 years). Total fertility rate in the country during 2005-2010 was 1.49 children per woman as compared to the average figure of 2.35 children per woman in Southeast Asia. The total fertility rate in the country is projected to increase to 1.9 children per woman during the period of 2045-2050. Improvements in maternal health and penetration of health benefits in rural areas have resulted in a significant reduction in infant mortality rate. For example, there were 120 infant deaths per 1000 live births during the period of 1950-1955; it decreased to 11 infant deaths per 1000 live births during 2010-2015. Infant mortality figure during this period (i.e., 2010-2015) in Thailand is less than half of that in Southeast Asia average (27 infant deaths per 1000 live births) (UN, 2015; WB, 2015). It is also interesting to note that Thailand's adult literacy rate was 93.5% during the period of 2005-2012. This figure is higher compared to the world average (i.e., 81.2%) (UNDP, 2014).

1.3. Primary Energy Supply and Final Energy Consumption

Growing economy and population resulted in increasing energy consumption in Thailand over the years. The change in total primary energy supply (TPES) during 1986-2012 is shown in Figure 1.4. During this period, Thailand's energy demand grew at average annual rate of almost 5.9%. In the 1980s, primary energy consumption comprised of mainly oil and biomass. In the early 90s and 2000s, due to concerns of supply security and price in the world oil market, the country's emphasis was on developing endogenous resources such as hydro, natural gas and biomass.

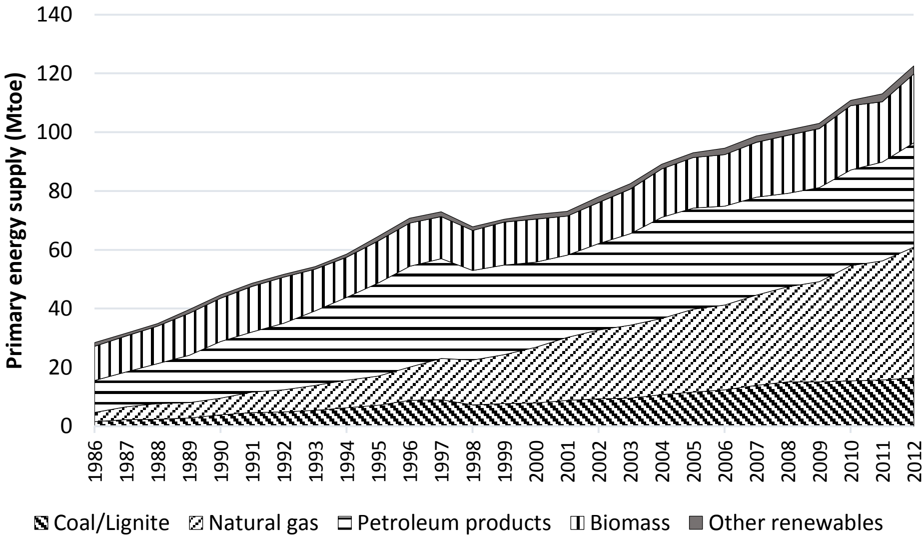

Figure 1.4: Primary energy supply during the period of 1986-2012
Sources: EPPO (2015)[3], IEA (2013)[4]

In 2012, the TPES was about 122.5 Mtoe. This corresponds to only 1% compared to the world TPES and 8.1% of that of Asia, excluding China, in 2010 (IEA, 2013). Throughout the period from 1986 to 2012, oil has been the most dominant fuel comprising of more than one-third of the total energy supply. However, during 1997 to 2012, natural gas and oil combined accounted for more than two-thirds of the TPES. Biomass had a significant share in TPES during 1986-2012; however, the share declined from 40% in 1986 to 19% in 2013. Currently, use of coal, domestic lignite and imported coal combined, is largely restricted due to environmental concerns. Coal use accounted for only 13.4% in the TPES in 2012.

[3] For data on coal/lignite, oil, natural gas, hydropower and purchased electricity
[4] For data on biomass from 1986 to 2012

The share of fossil fuels has been increasing rapidly over the years. In 2012, fossil fuels accounted for 78.6% of the total TPES. Biomass and hydro together accounted for almost all new and renewable energy consumption. However, biomass energy dominated all renewables accounting for almost 89% in 2013. The biomass energy mainly comprised of fuelwood, agricultural residues and animal dung's, biogas and biofuels. The contribution of wind, solar and geothermal energy to renewable sources is almost negligible.

Thailand reported almost a four-fold increase in total final energy demand (FED) from 1986 to 2012 (Figure 1.5). The total FED was 73.3 Mtoe in 2012. Sector-wise, the industry sector accounted for most of the final energy demand (36.7%), followed by the transport (35.8%), residential (15.1%), commercial (7.2%) and agriculture (5%) sectors. Between 1986 and 2012, the total FED grew by an average of 5.5% per year. However, average annual growth rate of FED vary widely at the sector level. For example, FED in the commercial sector grew by 10.2%, while FED in the transport sector grew by 6.9% and the industry sector grew by 6.6%. The growth of FED in the residential and agriculture sectors is relatively small, at 2.6% and 4.2% per year, respectively.

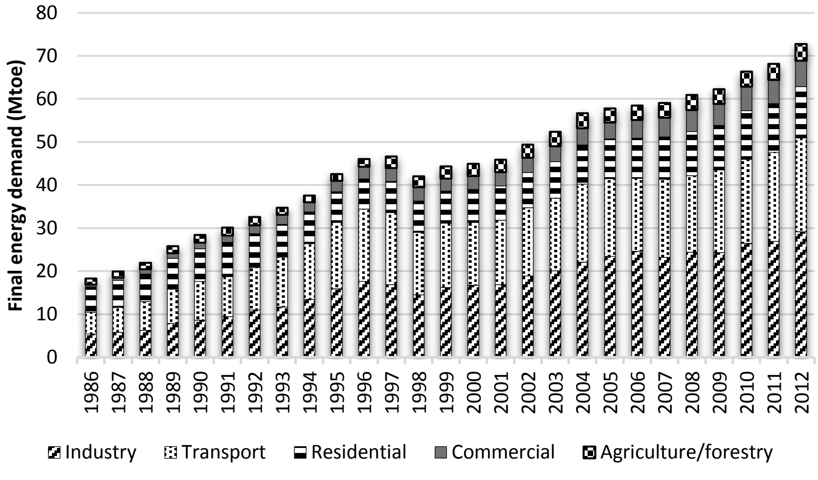

Figure 1.5: Final energy demand during 1986 – 2012
Source: IEA (2013)

1.4. Energy consumption in the residential sector

In 2010, the total FED in the residential sector was 10,963 ktoe in 2010. In the same year, about 78% of residential sector FED is concentrated in rural areas, while 13% is concentrated in Greater Bangkok area and the remaining 9% is concentrated in Municipal area (Figure 1.6). According to the 2010 population and housing census, there are 20.4 million private households and the average size of the private household (i.e., number of person per household) in Thailand was 3.1 (NSO, 2015). This corresponds to 531 kgoe of energy consumption per household in 2010.

The energy mix in the residential sector varies across the regions in the country (Figure 1.7). In the urban areas (Greater Bangkok and Municipal area), households mainly used electricity and LPG. In 2010, these two fuels combined accounted for 95% of total residential FED in the country. In contrast, biomass is the main fuel used in rural households. In 2010, biomass (mainly fuelwood and charcoal) accounted for almost 75% of total rural residential FED. Of the total biomass energy used, charcoal accounted for 51%, followed by fuelwood (48%) and paddy husk (remaining 1%) in 2010. In 2010, about 14% of the total rural residential FED was met by electricity and 11% of total rural residential FED was met by LPG.

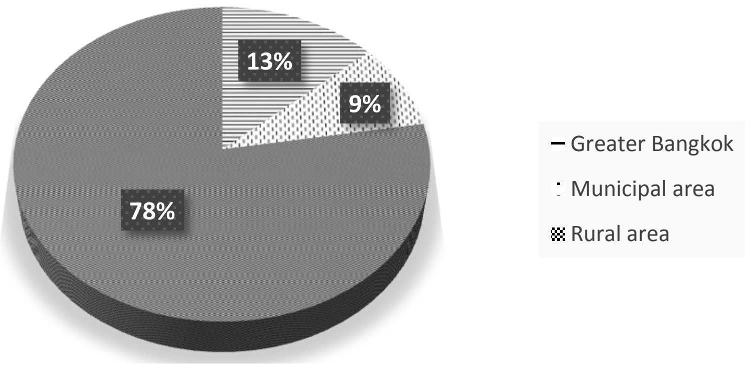

Figure 1.6: Share of residential sector energy consumption by area in 2010
Source: DEDE (2012a)

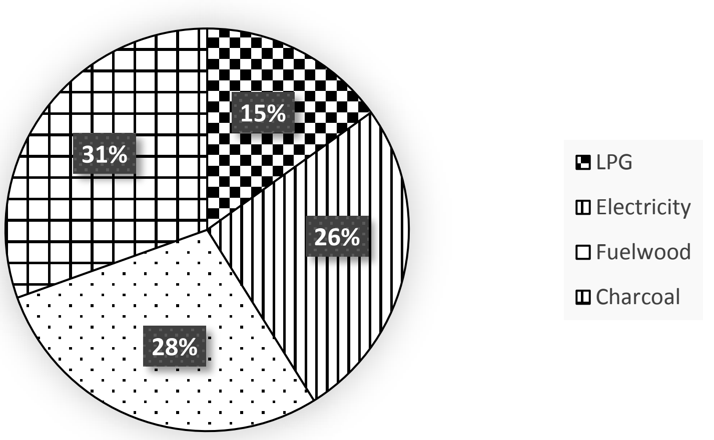

Figure 1.7: Residential sector energy consumption by fuel type in 2010
Source: DEDE (2012a)

1.5. Energy consumption in the industry sector

The industry sector consumed about 26.5 Mtoe in 2010. Manufacturing industries accounted for almost 96% of total industry sector FED, while construction and mining and quarrying industries account for the remaining 4%. The discussion in this section is focused mainly on manufacturing industries. In 2010, non-metallic minerals along with food and beverages together accounted for almost 60% of the total manufacturing industries' FED (Figure 1.8). Non-metallic minerals industry, mainly cement, is the single largest energy consumer in the manufacturing industry sector in the country; it accounted for 31% of total manufacturing industry FED in 2010. In terms of energy mix, coal accounted for the largest share (33%) in total manufacturing industry FED in 2010. This is followed by the renewables, mainly biomass (27%), electricity (21%), oil (10%) and natural gas (9%) (Figure 1.9). Non-metallic industry is in fact the highest consumer of coal, i.e., 64% of total coal consumed in manufacturing industries (i.e5.3 Mtoe) in 2010. Natural gas accounted for the second largest fuel used in the non-metallic industry accounting for 35% of total natural gas consumption in manufacturing (i.e., 0.76 Mtoe) in the same year. Food and beverages industry mainly includes sugar production. In 2010, Thailand was the world's fourth largest sugar producer with the production of 10 million tons of sugar (FAO, 2015). More than 80% of energy for food and beverages industry came from biomass. This is because bagasse from sugar cane is heavily used for cogeneration in sugar production. Oil and electricity together accounted for almost 92% of the non-renewable energy used in food and beverages industry in 2010. Production of chemicals is the third largest industry, which accounted for 16% of the FED of the manufacturing industries in 2010. Coal, electricity and natural gas are the most widely used energy types in chemical industry, accounting for almost 83% of the chemical industry's total FED. Fabricated metals industry is the fourth largest energy consumer in industry. This sub-sector is in fact the highest user of electricity among the manufacturing industries, accounting for one-fourth of the total manufacturing industry sector's electricity consumption.

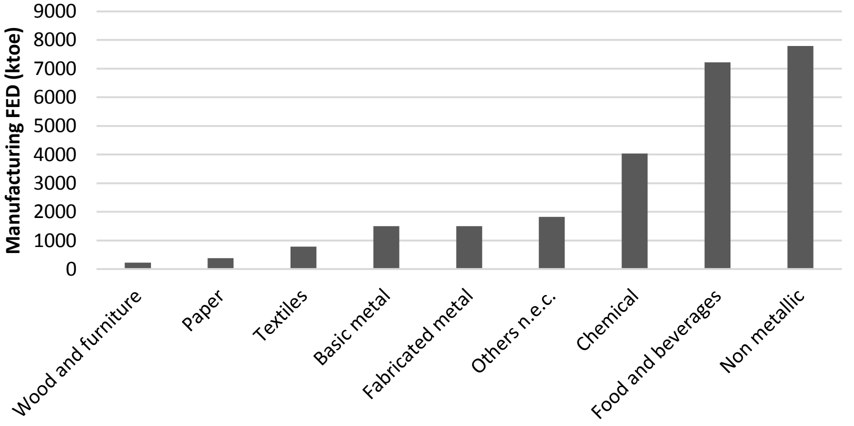

Figure 1.8: Energy consumption by manufacturing type in 2010
Source: DEDE (2012a)

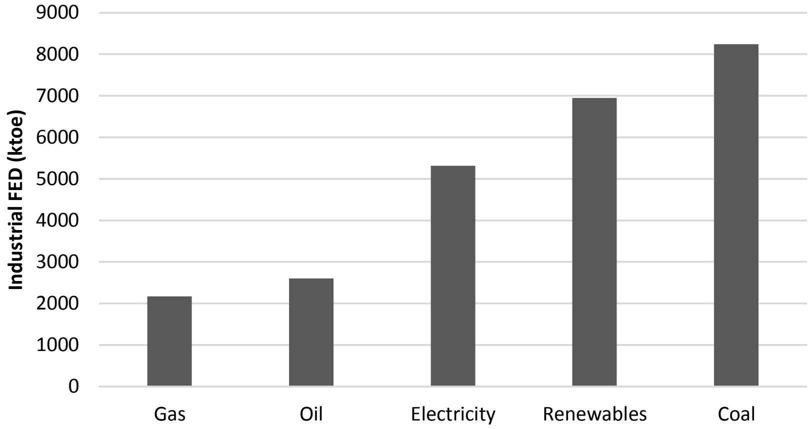

Figure 1.9: Industry sector energy consumption by fuel type in 2010
Source: DEDE (2012a)

1.6. Energy consumption in the transport sector

The transport sector in Thailand has undergone rapid expansion and modernization in recent years. As a result, energy consumption has also grown very rapidly over the years. In the 90s the country introduced a successful program to use unleaded gasoline in the road transportation (Sayeg, 1998). Currently, all of the gasoline used in the country is unleaded. The country has also introduced programs to promote CNG and biofuels. Its CNG program is intended to use its indigenous natural gas reserves. Currently CNG is used in a large number of buses, cars, vans and pickups. The biofuel program is to blend palm oil with diesel to produce biodiesel and blend ethanol with gasoline as a substitute for MTBE (PTT, 2007). It has also been expanding its subway and sky train networks in order to ease congestion in Bangkok city.

In Thailand, road transportation is the main transportation mode. Road transportation alone accounted for 78% of total transport sector FED in 2010, followed by air (domestic and international) transportation (16%) and water (inland waterways and oversea) transportation (6%) (Figure 1.10). The share of energy use for rail transportation in total transport sector energy FED is negligible.

In the past, almost all the energy in transport sector comes from fossil fuels. However, in recent years, biofuels (ethanol and biodiesel), palm diesel, compressed natural gas (CNG) and electricity have been emerging as new fuels, mainly used for road transportation. For example, over the past five years alone, the share of biofuels in total transport FED increased from 0.4% in 2006 to 2.2% in 2010. Likewise, as more natural gas vehicles were introduced, the use of natural gas for transportation increased from 82 ktoe in 2006 to 1597 ktoe in 2010; an increase by 19 folds. However, the share of these environmentally cleaner fuels in total transport sector FED remains very small. In transport sector, diesel is the main fuel accounting for almost 45% in 2010 (Figure 1.11). Gasoline is used with two different blends ULG

(ULG91 and ULG95)[5] with MTBE and Gasohol (E10, E20 and E85). The gasoline use accounted for about one fifth of total transport sector FED in 2010. The share of jet fuel is 16%.

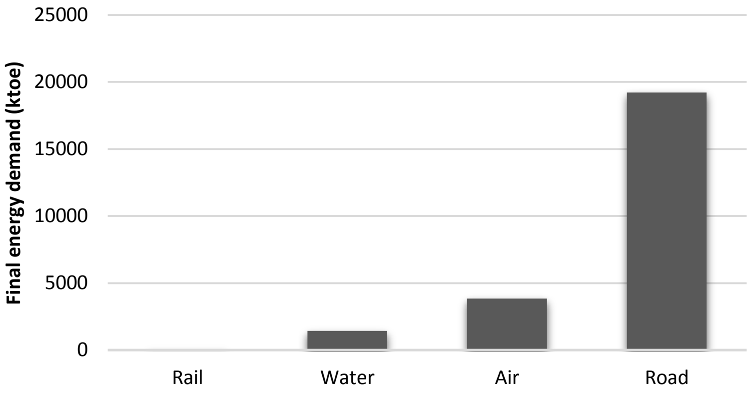

Figure 1.10: Transport sector final energy demand by sub-sector in 2010
Source: DEDE (2012a)

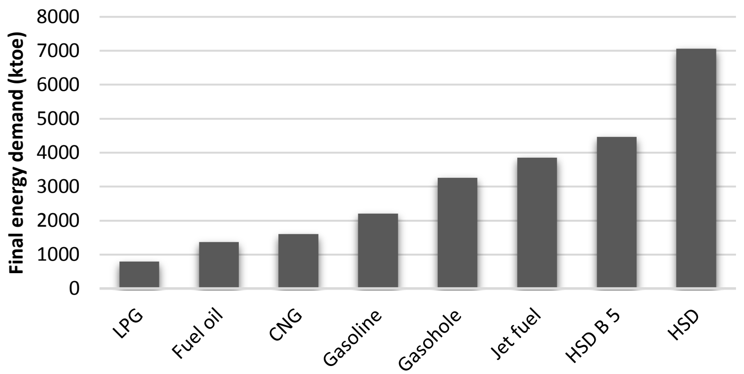

Figure 1.11: Transport sector final energy demand by fuel types in 2010
Source: DEDE (2012a)

1.7. Power generation

Power generation has been increasing steadily in the country (see Figure 1.12). Between 1986 and 2012, the gross electricity generation (including purchase) increased at a compound annual growth rate (CAGR) of 7.8%. The total gross electricity generation reached 179,484 GWh with generating capacity of 33,681 MW in 2012 (EPPO, 2015). During 1986-2012, the

[5] ULG refers to unleaded gasoline; ULG91 is 91% unleaded gasoline and 9% MTBE and ULG95 is 95% unleaded gasoline and 5% MTBE.

electricity consumption per capita increased from 420 kWh in 1986 to about 2,510 kWh in 2012, an increase of almost six-folds (EPPO, 2015).

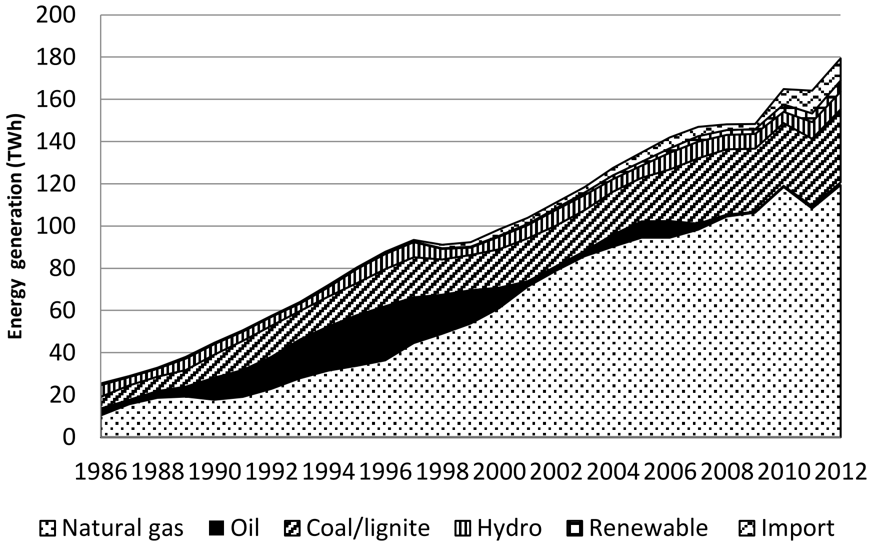

Figure 1.12: Electricity generation by fuel type during 1986-2012
Source: EGAT (2013)

The generation capacity increased at a CAGR of 6% during 1986 to 2012 from 6,624 MW in 1986 to 32,600 MW in 2012 (Figure 1.12). More than half of the total installed capacity in the power system was purchased in 2013. In the figure, the purchased power represents the total power purchased from Independent Power Producers (IPPs) and Small Power Producers (SPPs) as well as power import from neighboring countries (see Figure 1.13).

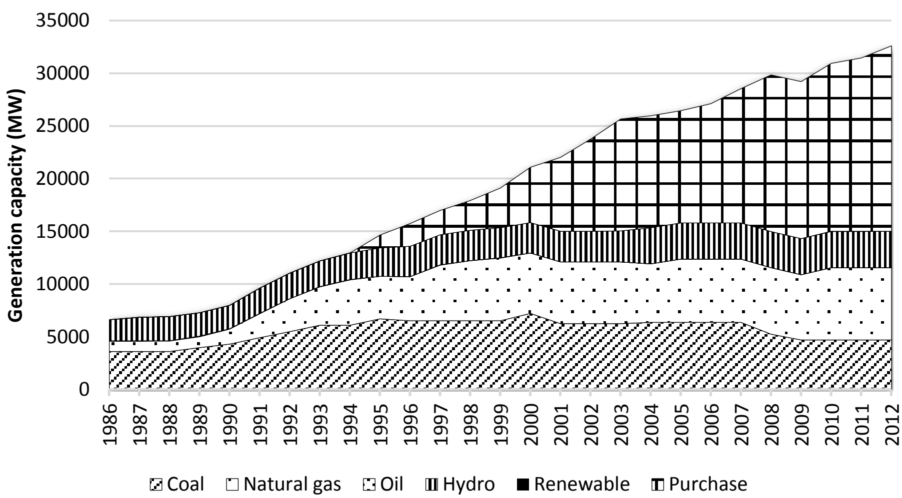

Figure 1.13: Generation capacity during 1986-2012
Source: EGAT (2013)

1.8. Availability of domestic energy resources

1.8.1. Fossil fuel resources

Thailand is endowed with a relatively small quantity of domestic fossil energy resources such as lignite, natural gas, crude oil and condensate. The total proven reserves of lignite is estimated at 2075 million tons (Table 1.1), About 55% of total lignite reserves are located in Mae Moh province, while the remaining 45% of lignite reserves are located in Saba yoi, Wiang Haeng, Krabi, Sin Pun and other provinces. The proven natural gas reserves of the country is estimated at 33.5 trillion cubic feet (Table 1.2) Almost 80% of these natural gas reserves are offshore reserves located in the gulf of Thailand. Limited onshore reserves (i.e., about 20% of total gas reserves in the country) are mainly located in Nam Phong and Sirikit. Besides coal and natural gas, there are some oil reserves in the country. The crude oil in the country is estimated at 902 million barrels (Table 1.3). About 71% of oil reserves are offshore oil fields located at Bechamas and the remaining 29% are onshore oil fields located at Sirikit.

Table 1.1: Proven reserves of lignite in Thailand as of December 2010, million tons

Location	Total quantity
Mae Moh	1131
Saba yoi	350
Wiang Haeng	93
Krabi	111
Sin Pun	91
Others	299
Total	2075

Source: DEDE, 2012a

Table 1.2: Natural gas reserves in Thailand as of December 2010, billion cubic feet

Location	Type of reserve			Total reserves
	Proven	Probable	Possible	
Offshore	10035	11402	5307	26744
Onshore	554	77	1080	1171
Total	10589	11479	6387	33,516

Source: DEDE, 2012a

Table 1.3: Crude oil reserves in Thailand, million barrels

Location	Type of reserve			Total reserves
	Proven	Probable	Possible	
Offshore	137	400	104	641
Onshore	60	61	140	261
Total	197	461	244	902

Source: DEDE, 2012a

1.8.2. Renewable energy resources

The consumption of alternative energy in Thailand is growing rapidly in the recent years. For example, during 2010-2013, electricity consumption from alternative energy sources increased by almost two-folds, i.e., from 807 ktoe in 2010 to 1341 in 2013 (Table 1.4). Likewise, heat from alternative energy sources and biofuels consumption also increased by 8% between 2012 and 2013 (DEDE, 2015a). The increasing use of alternative energy sources in the recent years (2010-2013) are also reflected by the rapid growth of their installed capacity for electricity generation in the country (Table 1.5). For example, installed capacity of solar increased by seventeen folds between 2010 and 2013. Among the renewable energy sources in the country, hydro and biomass are the two main sources currently used at a greater extent. The country has already exploited almost all economically viable hydro for electricity generation. The estimated energy potential of solar is estimated at 506 Mtoe (DEDE, 2015b). Likewise, the total energy potential of biomass, animal waste and MSW are 42.4 Mtoe, 0.3 Mtoe and 6.8 Mtoe, respectively. The use of solar, wind, plantation-based biomass, MSW and biogas are considered for power generation, while agricultural residues are considered for cogeneration and residential cooking in the future (DEDE, 2015b). It is assumed that biomass-based energy resources used for power generation will be supplied by energy plantations grown on a sustainable basis, hence the CO_2 emissions for biomass is assumed to be zero.

Table 1.4: Consumption of alternative electricity, heat and biofuels in Thailand (ktoe)

Alternative Energy Type	2010	2013
Electricity (Solar, wind, small hydro, biomass, MSW and biogas)	807	1341
Heat (Solar, biomass, MSW and biogas)	3763	5279
Biofuels		
Ethanol	334	707
Biodiesel	541	905

Source: DEDE (2015b)

Table 1.5: Installed capacity of alternative energy power plants in Thailand (MW)

	2010	2013
Solar	48.6	823.5
Wind	5.6	222.7
Small hydro	58.9	108.8
Biomass	1650.2	2320.8
Biogas	103.4	265.7
MSW	13.1	47.5

Source: DEDE (2015b)

1.9. Emissions

1.9.1. CO_2 emissions

The CO_2 emissions from fuel combustion in the country increased from 49 Mt in 1987 to 251 Mt in 2014, an increase at the rate of 6% per year (Figure 1.14). This is five times increase between 1987-2014 year (EPPO, 2015). However, when compared with world's CO_2 emissions from fossil fuel combustion, IEA (2014) shows that the share of Thailand was merely 0.8% in 2012. Combined together, the power, industry and transport sectors accounted for more than 92% of total CO_2 emissions in 2014. Sector-wise, power and industry sectors are the two largest sectors responsible for CO_2 emissions. These two sectors together contributed to more than two-thirds of the total CO_2 emissions in 2014.

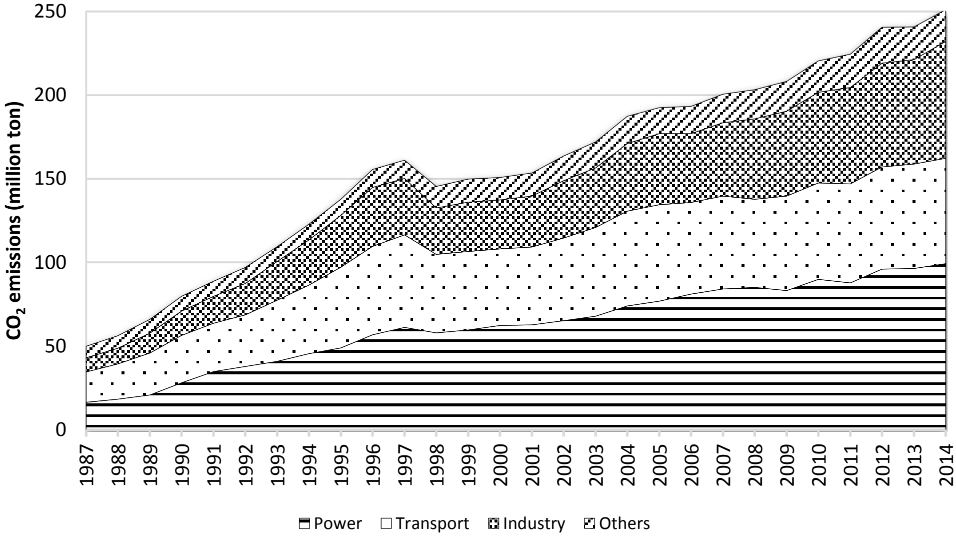

Figure 1.14: Sector-wise CO_2 emission during 1987-2014
Source: EPPO (2015)

By fuel type, oil is by far the largest contributor as it emitted about 36% of total CO_2 emissions in 2012, followed by natural gas (34%) and coal (29%)(EPPO, 2015) (see Figure 1.15).

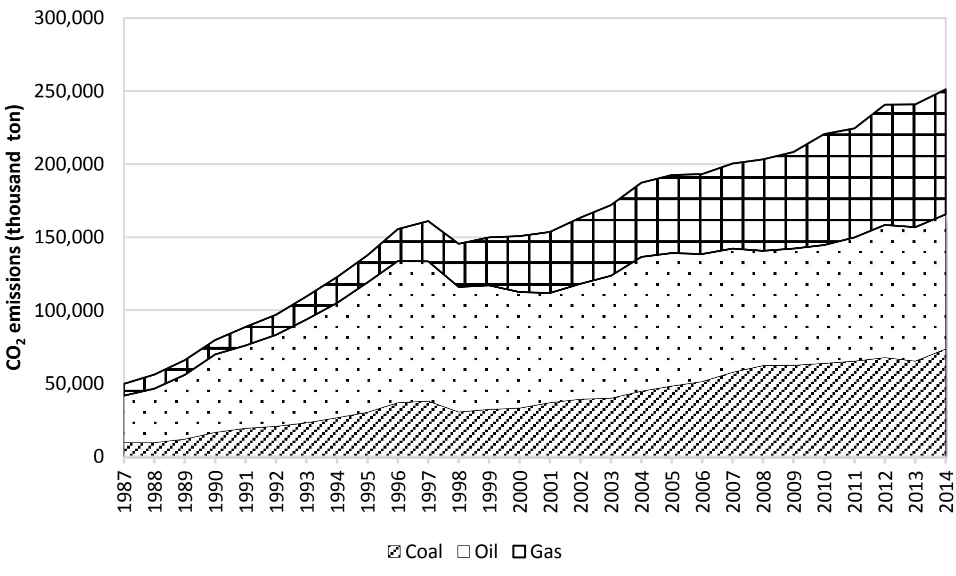

Figure 1.15: Fuel wise CO_2 emission during 1987-2014
Source: EPPO (2015)

The CO_2 intensity (i.e., kg of CO_2 emissions per PPP US$ of GDP at 2011 price) was seen to be increasing from 0.27 kg/US$ in 1990 to 0.37 kg/US$ in 2004 at an AAGR of 2.4%. A decline in the intensity was observed from 0.37 kg/GDP in 2004 to 0.33 kg/GDP in 2008 at an AAGR of -2.9% (see Figure 1.16). In the recent years (i.e., 2008-2011) the CO_2 intensity has been observed to be increasing at the AAGR of 2.9%.

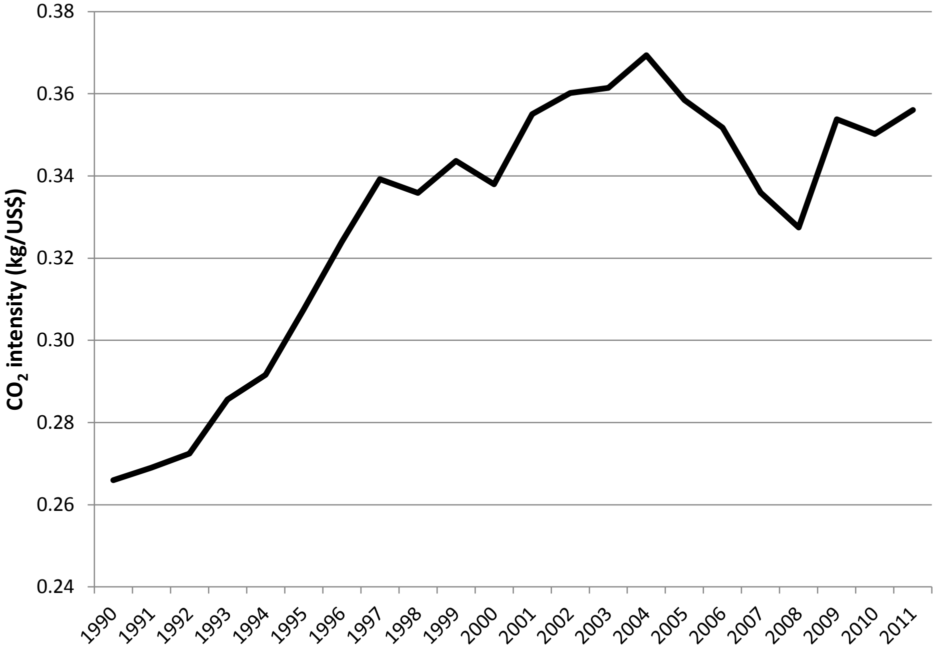

Figure 1.16: The trend of CO_2 intensity in Thailand during 1990-2011
Source: WB (2015)

1.9.2. Other greenhouse gas emissions

The IPCC guidelines (2006) have distinguished between direct and indirect GHGs in terms of the gas's contribution to the greenhouse gas effect. Direct GHGs are those that cause a direct greenhouse gas effect whereas indirect GHGs are those that, after being emitted, form substances in the atmosphere which contribute to the greenhouse gas effect. Due to this reason, CH_4 is known as a direct GHG whereas, NO_x, CO and SO_2 are known to be indirect GHGs. In this study, the NO_x and CO emissions remained about the same while SO_2 and CH_4 emissions increased during 2006-2010 period (Figure 1.17). Between 2006 and 2010, NO_x emissions increased by 1.3 times, from 731 kt in 2006 to 951 kt in 2010. The transport, power and industry sectors are the largest NO_x emitters, contributing together to almost 78% of total NO_x emission in 2010. In contrast, SO_2 emissions remained about the same from 462 kt in 2006 to 559 kt in 2010. Power and industry sectors are the main contributor to SO_2 emissions. These two sectors combined accounted for almost 97% of the SO_2 emissions in 2010.

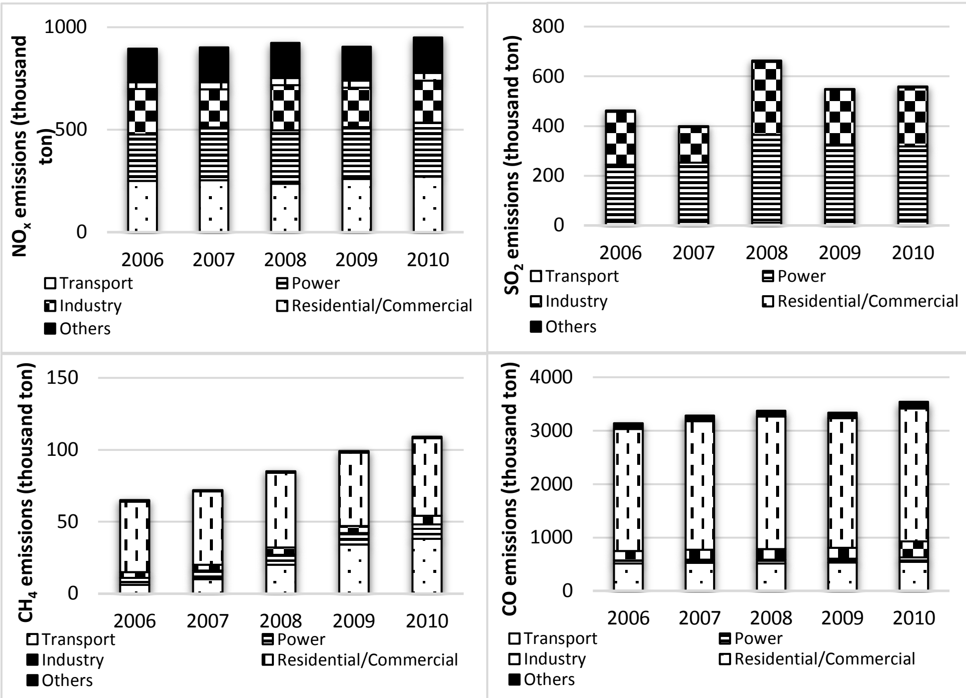

Figure 1.17: Emissions of NO_x, SO_2, CH_4 and CO during 2006-2010
Source: DEDE (2012a)

1.10. Climate Friendly Policies

Thailand has submitted its Second National Communication to UNFCCC in 2011. Several climate change policies and measures have been addressed in order to drive toward sustainable development and low carbon resilient society, as described in its 11th national Economic and Social Development Plan 2012-2016. In 2015, the Royal Thai Government has endorsed the National Climate Change Master Plan (2015-2050) under vision of "Thailand will achieve sustainable low carbon growth and climate change resilience by 2050". It includes target by 2020 under NAMA roadmap, and 2030 under INDC. Both mitigation and adaptation issues are addressed in its National Climate Change Master Plan. Related policies and measures are proposed across the related ministries.

Ministry of Energy formulated 20-year Energy Efficiency Development Plan (2011-2030) and targeted to reduce Thailand's energy intensity by 25% in 2030 with respect to 2005 level (MoE, 2011).

With an aim to promote the share of renewable energy, Alternative Energy Development Plan (AEDP) (2012-2021) was formulated with a target to increase the share of renewable energy to 25% in the national energy mix (DEDE, 2012b). In order to achieve this target, AEDP also provided financial mechanisms to promote renewable based electricity in the form of adder on buy back rates. The added rates vary for different types of renewables. AEDP was revised in 2015 and 20 year AEDP 2015-2036 (AEDP-2015) was developed. AEDP-2015 has a target to increase the share of renewable in total energy consumption to 30% by 2036 (DEDE, 2015a) while AEDP 2015 under Power Development Plan 2015-2036 (PDP-2015) has set a target to increase the share of renewable and large hydro to 18% and 2% respectively in power generation mix in 2036 (DEDE, 2015b).

Under AEDP (2012-2021), the production target of ethanol, biodiesel, and advanced biofuels is set to be 9 million liters/day (ML/d), 7.2 ML/d and 3 ML/d respectively. The production of ethanol and biodiesel in 2013 was 2.6 ML/d and 2.9 ML/d respectively (DEDE, 2012a). AEDP was revised to AEDP 2015 and new target was set. The production target for ethanol is 7 million liters/day and 11.3 million liters/day by 2026 and 2036, respectively. Similarly, the target for biodiesel production is 5 million liters/day and 14 million liters/day by 2026 and 2036 respectively (DEDE, 2015a).

National Transport Master Plan (2011-2020) focused on promoting environmentally friendly transport technologies, cost-effective modal shift, reduce emission and energy consumption in transport sector.

Thailand's National Industrial Development Master Plan (2012-2031) focused on promoting environmentally friendly production and sustainable development of green industries (MoI, 2011).

Besides, implementing various climate friendly plans and policies, Thailand also agreed to reduce its GHG emissions level. Thailand had to reduce its emission by 20% compared to BAU level by 2030 in its Intended Nationally Determined Contribution (INDC) report submitted to UNFCCC. The INDC target has been formulated based on various approved and in the pipeline plans and policies. Earlier, Thailand had also agreed to take part in Nationally Appropriate Mitigation Actions (NAMAs) to reduce emission. In NAMA, Thailand had targeted to achieve 7 to 20% reduction in its emission compared to the BAU level by 2020 (UNFCCC, 2015).

1.11. Summary

Thailand is the second largest economy among the ASEAN and is considered as an upper middle income developing country. Despite the economic growth temporarily decelerated over the past decade or so, Thailand's economy is projected to remain slightly growing over the next few years. Although Thai population more than tripled over the past five decades, however the population growth is projected to decline steadily from 2023 onwards. One important demographic change in Thailand is the rising aging population.

The growth of the economy and population over the past few decades has resulted in a rapid growth in energy supply and demand. During 1990-2010, the TPES increased by more than five-folds and FED increased by more than two-folds. Petroleum products are the most dominant component of TPES and the industry sector has the most dominant share in FED. Due to an increase in energy consumption, the emissions of CO_2 and other GHGs have been also increasing significantly over the years: about five folds during 1990-2010. Currently, Thailand has voluntary commitments for CO_2 emissions mitigation under NAMA and INDC until 2030. Some of the programs implemented by the government will eventually contribute to reducing CO_2 emissions. Cleaner energy programs such as the biofuel promotion program, use of CNG in transport sector, expansion of the mass transit system, consideration of clean energy sources for power generation, energy efficiency improvement programs and demand-side management programs will no doubt have a positive impact on the environment. In addition, there are also several programs that have been carried out under the CDM. In years to come the country would require more robust methods for controlling CO_2 emission. Currently, there is much emphasis on developing more advanced and cleaner energy options. In the long-run solar would become cost effective options, nuclear energy would be more reliable and safe. Carbon capture and storage would be carried out as a part of burden sharing. In such a case, Thailand could align its economic development plans with plants to reduce environmental emissions.

References

Asian Development Bank (ADB), 2015. Key Indicators for Asia and the Pacific 2015. ADB, Manila.

Department of Alternative Energy Development and Efficiency (DEDE), 2012a. Thailand energy situation: 2010 Annual Report. DEDE, Ministry of Energy, Bangkok.

DEDE, 2012b. Alternative Energy Development Plan (2012-2021), DEDE, Ministry of Energy, Bangkok.

DEDE, 2015a. Biofuel Status and Policy. DEDE, Bangkok. Accessed online on 12/09/2015 from https://www.mtec.or.th/files/chanpen/1_DEDE.pdf

DEDE, 2015b. Alternative Energy Development Plan (AEDP 2015) under Power Development Plan 2015-2036 (PDP, 2015). DEDE, Bangkok. Accessed online on 12/09/2015 from http://thailand.ahk.de/fileadmin/ahk_thailand/Projects/Biogas_Presentation/AEDP-Biogas-GT-_08-06-15.pdf

Electricity Generating Authority of Thailand (EGAT), 2013. Gross Energy Generation and Purchase by Type of Fuel. EGAT, Nonthaburi.

EGAT, 2013. Statistical data. EGAT, Nonthaburi. Accessed online on 11/25/2015 http://www.egat.co.th/en/index.php?option=com_content&view=article&id=76&Itemid=116.

Energy Policy and Planning Office (EPPO), 2015. Energy Statistics. EPPO, Ministry of Energy, Bangkok. Accessed online on 03/30/2015 http://www.eppo.go.th/info/1summary_stat.htm.

Food and Agriculture Organization (FAO), 2015. FAOSTAT, FAO, United Nations. Available online at <http://faostat3.fao.org/home/E>

IEA, 2013. Energy Balances of Non-OECD Countries (CD-ROM). IEA, Paris.

International Energy Agency (IEA), 2014. CO_2 Emissions from Fuel Combustion: Highlights. IEA, Paris.

Intergovernmental Panel on Climate Change (IPCC), 2006. IPCC (2006) guidelines. Available online at http://www.ipcc-nggip.iges.or.jp/faq/faq.html.

International Monetary Fund (IMF), 2015. World Economic Outlook: Legacies, Clouds, Uncertainties. IMF, Washington, D.C.

Ministry of Information and Communication Technology (MICT), 2015. The Population and Housing Census 2010. National Statistical Office, MICT, Bangkok.

Ministry of Energy, (MoE) 2011. Thailand 20-Year Energy Efficiency Development Plan. MoE, Thailand.

Ministry of Industry (MoI). 2011. Thailand Industrial Development Master Plan 2012-2031. MOI, Thailand.

National Statistical Office (NSO), 2015. The 2010 Population and Housing Census: Executive Summary. NSO, Bangkok. Available online at <http://popcensus.nso.go.th/en/.

PTT, 2007. Petroleum Products, PTT Public Company Limited (PTT), Bangkok (see http://www.pttplc.com/en/ptt_core.asp?page=ps_pr_fu_ga_ng_05).

Sayeg, P., 1998. Successful conversion to unleaded gasoline in Thailand, World Bank, Washington DC (see http://ideas.repec.org/p/fth/wobate/410.html).

United Nations (UN), 2013. World population prospects: The 2012 revision. Department of Economic and Social Affairs, Population Division, UN, New York.

UN, 2015. World population prospects: The 2015 revision. Department of Economic and Social Affairs, Population Division, UN, New York.

United Nations Development Program (UNDP), 2014. Human Development Report 2014. UNDP, New York.

United Nations Framework Convention on Climate Change (UNFCCC), 2015. Thailand's Indented Nationally Determined Contribution (INDC), The Office of Natural Resources and Environmental Policy and Planning (NEPO). Climate Change Secretariat, UNFCCC, Bonn. Accessed online on 11/25/2015 http://www4.unfccc.int/submissions/INDC/Published%20Documents/Thailand/1/Thailand_INDC.pdf

World Bank (WB), 2015. World Development Indicators. WB, Washington. Thailand. Accessed online on 11/25/2015 http://data.worldbank.org/country/thailand

Chapter 2

Thailand AIM/Enduse Model

2.1. Introduction

Most of the analyses carried out in this volume are focused on energy related emissions and the potential for mitigation of GHG and other emissions in the case of Thailand. In order to carry out these analyses, an energy system model (hereafter called "Thailand AIM/Enduse model") was developed and used. The Thailand AIM/Enduse model is a country specific model of the energy system of Thailand developed at the Asian Institute of Technology (AIT), Thailand with the technical assistance from experts at the National Institute of Environmental Studies (NIES) and Mizuho Information & Research Institute, Japan.[1] The model has been developed by using the framework of AIM/Enduse model, which is a member of the Asia-Pacific Integrated Model (AIM) family of models (Kainuma et al., 2003). The AIM/Enduse modeling framework was developed by the NIES, Japan in collaboration with the Kyoto University. The AIM/Enduse framework is designed to determine the cost-effective energy and technology options as well as to estimate the energy related emissions of GHG and other related gases. Like all other country level AIM/Enduse models, the Thailand AIM/Enduse model assesses the energy resource and technology options as well as estimates emissions of GHGs and other gases from Thailand. It also helps to estimate the GHG abatement potential of cleaner technology and energy resource options.

This chapter describes the structure and key elements of the Thailand AIM/Enduse model. The chapter is organized as follows: Section 2.2 describes the structure of the Thailand AIM/Enduse model. Section 2.3 outlines the data requirements to run the model. Finally, Section 2.4 discusses the technology options considered in different sectors of Thailand.

2.2. Thailand AIM/Enduse model

The Thailand AIM/Enduse model is an analytical framework for selection of cost-effective technologies and energy resource options in different sectors of an economy. The model uses a bottom-up cost minimization modeling framework based on linear programming. A schematic diagram of Thailand AIM/Enduse model is shown in Figure 2.1 (see Kainuma et al., 2003 and and AIM Team (2013) for a detailed description of the AIM/Enduse model). The model considers the flows of energy in an economy from the sources of primary energy through their conversion into secondary forms of energy to end-use devices that meet the demands for different energy services. It also

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[1] A number of similar country level AIM/Enduse models have been developed for several countries of Asia including China, India, Indonesia, Japan, Malaysia, Nepal, South Korea, and Vietnam.

considers the flow of materials in the case of process industries. The paths for the flow of energy and materials are characterized by technologies involved along the respective paths. The model is driven by demands for different energy services, which are determined exogenously based on relevant socioeconomic and demographic factors. The minimum total cost of meeting energy service demands in different sectors of the economy is determined by considering the costs of all available technology and energy options (included in the technology and energy databases).

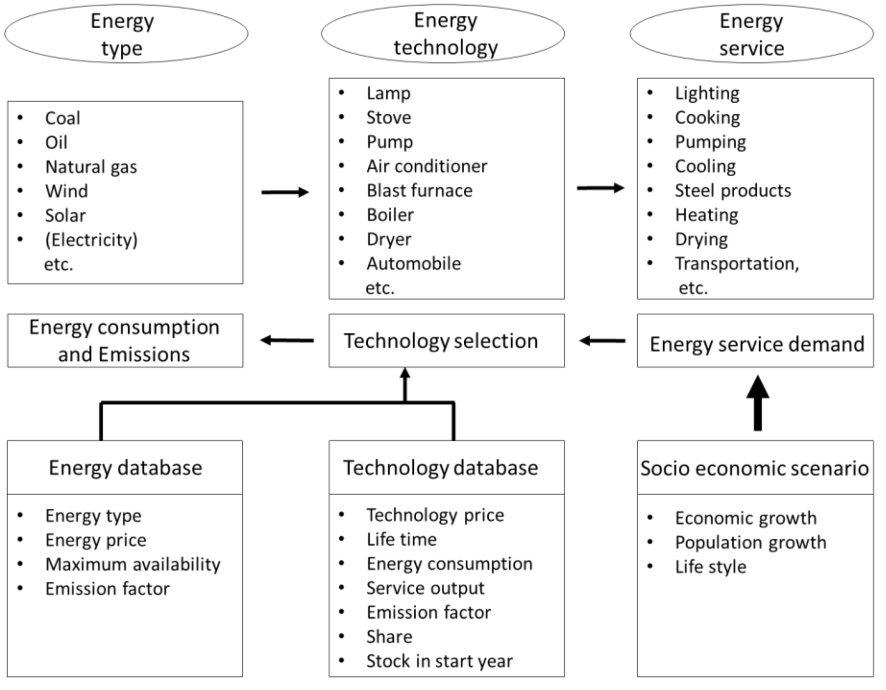

Figure 2.1: A schematic diagram of the Thailand AIM/Enduse model
Source: Adapted from Kainuma et al. (2000) and Shrestha et al. (2007)

The linear programming formulation of the model comprises of an objective function to minimize the total energy system cost subject to a number of constraints related to service demands to be met, energy resources availability, existing device stock, maximum allowable quantity of devices and emissions. The total cost comprises of annualized fixed cost of recruited devices during that year, variable operating cost (operation and maintenance cost of devices, and fuel cost), cost of installing removal devices (flue gas desulfurizers for pulverized coal fired power plants etc.) and cost of energy/emission taxes (carbon tax, energy tax etc.). The formulation also provides functions to consider the existing device quantities in the starting year of the planning horizon and to calculate the retirement of the devices at the end of their life time. Detailed theoretical formulation and mathematical equations of the AIM/Enduse model are provided in Kainuma et al. (2003).

The AIM/Enduse model, in general, considers year by year optimization from the beginning till the end year of the desired planning period.

2.3. Thailand AIM/Enduse Model Inputs

2.3.1. Start year, end year and discount rate

The start year of the analysis in Thailand AIM/Enduse is considered as 2000.[2] Note that at the time of this research study is conducted in 2006, the reasonable amount of data were available from various national and international publications for the year 2000. The adverse effects of climate change are often studied over medium-term (10-30 years) and long-term (50-100 years) horizon (UNFCCC, 2004; Shukla et al., 2004 and Kainuma et al., 2003). In the subsequent chapters, using the Thailand AIM/Enduse model, the medium-term (up to 2035) and the long-term (up to 2050) energy use and its implications of GHG emissions are assessed and and discussed. Throughout the study, the 10% discount rate is considered.

2.3.2. Classification of energy, sectors and services

The Thai economy is broadly classified into energy production, conversion and supply, and energy demand sectors. For sector classification, government reports and past studies on energy demand analysis and energy balance are used (NEPO, 1999; DEDE, 2002; IEA, 2004b). Energy production, conversion and supply sector includes production and supply of coal, oil, natural gas, primary electricity generation, biofuels and hydrogen. In the energy supply-side, extraction of domestic resources of coal, crude oil and natural gas, and imports are considered. On the demand-side, agriculture, commercial, residential, industrial and transportation sectors are considered. Energy demand sectors are further classified into sub-sectors. For example, residential sector is further classified as Metropolitan Electricity Authority (MEA) and Provincial Electricity Authority (PEA) based on electricity supply system. Likewise, industry sector is sub-divided into cement, chemicals, equipment, food, textiles, steel, sugar, paper and other sub-sectors. The other industrial sub-sectors include non-metallic industries (e.g., aluminum, glass production, woods and furniture products) and industries non-classified elsewhere. Similarly, the transport sector is also sub-divided into passenger and freight transportation. The passenger transportation is further divided by modes of transportation such as road, rail, air and water. All trade, hotels, restaurants, and financial and telecommunication establishments are included in the commercial sector.

The energy related services are identified based on their relative contribution to total energy consumption in each sector and data availability. Appendix 2.A shows the classification of these services and their service units in the Thailand AIM/Enduse model.

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[2] Note, however, that the model allows flexibility to choose any other start year and the length of the planning period as desired provided the input data are provided accordingly.

2.3.3. Projection of service demand

In Thailand AIM/Enduse model, that is used for the set of studies in the present book, the projection of service demand in agriculture, commercial, industry and freight transport sectors are based on sub-sectoral value added. It is assumed that service demand in a given year is linearly proportionate to the ratios of value added between the year under consideration and the base year. Alternative rigorous procedure in estimating the future service demand can be estimated through the regression analysis of historical data. However, due to limitations in country specific past and future techno-economic data, estimation of service demand is carried out based on the value added approach. The types of end-use energy services and number of technology options considered in different sectors are presented in Appendix 2B. The measures of activity levels used to estimate the service demands are also included in the appendix. The service demand for sector *i* and sub-sector *k*, based on value added approach, is estimated using the following equation[3]:

$$SD_{i,k,t} = SD_{i,k,0} \times \frac{VA_{i,k,t}}{VA_{i,k,0}}$$

where,

$SD_{i,k,t}$ = Service demand of sector *i* sub-sector *k* in year *t*;

$SD_{i,k,0}$ = Service demand of sector *i* sub-sector *k* in base year 0;

$VA_{i,k,t}$ = Value added of sector *i* sub-sector *k* in year *t*;

$VA_{i,k,0}$ = Value added of sector *i* sub-sector *k* in base year 0.

The approach described above is possible since data for sectoral value added was available until 2016 (TDRI, 2004). The sectoral and sub-sectoral value added is extended till 2050 considering structural change in the economy and experts' opinion. Considering the structural changes in the economy, based on the present dynamics as well as from the experiences of other countries and discussion with the experts, it is unlikely that the economy will reach the point of saturation during the planning period considered in the study. The Thai economy is driven by agriculture, industry and service related sectors. However, Thailand's population projection from 2025 onwards is projected to decline (UN, 2006). Based on declining population projection over the long-term, it is assumed that there will be a slight decrease in annual growth rate of agriculture and selected industry sub-sectors value added from 2030 onwards. The projected sector and sub-

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[3] Note that the sectoral value added elasticities of service demands in this study are assumed to be unity in the absence of the estimates of such elasticities in the case of Thailand.

sectors value added for Thailand over the period 2000-2050 are presented in Table 2.1.

Table 2.1: Thailand's sector and sub sector value added projection during 2000-2050 (Index 2000=1)

Sectors	2000	2010	2020	2030	2040	2050
Agriculture	1.00	1.26	1.63	2.17	2.75	3.49
Industry	1.00	1.69	2.68	4.26	6.80	10.38
Food	1.00	1.45	2.12	3.17	4.74	6.76
Textile	1.00	1.46	2.07	2.94	4.19	5.69
Paper	1.00	1.73	2.82	4.51	7.21	10.99
Chemicals	1.00	1.84	3.20	5.45	9.27	15.09
Cement	1.00	1.85	3.26	5.62	9.69	15.94
Metals	1.00	2.21	4.34	7.91	14.44	23.98
Equipment	1.00	1.77	2.88	4.56	7.22	10.90
Other	1.00	1.76	2.77	4.39	6.95	10.49
Transport	1.00	1.63	2.77	4.68	7.92	12.78
Commercial	1.00	1.78	3.25	5.93	10.82	18.84
Total	1.00	1.61	2.61	4.27	6.80	10.32

Note: Values for 2020-2050 are estimated based on 2000-2020.
Source: TDRI (2004).

The projection of service demand of air conditioners, fans, irons, televisions and refrigerators in residential sector is based on the appliance ownership in each household and the number of projected future households. The Metropolitan Electricity Authority (MEA) has a relatively higher appliance ownership compared to Provincial Electricity Authority (PEA). The appliance ownership in the residential sector is provided in Table 2.2.

Table 2.2: Number of appliances per household in residential sector

	2000		2010		2030		2050	
	MEA	PEA	MEA	PEA	MEA	PEA	MEA	PEA
Air-conditioners	0.16	-	0.18	-	0.30	-	0.60	-
Fans	1.19	0.97	1.25	1.00	2.00	1.25	3.00	1.50
Irons	0.89	0.55	0.91	0.60	1.00	0.80	2.00	1.00
Refrigerators	0.93	0.73	0.95	0.75	1.00	0.85	2.00	1.00
Televisions	0.98	0.91	1.00	0.95	1.50	1.00	2.00	1.50
Other appliances	0.55	1.27	0.60	1.27	0.70	1.50	0.80	2.00

Note: Figures for 2010-2050 are estimated based on experts' opinion.
Source: KMUTT, 2003a,b.

The total demand for number of appliances by sub-sector m and type l in year t is estimated using the following equation:

$$R_{m,l,t} = N_{m,l,t} \times HH_{m,t}$$

where,

$R_{m,l,t}$ = Number of appliances used in residential sub-sector m of type l in year t;

$N_{m,l,t}$ = Appliance ownership per household in residential sub-sector m of type l in year t;

$HH_{m,t}$= Number of household in residential sub-sector *m* in year *t.*

Likewise, the demand for cooking is based on useful energy units. The useful energy is the energy value net of efficiency. The basis for cooking demand projection is per capita useful energy demand and population. The per capita cooking energy demand considered was 28 kgoe/capita in MEA and 38 kgoe/capita in PEA in 2000. However, it is estimated that these values will remain the same (i.e., 28 kgoe/capita) in MEA but it will reach 84 kgoe/capita in PEA by 2035. The cooking energy demand in sub-sector *m* and year *t* is estimated using the following equation:

$$C_{m,t} = K_{m,t} \times POP_{m,t}$$

where,

$C_{m,t}$ = Total useful energy demand for cooking in residential sub-sector *m* in year *t*;

$K_{m,t}$ = Per capita useful energy demand for cooking in residential sub-sector *m* of type *l* in year *t;*

$POP_{m,t}$= Population in residential sub-sector *m* in year *t.*

The demand for lighting is measured in billion lumen hours. Between 2000 and 2035, the lighting demand per household is estimated to increase from 0.15 to 0.35 billion lumen hours in MEA and 0.03 to 0.15 billion lumen hours in PEA. The lighting energy demand in sub-sector *m* and year *t* is estimated using the following equation:

$$L_{m,t} = K_{m,t} \times HH_{m,t}$$

where,

$L_{m,t}$ = Lighting demand in residential sub-sector *m* in year *t*;

$K_{m,t}$ = Per household lighting requirement in residential sub-sector *m* of type *l* in year *t;*

$HH_{m,t}$= Number of households in residential sub-sector *m* in year *t.*

In the transport sector, the service demand for passenger road transport is estimated based on number of registered vehicles, average distance traveled during a given year and vehicle occupancy rate. The demand for road transport is considered in passenger kilometers traveled during a given year. Similar approach is used in other studies (see e.g., Dhakal, 2003; Bose and Srinivasachary, 1997). Based on the vehicle classification defined in DLT (2000) and following the approach of NEPO (1999) and Tanatvanit et al. (2003), the travel demand for the base year by vehicle type *i* is estimated using the following equation:

$$TD_{i,0} = V_{i,0} \times D_{i,0} \times OF_{i,0}$$

where,

$TD_{i,0}$ = Total travel demand for vehicle type *i* in base year (passenger kilometers);

$V_{i,0}$ = Number of vehicles for type *i* in base year;

$D_{i,0}$ = Average distance traveled by type *i* in base year (kilometers);

$OF_{i,0}$ = Occupancy factor of vehicle type *i* in base year (number of persons per vehicle).

Since there is a causal relationship between passenger transport demand with population and the income (Bose and Srinivasachary, 1997), per capita income is considered as the basis for projecting the passenger transport sector. The future travel demand for vehicle type *i* is estimated using the following equation:

$$TD_{i,t} = TD_{i,0} \times \frac{I_t}{I_0}$$

where,

$TD_{i,t}$ = Total travel demand for vehicle type *i* in year *t* in passenger kilometers;

I_0 = Per capita income in base year;

I_t = Per capita income in year *t*.

2.3.4. Energy Sources

All forms of modern and traditional energy types used in the country and potential future energy types are considered in developing the energy systems model of Thailand. The primary energy forms comprised of fossil fuels and renewable energy. Both domestic (i.e., extraction of indigenous energy resources) and import of fossil fuels and all potential availability of renewable energy sources are considered. Furthermore, production of secondary energy types including electricity and hydrogen are also represented in the reference energy system of Thailand.

The energy supply sector considers both imports and domestically produced forms of primary energy sources. The imports of primary energy constitute coal, oil and natural gas. Due to environmental concerns (The Nation, 2002), only the imports of high quality coal (i.e., anthracite), which contains low sulfur content, is considered. Thailand imports natural gas from neighboring countries (Malaysia and Myanmar) through pipelines (DEDE, 2012). No maximum limit is set on primary energy imports.

The secondary energy types considered include oil refinery products, electricity, biofuels and hydrogen. The refinery products includes diesel, gasoline, kerosene, LPG and fuel oil. Production of biodiesel and gasohol are considered under biofuels. Biodiesel comprised of 10% palm oil and 90% diesel, and gasohol comprised of 10% ethanol and 90% gasoline. Hydrogen production is considered using coal and natural gas-based fuel cell technologies.

2.3.5. Domestic energy resource availability

Thailand is endowed with domestic fossil fuel energy resources such as lignite, natural gas, crude oil and condensate. The total proven reserves of lignite is estimated at 2,075 million tons. As summarized in Table 2.3, about 55% of total lignite reserves are located in Mae Moh province while the remaining 45% of lignite reserves are located in Saba yoi, Wiang Haeng, Krabi, Mae Ramat, NGAO, Sin Pun and other provinces (DEDE, 2012). The proven natural gas reserves of the country are estimated at 10.6 trillion cubic feet. As seen from Table 2.4, almost 95% of these natural gas reserves are offshore reserves located in the gulf of Thailand. Limited onshore reserves (i.e., about 5% of total gas reserves in the country) are located in Nam Phong and Sirikit (DEDE, 2012). Besides coal and natural gas, there is limited oil reserves in the country: estimated at 516 million barrels (Table 2.5). About 71% of oil reserves are offshore oil fields located at Bechamas and the remaining 29% are onshore oil fields located at Sirikit (DEDE 2012).

Table 2.3: Proven reserves of lignite in Thailand in 2010, million tones

Location	Total quantity
Mae Moh	1,131
Saba yoi	350
Wiang Haeng	93
Krabi	111
Mae Ramat	38
NGAO	48
Sin Pun	91
Others	213
Total	2,075

Source: DEDE, 2012

Table 2.4: The details of Natural gas reserves in Thailand in 2010, billion cubic feet

Location	Type of reserve			Total reserves
	Proven	Probable	Possible	
Offshore	10,035	11,402	5,307	26,744
Onshore	554	77	1,080	1,711
Total	10,589	11,479	6,387	28,455

Source: DEDE, 2012

Table 2.5: The details of crude oil reserves in Thailand in 2010, million barrels

Location	Type of reserve			Total reserves
	Proven	Probable	Possible	
Offshore	137	400	104	641
Onshore	60	61	140	261
Total	197	461	244	902

Source: DEDE, 2012

Among the renewable energy sources in the country, hydro and biomass are the two main sources used at a greater extent. In 2010, the country had 15,112 MW of indigenous and 11,328 MW of international hydro projects (DEDE, 2012). The maximum potential of solar and wind considered in the study are estimated at 42,356 and 14,141 MW MW, respectively (DEDE, 2012). The maximum exploitable potential of agricultural residues is considered at 15 Mtoe (Prasertsan and Sajjakulnukit, 2006). Likewise, plantation-based biomass is estimated to supply an installed capacity up to 10,000 MW (Sajjakulnukit and Verapong, 2003). In addition, the total availability of municipal solid waste (MSW) is estimated at 2,064 ktoe and biogas is estimated at 570 ktoe (ONEP, 2006). The use of solar, wind, plantation-based biomass, MSW and biogas are considered for power generation while agricultural residues are considered for cogeneration and residential cooking in the future. It is assumed that biomass-based energy resources used for power generation will be supplied by energy plantations grown in a sustainable basis, hence the CO_2 emissions for biomass is assumed zero.

2.3.6. Energy prices and emission factors

The cost including insurance and freight (CIF) based price is considered for the imports of crude oil and coal. In the case of petroleum products, the ex-refinery price is used in the analysis. The ex-refinery price excludes the contributions to oil and energy conservation funds and excise, municipal and value added taxes. The import price of fossil fuels and price of petroleum products are taken from EPPO (2006) and DEDE (2004). The electricity price is the average price of electricity for a given sector based on DEDE (2004). Likewise, natural gas price for end users are taken from EPPO (2006). The price of plantation based biomass reported in Sajjakulnukit and Verapong (2003) is considered too low. Therefore, biomass price is taken from ARRPEEC (2006). The price of hydrogen is taken from IEA (2005) and Tseng (2005) based on the assumption that hydrogen will be centralized production using natural gas or coal with carbon capture and storage (CCS). The price escalation of coal, oil and natural gas over the study period is taken from IEA (2004a). In the case of biomass, it is assumed that its price escalation is equivalent to half that of coal. Since it is expected that electricity generation in Thailand will come from coal and natural gas in the future, the price escalation of electricity is assumed as the average escalation prices of coal and natural gas.

Emission factors - quantity of emissions per unit of energy consumed - by fuel types and by sectors considered in estimating CO_2 and NO_x emissions are taken from IPCC (1996), because of lack of national level emission factors data in the country. The emission factor for SO_2 emissions is taken from Foell et al. (1995).

2.4. Technology and Energy Options

There are altogether 375 existing and candidate technology options considered in the model of which 293 are end-use device technologies. The data for technology representation is mainly based on studies carried out by NEPO (1999), Kainuma et al. (2003) and expert opinion. The data on technology options in Thailand are obtained from various national sources. Whenever Thailand specific data are not available, similar data from other countries are adopted (e.g., Kainuma et al. (2003). The energy resource and end-use device options considered in different sectors in the model include the following:

(i) Agriculture

Energy resource options: Electricity and diesel

End-use device options: Conventional tractor, efficient tractor, pump with standard motor, pump with efficient motor

(ii) Residential (metropolitan & provincial)

Energy resource options: Electricity, biomass/charcoal, lignite, kerosene, LPG

End-use device options: Stove (biomass, LPG, kerosene, solar, electric, lignite), efficient stove (LPG, electric), lamp (incandescent, florescent, compact florescent), fan (standard, efficient), air conditioner (standard, efficient), television (standard, new), refrigerator (standard, efficient), iron.

(iii) Commercial

Energy resource options: Electricity, biomass/charcoal, LPG, residual oil

End-use device options: air conditioner (standard, efficient), lamp (incandescent, florescent, compact florescent), refrigerator (standard, efficient), fan (standard, efficient), oven (electric, LPG, residual oil, biomass/charcoal), stove (LPG, residual oil, electric)

(iv) Industry

a) Cement

Energy resource options: Electricity, residual oil, biomass, lignite, natural gas, kerosene and LPG

End-use device options: Cogeneration, standard boiler (lignite, natural gas, kerosene, LPG, residual oil), advanced boiler (natural gas, residual oil),

Process options: Raw meal preparation (vertical mill, tube mill), kiln burner (existing, improved, fluidized bed synthetic furnace), clinker cooler (coal existing, coal improved, natural existing, natural gas advanced), Grinding (with/without pre grinding), final milling (vertical mill, ball mill)

a) Pulp and paper

Energy resource options: Electricity, coal, natural gas.

End-use device options: Cogeneration, standard boiler (lignite, natural gas, kerosene, LPG, residual oil), advanced boiler (natural gas, residual oil).

Process options: stock preparation (small and large), pulp preparation methods (kraft, soda, Secondary fiber pulping, improved kraft), bleaching (conventional and displacement), rolling (standard and improved),

b) Chemical processes

Energy resource options: Electricity, diesel, gasoline, biomass, coal, LPG, natural gas, residual oil, kerosene

End-use device options: Mechanical power (diesel engine, gasoline engine, electric motor, energy efficient motor), dryer (biomass, coal, electricity, LPG, natural gas, residual oil, kerosene), standard boiler (coal, natural gas, kerosene, LPG, residual oil), advanced boiler (natural gas, residual oil).

c) Food processing

Energy resource options: Electricity, diesel, gasoline, biomass, coal, LPG, natural gas, residual oil, kerosene

End-use device options: Mechanical power (diesel engine, gasoline engine, electric motor, energy efficient motor), standard boiler (coal, natural gas, kerosene, LPG, residual oil), advanced boiler (natural gas, residual oil).

d) Equipment manufacturing

Energy resource options: Electricity, diesel, gasoline, biomass, coal, LPG, natural gas, residual oil, kerosene

End-use device options: Mechanical power (diesel engine, gasoline engine, electric motor, energy efficient motor), kiln (electric, natural has, residual oil, biomass), standard boiler (coal, natural gas, kerosene, LPG, residual oil), advanced boiler (natural gas, residual oil), dryer (biomass, coal, electricity, LPG, natural gas, residual oil, kerosene).

d) Steel production

Primary steel

Energy resource options: Electricity, coal

Process options: Coke production (coke oven, coke oven of Japan type, coke oven+ coke dry quenching, coking with coke wetting, coke oven of Japan type + coke dry quenching),

Smelting (COREX, direct Iron Ore Smelting, converter – small/large/ZFG collection, flow control technology),

Sintering (standard furnace, large size furnace, advanced furnace), Steel making (open-hearth furnace, basic oxygen furnace),

Pig iron production (blast furnace – advanced/small/large/dry Top-pressure Recovery Turbine/ wet Top-pressure Recovery Turbine/ wet Top-pressure Recovery Turbine + 100kg cast pig iron/ wet Top-pressure Recovery Turbine + 250kg cast pig iron / dry Top-pressure Recovery Turbine + 250kg cast pig iron),

Slab production (Casting – standard/ advanced/ continuous/ advanced continuous)

Finished steel production (direct hot strip mill, primary rolling machine, large primary rolling machine, advanced heating furnace)

Secondary steel

Energy resource options: Electricity, coal

Process options: Crude steel production (AC arc furnace – small/large/advanced, DC arc furnace – standard/advanced),

Slab production (standard, continuous, advanced, advanced continuous),

	Finished steel production (rolling machine - large/small, direct hot strip mill machine)

d) Textile manufacturing

Energy resource options:	Electricity, diesel, gasoline, biomass, coal, LPG, natural gas, residual oil, kerosene
End-use device options:	Mechanical power (diesel engine, gasoline engine, electric motor, energy efficient motor), standard boiler (coal, natural gas, kerosene, LPG, residual oil), advanced boiler (natural gas, residual oil), dryer (biomass, coal, electricity, LPG, natural gas, residual oil, kerosene).

e) Sugar production

Energy resource options:	Electricity, residual oil, biomass, natural gas
End-use device options:	Cogeneration, boiler (natural gas, residual oil),
Process options:	Juice extraction (existing, improved), evaporation (existing, falling film), crystallization (existing, improved), centrifugal and final processing (continuous, batch)

g) Others

Energy resource options:	Electricity, diesel, gasoline, biomass, coal, LPG, natural gas, residual oil, kerosene
End-use device options:	Mechanical power (diesel engine, gasoline engine, electric motor, energy efficient motor), standard boiler (coal, natural gas, kerosene, LPG, residual oil), advanced boiler (natural gas, residual oil), dryer (biomass, coal, electricity, LPG, natural gas, residual oil, kerosene).

(v) Transport

a) Air transport

Energy resource options:	Jet fuel
End-use device options:	Plane (standard, new)

b) Water transport

Energy resource options:	Diesel, biodiesel, gasoline
End-use device options:	Ship (standard, new), boat (standard, new)

c) Rail transport (Passenger/Freight)

Energy resource options: Diesel, biodiesel, electricity

End-use device options: locomotive (diesel – standard/new, electric, steam)

c) Road transport (Passenger/Freight)

Energy resource options: Diesel, biodiesel, gasoline, gasohol, CNG, hydrogen, electricity

End-use device options: Passenger car (conventional – gasoline/ gasohol/ diesel/ biodiesel/ LPG/ CNG, conventional efficient – diesel/ biodiesel, direct injection – gasoline/ gasohol, hybrid – gasoline/ gasohol, electric, fuel cell)

Fixed route taxi (conventional – gasoline/ diesel/ biodiesel/ gasohol/ LPG/ CNG, efficient – gasoline/ gasohol

Truck (conventional – diesel, biodiesel, efficient – diesel, biodiesel)

Motor tricycle taxi (gasoline, gasohol, LPG)

Urban taxi (conventional – gasoline/ gasohol/ diesel/ biodiesel/ LPG/ CNG, conventional efficient – diesel/ biodiesel, direct injection – gasoline/ gasohol, hybrid – gasoline/ gasohol, electric, fuel cell)

Urban electric train

Van and pickup (conventional – gasoline/ gasohol/ diesel/ biodiesel/ CNG, conventional efficient – diesel/ biodiesel, hybrid – diesel/ biodiesel, fuel cell)

Bus for hire (conventional – gasoline/ gasohol/ diesel/ biodiesel/CNG, conventional efficient – diesel/ biodiesel, hybrid – diesel/ biodiesel, fuel cell)

Fixed route bus (conventional – diesel/ biodiesel/ CNG, efficient – diesel/ biodiesel, hybrid – diesel/ biodiesel, fuel cell)

Micro bus & pickup (conventional – diesel/ biodiesel/ gasoline/ gasohol, conventional efficient – diesel/ biodiesel, hybrid – diesel/ biodiesel, fuel cell)

Motorcycle (conventional – gasoline/ gasohol, conventional efficient – gasoline/ gasohol)

Motor tricycle (gasoline/LPG)

Private bus (conventional – gasoline/ gasohol/ diesel/ biodiesel/ CNG, conventional efficient – diesel/ biodiesel, hybrid – diesel/ biodiesel, fuel cell)

Small rural bus (diesel/ efficient diesel/ biodiesel)

(vi) Power generation

Energy supply includes technology systems for processing of primary energy types such as oil refineries, power plants, biofuel production and hydrogen production. In refining oil, both conventional and efficient refinery types are considered. In power generation, twenty five existing and candidate power generation technologies are considered (Table 2.6). Different technology systems to represent the production of biodiesel and gasohol from ethanol and palm oil are also considered. Hydrogen production is considered using coal and natural gas using technology systems with CCS.

Table 2.6: Existing and candidate power generation technologies

Technology	Fuel used
A. Fossil fuel and biomass based technologies	
Conventional steam	Lignite, natural gas, fuel oil and biomass
Integrated gasification combined cycle (IGCC)	Lignite and coal
Pressurized fluidized bed combustion (PFBC)	Lignite and coal
Integrated gasification combined cycle (IGCC) with CCS	Lignite and coal
Pressurized fluidized bed combustion (PFBC) with CCS	Lignite and coal
Combined cycle	Natural gas and fuel oil
Combined cycle - advanced	Natural gas
Combined cycle – advanced with CCS	Natural gas
Gas turbine	Natural gas and fuel oil
Biomass integrated gasification combined cycle (BIGCC)	Biomass
B. Advanced technologies	
Advanced Fuel Cell	
C. Renewable based technologies	
Hydro, biogas, MSW, wind, solar photovoltaic, solar thermal and geothermal	

Appendices

Appendix 2.A

Classification of sectors, sub-sectors and services in Thailand AIM/Enduse

Sector and final service	Service unit
Agriculture	
Irrigation (pump)	ktoe
Farm land preparation (Tractor)	ktoe
Harvesting (Tractor)	ktoe
Transportation - Road passenger	
Motor tricycle taxi	10^6 passenger kilometer
Fixed route taxi	10^6 passenger kilometer
Urban taxi	10^6 passenger kilometer
Urban train	10^6 passenger kilometer
Van & pickup	10^6 passenger kilometer
Bus for hire	10^6 passenger kilometer
Passenger car	10^6 passenger kilometer
Fixed route bus	10^6 passenger kilometer
Micro bus & pickup	10^6 passenger kilometer
Motor cycle	10^6 passenger kilometer
Motor tricycle	10^6 passenger kilometer
Private bus	10^6 passenger kilometer
Small rural bus	10^6 passenger kilometer
Transportation -Freight	
Pickup	1000 units
Truck	1000 units
Transportation - Rail	
Passenger	10^9 passenger kilometer
Freight	10^9 ton kilometer
Transportation - Air	
Domestic passenger	10^9 passenger kilometer
International passenger	10^9 passenger kilometer
Freight	10^9 ton kilometer
Transportation -Water	
Freight	10^9 ton kilometer
Residential - MEA	
Cooking	ktoe
Lighting	billion lumen hours
Cooling (fan, air-conditioning)	1000 units
Refrigeration	1000 units
Television	1000 units
Ironing	1000 units
Other electrical appliances	1000 units
Residential - PEA	
Cooking	ktoe
Lighting	billion lumen hours
Cooling (fan)	1000 units
Refrigeration	1000 units
Television	1000 units
Ironing	1000 units
Other electrical appliances	1000 units
Commercial sector	
Lighting	billion lumen hours
Air conditioning	ktoe
Refrigeration	ktoe
Thermal use	ktoe
Electricity others (except refrigeration)	ktoe
Industry-Primary steel	
Pig iron	kton
Crude steel	kton

Slabs	kton
Rolled steel products	kton
Industry-Secondary steel	
Rolled steel products	kton
Industry-Cement	
Raw meal	kton
Portland clinker	kton
Ground Cement	kton
Final Product	kton
Industrial-Paper	
Pulp	kton
Bleached pulp	kton
Stock	kton
Final Product	kton
Industrial-Sugar	
Juice	kton
Slurry	kton
Crystals	kton
Sugar	kton
Industrial-Equipment	
Mechanical	ktoe
Thermal	ktoe
Industrial-Food	
Mechanical	ktoe
Thermal	ktoe
Industrial-Textile	
Mechanical	ktoe
Thermal	ktoe
Industrial-Textile	
Mechanical	ktoe
Thermal	ktoe
Industrial-Others	
Mechanical	ktoe
Thermal	ktoe
Conversion and supply	
Electricity generation	
Electricity	ktoe
Oil refinery	
Oil products	ktoe

Appendix 2.B

Classification of service demand component of the Thailand AIM/Enduse Model

Sector/sub sector	Type of Energy Service	Number of Technology Options	Activity Measures
Agriculture	Pumping, tilling	4	Agricultural sector value added
Commercial	Air-conditioning, lighting, thermal use	9	
Industry			
Cement	Mixing, clinker production, milling, others	11	value added for cement
Steel	Primary steel production (coke, sinter, pig iron, crude and rolled steel production) Secondary steel production (crude steel and finished steel production)	44	Value added for steel
Sugar	Juice extraction, slurry production, crystallization and grinding	9	Value added for food
Paper	Pulp production, bleaching, stock production and others	11	Value added for paper
Others (chemicals, food and beverages, fabricated metals, textiles, others)	Thermal and mechanical energy	72	Value added of the respective sub sectors
Residential	Air-conditioning, cooking, lighting, fan, iron, refrigerator, television, other	32	Number of house holds, appliance ownership per household
Transport			
Passenger	Road (passenger car, micro bus and pickup, van and pickup, three wheeler, urban taxi, fixed route taxi, motor tricycle taxi, motorcycle, fixed route bus, bus for hire, private bus, small rural bus, urban train)	79	Per capita GDP, average distance traveled by each vehicle, occupancy factor #
	Rail and air	9	Per capita GDP
Freight	Road and water	12	Transport sector value added

Note: *Appliance ownership is the number of houses that own a specific appliance as a fraction of total number of houses. # Occupancy factor is the average number of persons per vehicle at a given time of travel.

References

Asia-Pacific Integrated Model (AIM) Team, 2013. AIM/Enduse Model Manual Ver3. AIM Team, National Institute of Environmental Studies (NIES), Japan.

Asian Regional Research Programme in Energy, Environment and Climate (ARRPEEC), 2006. Implications of Carbon and Energy Taxes as Instruments for GHG Reduction. Final report submitted to Swedish International Development Agency (Sida), ARRPEEC, Asian Institute of Technology, Pathumthani.

Bose, R.K., Srinivasachary, V., 1997. Policies to reduce energy use and environmental emissions in transport sector: A case of Delhi city. Energy Policy 25, 1137–1150.

Department of Alternative Energy Development and Efficiency (DEDE), 2002. Thailand Energy Situation. DEDE, Ministry of Energy, Bangkok (Accessed online from http://www.dede.go.th/dede/index.php?id=152).

DEDE, 2004. Oil and Thailand. DEDE, Ministry of Energy, Bangkok.

DEDE, 2012. Thailand energy situation: 2010 Annual Report, DEDE, Ministry of Energy, Bangkok. Accessed online from http://www.dede.go.th/article_attach/THAILAND%20ENERGY%20SITUATION%202010.pdf

Dhakal, S., 2003. Implications of transportation policies on energy and environment in Kathmandu Valley, Nepal. Energy Policy 31, 1493–1507.

Department of Land Transport (DLT), 2000. Number of Vehicles Registered in Thailand. DLT, Ministry of Transport and Communications, Bangkok.

Energy Planning and Policy Office (EPPO), 2006. Energy Strategy: Energy for Thailand's Competitiveness. EPPO, Bangkok. (Accessed online from http://www.eppo.go.th/doc/strategy2546/strategy.html).

Foell W., Amann M., Carmichael G., Chadwick M., Hettelingh J.P., Hordijk L., Dianwu Z. (eds.) 1995: RAINS_ASIA: An assessment model for air pollution in Asia. Final report submitted to the World Bank, December (Accessed online from http://www.iiasa.ac.at/~rains/asia1/).

International Energy Agency (IEA), 2004a. World Energy Outlook 2004. IEA, Paris.

IEA, 2004b. Energy balances of non-OECD countries. CD-ROM Database, IEA, Paris.

IEA, 2005. Prospects for Hydrogen and Fuel Cells. IEA, Paris.

Inter Governmental Panel on Climate Change (IPCC), 1966. Revised IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual, Vol. 3., IPCC, Bracknell.

Kainuma, M., Matsuoka, Y., Morita, T. (Eds.), 2003. Climate policy assessment: Asia-pacific integrated modelling. Springer-Verlag, Tokyo.

Kainuma, M., Matsuoka, Y., Morita, T., 2001. The AIM/end-use model and its application to forecast Japanese carbon dioxide emissions. European Journal of Operational Research, v122, 2, 416-425.

King Mongkut's University of Technology Thailand (KMUTT), 2003a. Survey of residential energy consumption in non-municipal area. Final report submitted to Department of Energy Development and Promotion, KMUTT , Bangkok.

KMUTT, 2003b. Survey of residential energy consumption in municipal area. Final report submitted to Department of Energy Development and Promotion, King Mongkut's University of Technology Thailand, Bangkok.

National Energy Policy Office (NEPO), 1999. Thailand's energy strategy and policy. Final report, NEPO, Bangkok.

Office of Natural Resources and Environmental Policy and Planning (ONEP), 2006. Study on CDM case studies in Thailand. ONEP, Bangkok. (Accessed online from http://www.onep.go.th/CDM/en/ publication.html).

Prasertsan, S., Sajjakulnukit, B., 2006. Biomass and biogas energy in Thailand: Potential, opportunity and barriers. Renewable Energy 31, 599–610.

Sajjakulnukit, B., Verapong, P., 2003. Sustainable biomass production for energy in Thailand. Biomass and Bioenergy 25, 557-570.

Shrestha, R.M., Malla, S., Liyanage, M.H., 2007. Scenario-based Analyses of Energy System Development and its Environmental Implications in Thailand. Energy Policy 35, 3179-3193.

Shukla, P.R., Rana, A., Garg, A., Kasphe, M., Nair, R., 2004. Climate policy assessment for India: applications of Asia-pacific integrated model. University Press, Hyderabad.

Tanatvanit, S., Limmeechokchai, B., Chungpaibulpatana, S., 2003. Sustainable energy development strategies: implications of energy demand management and renewable energy in Thailand. Renewable and Sustainable Energy Reviews 7, 367-395.

Thailand Development and Research Institute (TDRI), 2004. GDP forecast 2000-2016. TDRI, Bangkok.

The Nation (2002). Stop 'dirty energy' now – Greenpeace. Article, August 16, The Nation daily newspaper, Bangkok (Accessed online from http://www.nationmultimedia.com/search/page.arcview.php?clid=3&id=64226&usrsess=).

Tseng, P., Lee J., Friley P., 2005. A hydrogen economy: opportunities and challenges. Energy 30, 2703-2720.

United Nations (UN), 2006. World population prospects: The 2006 revision. Department of Economic and Social Affairs, Population Division, UN, New York.

United Nations Framework Convention on Climate Change (UNFCCC), 2004. The First ten years. Climate Change Secretariat, UNFCCC , Bonn.

Chapter 3

Energy Development and Environmental Implications in the BAU Scenario

Abstract

This chapter presents estimates of the future energy consumption and energy related emissions of Thailand in the business-as-usual scenario (BAU) during 2000-2035. AIM/Enduse is the analytical tool used for this study. The present analysis shows that energy consumption would increase from 75 Mtoe in 2000 to 285 Mtoe in 2035 in the BAU scenario, i.e. an increase by nearly three-folds. Fossil fuels would remain the dominant source of energy supply. CO_2 emissions would increase by more than three times, i.e., from 158 Mt-CO_2 in 2000 to 676 Mt-CO_2 in 2035. Oil consumption would be the largest contributor to CO_2 emissions during the study period.

3.1. Introduction

Energy and emissions have been a topic of concern in Thailand due to the country's relatively small endowment of renewable and low carbon energy resources. Fossil fuels are the major sources of energy in the country; the associated GHG emissions make Thailand the second highest GHG emitter in Southeast Asia. This chapter discusses the energy consumption and emissions outlook to 2035 in the country in the business-as-usual (BAU) scenario, i.e. without any policy interventions.

This chapter is divided into six sections. The next section presents the Methodology used in modeling and gives a description of the BAU scenario. The implications of energy use in Thailand during 2000-2035 are given in Section 3.3. The following section (i.e., Section 3.4) covers emissions resulting from energy use. The energy-economic implications of energy use are presented in Section 3.5. The final section (i.e., Section 3.6) provides the conclusion.

3.2. Methodology and BAU Scenario Description

For the purpose of the analysis in the BAU scenario, the Thailand AIM/Enduse model has been used in this study. For the detailed description of the model as well as the technology and energy resource options considered in the study, see Chapter 2.

The BAU scenario is considered as the continuation of current economic, demographic and energy sector trends and policies, and there is no climate and environmental friendly policy. In the BAU scenario, the GDP is assumed to grow at the rate of 6% per annum during 2000-2020 and 5% per annum during 2021-2035. The population is considered to grow at the rate of 0.74% per annum. In addition, the medium per capita appliance ownership in the households, as well as the energy efficiency improvement of 0.2% per annum was considered in the scenario. Appendix 3.A summarizes the maximum availability of domestic fossil-fuel resources (coal, oil and natural gas) during 2000-2035 under the base case. However, no limit is imposed on imports of these fossil-fuel resources. Renewable energy (RE) sources include solar, wind, hydro, geothermal, firewood, charcoal, municipal solid waste (MSW), biogas, agricultural residues, plantation-based biomass and biofuels (i.e., ethanol and biodiesel). The maximum potential of solar and wind for power generation are considered as 42,356 MW and 14,144 MW, respectively (DEDE, 2012). Likewise, the total technical energy potential of agricultural residues considered is 6,642 ktoe (at 2014) which comprise of residues from rice, sugar cane residues (i.e., bagasse and top and leaves), paddy husk, corncob and others (DEDE, 2015). Considering the land area availability, the potential of plantation-based biomass considered is 7,500 ktoe (Sajjakulnukit and Verapong, 2003 and Santisirisomboon et. al., 2003). The plantation-based biomass, considered only for power generation, is produced on a sustainable basis and therefore the corresponding CO_2 emissions is assumed zero. Following DEDE (2006d) the production potential of biofuels considered are 3 million liters per day of ethanol and 8.5 million liters per day of biodiesel. The discount rate considered is 10%. All costs are expressed in constant 1995 US$.

The data on economic and demographic parameters, service demand, technology characteristics, energy price, domestic resources availability, emission factors for CO_2, SO_2 and NO_x, appliance stock in the start year (i.e., 2000) and the maximum share of each technology type are collected from several sources as described in Appendix 3.B.

3.3. Future Energy Requirements

3.3.1. Primary energy supply mix

Increasing share of fossil fuels and dominant shares of transport and industry sectors in the total primary energy supply (TPES) in the country characterizes the BAU scenario. The TPES is estimated to increase by almost three-folds from 75 Mtoe in 2000 to 285 Mtoe in 2035 (Figure 3.1). The share of fossil fuels in TPES is expected to increase from 81% in 2000 to 87% in 2035. Oil would account for little less than half of the TPES in 2000 in the energy mix. Although the demand for oil is expected to increase in absolute terms in the future, its share in TPES would fall to 34% by 2035. This decrease in the share of oil in TPES during 2000-2035 is attributed to the partial substitution of gasoline and diesel by biofuels (ethanol and palm oil) and natural gas in road transport. In contrast, the share of coal in TPES is expected to increase from 11% in 2000 to 28% by 2035. The use of coal in the country is essentially restricted to industries (mainly in cement and iron & steel) and electricity generation. Almost a quarter of the TPES would come from natural gas in 2035. The share is almost the same in 2000. In terms of sectoral use of natural gas, the electricity sector would be the largest user in 2035; this would be followed by industrial applications and road transport. In contrast to fossil fuels, the share of renewables (primarily biomass and hydro) is expected to fall from 19% in 2000 to about 13% in 2035. In the figure, others represent hydro, solar, wind and geothermal. More than 85% of the total renewables is estimated to come from biomass (as biofuels, agricultural residue and plantation-based firewood) during 2000-2035. The declining share of renewable energy sources is largely due to the limitations in the availability of domestic renewable resources. The estimated potential for the wind, solar and geothermal are merely a fraction of the TPES in 2035. Therefore, in case of Thailand, it is estimated that renewable energy, with respect to wind, solar and geothermal, would not play a major role in reducing energy imports and greenhouse gases emissions.

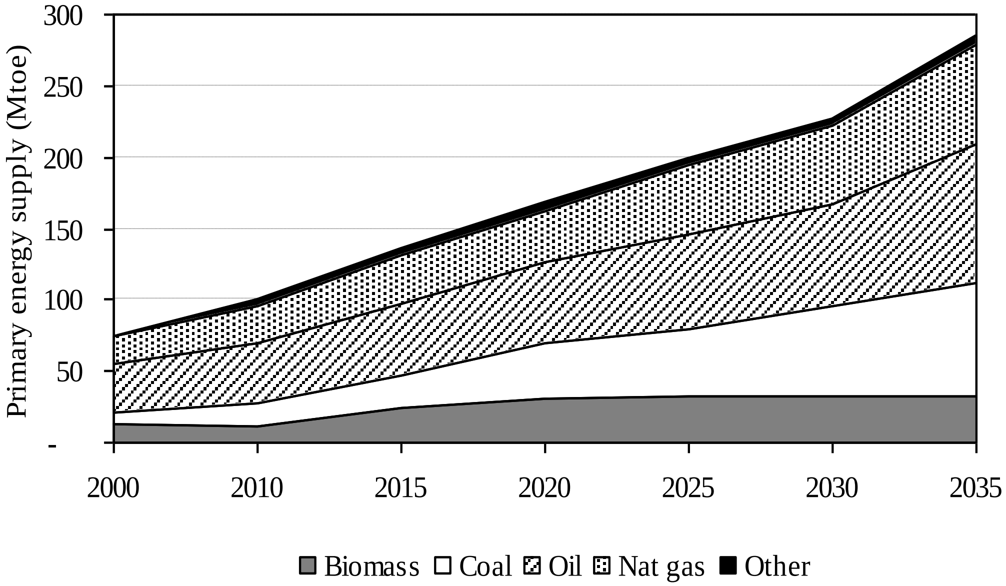

Figure 3.1: Changes in the primary energy supply mix in the BAU case (2000-2035)

3.3.2. Energy security

Thailand does not have abundant reserves of natural gas coal and oil[1]. At the current rate of increase in energy demand these resources will not be sufficient to meet the demand in the future. Thus, concerns of energy security will remain as a leading issue in years to come. It is estimated that the energy import dependency (EID) would increase from 44% in 2000 to 78% in 2035. Therefore, it is important to use energy efficiently and promote

[1] According to DEDE (2004a), Thailand's proven reserves of lignite and natural gas stand at 2,780 Mt and 354 billion m3 respectively. Assuming the current rate of production and no new reserves discovery in the future, indigenous natural gas resource would be exhausted by 2020 while lignite would last for next 140 years or so.

the use of indigenous resources and renewables as a measure of reducing these imports.

While the country has some reserve of lignite, the quality of the resource as a fuel is low. As such, its use has been limited due to environmental concerns. Some amount of lignite was used for electricity generation in 2000[2]. However, in order to promote energy security in the country, lignite would be considered for future applications in an environmentally efficient way. Lignite is considered as an energy option in future years for power generation using environmentally friendly advanced power plant technologies.

Domestic coal/lignite was used only for electricity generation in 2000. For industrial applications, only imported coal was used in that year. However, in order to meet the future demand, more imported coal would be required for electricity generation and for industrial applications. Imported coal would account for almost 70% of the coal-based electricity generation in 2035 (see Figure 3.2). Of the total coal use of 80 Mtoe, almost 81% would come through imports in 2035.

The country's import dependency on natural gas is shown in Figure 3.3. Thailand's domestic natural gas reserves were sufficient to meet the demand in 2000.[3] With the increasing demand for energy in the future and as a cleaner and more efficient form of fossil fuel, natural gas use would be increasing in the future. However, the existing domestic reserves would not be sufficient to meet the increasing demand for a long time. It is estimated that about 85% of the natural gas supply in 2035 would come in terms of imports. The present study considers that the imports from neighboring countries would be sufficient to meet the natural gas demand in 2035. The natural gas costs considered in the present study are for those imports via pipelines as compressed gas. If natural gas is imported in liquid form, the costs would be different as it requires additional costs for transport, infrastructure and storage.

Thailand's oil reserves are not sufficient to meet its demand: it imported almost all of its oil in 2000.[4] Hence the dependence for oil will continue to increase from 8% in 2000 to 98% of the total oil use in 2035 (Figure 3.4).

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[2] According to DEDE (2012), in 2010, 100% of the lignite was used for power generation.

[3] Since the natural gas produced in the country was not enough, Thailand imported 463,393 MMscf. (26.6% of the natural gas supply) in 2010 (DEDE, 2012).

[4] Recent data shows that Thailand imported 85% of the oil supply in 2010 (DEDE, 2012).

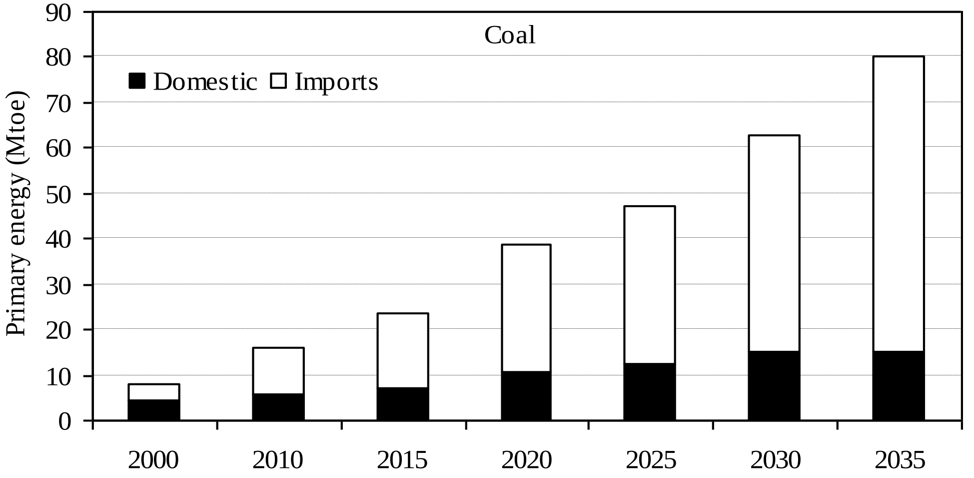

Figure 3.2: Coal import dependency during 2000-2035 in the BAU case

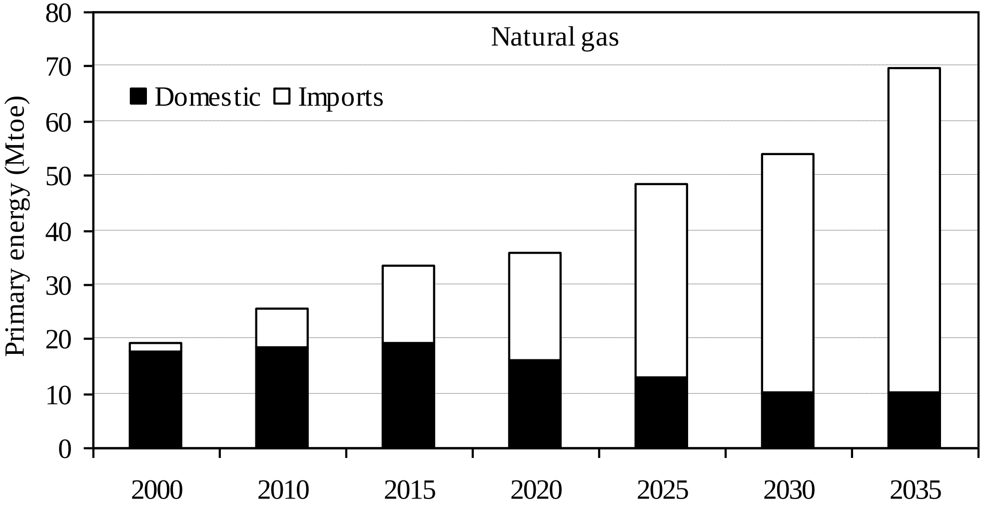

Figure 3.3: Natural gas import dependency during 2000-2035 in the BAU case

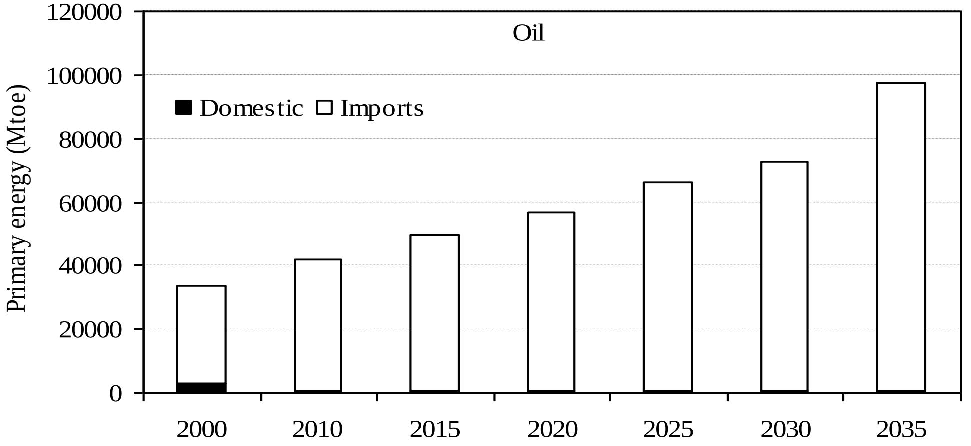

Figure 3.4: Oil import dependency during 2000-2035 in the BAU case

3.3.3. Final energy mix

As can be seen in Figure 3.5, the total final energy demand (FED) would increase from 49 Mtoe in 2000 to 215 Mtoe in 2035, an increase of more than four-folds. The AAGRs of sectoral FED during 2000-2035 are: 2.3% in agriculture, 6.1% in commercial, 5.0% in industry, 1.6% in residential and 4.1% in transport sectors. The transport and industry sectors together accounted for almost 74% of the total FED in 2000. As the country's economy is estimated to grow, it is estimated that the combined share of these two sectors in the total FED would further increase to 81% by 2035.

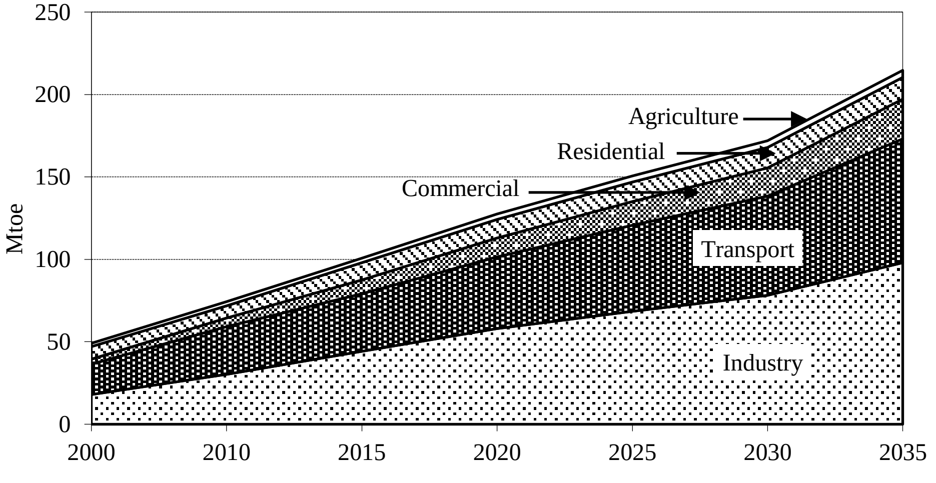

Figure 3.5: Final energy demand by sector in the BAU case during 2000-2035.

Energy mix in the commercial sector

The energy mix in the commercial sector is shown in Figure 3.6. The commercial sector comprises of service demand types such as lighting, air conditioning, refrigeration and thermal uses (mainly cooking). Except for thermal uses, all other end-use applications use electricity. Essentially, electricity is the source for lighting, air conditioning and refrigeration. Therefore, electricity had a considerable share in total final energy consumption in 2000. Nevertheless, its share is estimated to decrease from 80% in 2000 to 67% by 2035. LPG is found to be more economical than electricity in meeting the energy demand for thermal uses. Hence, it would constitute almost one-third of the commercial sector's energy demand by 2035.

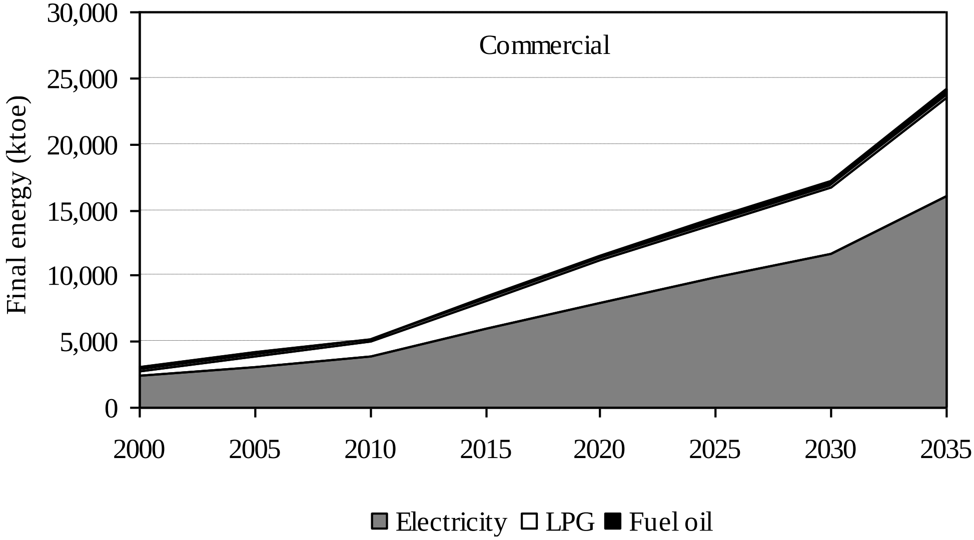

Figure 3.6: Energy mix in the commercial sector in the BAU case

Energy mix in the residential sector

The energy mix in the residential sector is shown in Figure 3.7. The residential sector comprises of energy service demands for cooking, lighting and others using electrical appliances. While biomass, electricity, LPG and kerosene are used for cooking, electricity is used for all other purposes. Biomass accounted for almost 62% of the sector's final energy use in 2000. This is because biomass is the main fuel for cooking in the rural Thailand and the efficiency of biomass-based cooking devices is considerably low. However, biomass and kerosene would be gradually substituted by LPG and electricity in the future. It is estimated that the share of biomass would decrease to about 36% by 2035. The share of LPG would increase from 16% in 2000 to 27% in 2035. Owing to the increase in the use of electricity for cooking and other applications, the share of electricity would increase from 21% in 2000 to about 37% in 2035. Unlike other sectors, the AAGR of the residential sector's total energy use would be about 1.6% during 2000-2035. This is largely due to the slow growth in the population and the use of efficient end-use devices.

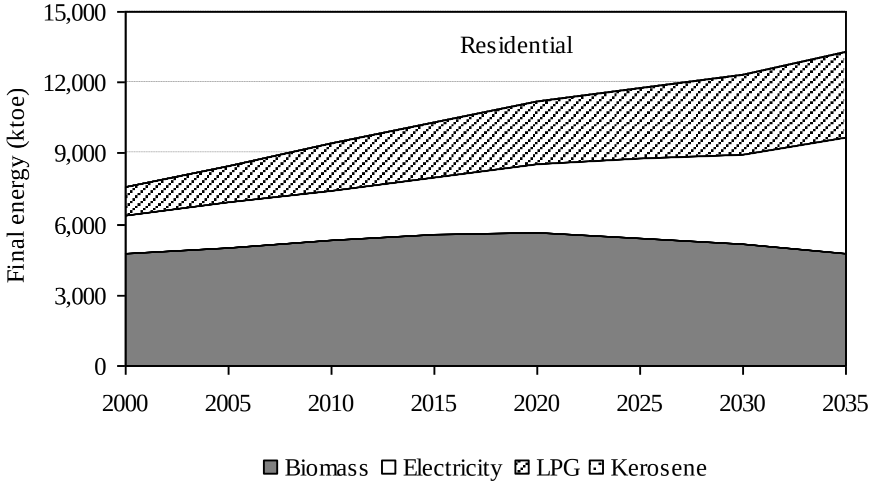

Figure 3.7: Energy mix in the residential sector in the BAU case

Energy mix in the industrial sector

The energy demand in the industry sector is estimated to grow very rapidly at 5.1% during 2000-2035 (Figure 3.8). This is largely due to the increase in energy intensive industries such as cement, iron and steel. During the period, biomass, oil and electricity would be substituted by coal and natural gas. Coal would be used by cement, chemicals, steel and textile industries. Growth of these industries would result in the increase in the share of coal from 25% in 2000 to 46% in 2035. It is found that natural gas would be used mainly by cement, chemicals, food, equipment and textile industries. It is estimated that the share of natural gas would increase from 10% in 2000 to 20% in 2035.

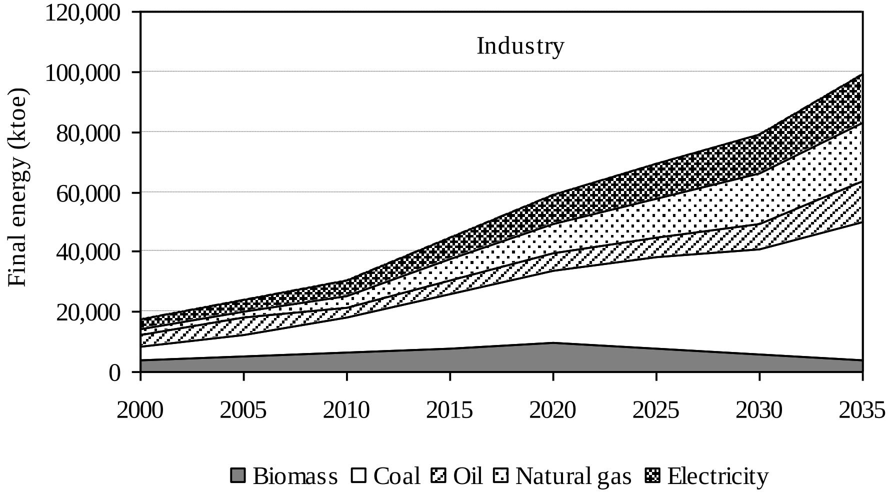

Figure 3.8: Energy mix in the industrial sector in the BAU case

Energy mix in the transport sector

Oil would account for almost the entire energy used in the transport sector (Figure 3.9). Of the oil products, diesel is found to be the most dominant fuel. Due to its extensive use in road, rail and water transport, it would account for more than half of the energy consumption in the transport sector. Gasoline accounted for almost one quarter of the total energy consumption in 2000. It is estimated that the share of oil would decrease to almost a three-quarters of the total energy used in the transport sector by 2035.

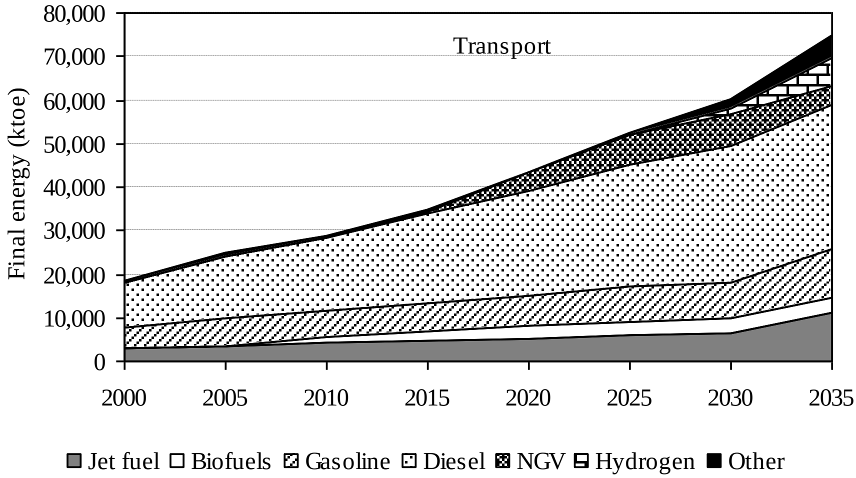

Figure 3.9: Energy mix in the transport sector in the BAU case

In order to reduce the dependence on foreign oil, the Thai government has introduced the use of biofuels and CNG. As a result, it is estimated that the use of biofuels in the transport sector would increase to about 4% in 2035. CNG is also found to be an economically viable source of energy in buses, vans and taxis. It is estimated that the use of natural gas would increase to about 13% by 2025.

3.3.4. Electricity Generation

Although electricity demand would grow at a faster rate at 4.5% compared to the rate of increase in primary energy supply, electricity intensity of GDP is expected to decrease from 539 kWh/US$ in 2000 to 347 kWh/US$ in 2035. During 2000-2035, electricity generation would register more than four-folds increase, i.e., from 93 TWh in 2000 to 433 TWh in 2035. Thus, the installed capacity would increase by almost 45,000 MW, i.e., from 21,074 MW in 2000 to 66,482 MW in 2035. During the period, it is estimated that the electricity generation efficiency of the thermal plants would increase from 35% in 2000 to 52% in 2035 largely due to the introduction of advanced technologies.

The energy input mix for electricity generation is shown in Figure 3.10. Natural gas accounted for almost two-thirds of the energy input for power generation in 2000. Although the quantity of natural gas would increase during 2000-2035, its share in total energy used in electricity generation would decrease. This is because of the increase in the use of coal-fired power plants with CCS, biomass and other renewable energy for power generation. By 2035, coal would have the highest share in total energy use for electricity generation, accounting for almost one-third of the energy inputs. This would be followed by natural gas with the share of almost 27%. The present analysis shows that the plantation-based biomass potential would be fully utilized for power generation by 2035 and almost 19% of energy input for electricity generation is estimated to come from biomass by 2035. There would be no oil used for power generation in the future. The power generation with CCS technology would be economically viable only after 2030.

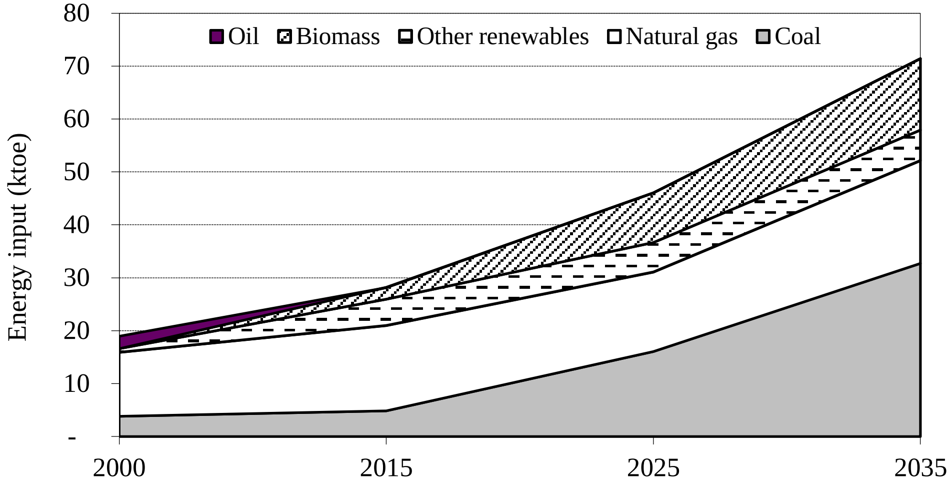

Figure 3.10: Energy mix in electricity generation

Table 3.1 shows electricity generation by plant type in the selected years during 2000-2035. Natural gas-based power plants would have the highest share in electricity generation in 2035. The share of natural gas is estimated to be 31% in 2035. It can be seen that the use of IGCC and PFBC technologies would become economically feasible in the future. These technologies would account for almost 26% of the total electricity generation in 2035. Natural gas-based electricity generation also would involve the use efficient plants. Biomass-based steam and biomass-based integrated gasification combined cycle technologies would generate almost 16% of the total electricity in 2035.

Although renewable-energy is normally expected to play a significant role in power generation in the future, its share would be restricted partly due to resource limitations and partly due to the high cost (particularly in the case of solar power). Renewable energy sources (i.e., wind, geothermal, MSW, and biomass) would account for almost 27 % of the electricity generation in 2035.

Table 3.1: Electricity generation by technology type (TWh)

Technology type		2000	2015	2025	2035
A. Fossil fuel and biomass based technologies					
Conventional steam	Lignite	16	18	22	20
	Natural gas	10	-	-	-
	Fuel oil	10	-	-	-
	Biomass	-	5	23	30
Integrated gasification combined cycle (IGCC)	Lignite	-	-	15	22
	Bituminous coal	-	-	18	35
Pressurized fluidized bed combustion (PFBC)	Lignite	-	-	4	12
	Bituminous coal	-	6	29	45
Combined cycle	Natural gas	39	9	-	-
Combined cycle – advanced	Natural gas	-	94	101	134
Biomass integrated gasification combined cycle (BIGCC)	Biomass	-	5	23	39
B. Carbon capture and storage		-	-	-	-
Integrated gasification combined cycle (IGCC)	Lignite	-	-	-	-
	Bituminous coal	-	-	-	30
Pressurized fluidized bed combustion (PFBC)	Lignite	-	-	-	-
	Bituminous coal	-	-	-	17
C. Renewables based technologies		-	-	-	-
Hydro		8	26	31	31
Wind		-	-	-	2
Geothermal		-	3	6	6
MSW		-	6	6	6
Biogas		-	3	3	3
D. Cogeneration	Coal	3	-	-	-
	Natural gas	6	-	0	-
Total		93	175	282	433

3.4. Emissions from Energy Use

3.4.1. CO_2 emissions

CO_2 emissions from coal, oil and natural gas use are shown in Figure 3.11. Although coal accounted for only 10% of the TPES, it was responsible for 22% of the CO_2 emissions in 2000. With an increase in coal use in the future, it is estimated that coal would contribute to almost 43% of the CO_2

emissions in 2035. However, it should be noted that coal-based CO_2 emission factor would decrease considerably from 4.2 ton/toe in 2000 to 3.7 ton/toe in 2035, because of the utilization of high quality coal and efficient devices (IGCC power plants, efficient boilers, etc.). In contrast, the share of natural gas and oil-based CO_2 emissions would decrease during 2000-2035. Oil accounted for almost 45% of the TPES and almost 55% of the CO_2 emissions in 2000. However, with the decrease in the share of oil in TPES, it is estimated that the share of CO_2 emissions would decrease to 40% in 2035. Similarly, CO_2 emissions from the use of natural gas is estimated to decrease from 23% in 2000 to 17% in 2035. This is attributed to the increase in efficiency of the natural gas based devices.

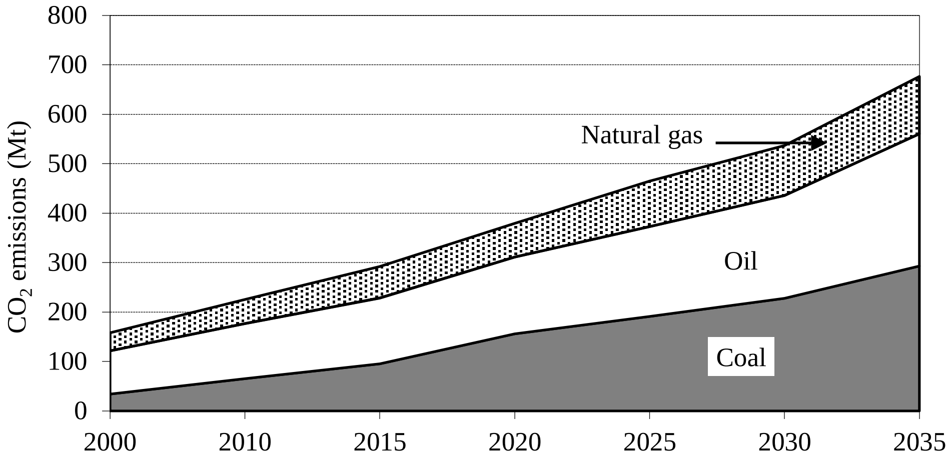

Figure 3.11: CO_2 emissions by fuel type in the BAU case

Thailand's energy related CO_2 emissions is estimated to increase at an AAGR of 4.1%, i.e., from 158 Mt in 2000 to 676 Mt in 2035. As shown in Figure 3.12, the power, industry and transport sectors together would contribute about 93% of total CO_2 emissions during 2000-2035. Others (i.e., residential, commercial and agriculture sectors) would contribute the remaining 7%. In 2035, the industry sector would contribute 40% of the total CO_2 emissions, followed by the transport (29%) and power (25%) sectors. In the same year, the agriculture, residential and commercial sectors together would contribute the remaining 7% of the total CO_2 emissions. The low share of the power sector as compared to that of the industry and transport sectors in the total CO_2 emissions in 2035 is due to the adoption of carbon capture and storage (CCS) based electricity generation technologies.

It is found that the per capita CO_2 emissions in Thailand would more than triple (i.e., from 2.7 tons per person in 2000 to about 9.2 tons per person in 2035) over the next 35 years in the base case. However, the estimated 2035 figure of CO_2 emission per capita in Thailand would still be comparable to year 2002 emission per capita figures of some of the industrialized countries (e.g., 10.2 tons per person in Germany, 9.5 tons per person in Japan and South Korea, and 8.9 tons per person in United Kingdom). The per capita emission in Thailand would be almost twice the projected 2030 level of the world as a whole (i.e., 4.7 tons per person) (IEA, 2004a,b; World Bank, 2006). In contrast, the overall CO_2 emission intensity of the country (defined as kg of CO_2 emission per US$ of GDP at 1995 prices using the market exchange rate) is estimated to decline by 22% during 2000-2035, i.e., from 0.98 in 2000 to about 0.72 in 2035. However, Thailand's CO_2 emission intensity would still be much higher than the corresponding projected figures in 2030 for the world (i.e., 0.45 kg per US$) and and OECD as a whole (i.e., 0.30 kg per US$).

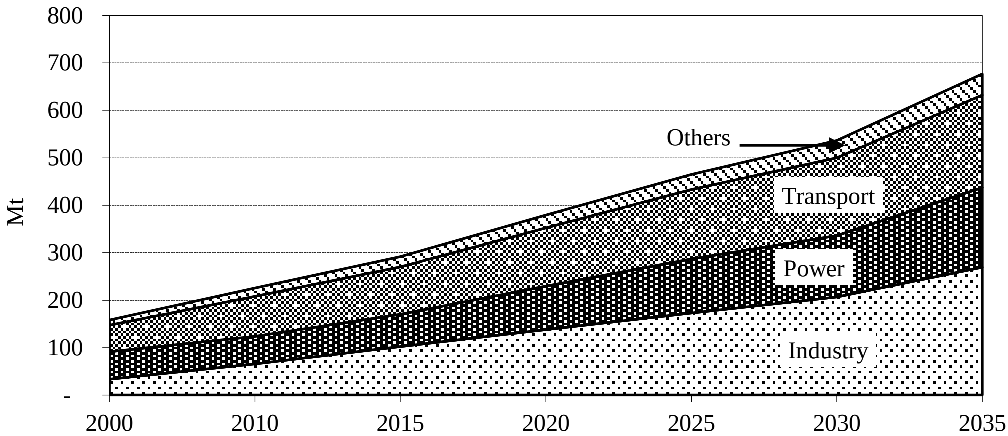

Figure 3.12: CO_2 emissions by sector in the BAU case during 2000-2035

Energy, emissions, electricity and GDP profiles in the BAU scenario

This study shows a comparison between the growths of electricity generation, primary energy supply and carbon emissions in the BAU scenario during 2000-2035 would follow the paths shown in Figure 3.13. The figure also compares the trend GDP and population growth assumed against the CO_2 emissions in the BAU scenario. As can be seen from the figure, the growth in energy consumption and carbon emission would occur at a much slower rate than the GDP, but at a higher rate than the population. This implies more efficient use of energy through the deployment of cleaner technologies (e.g., advanced boilers, efficient cars, advanced power plants technologies, etc.) in the future. Efficient use of energy is characterized by the decreasing energy intensity of the economy: The energy intensity would decrease from 0.44 toe/1000 US$ in 2000 to 0.23 toe/1000 US$ in 2035. The use of efficient devices, increase in autonomous efficiency and the use of cleaner fuels would result in increasing the carbon emission by only 4.3 times by 2035 (as compared to GDP increase by 7.3 times). Carbon intensity of the economy is also estimated to exhibit a declining trend during the period, i.e., from 0.92 ton/1000 US$ in 2000 to 0.54 ton/1000 US$ in 2035.

This is also due to the use of advanced and cleaner technologies.

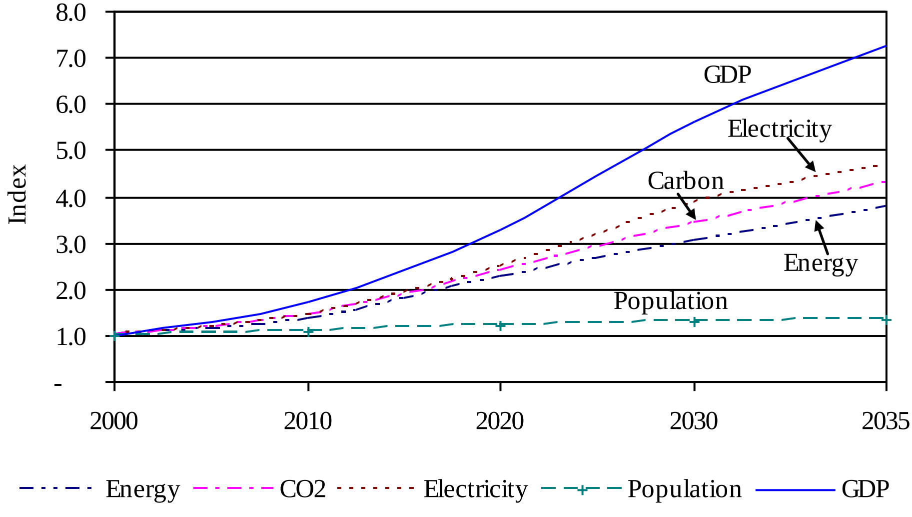

Figure 3.13: Growth of primary energy supply, CO_2 emissions, electricity generation, population and GDP

3.4.2. SO_2 emissions

Coal has a higher sulfur content compared to other fuels. Therefore, the ten-fold increase in the use of coal during 2000-2035 would significantly increase the emission of SO_2. As a result, coal's share in total SO_2 emissions would increase from one-third of the total sulfur emissions in 2000 to three-fourths in 2035 (Figure 3.14). However, the use of clean coal technologies (especially in power generation) would somewhat moderate the actual level of emissions.

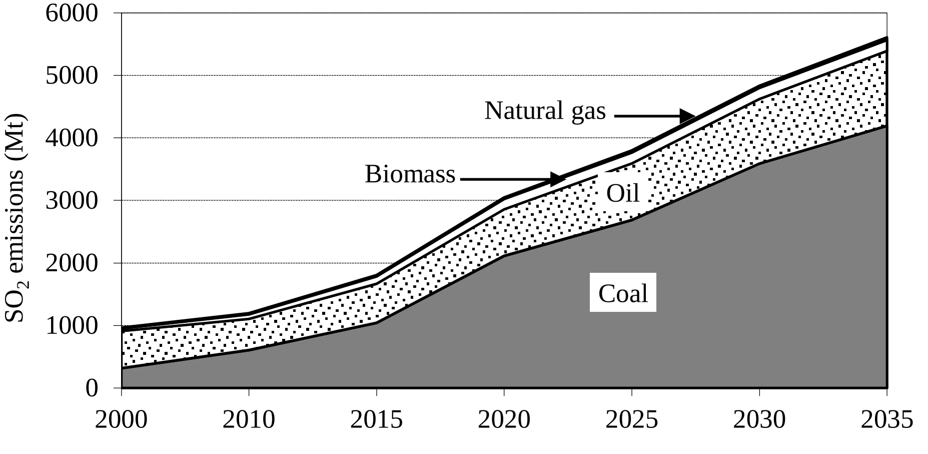

Figure 3.14: SO_2 emissions by fuel type in the BAU case

Oil use is also one of the main sources of SO_2 emissions. It had contributed to almost 62% of the SO_2 emissions in 2000. However, with the increase in the use of other fuels, its share in the total SO_2 emissions would decrease to about 21% in 2035. Natural gas has negligible sulfur content. Therefore, the effect of natural gas on the overall SO_2 emissions would be very small. The share of SO_2 emissions from biomass would be around 3.1% in 2035.

The SO_2 emission would increase by almost five-folds (from 899 kt in 2000 to 5,604 kt by 2035). The shares of SO_2 emission from different sectors are shown in Figure 3.15. Industry, power and transport sectors combined would contribute to more than 97% of total emission in 2035. Others (i.e. residential, commercial and agriculture sectors) would contribute the remaining 2.5%

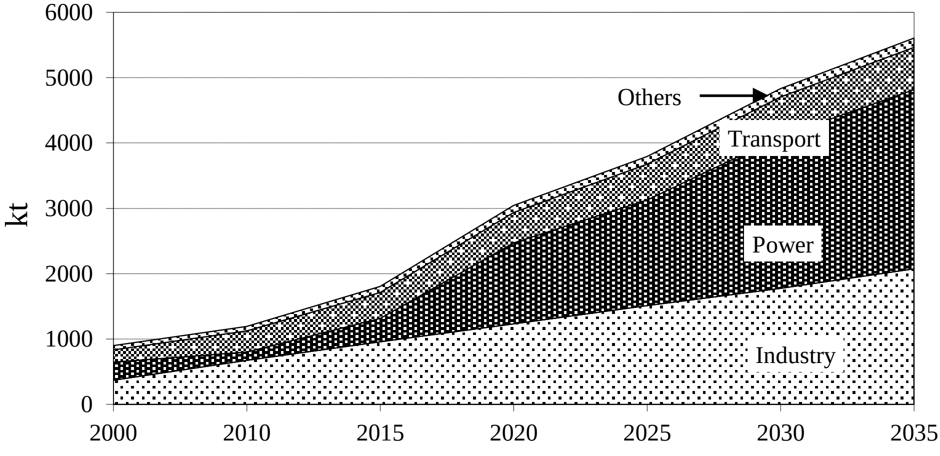

Figure 3.15: SO_2 emissions by sector in the BAU case during 2000-2035.

3.4.3. NO_x emissions

The emission of NO_x is largely technology dependent. Thus, oil using technologies were responsible for almost 73% of the total NO_x emissions in 2000 (Figure 3.16). Since oil use would decline in the future, it would account for only 57% of the NO_x emissions in 2035. Coal has the second highest contribution to NO_x emissions. With the increase in coal use, it would account for almost a quarter of the NO_x emissions by 2035. Combined together, the share of natural gas- and biomass-based emissions would remain almost constant. These fuels will contribute to almost 17% of the total NO_x emissions in 2035.

The emission of NO_x would increase by four-folds (926 kt in 2000 to 3,413 kt in 2035) during 2000-2035. The sector-wise contributions to NO_x emissions are shown in Figure 3.17. Transport sector would contribute to the highest (51.8%) in NO_x emission in 2035. Industry, power and others (i.e., residential, commercial and agriculture combined) would account for 22.7%, 18.2% and 7.3%, respectively of the total NO_x emission in 2035.

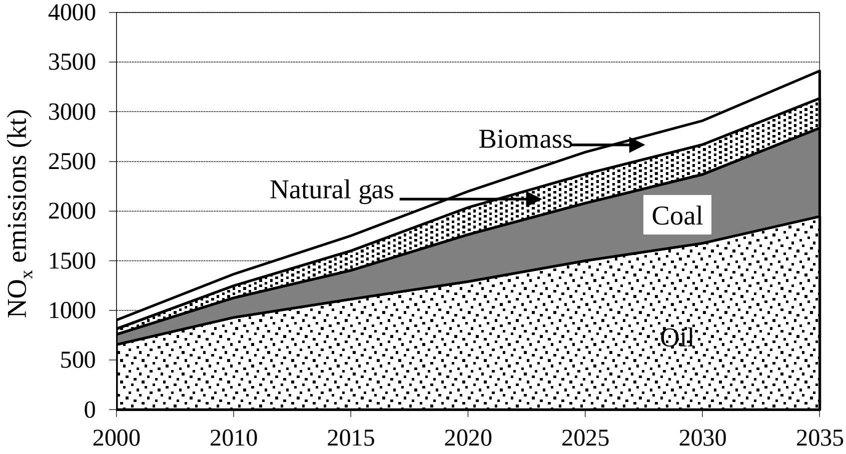

Figure 3.16: NO_x emissions by fuel type in the BAU case

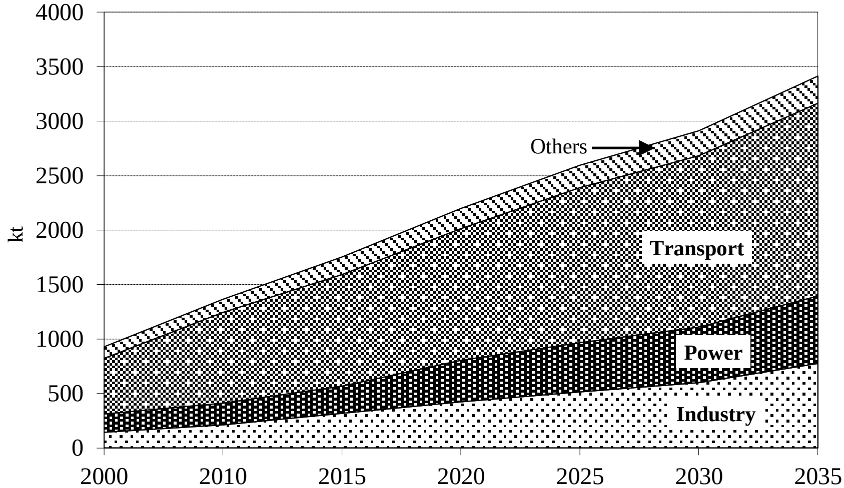

Figure 3.17: NO_x emissions by sector in the BAU case during 2000-2035

3.5. Energy Systems Cost

The present study estimates that in order to sustain the targeted economic growth, energy related expenditures would have to grow at a rate of 7.6% during the 2000-2035 period (Figure 3.18). The expenditures comprise of both capital investment and running cost of energy using devices, both in energy supply- and demand-sides (and include the fuel costs). Capital investment includes the fixed cost spending for both energy conversion devices such as power plants and energy using devices such as cars, machinery, boilers, etc. The study shows that there would be a seventeen-fold increase in the investment flows, i.e., from 19 billion US$ in 2000 to 323 billion US$ in 2035. Capital expenditures would account for almost 56% of the total energy related expenditure in 2000; they would account for about 73% in 2035. During the period, it is estimated that there would be an eight-fold increase in fuel expenses.

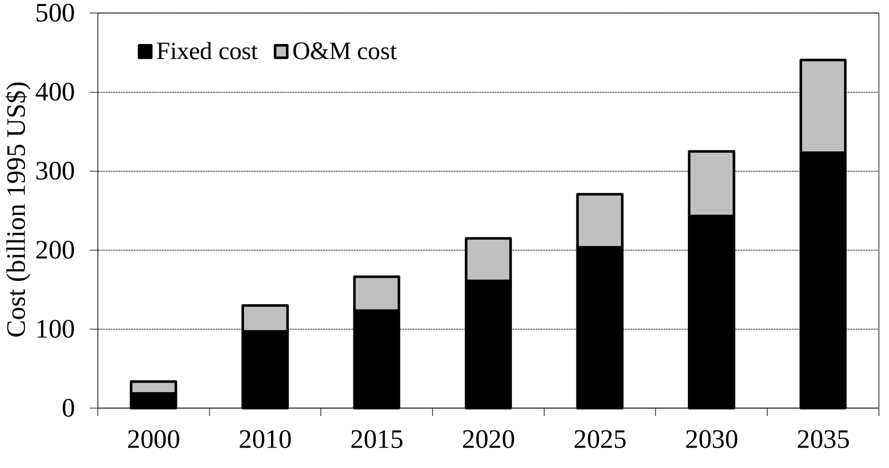

Figure 3.18: Fixed and operation maintenance cost of the energy system

3.6. Conclusion

This chapter analyzes the energy consumption and emission outlook of Thailand up to 2035 in the business-as-usual scenario using the Thailand AIM/Enduse model. The study estimates that the total primary energy supply would increase by almost three-folds from 75 Mtoe in 2000 to 285 Mtoe in 2035. It is found that in the BAU scenario fossil fuels would continue to dominate the primary energy supply mix in Thailand in the future years. Oil would account for the highest share in primary supply, during 2000-2035, although its share would decrease over time. The share of coal would increase from 11% in 2010 to 28% in 2035. The share of natural gas would remain almost same, whereas the share of renewable would decrease from 19% in 2000 to 13% in 2035. Biomass would account for more than 85% of the renewable energy supply. The shares of imported coal, natural gas and oil are found to increase during the period, thereby increasing the fuel import dependency. The energy import dependency would increase from 48% in 2000 to 78% in 2035.

Final energy demand in the commercial sector would be met mainly by electricity. However, the share of electricity would decrease from 80% in 2000 to 67% in 2035. Thermal end-uses, such as cooking, would be met by LPG and fuel oil. LPG would account for about one-third of the final energy demand in 2035. In case of the residential sector, biomass is the main source of energy in 2000 accounting for 62% of final energy demand followed by electricity and LPG with a share of 21% and 16%, respectively. The share of biomass would decrease during the study period to 35% by 2035, whereas the share of electricity and LPG would increase to 37% and 27% respectively. The AAGR of final energy use in the residential sector would be 1.6%.

The final energy demand in the industrial sector would grow at the AAGR of 5.1%, which is relatively very high compared to the residential sector. The demand for coal is estimated to increase along with the growth of the thermal energy intensive industries such as cement, iron & steel, textile, etc. The share of coal would increase from 25% in 2000 to 46% in 2035. Natural gas would also be an economically attractive option in thermal applications such as boilers. The share of natural gas is also estimated to increase from 10% in 2000 to 20% in 2035. On the contrary, the use of oil in industrial application seems to be less attractive; therefore, the share of oil would decrease from 23% in 2000 to 14% in 2035. The share of biomass used in industry is also estimated to decrease from 22% in 2000 to 4% in 2035. Similarly, the share of electricity would decrease from 19% in 2000 to 16% in 2035.

In the case of the transport sector, oil products would dominate the final energy mix during 2000-2035. Oil products had accounted for almost the entire energy consumption in 2000. The share of oil is estimated to decrease to be about 75% by 2035. Diesel would account for more than half of the total uses in the sector in 2035. By 2035, biofuels would account for 4% of the transport sector energy use. The share of natural gas would increase to about 13% by 2025, whereas it would decrease thereafter.

The present study also shows that in the BAU scenario, CO_2 emissions would increase by nearly four-folds during the 2000-2035. This is because the share of coal will increase over time substituting oil and natural gas. The share of coal in SO_2 emission would also increase during the period. In the case of NO_x emission, oil use would be the largest source of emission. The SO_2 emission is largely attributed to the increasing share of coal. However, the share of SO_2 emissions from biomass and natural gas will remain almost unchanged.

Electricity generation would increase by nearly four-folds during 2000-2035. The installed capacity would increase by almost 45,000 MW during the period. During the period, the share of oil and natural gas is estimated to decrease, mainly because they would be substituted by coal and biomass technologies along with CCS. In 2035, coal-based power generation would account for one-third of the power generation, while natural gas and biomass would have a share of 27% and 19% respectively in power generation. The overall thermal efficiency of the power generation would increase from 35% in 2000 to 52% in 2035.

Appendices

Appendix 3.A

Domestic fossil fuels resource availability in Thailand (Mtoe)

Fuel type	2005	2015	2033
Coal	8.4	11.5	15.2
Crude oil	0.4	0.5	0.6
Natural gas	14.6	19.2	10.2

Source: NEPO (1999).

Appendix 3.B

List of sources used in Thai Energy system development

Category	Source
Economic	NESDB, 2003; NIDA, 2006
Demographic	UN, 2004
Service demand	KMIT, 1997; KMUTT, 2003a,b; NEPO, 1999; NSO, 2003, IEA, 2005
Technology type	Kainuma et al., 2003; NEPO, 1999; Tseng et al., 2005;
Energy	DEDE, 2006a,b,c; DEDE, 2004; EGAT, 2004; DEDE, 2012; IEA, 2004b; Prasertsan and Sajjakulnukit, 2006; Sajjakulnukit and Verapong, 2003; Santisirisomboon et al., 2003
Emissions factors	IPCC, 1996; Foell et al., 1995
Appliance stock in the start year	NEPO, 1999; KMUTT, 2003a,b; DLT, 2000

References

Department of Alternative Energy Development and Efficiency (DEDE), 2004. Thailand alternative energy situation 2003. DEDE, Ministry of Energy, Bangkok.

DEDE, 2006a. Thailand energy situation. DEDE, Ministry of Energy, Bangkok (see http://www.dede.go.th/dede/index.php?id=152).

DEDE, 2006b. Electric power in Thailand. DEDE, Ministry of Energy, Bangkok.

DEDE, 2006c. Oil and Thailand. DEDE, Ministry of Energy, Bangkok.

DEDE, 2006d. Energy potentials. DEDE, Ministry of Energy, Bangkok (see http://www.dede.go.th/dede/ index.php?id=586).

DEDE, 2012. Annual Report: Thailand Energy Situation 2010. DEDE, Ministry of Energy, Bangkok.

DEDE, 2015. Alternative Energy Development Plan (AEDP 2015) under Power Development Plan 2015-2036 (PDP, 2015). DEDE, Bangkok. Accessed online on 12/09/2015

Department of Land Transport (DLT), 2000. Number of Vehicles Registered in Thailand. DLT, Ministry of Transport and Communications, Bangkok.

Electricity Generating Authority of Thailand (EGAT), 2004. Power development plan: 2004. Electricity Planning Division, EGAT, Bangkok.

Foell W., Amann M., Carmichael G., Chadwick M., Hettelingh J.P., Hordijk L., Dianwu Z. (eds.) 1995. RAINS_ASIA: An assessment model for air pollution in Asia. Final report submitted to the World Bank, December (see http://www.iiasa.ac.at/~rains/asia1/).

International Energy Agency (IEA, 2004a). CO_2 emissions from fuel combustion, 1971-2002. CD ROM data base, IEA, Paris.

IEA, 2004b. World energy outlook 2004. IEA, Paris.

IEA, 2005. Prospects for CO_2 capture and storage. IEA, Paris.

Intergovernmental Panel on Climate Change (IPCC), 1966. Revised IPCC guidelines for national greenhouse gas inventories: Reference manual, Vol. 3. IPCC, Bracknell.

Kainuma, M., Matsuoka, Y., Morita, T. (Eds.), 2003. Climate policy assessment: Asia-pacific integrated modelling. Springer-Verlag, Tokyo.

King Mongkut's Institute of Technology (KMIT), 1997. The strategy for using energy in rural area. Report submitted to Department of Energy Development and Promotion, KMIT, Bangkok.

King Mongkut's University of Technology Thailand (KMUTT), 2003a. Survey of residential energy consumption in non-municipal area. Final report submitted to Department of Energy Development and Promotion, KMUTT, Bangkok.

KMUTT, 2003b. Survey of residential energy consumption in municipal area. Final report submitted to Department of Energy Development and Promotion, KMUTT, Bangkok.

National Energy Policy Office (NEPO), 1999. Thailand's energy strategy and policy. Final report, NEPO, Bangkok.

National Economic and Social Development Board (NESDB), 2003. National income of Thailand. 1980-2001 edition. NESDB, Bangkok.

National Institute of Development Administration (NIDA), 2006. Thailand long–term load forecasts. Report submitted to Energy Policy and Planning Office, NIDA), Bangkok (see http://www.eppo.go.th/load/nida/eng/contents.html).

National Statistical Office (NSO), 2003. Transport and communication statistics of Thailand. NSO, Bangkok.

Prasertsan, S., Sajjakulnukit, B., 2006. Biomass and biogas energy in Thailand: Potential, opportunity and barriers. Renewable Energy 31, 599–610.

Sajjakulnukit, B., Verapong, P., 2003. Sustainable biomass production for energy in Thailand. Biomass and Bioenergy 25, 557-570.

Santisirisomboon, J., Limmeechokchai, B., Chungapaibulpatana, S., 2003. Least cost electricity generation options based on environmental impact abatement. Environmental Science and Technology 6, 533-541.

Tseng, P., Lee J., Friley P., 2005. A hydrogen economy: opportunities and challenges. Energy 30, 2703-2720.

United Nations (UN_, 2004. World population prospects: The 2004 revision. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, UN, New York.

World Bank (WB), 2006. World development indicators of 2006. WB, Washington.

Chapter 4

Scenario-based Analyses of Energy System Development and its Environmental Implications in Thailand[1]

Abstract

Thailand is one of the fastest growing energy-intensive economies in Southeast Asia. To formulate sound energy policies in the country, it is important to understand the impact of energy use on the environment over the long-period. This study examines energy system development and its associated greenhouse gas and local air pollutant emissions under four scenarios in Thailand through the year 2050. The four scenarios involve different growth paths for economy, population, energy efficiency and penetration of renewable energy technologies. The paper assesses the changes in primary energy supply mix, sector-wise final energy demand, energy import dependency and CO_2, SO_2 and NO_x emissions under four scenarios using end-use based Asia-Pacific Integrated Assessment Model (AIM/Enduse) of Thailand.

4.1. Introduction

In recent years, it has been acknowledged that adverse effects of climate change needs to be studied over a long-term horizon (UNFCCC, 2004). Signed in 1997, the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), require reduction of greenhouse gas (GHG) emissions by industrialized countries. Developing countries (DCs) are not legally required by the protocol to reduce the GHG emissions. Since the financial crisis in 1997, Thailand has undergone a remarkable economic transformation. The country's economic growth trend has improved, from -10.2% in 1998 to 6.2% in 2004.

Although economic growth in 2005 (4.5%) temporarily decelerated due to concerns over rising oil prices and short-term disturbances such as 2004 tsunami and outbreak of avian flu, the country's economic growth is projected to remain between 5% and 6% in 2006. The country is also the second largest economy among the ASEAN[2] countries with a total gross domestic product (GDP) of US$176 billion in 2005 and GDP per capita of

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[1] This chapter is a reproduction of an article published in the Energy Policy journal (Volume 35, Issue 6, June 2007, Pages 3179-3193). The article is available online at http://www.sciencedirect.com/science/article/pii/S0301421506004356

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[2] The Association of South East Asian Nations (ASEAN) includes Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam.

US$2,824 (BOT, 2006). As a result of high economic growth, the country has also recorded strong growth in energy consumption and this growth is expected to increase as well in the future. For example, Thailand's oil consumption in 2004 was about 718,422 barrels per day that rose at an average rate of 9.7% from the previous year (DEDE, 2006a). In 2005 alone, the value of energy imports in the country accounted for 9.6% of the GDP (US$17 billion). This increasing demand for energy would not only put pressure on the country's economy due to increased energy import dependency but it would also increase GHG and harmful local air pollutant emissions.

The existing long-term energy and emission scenarios that have been developed are either heavily aggregated at the regional levels or they are focused on the industrialized countries except in few cases[3]. Motivated by this fact and the rapidly changing economic and demographic structures in DCs, it is of interest to have country specific assessments of energy system development and its associated environmental implications in DCs over a long-term. There are number of studies focused on interrelationship between energy use and the environment in Thailand. Various aspects of these studies include sector specific energy planning and its impact on global and local air pollutants (see e.g., Dang et al., 1994; Shrestha et al., 1998; NEPO, 1999; Tanatvanit et al., 2003, 2004; Bhattacharyya and Ussanarassamee, 2004; Malla and Shrestha 2005; Limmeechokchai and Suksuntornsiri, 2007a,b). However, in order to formulate sound energy policies, a comprehensive understanding of national energy system development is important. In this regard, a least-cost energy system for Thailand is developed and its environmental implications are analyzed during 2000–2050 based on four scenarios. In particular, this study assesses changes in primary energy mix, sector-wise final energy demand (FED), use of renewable energy technologies, energy import dependency (EID) and sector-wise CO_2, SO_2 and NO_x emissions during 2000–2050. To assess these issues, an energy system optimization model for Thailand is developed in the framework of AIM/Enduse model—a model of the Asia-Pacific Integrated Assessment Model (AIM) (Kainuma et al., 2003). The model developed is essentially based on end-use approach that interrelate the energy service demand with the population, GDP, energy price and technological change.

The paper is divided into six sections. Section 4.2 describes the methodological approach. Section 4.3 gives a brief description of data and data sources. A detailed description of the four scenarios is discussed in Section 4.4. Analyses of results and key findings are presented in Section 4.5. The final section provides the conclusion.

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[3] See, for example, Nakićenović et al. (2000, 2006) at the regional/global levels, MOE (2001) and Masui et al. (2006) for Japan; DTI (2003a,b) for United Kingdom; Radanne (2004) for France; Deutscher Bundestag (2002) for Germany; Shukla et al. (2004,2006) for India; Jiang et al. (1999) and Jiang and Hu (2006) for China.

4.2. Methodological Approach

This study uses the bottom up modeling framework based on a cost minimum linear programming approach. Developed by the National Institute for Environmental studies (NIES), Japan, AIM/Enduse model is based on the partial equilibrium framework and the model is used as a tool to estimate the future energy demand and emissions at the regional- and country-levels. It simulates the flows of energy and materials in an economy, from the source or supply of primary energy and materials, through conversion into secondary energy and materials, to the delivery of various forms of energy to the end-use services. In the model, these flows of energy and materials are characterized through detailed representation of technologies providing an end-use scenario-driven analysis. Figure 4.1 shows the simplified structure of the AIM/Enduse modeling framework of Thailand.

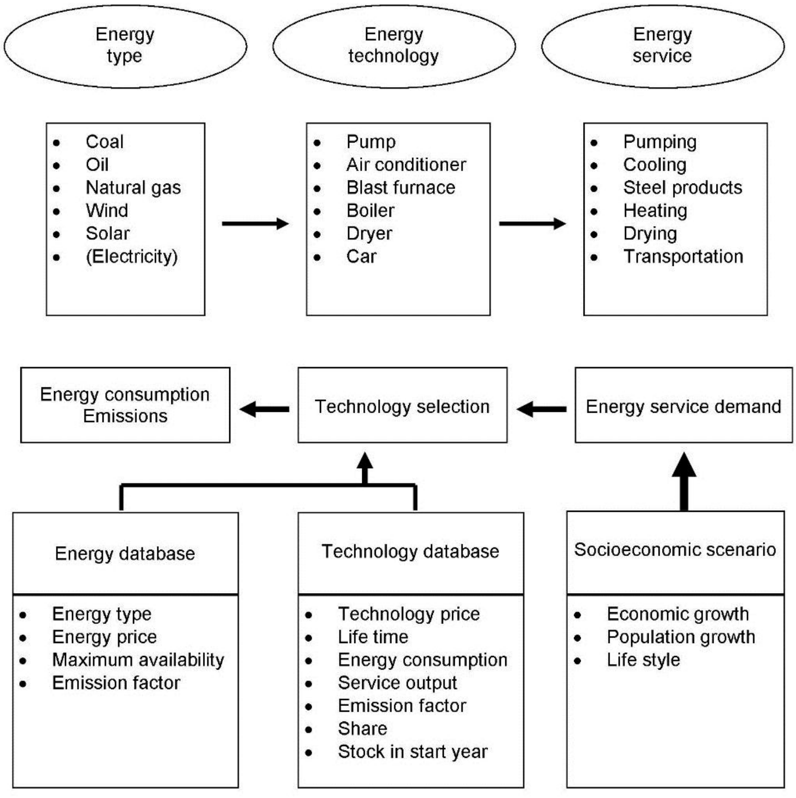

Figure 4.1: Structure of the Asia-Pacific integrated assessment modeling framework of AIM/Enduse.

The database in AIM/Enduse model includes details of energy types, energy technologies, energy-related services and counter measures. The energy database comprise of different energy types and their prices and maximum availability as its parameters while the energy technology database comprise of details corresponding to technology price, life time energy consumption per unit of output and the availability factor. Likewise, the energy service database considers the demand for each service in the economy. The model also considers the quantity of each device at the beginning of planning horizon. The options in counter measures database could incorporate environmental taxes, emission regulations or subsidies on energy or devices. Based on the energy consumption, emissions are estimated. The database comprise of input parameters that represent each stage of an energy system including primary energy production (e.g., mining), conversion of primary energy to secondary energy (e.g., electricity generation) and secondary energy consumption (e.g., petroleum products).

The linear programming framework of the model comprises an objective function to minimize total energy system cost year by year subject to a number of constraints including those on service demand, energy resource availability, existing device stock, maximum allowable quantity of devices and emissions. The total cost comprises of annualized fixed cost of recruited devices during that year, variable operating cost (operation and maintenance cost of devices, and fuel cost), cost of installing removal devices (flue gas desulfurizers for pulverized coal fired power plants, etc.) and cost of emissions taxes (carbon tax, energy tax, etc.). The formulation also provides functions to consider the existing device quantities in the starting year of the planning horizon and to calculate the retirement of the devices at the end of its life time.

In this study, the energy system of Thailand is broadly classified into two components: energy supply and conversion, and service demand. Energy supply and conversion represents energy extraction, imports and conversion of primary energy to secondary energy. In this component, coal mining, natural gas extraction, refining of crude oil and power generation is considered. For power generation, altogether twenty existing and new technology options are considered (Appendix 4.A). A study by NEPO (1999) is used as the basis for classification of sectors and sub-sectors of the service demand. The detailed classification of service demand, technologies and activity parameters are given in Appendix 4.B. The activity parameters, exogenous inputs to the model, are used to estimate the future service demand.

4.3. Data and Data Sources

The data on economic and demographic parameters, service demand, technology characteristics, energy price, domestic resources availability, emission factors for CO_2, SO_2 and NO_x, appliance stock in the start year (i.e., 2000) and the maximum share of each technology type are collected from several sources and these sources are summarized in Appendix 4.C. The data obtained from the original source are processed to meet the input requirements of AIM/Enduse framework.

Table 4.1 summarizes maximum availability of domestic fossil-fuel resources (coal, oil and natural gas) during 2000-2050. However, no limit is imposed on imports of these fossil-fuel resources. New and renewable energy (NRE) sources include solar, wind, hydro, geothermal, firewood, charcoal, agricultural residues, plantation-based biomass and biofuels (i.e., ethanol and biodiesel). The maximum potential of solar and wind for power generation are considered as 5,000 MW and 1100 MW, respectively (Greacen, 2005). Likewise, the maximum exploitable potential of agricultural residues considered is 14,112 ktoe which comprise of sugarcane residues (i.e., bagasse and top and leaves), paddy husk, corncob and others (Santisirisomboon et. al., 2003; Prasertsan and Sajjakulnukit, 2006 and DEDE, 2006e). Considering the land area availability, the potential of plantation-based biomass considered is 7500 ktoe (Sajjakulnukit and Verapong, 2003; Santisirisomboon et. al., 2003). The plantation-based biomass, considered only for power generation, is produced on sustainable basis and therefore the corresponding CO_2 emissions is assumed zero. Following the government's plan, the potential of biofuels considered are 3 million liters per day of ethanol and 8.5 million liters per day of biodiesel (DEDE, 2006d). The discount rate considered is 10%. All costs are expressed in constant 1995 US$.

Table 4.1: Domestic fossil fuels resource availability in Thailand (Mtoe)

Fuel type	2005	2015	2030	2050*
Coal	8.4	11.5	15.2	15.2
Crude oil	0.4	0.5	0.6	0.6
Natural gas	14.6	19.2	10.2	10.2

Source: NEPO (1999);
*Assumed same figures as that of 2030.

4.4. Scenarios Description

The future state of the Thai economy in the long-term can be broadly visualized as a combination of market integration (i.e., extent of liberalization, globalization and the integration with the world markets) and the nature of governance (i.e., centralization vs. decentralization). These two dimensions are similar to those considered in the Intergovernmental Panel on Climate Change's (IPCC) Special Report on Emissions Scenarios (SRES) report and they are adapted to the Thai context (IPCC, 1996). Altogether four scenarios are constructed, the characterization of scenarios is illustrated in Figure 4.2. The following names are given to four scenarios: *global market integration* (TA1); *dual track* (TA2); *sufficiency economy* (TB1); and *local stewardship* (TB2). The four scenarios can be best understood as taking a position in a combination of locus points on the two continuums: extent of market integration and the nature of governance. There may be several other scenarios on the continuum, which are also likely, but only four scenarios are constructed to cover a plausible range, in which future evolution of economy and energy is expected to lie. A brief quantitative summary of the four scenarios are presented in Appendix 4.D.

Governance / *Market integration*	High	Low
Centralization	**TA1** **Global market**	**TA2** **Dual track**
Decentralization	**TB1** **Sufficiency economy**	**TB2** **Local stewardship**

Figure 4.2: Characteristics of four scenarios for Thailand.

Global market integration scenario (TA1): It is characterized by Thailand being more and more integrated into global markets. The role of market forces is predicted to strongly lead to high economic growth and there is a faster transition of the economy towards industry- and commerce- based economy. The GDP would grow by 7.5% per year during the first 20 years (2000-2020) based on the target scenario of NIDA (2006) study and by 5.5% per year for the remaining years (2021-2050) reflecting the possible slowdown of country's economic growth. The main driving force of the economic growth would be energy-intensive manufacturing of cement, steel and chemicals in the industry sector and increasing growth of commercial sector. Because of easy access to global technology market and modernization of economic sectors under this scenario, significant improvement in the efficiency of end-use devices (i.e., an average rate of 0.3% per year) is considered. In the demographic front, the country's average annual population growth is low (0.02%) due to low total fertility rate based on the United Nations low variant population projection over the study period (UN, 2004). Compared to 2000, the urbanization rate would double (62%) in 2050 due to migration from rural to urban areas and transformation of big villages into cities. The increased urbanization would lead to a rapid expansion of infrastructure, especially the transportation demand and facilities. In terms of per capita GDP, it would increase by twenty-folds in 2050 compared to 2000 value due to both high economic growth and low population growth. Households would have high home appliances and car ownership. Demand for energy would be high in order to sustain high economic growth. The price of fossil fuels would increase by a factor of 1.5 times that of International Energy Agency's (IEA) projected annual growth over the study period (IEA, 2004b). The priority is more on the economic growth than on the conservation of environment. Overall, in this scenario, the general development mode of Thai economy is completely market-driven.

Dual track[4] *scenario (TA2)*: This scenario is characterized by the Thai economy that is concentrated on the industries that have the comparative advantage in the world market. In this scenario, Thailand follows closely the national development plans and policies. The GDP growth is moderate at an average rate of 6% per year during 2000-2020 and it would slow down to 5% per year for the remaining years until 2050. Population projection would be high at an average rate of 0.74% per year based on the United Nations high variant projection but aging population in the country would rise. In this scenario, more effective conservation measures in all economic sectors and moderate energy efficiency improvement (0.2% per year) is proposed. Households would have moderate ownership of home appliances and cars. The price of fossil fuels would increase gradually and follows IEA's projection over the study period. This scenario can be considered as a reference scenario reflecting the country's national development plan and policies. The consideration of this scenario is important to show the country's energy strategy that focuses on promotion and development of alternative and renewable energy sources, and energy management and conservation.

Sufficiency economy[5] *scenario (TB1)*: This scenario focuses and supports activities that promote sustainable development. GDP growth is considerable. The average annual economic growth rate would be 6.5% based on the medium scenario of NIDA (2006) study during 2000-2020 and 5.5% for the remaining years until 2050. However, the population growth would be the same as that of TA1. Clean energy and clean production would be the mainstream of the society in this scenario. Accordingly, a higher share of renewable energy technologies is introduced. The energy efficiency improvement for energy using devices would be high at 0.4% per year over the study period. The price of fossil fuels would increase by a factor of 0.5 times as that of annual growth rate of TA2. Household would have moderate appliance ownership and use of public transport is emphasized. This scenario is a consequence of active polices towards balanced economic and social differences in the country.

Local stewardship scenario (TB2): This scenario is characterized by the global economy that is unbalanced with strong economic turmoil in different

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[4] Thai government continues to pursue the explicit policy focus on the duality of the export and the domestic sectors (dual track policy) to bring economic growth with stability. This approach represents a new policy paradigm of simultaneously pursuing the development of a strong domestic foundation for the economy as well as promoting the linkages through international trade, investment and financial cooperation (Chaipravat, 2003).

[5] The philosophy of sufficiency economy, based on adherence to the middle path, is advocated to overcome the 1997-1998 Asian economic crisis that was brought about by unexpected change under conditions of rapid globalization and achieve sustainable development (NESDB and UNRC, 2004).

regions of the world. Hence, this scenario is based on the necessity of strong local communities. Due to global turmoil, economic growth in the country is at low level, 4% per year based on low scenario of NIDA (2006) study during 2000-2020 and 3.5% per year for the remaining years until 2050. Population growth is moderate at an average 0.39% per year based on the United Nations medium variant projection. There is also low energy efficiency improvement at 0.1% per year. Household would have low home appliances ownership and high public transport use. The price of fossil fuels would remain the same as that of the current price.

4.5. Results and Discussions

According to the formulated socio-economic and technological parameters, the Thai energy system is developed over the study period. The corresponding changes in primary energy supply mix, sector-wise FED, EID and CO_2, SO_2 and NO_x emissions under the four scenarios are presented below.

4.5.1. Primary energy supply

Table 4.2 shows the total primary energy supply (TPES) mix in 2000 and selected future years under four scenarios. Thailand is a fossil fuel intensive economy. In the year 2000, the share of fossil fuels (i.e., coal, oil and natural gas) in TPES accounted for about 81% (62 Mtoe) and the remaining share of 19% (15 Mtoe) came from NRE sources. Also in the same year, oil accounted for more than 56% of the total fossil fuels used while biomass (i.e., firewood, charcoal, agricultural residues, plantation-based biomass and biofuels) accounted for more than 93% of the total NRE sources.

Table 4.2: Primary energy supply mix under four scenarios during 2000-2050 (Mtoe)

	2000	TA1			TA2			TB1			TB2		
		2010	2030	2050	2010	2030	2050	2010	2030	2050	2010	2030	2050
Coal	9	17	67	149	16	61	128	16	50	105	14	39	57
Oil	35	43	97	196	40	80	168	42	77	163	38	53	106
Gas	18	27	60	218	26	53	124	25	51	112	24	24	61
Biomass	14	21	34	34	14	34	34	19	28	28	19	24	31
Others[a]	1	1	4	4	1	3	4	1	3	3	1	3	3
Total	77	110	261	601	97	231	456	104	209	409	96	144	258

[a] Others include hydro, solar, wind, municipal solid waste (MSW), bio-gas and geothermal.

As seen from Table 4.2, the TPES between years 2000 and 2050 is estimated to grow from more than three-folds under TB2 to about eight-folds under TA1. Fossil fuels would continue to dominate the country's primary energy supply mix accounting for more than 86% of the TPES under all scenarios in 2050. Oil would remain a single largest fuel in the primary energy supply mix over the study period except under TA1 scenario in 2050. Among the fossil fuels use over the study period, coal would essentially be restricted to all industrial applications except fabricated metals and electricity generation, while oil would essentially be restricted to manufacturing and transportation. In the case of natural gas use, electricity generation would account for the most followed by industries (food beverages, chemicals, cement and fabricated metals production) and road transportation. In contrast, the share of NRE sources in TPES would fall from 19% in 2000 to the lowest at 6% under TA1 to about 14% under TB2 in 2050. The fall in the share of NRE sources over the study period is due to the limited domestic resource availability of biomass and limited potential of hydro, solar, wind and geothermal in the country. Renewables (i.e., biomass and hydro) would account for more than 99% of total NRE sources over the study period. New renewables (i.e., solar, wind and geothermal), however, would account for only a negligible part in TPES over the study period. By 2050, use of biofuels (i.e., ethanol and biodiesel) in transportation sector would reach about 12.7% of the total biomass requirements which corresponds to about 1% of the TPES under the reference scenario.

Thailand is a net energy import country in the past. The EID was about 50% in 2000 and it is estimated to reach ranging from 80% under TB2 to 89% under TA1 in 2050 (Figure 4.3). The increase in EID over the study period is mainly due to growing energy demand and the limited domestic energy resources availability in the country. In 2000 alone, almost all oil consumption, more than 33% of total coal consumption and 10% of total natural gas consumption were imported in Thailand. Under the high growth TA1 scenario, coal and natural gas imports by 2050 are estimated to reach up to 90% and 95% of total coal and natural gas requirements, respectively. The results suggest that concerns of energy security in the country would remain in decades to come.

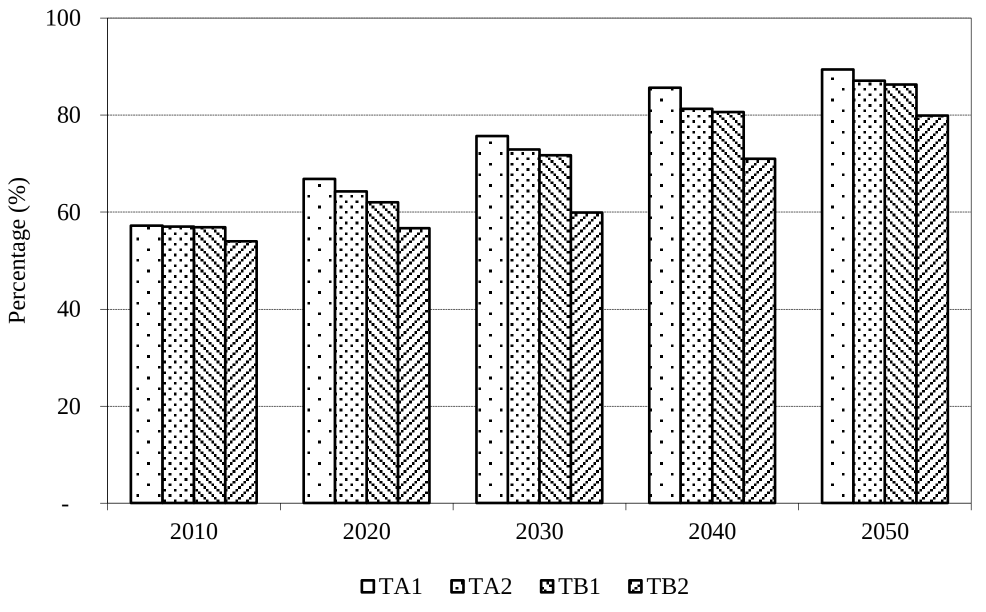

Figure 4.3: Energy import dependency under four scenarios during 2010-2050 (%)

4.5.2. Final energy demand

In the past, transport and industry are the two major final energy consumption sectors in the country. As seen from Table 4.3, these two sectors together consumed about 74% of the total FED, while the remaining 26% is consumed by residential (16%), commercial (6%) and agriculture (4%) sectors in 2000. Over the study period, the two sectors (i.e., transport and industry) together would continue to have a growing share in total FED, ranging from 81% under TB2 to 83% under TA1 in 2050. Between 2000 and 2050, the total FED is estimated to grow at an average annual rate of 4.5%, 4.0%, 3.9% and 2.9% under TA1, TA2, TB1 and TB2, respectively.

Table 4.3: Sector-wise final energy demand under four scenarios during 2000-2050 (Mtoe)

	2000	TA1			TA2			TB1			TB2		
		2010	2030	2050	2010	2030	2050	2010	2030	2050	2010	2030	2050
Agriculture	2	2	4	4	2	4	5	2	4	4	2	4	6
Commercial	3	5	20	56	5	17	43	5	17	43	5	10	19
Industry	18	33	88	197	31	78	156	32	78	155	28	53	83
Residential	8	10	13	17	7	13	18	9	9	11	9	10	12
Transport	18	32	71	176	29	60	114	29	56	113	25	38	81
Total	49	82	197	450	75	173	337	77	165	326	69	114	201

Compared to the situation in 2000, the sectoral structure in total FED is estimated to change remarkably in the future. Between years 2000 and 2050, the share of transport sector in total FED is estimated to increase from 38% to 40% under TB2, while its share is estimated to fall from 38% to 34% under TA2. On the other hand, the share of industry sector in total FED over the study period is estimated to increase under all scenarios ranging from 41% under TB2 to 47% under TA2 in 2050 compared to 37% in 2000. Likewise, the share of commercial sector is estimated to increase by more than double (i.e., from 6% to 13%) under TA2. However, the share of residential sector in total FED is estimated to decrease from 15% in 2000 to 3% in 2050 under TB1. The decrease in the share of residential sector in total FED over the study period under TB1 is mainly due to slower population growth and the use of more efficient energy consuming appliances. Likewise, the share of agriculture sector in total FED is estimated to decrease from 4% in 2000 to 1% in 2050 under TA1, TA2 and TB1. Although the share of commercial sector in total FED is relatively low in absolute value, its demand would grow most rapidly, at an average annual rate of 5.5% during 2000-2050 under the reference scenario, followed by industry (4.4%), transport (3.7%), residential (1.8%) and agriculture (1.8%) sectors. The results suggest that Thai economy would remain energy intensive over the study period.

4.5.3. Electricity generation and demand

Due to limitation of space, in the following, only the results of reference scenario are highlighted as it represents the most likely scenario in Thailand. Over the past 30 years, demand for electricity grew much faster than Thai economy. The Thai economy grew at an average rate of 3.7% per year, while the total electricity generation grew at an average rate of 10.3% per year during 1971-2002 (IEA, 2004c). Nonetheless, the total electricity generation over the study period is estimated to increase at much lower rate (4.4% per year), i.e., from 92 TWh in 2000 to 793 TWh in 2050 (Figure 4.4). In terms of electricity generation mix, coal- and gas-fired generation would provide 85% of total electricity generation in 2050, while the remaining 15% of the electricity generation would come from NRE sources. The limited role of NRE sources in total electricity generation over the study period is due to barriers of high investment requirements and their limited domestic resource availability in the country.

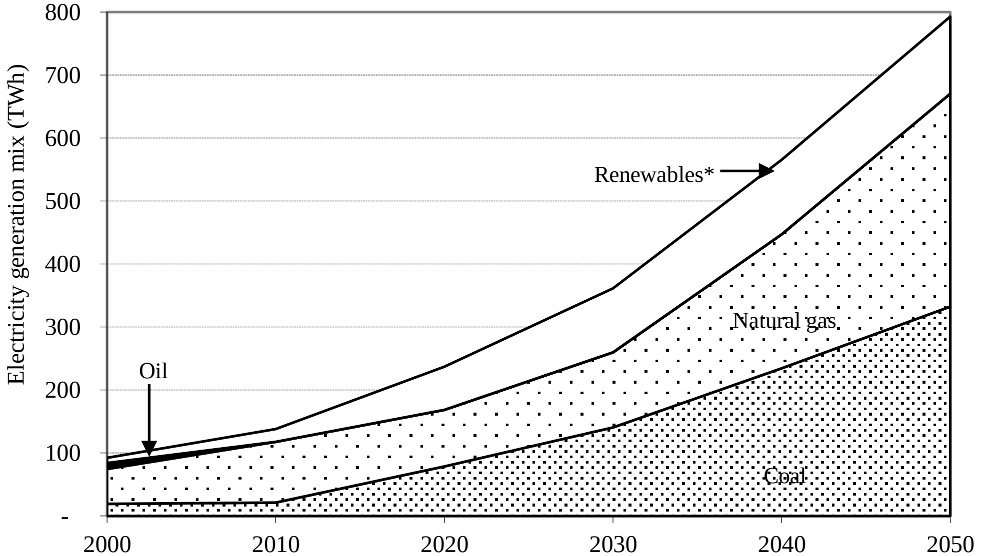

Figure 4.4: Electricity generation mix under the reference scenario (TA2) during 2000-2050 (TWh).

Note: * Renewables include biomass, hydro, solar, wind and geothermal.

The contribution of natural gas in total electricity generation is estimated to decrease from 60% in 2000 to about 43% in 2050 but remains the mainstay of electricity generation. In contrast, the corresponding figure for coal increases steadily from 21% in 2000 to about 42% in 2050. The increasing share of coal over natural gas in total electricity generation is mainly due to relatively cheaper price of coal as compared to price of natural gas and the limitation of domestic natural gas resource availability in the country. The share of oil, already low (10% in 2000), is estimated to decline further during 2000-2050. Among the share of NRE sources in total electricity generation in year 2000, hydro and new renewables together accounted for about 10% and there was no biomass-based electricity generation in the country. However, the share of NRE sources in total electricity generation would increase to 15% in 2050 and this share comprises of biomass (8%), hydro (4%) and new renewables (3%).

Table 4.4: Sector-wise electricity demand under the reference scenario (TA2) during 2000-2050 (TWh)

	2000	2010	2020	2030	2040	2050	Average annual growth rate (%)
Agriculture	0.3	0.3	0.4	0.5	0.6	0.6	1.6
Commercial	27.9	44.4	92.6	135.6	236.7	332.9	5.1
Industry	39.3	64.9	119.6	169.5	246.8	318.6	4.3
Residential	18.9	22.6	35.1	47.0	77.2	107.4	3.5
Transport	<0.0	0.1	0.2	0.4	0.5	0.8	6.4
Total	86.4	132.3	247.9	353.0	561.7	760.3	4.4

Sector-wise, the average annual growth of electricity demand would be the highest in transport sector (6.4%), followed by commercial (5.1%), industry (4.3%), residential (3.5%) and agriculture (1.6%) sectors (Table 4.4). Although the share of transport in total electricity demand is small in absolute value, the highest growth of electricity demand in transport sector is due to Thailand's plan of extending the current electricity operated mass transit rail system from around Bangkok city area to Greater Bangkok area. Industry sector is estimated to remain the largest final consumer of electricity during 2000-2040, with its consumption increasing from 39 TWh (45%) in 2000 to 247 TWh (44%) in 2040. In 2050, however, the share of commercial sector in total electricity demand is estimated to be the largest (44%), followed by industry (42%) and residential (14%) sectors.

4.5.4. Technology deployment in road transportation

In the past, gasoline and diesel have become the dominant fuels used in the transportation sector in the country. However, increasing international fuel price, limited domestic availability of these fuels and the concerns of cleaner environment in the country have prompted consideration of various alternative technologies (e.g., biofuels, hybrid engines, natural gas, fuel cells, electric vehicles). Indeed, although relatively small in the share, biofuels- and natural gas-based vehicles are already introduced in the country. Figure 4.5 depicts the relative share of penetration of conventional, efficient conventional and new vehicle technologies during 2000-2050 under the reference scenario. As seen from Figure 5, the penetration of conventional efficient vehicles is estimated to be about 4.8% of total vehicle technology types in 2010 and gradually decreases thereafter. Among the technologies, the share of hybrid and fuel cell vehicle stocks together in total vehicles types is estimated to reach 81% in 2050, followed by conventional vehicle stocks (8%), electric (6%), conventional efficient (4%) and natural gas vehicles (0.4%). Over the study period, the results show that conventional vehicles would gradually be replaced by efficient conventional vehicles and these vehicles in turn would be gradually replaced by new vehicle technologies such as hybrid and fuel cell vehicles.

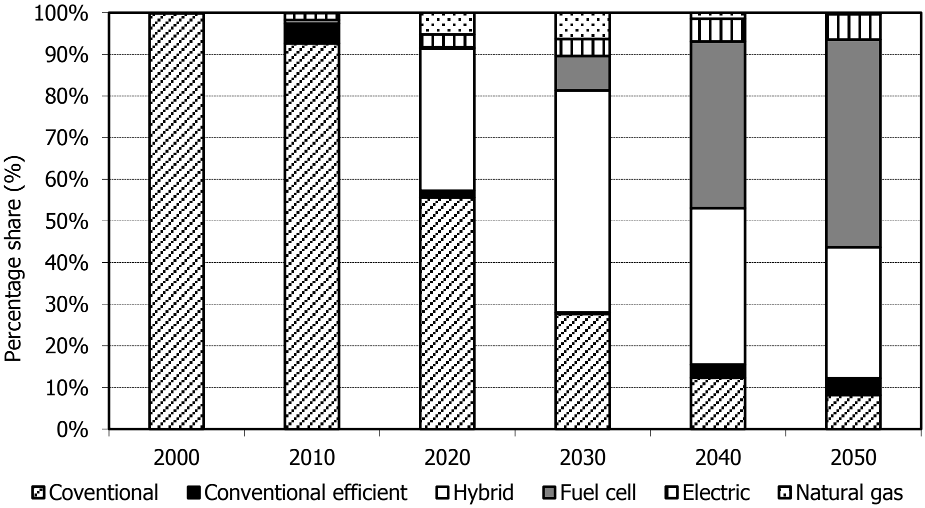

Figure 4.5: Shares of existing and new technologies in road transport sector under the reference scenario (TA2) during 2000-2050 (%).

Note: Conventional technologies include gasoline-, diesel- and LPG- cars and pickups, gasoline- and diesel- vans, diesel buses and trucks, and two wheelers; Conventional efficient technologies include new diesel car, direct ignition gasoline car, new diesel truck, new diesel air conditioned bus, new two wheeler, new diesel van and new diesel pickup.

4.5.5. Environmental effects of the energy and emission scenarios

The country's CO_2 emissions in year 2000 corresponds to only about 0.7% of the world's total energy-related CO_2 emissions and about 7% of the corresponding figure of Asia excluding China (IEA, 2004a). However, the estimated trends of energy use under four scenarios imply that energy-related CO_2, SO_2 and NO_x emissions would increase over the study period. As seen from Figure 4.6, the total CO_2 emissions in the country vary significantly across the scenarios, i.e., from 158 Mt in 2000 to 647 Mt under TB2 and 1312 Mt under TA1 in 2050. In the reference scenario, the total CO_2 emissions is estimated to reach 1155 Mt in 2050, an increase of 997 Mt over the 2000 level at an average annual growth rate of 4.1%.

In conformity with the global trends, the CO_2 emissions in Thailand from the power, industry and transport sectors would have the strongest tendency to increase in the future (Figure 4.7). Under the reference scenario, the three sectors together would contribute more than 94% of the total CO_2 emissions in 2050. The corresponding figures for the other three scenarios also show the similar trends varying from 93% under TB2 to 96% under TB1. In the reference scenario, industry sector would account for 38% of the increase in CO_2 emissions during 2000-2050, power sector for 33%, transport sector for 23% and the remaining sectors (i.e., agriculture, commercial and residential) for 6%.

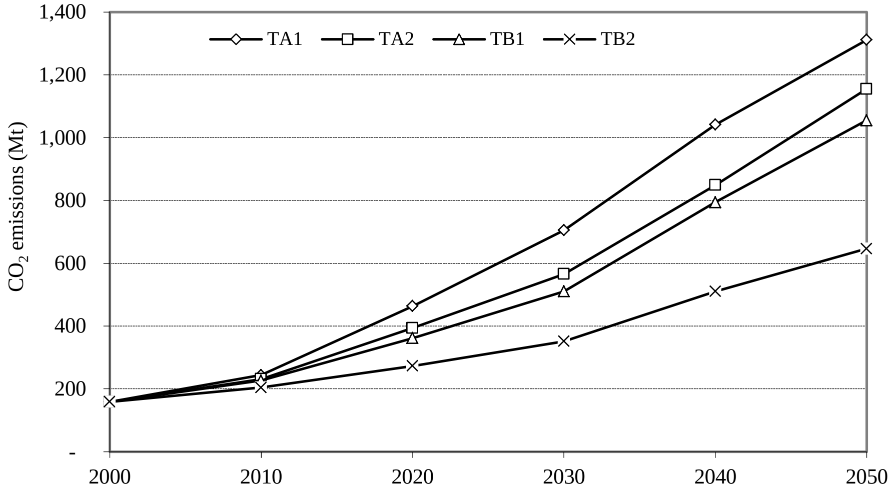

Figure 4.6: Total CO_2 emissions under four scenarios during 2000-2050 (Mt).

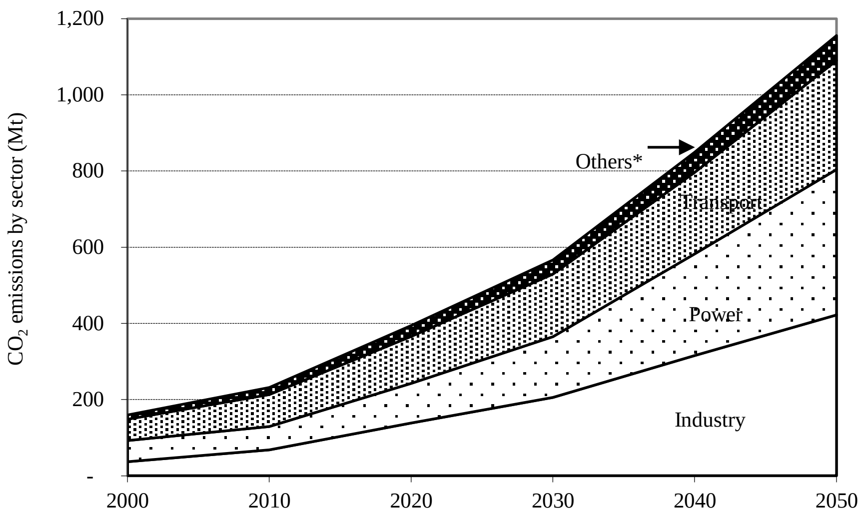

Figure 4.7: Sector-wise CO_2 emissions under the reference scenario (TA2) during 2000-2050 (Mt).

Note: * Others include agriculture, commercial and residential sectors.

A simple decomposition analysis[6] reveals the important effects of energy use in the increase of CO_2 emissions in the country over the study period under

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[6] In the literature, different decomposition techniques are available and these techniques are broadly grouped into those based on the Divisia index and those based on the Laspeyres index. The method applied in this study is a simple complete decomposition based on the Laspeyres

the reference scenario (Figure 4.8). In Figure 4.8, the changes in CO_2 emissions are shown in comparison with the benchmark year 2000. The total change in the country's CO_2 emissions would be 792% increase between 2000 and 2050. Among the different factors, fuel shift (CO_2/TPES) shows that country would continue to have fossil fuels dominated energy system that leads to about 20% increase in CO_2 emissions in 2050 compared to the level of 2000. On the other hand, the efficiency increase gained by energy transformation (TPES/FED) would decrease CO_2 emissions by 7%. The modest change in energy intensity (FED/GDP) due to structural shift in the economy would decrease CO_2 emissions by 49% while the modest increase of population growth (POP) would increase CO_2 emissions by 47%. However, the per capita economic growth (GDP/POP) would be the most significant factor in the increase of CO_2 emissions and this factor accounts for over 782% increase in the total CO_2 emissions.

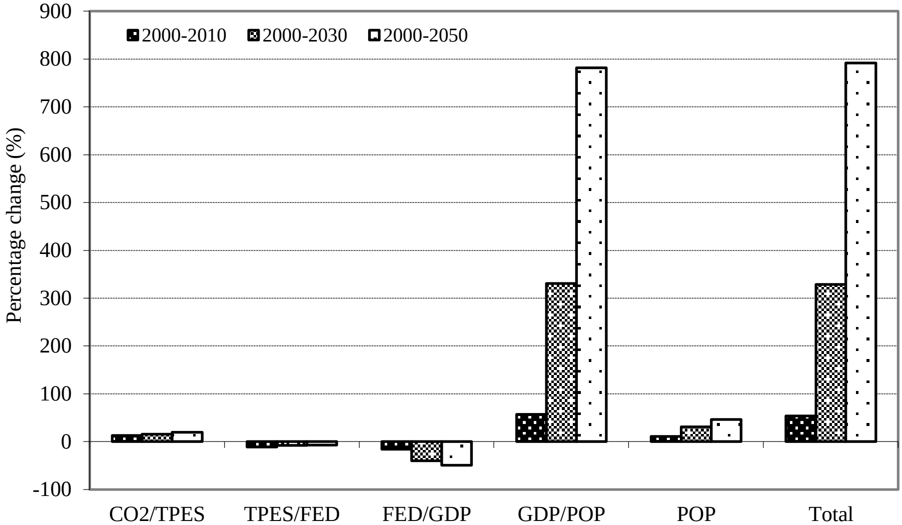

Figure 4.8: Decomposition analysis for the factors affecting CO_2 emissions under the reference scenario (TA2) during 2000 – 2050 (%).

Note: CO_2: carbon dioxide; TPES: total primary energy supply; FED: final energy demand; GDP: gross domestic product; and POP: population.

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index (Sun, 1996). The factors behind the change in CO_2 emissions from fuel combustion is based on the partition presented in the following equation:

$$CO_2 = \left(\frac{CO_2}{TPES}\right) \times \left(\frac{TPES}{FED}\right) \times \left(\frac{FED}{GDP}\right) \times \left(\frac{GDP}{POP}\right) \times POP .$$

The first factor (*CO_2/TPES*) in the equation refers to CO_2 emission intensity of entire energy system; the second factor (*TPES/FED*) refers to efficiency of energy transformation system; the third factor (*FED/GDP*) refers to energy intensity; the fourth factor (*GDP/POP*) refers to per capita GDP; and the fifth factor (*POP*) refers to population. For different decomposition techniques used in energy modeling studies see Ang, 2004; Ang and Zhang, 2000; and Rose and Casler, 1996.

As seen from Table 4.5, the CO_2 emissions per capita is estimated to increase between years 2000 and 2050 ranging from about 3.5 times under TB2 to about 10 times under TA1. In contrast, the CO_2 emissions intensity of 0.91 kg/US$, 1995 price under market exchange rate (MER) in year 2000 is estimated to decrease by almost half under TB1 (i.e., 0.43 kg/US$, 1995 price using MER) and by about one-fourth under TB2 (i.e., 0.63 kg/US$, 1995 price) in 2050. Likewise, the primary energy intensity of 0.44 kgoe/US$, 1995 price using MER in year 2000 is estimated to decrease by one-third under TB1 (i.e., 0.14 kgoe/US$, 1995 price using MER) and by more than half under TA1 (i.e., 0.23 kgoe/US$, 1995 price using MER) in 2050.

The significant increase in energy demand over the study period also induces substantial increase in emissions of local pollutants in the country. Table 4.6 summarizes the results of total SO_2 and NO_x emissions under four scenarios during 2000-2050. Both SO_2 and NO_x emissions are estimated to increase considerably in the future: SO_2 emission is estimated to increase by about 5.3 times under TB2 and by about 9.2 times under TA1; while NO_x emission is estimated to increase by 3.6 times under TB2 and by 6.2 times under TA1 in 2050 compared to year 2000. The results also indicate that increase in SO_2 emissions is relatively higher compared to increase in NO_x emissions during 2000-2050 under all four scenarios. This is mainly due to increasing use of coal in electricity generation over the study period.

Sector-wise, the power sector would contribute the most (58%) in the total SO_2 emissions in 2050 under the reference scenario, followed by industry (28%), transport (12%) and others (2%) (Figure 4.9). In contrast, the transport sector would contribute the most (49%) in total NO_x emissions in 2050 under the reference scenario with the remaining emissions coming from power (23%), industry (23%) and others (6%) (Figure 4.10).

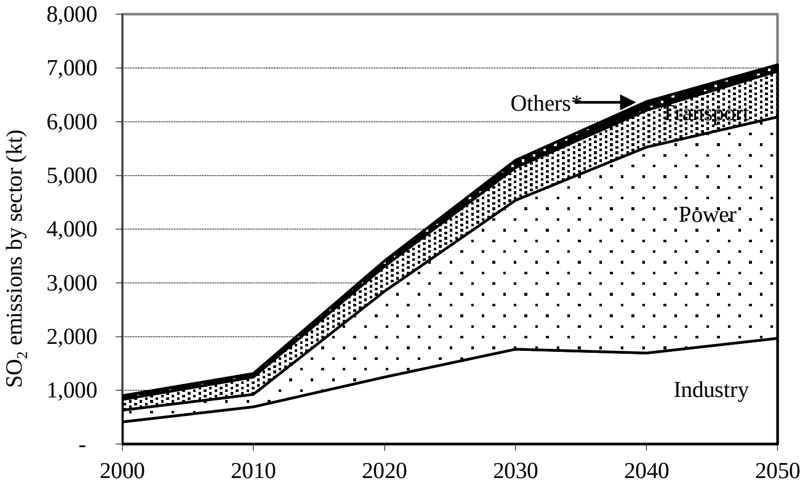

Figure 4.9: Sector-wise SO_2 emissions under the reference scenario (TA2) during 2000-2050 (kt).

Note: * Others include agriculture, commercial and residential sectors.

Table 4.5: CO_2 emissions per capita, CO_2 emissions intensity and primary energy intensity in 2000 and selected future years under four scenarios

	2000	Global Market		Dual track		Sufficiency economy		Local stewardship	
		2030	2050	2030	2050	2030	2050	2030	2050
Per capita CO_2 emission (tons/capita)	2.56	9.70	25.43	7.26	14.12	7.51	17.94	4.92	8.99
CO_2 emission intensity (kg/US$,1995price)	0.91	0.55	0.46	0.60	0.57	0.50	0.43	0.64	0.63
Primary energy intensity (kgoe/US$,1995price)	0.44	0.20	0.15	0.23	0.19	0.18	0.14	0.27	0.23

Table 4.6: SO_2 and NO_X (as NO_2) emissions under four scenarios during 2000-2050 (kt)

	SO_2 emissions				Ratio	NO_x emissions				Ratio
	2000	2010	2030	2050	2050/2000	2000	2010	2030	2050	2050/2000
TA1	899	1,324	5,813	8,288	9.2	926	1,510	3,307	5,772	6.2
TA2	899	1,314	5,283	7,061	7.9	926	1,380	3,003	5,283	5.7
TB1	899	1,112	4,221	6,798	7.6	926	1,281	2,795	5,023	5.4
TB2	899	979	4,015	4,768	5.3	926	1,224	1,978	3,375	3.6

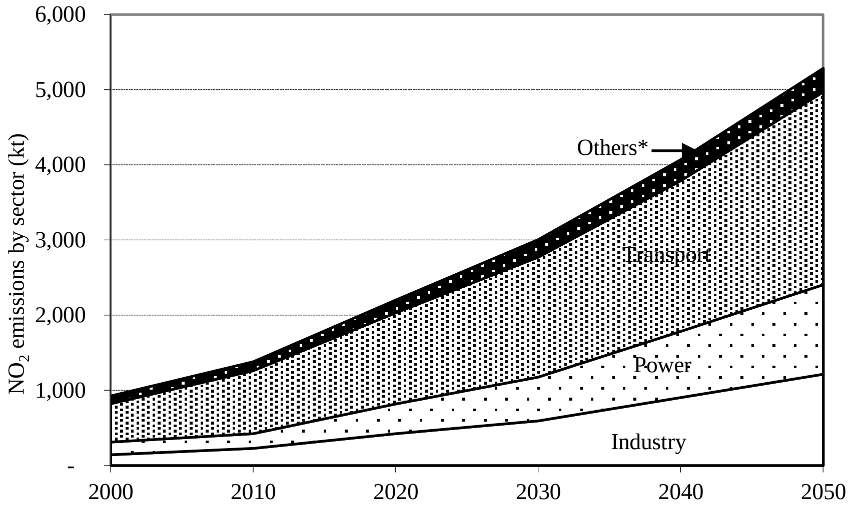

Figure 4.10: Sector-wise NO_x emissions under the reference scenario (TA2) during 2000-2050 (kt).

Note: * Others include agriculture, commercial and residential sectors.

4.6. Concluding remarks

This paper examined the least cost energy system development and analyzed its implications for GHG and other local pollutant emissions under four scenarios for Thailand using AIM/Enduse model during 2000-2050. The four scenarios follow closely with the scenarios of global IPCC SRES report. Under the reference scenario (i.e., dual track), the TPES is estimated to increase by almost six-folds from 77 Mtoe in 2000 to 456 Mtoe in 2050. Fossil fuels would continue to remain the dominant energy source, contributing about 90% of the total TPES under all four scenarios in 2050. Among the fossil fuels, oil use is estimated to dominate the TPES over the study period. Coal and natural gas are also estimated to remain the mainstay of TPES over the study period. Despite the Thai government's policy to promote new and renewable energy sources, its share in TPES is estimated to remain low in between 6% under TA1 to 13% under TB2 in 2050. This is mainly due to higher initial costs and lower plant factor of renewable energy technologies used for electricity generation, and limited domestic resource availability of the new and renewable energy sources in the country. Sector-wise, energy demand in industry sector would increase by almost nine-folds from 18 Mtoe in 2000 to 156 Mtoe in 2050, while transport sector would increase by more than six-folds from 18 Mtoe in 2000 to 114 Mtoe in 2050 under the reference scenario. Industry and commercial sectors are likely to remain the largest final consumer of electricity throughout the study period. In the power sector, the share of coal and natural gas combined in total electricity generation under the reference scenario is estimated to account for 85% by 2050. In contrast, the share of new and renewables (mainly biomass and hydro) in total electricity generation is estimated to increase from 9% in 2000 to about 15% in 2050. Energy use in the road transportation is estimated to become increasingly important over the study period compared to other modes of transportation (e.g., rail, air and water). Compressed natural gas-, hybrid-, fuel cell- and other efficient technology based- vehicles would play an increasingly important role during the latter two decades of the study period. Thailand is a net energy importing country and its energy import dependency is estimated to increase from 50% in 2000 to as high as 89% under global market scenario in 2050. With increasing use of fossil fuels and limited domestic resources availability, the concern over energy security would be an important issue in the country during the study period.

Owing to increasing demand for energy and increasing motor vehicles in the country, total CO_2 emissions is also estimated to increase in the future. Under the reference scenario, the total CO_2 emissions is estimated to reach 1155 Mt in 2050, an increase of more than seven-folds over the 2000 level at an average annual growth rate of 4.1%. Industry sector would account for the most in total CO_2 emissions in 2050 at 38%, followed by power (33%), transport (23%) and the agriculture, commercial and residential sectors combined (6%). In per capita term, the CO_2 emission in Thailand is estimated to increase by more than five-folds from 2.6 tons in 2000 to 14.1 tons by 2050. In contrast, the CO_2 emission intensity is estimated to fall by one-third in 2050 as compared to 2000 level due to cleaner energy substitution and penetration of more efficient technologies over the study period. However, the country's estimated CO_2 intensity in 2050 would remain high compared to the corresponding 2000 value of OECD- and world-average. Both SO_2 and NO_x emissions are also estimated to increase considerably over the study period: SO_2 emission is estimated to increase by almost eight-folds while NO_x emission is estimated to increase by almost six-folds between 2000 and 2050 under the reference scenario. In 2050, about 86% of the total SO_2 emissions would come from power and industry sectors combined, while 49% of the total NO_x emissions would come from the transport sector alone. In all four scenarios, SO_2 emission is estimated to grow much faster than the NO_x emission over the study period mainly due to the substantial use of coal for electricity generation.

In general, bottom up approach includes detailed sectoral analyses but includes much less detail about the entire economy. Conversely, top down approach provide little sectoral details. Therefore, linking bottom up approach with top down approach for scenario analysis of developing countries like Thailand would be an interesting further study.

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Appendix 4.A. Existing and candidate power generation technologies considered in the study

Technology	Fuel type
A. Fossil fuel and biomass based technologies	
Conventional steam	Lignite, natural gas, fuel oil,
Integrated gasification combined cycle (IGCC)	biomass
Pressurized fluidized bed combustion (PFBC)	Lignite and bituminous coal
Combined cycle	Lignite and bituminous coal
Combined cycle – advanced	Natural gas and fuel oil
Gas turbine	Natural gas
Biomass integrated gasification combined cycle	Natural gas and fuel oil
(BIGCC)	Biomass
B. Renewables based technologies	
Hydro, wind, solar photovoltaic, solar thermal and geothermal	-
C. Proton exchange membrane fuel cell	Natural gas

Appendix 4.B. Classification of service demand component of energy system development of Thailand

Sector/sub sector	Energy Service	Number of Technology options	Activity Parameters
Agriculture	Pumping, tilling	4	Agricultural sector value added
Commercial	Air-conditioning, lighting, thermal use	9	
Industry			
Cement	Mixing, clinker production, milling, others	11	value added for cement
Steel	Primary steel production (coke, sinter, pig iron, crude and rolled steel production) Secondary steel production (crude steel and finished steel production)	44	Value added for steel
Sugar	Juice extraction, slurry production, crystallization and grinding	9	Value added for food
Paper	Pulp production, bleaching, stock production and others	11	Value added for paper
Others (chemicals, food and beverages, fabricated metals, textiles, others)	Thermal and mechanical energy	72	Value added of the respective sub sectors
Residential			
Metropolitan Electricity Authority (MEA)/Provincial Electricity Authority (PEA)	Air-conditioning, cooking, lighting, fan, iron, refrigerator, television, other	32	Number of house holds, appliance ownership per household
Transport			

Passenger	Road (passenger car, micro bus and pickup, van and pickup, three wheeler, urban taxi, fixed route taxi, motor tricycle taxi, motorcycle, fixed route bus, bus for hire, private bus, small rural bus, urban train)	79	Per capita GDP, average distance traveled by each vehicle, occupancy factor #
	Rail and air	9	Per capita GDP
Freight	Road and water	12	Transport sector value added

Note: *Appliance ownership is the number of houses that own a specific appliance as a fraction of total number of houses. # Occupancy factor is the average number of persons per vehicle at a given time of travel.

Appendix 4.C. List of sources used in Thai Energy system development

Category	Source
Economic	NESDB, 2003; NIDA, 2006
Demographic	UN, 2004
Service demand	KMIT, 1997; KMUTT, 2003a,b; NEPO, 1999; NSO, 2003, IEA, 2005
Technology type	Kainuma et al., 2003; NEPO, 1999; Tseng et al., 2005;
Energy	DEDE, 2006a,b,c; DEDE, 2004; EGAT, 2004; Greacen, 2005; IEA, 2004b; Prasertsan and Sajjakulnukit, 2006; Sajjakulnukit and Verapong, 2003; Santisirisomboon et al., 2003
Emissions factors	IPCC, 1996; Foell et al., 1995
Appliance stock in the start year	NEPO, 1999; KMUTT, 2003a,b; DLT, 2000

Appendix 4.D. Summary of main features of four scenarios

Scenario	Main Features
TA1	Economy: GDP growth rate of 7.5% per year during 2000-2020 and 5.5% per year during 2021-2050. Demography: low population growth rate of 0.02% per year. Life style: high per capita appliance ownership in households, car ownership and mobility. Technology: energy efficiency improvement of 0.3% per year.
TA2	Economy: GDP growth rate of 6% per year during 2000-2020 and 5% per year during 2021-2050. Demography: high population growth rate of 0.74% per year. Life style: medium per capita appliance ownership in households. Technology: energy efficiency improvement of 0.2% per year.
TB1	Economy: GDP growth rate of 6.5% per year during 2000-2020 and 5.5% per year during 2021-2050. Demography: low population growth rate of 0.02% per year. Life style: medium per capita appliance ownership in households and use of public transport. Technology: energy efficiency improvement of 0.4% per year.
TB2	Economy: GDP growth rate of 4% per year during 2000-2020 and 3.5% per year during 2021-2050. Demography: Medium population growth rate of 0.39% per year. Life style: Low per capita appliance ownership in households and use of more public transport. Technology: energy efficiency improvement of 0.1% per year.

References

Ang, B.W., 2004. Decomposition analysis for policymaking in energy: which is the preferred method? Energy Policy 32, 1131-1139.

Ang, B.W., Zhang, F.Q., 2000. A survey of index decomposition analysis in energy and environmental studies. Energy 25, 1149-1176.

Bhattacharyya, S.C., Ussanarassamee, A., 2004. Decomposition of energy and CO_2 intensities of Thai industry between 1981 and 2000. Energy Economics 26, 765-781.

BOT, 2006. Thailand's key economic indicators. Bank of Thailand (BOT), Bangkok (see www.bot.or.th/bothomepage/databank/EconData/Thai_Key/Thai_KeyE.as. Chaipravat, O., 2003. Thailand's positioning in a new global economic paradigm. Paper presented at the Fiscal Policy Research Institute symposium, Bangkok, 23 June.

Dang, G., Minh, L.B, Yodomani, S., 1994. Key challenges facing Thailand in the context of global CO_2 emission abatement. Energy Policy 22, 971- 980.

DEDE, 2004. Thailand Alternative Energy Situation 2003. Ministry of Energy, Bangkok.

DEDE, 2006a. Thailand energy situation: 2000 - 2004. Annual reports, Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy, Bangkok (see www.dede.go.th/dede/index.php?id=152).

DEDE, 2006b. Electricity in Thailand: 2000 - 2004. Annual reports, Department of Alternative Energy Development and Efficiency, Ministry of Energy, Bangkok (see http://www.dede.go.th/dede/index.php?id=152).

DEDE, 2006c. Oil in Thailand: 2000 - 2004. Annual reports, Department of Alternative Energy Development and Efficiency, Ministry of Energy, Bangkok (see http://www.dede.go.th/dede/index.php?id=152).

DEDE, 2006d. Energy potentials. Department of Alternative Energy Development and Efficiency, Ministry of Energy, Bangkok (see http://www.dede.go.th/dede/ index.php?id=586).

DEDE, 2006e. Biomass potentials in Thailand. Department of Alternative Energy Development and Efficiency, Ministry of Energy, Bangkok (see http://www.dede. go.th/dede/fileadmin/usr/berc/energysave/BiomassPotentialsinThailand.pdf).Deutscher Bundestag, 2002. Enquete commission on sustainable energy supply against the background of globalization and liberalization. Summary of the Final Report (see http://www.wupperinst.org/renewables/).

DLT, 2000. Number of vehicles registered in Thailand. Department of Land Transport (DLT), Ministry of Transport and Communications, Bangkok.

DTI, 2003a. Energy white paper: Our energy future - creating a low carbon economy. Department of Trade and Industry (DTI), London.

DTI, 2003b. Options for a low carbon future, DTI Economic Paper No. 4, Department of Trade and Industry, London.

EGAT, 2004. Power development plan: 2003. Generation System Development Planning Division, Electricity Generating Authority of Thailand, Bangkok.

Foell W., Amann M., Carmichael G., Chadwick M., Hettelingh J.P., Hordijk L., Dianwu Z. (eds.), 1995: RAINS_ASIA: An assessment model for air pollution in Asia. Final report submitted to the World Bank, December.

Greacen, C., 2005. Renewable energy potential in Thailand. Palang Thai, Bangkok (see http://www.palangthai.org/ docs/).

IEA, 2004a. CO_2 Emissions from fuel combustion (CD-ROM). International Energy Agency (IEA), Paris.

IEA, 2004b. World energy outlook 2004. International Energy Agency (IEA), Paris.

IEA, 2004c. Energy balances of non-OECD countries (CD-ROM). International Energy Agency (IEA), Paris.

IEA, 2005. Prospects for hydrogen and fuel cells. International Energy Agency (IEA), Paris.

IPCC, 1996. Revised IPCC guidelines for national greenhouse gas inventories: Reference manual Volume 3. Inter Governmental Panel on Climate Change, Bracknell.

Jiang, K., Hu, X., 2006. Energy demand and emissions in 2030 in China: scenarios and policy options. Environmental Economics and Policy Studies 7, 233-250.

Jiang, K., Morita, T., Masui, T., Matsuoka, Y., 1999. Long-term emission scenarios for China. Environment Economics and Policy Studies 2, 267-287.

Kainuma, M., Matsuoka, Y., Morita, T. (Eds.), 2003. Climate policy assessment: Asia-pacific integrated modeling. Springer-Verlag, Tokyo.

KMIT, 1997. The strategy for using energy in rural area. Report submitted to Department of Energy Development and Promotion, King Mongkut's Institute of Technology, Bangkok.

KMUTT, 2003a. Survey of residential energy consumption in non-municipal area. Final report submitted to Department of Energy Development and Promotion, King Mongkut's University of Technology Thailand, Bangkok.

KMUTT, 2003b. Survey of residential energy consumption in municipal area. Final report submitted to Department of Energy Development and Promotion, King Mongkut's University of Technology Thailand, Bangkok.

Limmeechokchai, B., Suksuntornsiri, P., 2007a. Assessment of cleaner electricity generation technologies for net CO_2 mitigation in Thailand. Renewable and Sustainable Energy Reviews 11, 315-330 (in press).

Limmeechokchai, B., Suksuntornsiri, P., 2007b. Embedded energy and total greenhouse gas emissions in final consumptions within Thailand. Renewable and Sustainable Energy Reviews 11, 259-281 (in press).

Malla, S, Shrestha, R.M., 2005. Implications of carbon tax and energy efficiency improvement on Thai economy. The 6th IHDP open meeting 2005 conference paper, Bonn.

Masui, T., Matsuoka, Y., Kainuma, K., 2006. Long-term CO_2 emission reduction scenarios in Japan. Environmental Economics and Policy Studies 7, 347-366.

MOE, 2001. Four socio-economic scenarios: Development of GHGs emission reduction scenarios (in Japanese). Global Environmental Bureau, Ministry of Environment Japan, Tokyo.

Nakićenović, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, B., Gaffin, S., Gregory, K., Grübler, A., Jung, T.Y., Kram, T., La Rovere, E.E., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Raihi, K., Roehrl, A., Rogner, H.-H. , Sankovski, A., Schlesinger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., Victor, N., Dadi, Z., 2000. Emissions scenarios. A special report of working group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge.

Nakićenović, N., Kolp, P., Riahi, K., Kainuma, M., Hanaoka, T., 2006. Assessment of emissions scenarios revisited. Environmental Economics and Policy Studies 7, 137-173.

NEPO, 1999. Thailand's energy strategy and policy. Final report, National Energy Policy Office, Bangkok.

NESDB, 2003. National income of Thailand" 1980-2001 edition. Office of the National Economic and Social Development Board, Bangkok.

NESDB, UNRC, 2004. Thailand millennium development goals Report 2004. National Economic and Social Development Board and United Nations Resident Coordinator, Bangkok.

NIDA, 2006. Thailand long–term load forecasts. Report submitted to Energy Policy and Planning Office, National Institute of Development Administration (NIDA), Bangkok (see http://www.eppo.go.th/load/nida/eng/contents.html).NSO, 2003. Transport and communication statistics of Thailand. National Statistical Office (see http://www.nso.go.th/eng/stat/subject/subject.htm#cata5).

OCLMT, 2000. Transport Data and Model Center: Final Report. Office of the Commission for the Management of Land Traffic (OCLMT), Bangkok.

Prasertsan, S., Sajjakulnukit, B., 2006. Biomass and biogas energy in Thailand: Potential, opportunity and barriers. Renewable Energy 31, 599–610.

Radanne, P., 2004. Reducing CO_2 emissions fourfold in France: Introduction to the debate. Inter-ministerial Task Force on Climate Change (MIES), Paris.

Rose, A., Casler, S., 1996. Input-output structural decomposition analysis: A critical appraisal. Economic Systems Research 8, 33-62.

Sajjakulnukit, B., Verapong, P., 2003. Sustainable biomass production for energy in Thailand. Biomass and Bioenergy 25, 557-570.

Santisirisomboon, J., Limmeechokchai, B., Chungapaibulpatana, S., 2003. Least cost electricity generation options based on environmental impact abatement. Environmental Science and Technology 6, 533-541.

Shrestha, R.M., Khummongkol, P., Biswas, W.K., Timilsina, G.R., Sinbanchongjit, S., 1998. CO_2 mitigation potential of efficient demand-side technologies: the case of Thailand. Energy Sources 20, 301-316.

Shukla, P.R., Rana, A., Garg, A., Kasphe, M., Nair, R., 2004. Climate policy assessment for India: applications of Asia-pacific integrated model. University Press, Hyderabad.

Shukla, P.R., Rana, A., Garg, A., Kapshe, M., Nair, R., 2006. Global climate change stabilization regimes and Indian emission scenarios: lessons for modeling of developing country transitions. Environmental Economics and Policy Studies 7, 205-231.Sun, J.W., 1996. Quantitative analysis of energy consumption, efficiency and saving in the world: 1973-1990. Series A-4:1996, Turku School of Economics and Business Administration, Turku.

Tanatvanit, S., Limmeechokchai, B., Chungpaibulpatana, S., 2003. Sustainable energy development strategies: implications of energy demand management and renewable energy in Thailand. Renewable and Sustainable Energy Reviews 7, 367-395.

Tanatvanit, S., Limmeechokchai, B., Shrestha, R.M., 2004. CO_2 mitigation and power generation implications of clean supply-side and demand-side technologies in Thailand. Energy Policy 32, 83-90.

Tseng, P., Lee J., Friley P., 2005. A hydrogen economy: opportunities and challenges. Energy 30, 2703-2720.

UN, 2004. World population prospects: The 2004 revision. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, United Nations, New York.

UNFCCC, 2004. The First ten years. Climate Change Secretariat, United Nations Framework Convention on Climate Change, Bonn.

Chapter 5

Multi-gas Emissions in Thailand[1]

Abstract

This paper estimates the greenhouse gases emissions of Thailand in 2000 and an estimation of future emissions of these gases during 2000-2035. The direct greenhouse gases considered in this study include CO_2, CH_4, N_2O, and the indirect GHG pollutant emissions include NO_x and CO. The emissions were estimated for the base year by following the IPCC (1996) guidelines for emissions inventory development. These emissions were estimated for future years considering growth in economic and demographic factors such as the GDP, sectoral value added and population. The future energy mix in different sectors in the BAU scenario, based on Thailand AIM/Enduse model results, is used to estimate the future emissions related to energy combustions. The estimation of emissions from activities not related to energy combustion is also based on the 1996 IPCC guidelines (IPCC, 1996b). The emission analysis shows that the GHG emission in Thailand would almost triple during 2000-2035, i.e., from 401 $MtCO_2e$ in 2000 to 1,159 $MtCO_2e$ in 2035.

5.1. Introduction

Thailand is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and a non-Annex I country. The country endorsed the UNFCCC on 12 June 1992 and later ratified it in December 1994 which became effective three months later, on 28 March 1995.

The UNFCCC calls upon all Parties to report the steps they take or envisage undertaking to implement the Convention (Articles 4.1 and 12). Currently the non-Annex I parties, such as Thailand, have only voluntary mitigation commitments. In accordance with the principle of "common but differentiated responsibilities" enshrined in the Convention, Annex I and non-Annex I Parties were obligatory to submit their initial communication within three years of the Convention for that Party entering into force (UNFCCC, 2007).

The first official greenhouse gas inventory was prepared in 1997 for the year 1990. The second official inventory for greenhouse gases was prepared in 2000 for year 1994. Thailand's 1994 inventory of greenhouse gases was the result of studies conducted by various researchers throughout the country (MoSTE, 2000). In estimating the 1994 GHG emission inventory, the researchers used the guidelines provided in IPCC (1996b).

The national greenhouse gas (GHG) emission inventories, besides meeting the national communication requirements of the UNFCCC, would also serve

[1] Bundit Limmeechokchai.is a co-author of this chapter.

as a benchmark for assessing various mitigation options. Energy and environment related studies on Thailand so far have focused mostly on energy related CO_2 emissions. However, this does not mean that emissions from activities not using energy are insignificant. The energy related GHG emission from Thailand was second largest, while the non-energy emission was fourth largest among the ASEAN countries in 2010 (IEA, 2012). In fact, non-energy sources have a significant share in the total GHG emission in the country level since Thailand is a major producer of agricultural and livestock products in world (FAO, 2015). In 2010 alone it contributed to almost 12.4% of the total GDP (WB, 2015). Thus, it is important to assess both energy and non-energy related future GHG emissions in the country.

The revised IPCC guidelines (IPCC, 1996b) provide the basis to identify the sources of GHGs and the methodology to estimate the emission quantities. This chapter analyzes GHG emissions from direct energy use, fugitive emissions in energy extraction and transport, industrial processes, agriculture, waste and land-use change and forestry. The emission estimations in this chapter cover direct GHG, such as CO_2, CH_4, N_2O, and indirect GHG such as NO_x and CO during 2000-2035 (IPCC, 2006).

This paper is comprised of 5 sections. Section 5.2 describes the methodology and assumptions. Section 5.3 focuses on sources identified from greenhouse gas emitters and Section 5.4 discusses the results. The conclusion and final remarks are given in section 5.5.

5.2. Methodology and Assumptions

The present study uses a bottom-up approach for the estimation of GHG emissions. The basic methodology to estimate the total emissions of a particular gas uses the following formula, which is consistent with the IPCC (1996a,b).

$$\text{Total emissions} = \sum_{\substack{\text{Source}\\\text{categories}}} \sum_{\text{Sectors}} \text{Activity level} \times \text{Emission coefficient}$$

The estimation of emissions of the GHGs considered in this study is carried out for each of the emission source categories in different sectors (i.e. agriculture, commercial, transport, industry etc.). Once the emission of each GHG is estimated, the total CO_2 equivalent emissions are estimated using the following equation.

$$\text{Total CO}_2\text{ equivalent GHG} = \sum_{\substack{\text{pollutant}\\\text{type}}} \text{emissions} \times \text{global warming potential}$$

The details of these source categories and global warming potentials of each of the gases are given in Table 5.1. Note that estimation of total CO_2 equivalent emissions in this chapter is based on the Third Assessment Report of IPCC (IPCC, 2001a,b).

Table 5.1: Emission source categories and global warming potential[1] of the gases

Pollutant	Emissions source categories	Global warming potential[2]
CO_2	Direct fossil fuel combustion, land use, land use change, forestry and industrial processes	1
CH_4	Fossil fuel extraction, transportation and storage, direct fuel combustion, rice cultivation, enteric fermentation, manure management, industrial processes, field burning of agricultural residues and waste	23
N_2O	Direct fossil fuel combustion, Emissions from soil, manure management, industrial processes and field burning of agricultural residues	296
NO_x	Direct fossil fuel combustion, Field burning of agricultural residues and field burning of agricultural residues	-
CO	Direct fossil fuel combustion, Field burning of agricultural residues and field burning of agricultural residues	-

[1] Given in the unit of tons of equivalent CO_2 per ton of pollutant emissions, on a 100 year life time of the pollutant.
[2] IPCC (2001a,b)

Emissions from direct fossil fuel combustion is estimated based on the energy supply mix obtained using the Thailand AIM/Enduse model. Based on the estimations from AIM/Enduse model for energy supply in each year, emissions are calculated using the IPCC emission factors of each fuel. The energy related fugitive emissions are also estimated in a similar manner considering the level of domestic resource extraction and imports of coal, oil and gas which are obtained as an output of the model. The emissions are estimated considering the respective activity levels (e.g., ton of coal extraction, etc.) and emissions per unit activity as given in IPCC (1996a,b). The greenhouse gas emissions from activities not using energy such as industrial processes, agriculture (enteric fermentation, manure management, rice cultivation, emissions from soils, field burning of agricultural residues) and waste management are estimated based on emission factors and methodology given in IPCC (1996a,b). This approach for estimating GHG emissions from energy use and all the other sources has been used in previous studies by Li et al. (1999) and Shukla et al. (2004). Due to the absence of emission factors specific to Thailand, these factors were based on IPCC (1996a,b).

In estimating future emissions, the BAU presented in Chapter 3 was considered as the business as usual case. It was assumed that the economy will grow at a rate of 6% per year during 2000-2020 and 5% per year during 2021-2035. A population growth rate of 0.74% per year was considered with a moderate ownership of home appliances and cars. This GDP projection is based on NIDA (2006) and population projection is taken from UN (2004). The sub-sectoral value added is based on the projections given in TDRI (2004). Note here that it is assumed that sectoral emission in future years would increase at the same rate as that specified in TDRI (2004) where sectoral value added data till year 2016 is provided. From 2016 to 2035, these sectoral value added forecasts are extended under the following assumptions: for the period of 2017-2030, the AAGR of 2016 is assumed in all sectors except for that of steel in the industrial sector. In the industrial sector, for the period of 2031-2050, the AAGR for every 20 years of all the subsectors are assumed to decrease by 0.5% except for that of steel; and the AAGR for every 10 years for steel is assumed to decrease by 0.5% during the period of 2020-2030 and 1% during the period of 2030-2050. In the agricultural, transport and commercial sectors, for the period of 2031-2050, the AAGR for every 10 years is assumed to decrease by 0.5%.

5.3. Sources of Greenhouse Gas Emissions in Thailand

5.3.1. Energy use: fuel combustion and fugitive emissions

The energy sector is considered as one of the main sources of anthropogenic greenhouse gas emissions. Under the energy sector, there are two distinct types of emissions. They are the emissions from direct fuel combustion and fugitive emissions.

In the category of GHG emissions from direct fuel combustion, the emissions from stationary and mobile energy sources have been included. The direct emissions from fuel use in the agriculture, commercial, industrial, residential, transport and power sectors are considered. The emission factors used for estimating emissions from direct fuel combustion for different fuels are given in Table 5.2 and are based on IPCC (1996a,b).

Table 5.5.2: Emission factors considered for direct fuel combustion (ton/ktoe)

Fuel type	CO_2	CH_4	N_2O	NO_x	CO
Coal (Imports)	4119	0.168	0.059	12.6	4.2
Coal (Domestic)	4242	0.168	0.059	12.6	4.2
Natural gas	2643	0.084	0.004	6.3	1.0
Biomass	0	1.256	0.168	4.2	167.5
Jet fuel	2997	0.021	0.084	12.6	4.2
Gasoline	2905	0.838	0.025	25.1	335.0
Kerosene	3012	0.419	0.025	12.6	0.8
Diesel	3104	0.209	0.025	33.5	41.9
Heavy Oil	3243	0.209	0.025	8.4	41.9
LPG	2643	0.084	0.004	6.3	1.0

Source: IPCC (1996a,b).

Fugitive CH_4 emissions released from coal, oil and natural gas fuels are also considered in this study. Currently, domestic resources constitute a large proportion of energy use in Thailand. CH_4 Emissions from Lignite mining in Mae Moh and other sites are considered in this study. For the CH_4 Emissions from crude oil extraction, extraction activities in Benchamas, Sirikit, Tantavan and other sites, methane emission during production, refining and storage activities have been considered. For natural gas, methane emissions during domestic resource extraction from sites such as Bongkot, Erawan, Pailin and other sites, pipe line losses during transmission and distribution of both domestic and imported sources, and leakage during storage and flaring have been considered. The quantities of their domestic production were determined by the AIM/Enduse model (see Chapter 2 for the description of the model). The emission factors used for estimating emissions from activities related to energy extraction, storage and transport for different fuel types are given in Table 5.3.

Table 5.3: Emission factors considered for fugitive emissions from energy (ton CH_4/ktoe)

Activity	Emissions factor
Coal	
Mining	3.35
Post-mining	0.28
Oil	
Production	2.93
Refining	0.04
Storage	0.00
Natural Gas	
Production	2.93
Processing transport and distribution	8.38
Venting and flaring	8.38
Leakage	4.19

Source: IPCC (1996a,b).

5.3.2. Industrial processes

This category considers greenhouse gas emissions which result from various industrial processes and activities that are not a part of direct fuel combustion in the industry sector. It accounts for the pollutant emissions which result during all chemical or physical transformations during industrial production processes (IPCC, 1996a,b). During some of these processes, greenhouse gases, including CO_2, CH_4 and N_2O are released. This study focuses on cement, pulp and paper and steel production to estimate emissions under the industrial processes category. Industrial production data needed for the estimation of emissions were obtained from OIE (2006). It was assumed that emissions from industrial processes in future years would increase at the same rate as the industrial value added for the years as given in TDRI (2004).

5.3.3. Agriculture

Agricultural activities can result in a significant amount of greenhouse gas emissions. Farm land preparation, irrigation, water pumping, ploughing and threshing require energy. Emissions resulting from these activities are considered under the category of direct energy combustion. But a major proportion of anthropogenic GHG emissions from the agriculture sector are from enteric fermentation, manure management, rice and crop cultivation, agricultural soils and field burning of agricultural residues.

The base year values and estimations for future years for the number of farmed animals were obtained from MoAC (2004). The details of rice and other agricultural crop production as well as the agricultural land use data were obtained from CAE (2000), MoAC (2004) and FAO (2005).

Enteric Fermentation of Livestock

Enteric fermentation is the production of methane in herbivorous animals as a by-product of their digestive processes. Both ruminant and some non-ruminant animals produce methane, although ruminants are the largest source (IPCC, 1996a,b). Under this category, emissions from both ruminant animals (cattle, non-dairy cattle and buffalo) and non-ruminant animals (poultry and swine) are considered.

Manure Management

This study also considers the emissions from cattle, non-dairy cattle, buffalo, poultry and swine. Emissions of N_2O related to handling of manure before adding it into the soil are included in this category. The emission factors used for estimation of CH_4 and N_2O are given in Table 5.4.

Table 5.4: Emission factors for livestock (kg/head/year)

	CH_4		
Type	Enteric Fermentation	Manure Management	N_2O
Buffalo	55	3	0.8
Dairy Cattle	56	27	1.2
Non Dairy Cattle	44	2	0.8
Swine	1	7	0.32
Poultry	Not Estimated	0.023	0.012

Source: IPCC (1996a,b)

Rice cultivation

Rice cultivation is an important part of Thailand's economy. It was the seventh largest rice producer in the world in 2013 (FAO, 2015). Some of the current farming practices carried out in Thailand results in releasing large amounts of CH_4 to the atmosphere. Rice cultivation is divided mainly into two categories i.e., major rice and secondary rice.

Major rice-growing areas in the country are divided mainly into upland and lowland. The upland rice cultivation can be classified as rain-fed and irrigated. The irrigated cultivation could be further divided into two categories, i.e., continuously-flooded organic matter type and continuously flooded type. The lowland category is subdivided into rain-fed and deep-water types. The rain-fed type is further divided into flood-prone and drought-prone types. Each of these types was further subdivided considering the organic matter in the fields. The deep-water types of rice-growing areas are the areas with water depth of greater than 100 cm. The secondary rice growing areas are considered as irrigated and continuously flooded. Emission factors of methane generated from rice fields are given in Table 5.5.

5.3.4. Soils

Emissions of N_2O which results from soils used for agricultural purposes occur primarily due to the microbial processes of nitrification and de-nitrification in the soil. Increased use in nitrous fertilizer generally results in higher N_2O emissions from soils (Bouwman, 1990). Under the category of emissions from agricultural soils there are three different types of emissions: direct emissions from soil, emissions of N_2O in soils from animal production (including stable emissions to be reported under manure management) and indirect emissions. Direct soil emissions may result from the following sources of nitrogen input to soils:

1. synthetic fertilizers
2. nitrogen from animal waste
3. biological nitrogen fixation
4. reutilized nitrogen from crop residues, and
5. sewage sludge application.

Table 5.5: Emission factors considered for methane emissions from paddy cultivation (ton CH_4/ha)

Category	Sub category		Emission factor
Major rice			
Upland	Rain fed		0
	Irrigated	Continuously flooded + OM	0.440
		Continuously flooded	0.187
Lowland	Rain fed	Flood prone + OM	0.150
		Flood prone	0.352
		Drought prone + OM	0.176
		Drought prone	0.075
	Deepwater	water depth>100cm	0.153
Second rice	Irrigated	Continuously flooded	0.440

Source: CAE, 2000

Table 5.5.6: Emission factors used to estimate the emissions from agricultural soils

Source		Unit	Amount (ton N_2O/unit) [a]
Direct Emissions	Synthetic fertilizer	1000 ton	11.3
	Animal waste	100,000 animals	2.1
	Crop residues	100,000 ton [b]	15.5
	N-fixing crops	100,000 ton [c]	75.0
Indirect Emissions	Synthetic fertilizer	1,000 ton	13.8
	Animal waste	1,000 animals	32.2
Grazing Animals		100,000 animals	3.0

Notes: [a.] Estimated considering number of livestock, crop production and synthetic fertilizer use in 2000 based on IPCC (1996a,b); [b, c.] per ton of crop production

The present study has considered direct as well as indirect N_2O emissions from the synthetic fertilizer use and grazing animals. Table 5.6 gives the emission factors used to estimate the emissions from agricultural soils.

These emission factors were estimated based on the methodologies provided in the IPCC (1996) for the estimation of N_2O from agricultural soils.

5.3.5. Field burning of Agricultural Residues

Burning of agricultural residue in fields results in the release of CO_2, CH_4, CO, N_2O and NO_x emissions. The burning of crop residues is not considered to be a net source of CO_2 emissions because the carbon released to the atmosphere is reabsorbed during the next growing season. However, the net release in pollutants of CH_4, CO, N_2O and NO_x emissions is significant. Therefore, the emissions of these pollutants during the burning of agricultural residues are accounted in emissions inventory development (IPCC, 1996a,b). Recently the use of agricultural residues is promoted as a source of energy, especially in cogeneration. In this study, it has considered that bagasse and straw are used for cogeneration in sugar and paper industries. As to field burning of residues, this study considers residue burning from crops that include paddy, maize and potato. However, the amount of agricultural residues burnt on site remains to be a debatable issue. There exist no direct data or studies conducted specifically on the subject. According to a study by Yevich and Logan (2002), 53% of the crop residue is burnt in the field in Thailand. The emission factors that were used to estimate the emissions from agricultural crop residues are given in Table 5.7. These emission factors were estimated based on the methodologies provided in the IPCC (1996a,b) for estimation of pollutant emissions from agricultural crop residues.

Table 5.7: Emission factors considered in burning of crop residues (kg/ton)*

Crop	CH_4	CO	N_2O	NO_x
Rice	0.56	11.86	0.67	0.12
Maize	0.23	4.79	-	-

* The unit refers to the kg of pollutant per ton of crop produced
Source: IPCC, 1996a,b

5.3.6. Forests and land use

The amounts of CO_2 emitted and sequestered from forests are difficult to estimate because of complex biological factors and the lack of reliable data, especially with regards to the rate of change of land use, the use of converted forest land, and the biomass density of forests.

The emissions and sequestration of greenhouse gases in Thailand during 2000 were estimated using the methodologies given in IPCC (1996b). The IPCC methodology was modified under specific assumptions in order to improve the accuracy of estimates and to ensure an accurate reflection of conditions prevailing in local forests. A similar approach was used in MOSTE (2000). The land use and forestry data for the calculation were obtained from RFD (2006) and MOSTE (2000).

5.3.7. Waste (solid waste, waste water treatment)

Human activities in commercial, residential and industrial sectors result in generating wastes. These wastes are released as solid waste and as waste water. Anaerobic decomposition of organic matter by methanogenic bacteria in solid waste disposal sites result in the release of CH_4 to the atmosphere. This source is estimated to account for about 5 to 20 per cent of global anthropogenic CH_4 emissions. Also handling of wastewater streams with high content of organic materials, including domestic and commercial wastewater and some industrial wastewater streams can emit significant amounts of methane (IPCC, 1996a,b).

This study has considered the CH_4 emissions from solid waste disposal sites and waste water in Thailand. It considers municipal and industrial solid waste disposal from 540 sites in 2000 described in (Shrestha et al., 2006). The solid waste dumps are classified into three major types i.e. open dumps, land fill and centralized. Both domestic and industrial wastewater types are considered under the wastewater. Under the industrial wastewater, 13,695 factories have been considered. Out of the 13,695 factories, only 5,639 had discharged wastewater DoIW (2006). MOSTE (2000) considered only a limited number of solid waste disposal sites and waste water releasing industries. Solid waste, domestic waste water and industrial waste water was assumed to grow at a rate proportional to per capita GDP, population and industry sector value added as given in TDRI (2004).

5.4. Results

5.4.1. Carbon dioxide emissions

Figure 5.1 shows the share of CO_2 emissions from fuel combustion, industrial processes and land use change. According to MOSTE (2000), despite a reduction of net emissions from the forestry sector, the total CO_2 emissions from both the energy and forestry sectors are predicted to increase from about 220 Mt in 2000, to more than 510 Mt in 2020. The present study estimates that there would be a 3.4 times increase in the total CO_2 emissions, from 281 Mt in 2000 to 957 Mt in 2035 (565 Mt in 2020).

The study shows that the increase in CO_2 emissions is largely attributed to fuel combustion. Increased economic growth will result in greater travel demand, more power generation and increase in energy intensive industries. Limitation in renewable resources will result in using more fossil fuels to meet the rising energy demands. Combined together, the direct fuel combustion and industrial processes would account for almost 93% of the total CO_2 emissions in 2035. On the contrary, the share of land use related activities are expected to decrease over time. The share would be decreasing from 31% in 2000 to 7% in 2035. The share of land use related CO_2 emissions would be decreasing as it is expected that there would be better forest management practices and a slow growth in population.

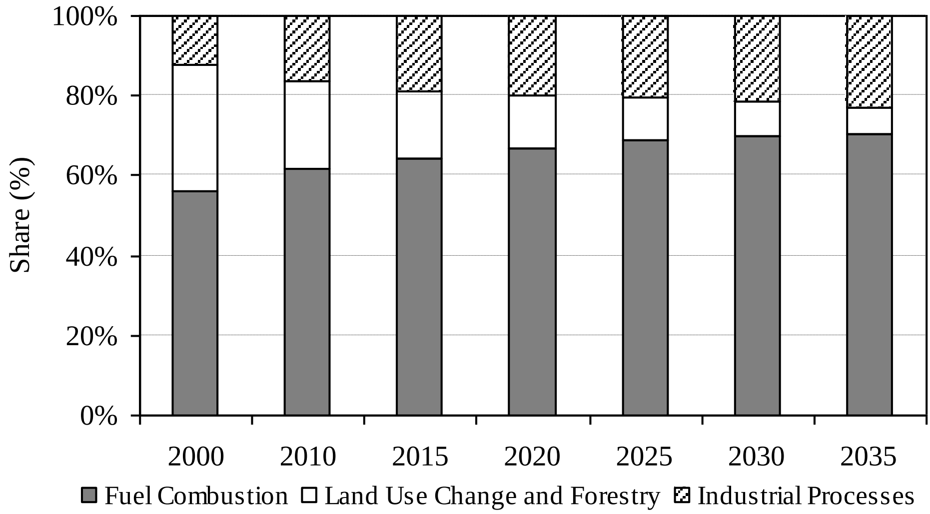

Figure 5.1: Share of CO_2 emissions from fuel combustion and industrial processes.

CO_2 emissions from energy using activities

This study shows that the energy related CO_2 emissions would increase from 158 Mt in 2000 to 676 Mt in 2035 at an AAGR of 4.2%. Note that according to MOSTE (2000), the energy related CO_2 emissions would increase from 151 Mt in 1995 to 475 Mt in 2020 at an AAGR of 4.7%. Use in fossil fuels in industries, power generation and road transportation has mainly contributed to these emissions. The total cumulative CO_2 emissions from 2000 to 2035 amounted to 10,400 Mt. This is five times higher compared to its cumulative value during the period 1970-2000 given in IEA (2004). The energy using sectors are expected to play an ever-increasing role in GHG emissions in years to come.

The profile of CO_2 emissions during 2000-2035 by fuel type is presented in Figure 5.2. Oil accounted for more than half of the total CO_2 emissions in 2000. Combined together, natural gas and coal accounted for only 45% of the total emissions during that year. The present study finds that there would be a significant increase in coal use in the industry and power sectors in the future, because it is relatively cheaper than other fuels. Therefore, CO_2 emissions associated with the coal use is expected to increase significantly in the future. Coal would contribute to 43% of the total CO_2 emissions in 2035. During 2000-2035 the emissions from oil use would decrease and contribute to almost 40% of the total emissions. Natural gas is expected to contribute only one sixth of the total CO_2 emissions by 2035 despite its increased use. Currently, the biomass energy resource (firewood, charcoal and agricultural residues) is used at a sustainable basis, as are other types of biomass (including plantation based biomass and biofuels). Therefore, the net emission of CO_2 is assumed to be negligible in absolute quantity. Considering the sectoral shares (Table 5.8), in 2000 the power sector contributed to almost 37% of the CO_2 emissions and the transport sector accounted for almost 35%. There would be an increasing contribution of the industry sector in total CO_2 emissions over time. The sector would be the single largest emitter of CO_2 in 2035, accounting for almost 40% of the CO_2 emissions.

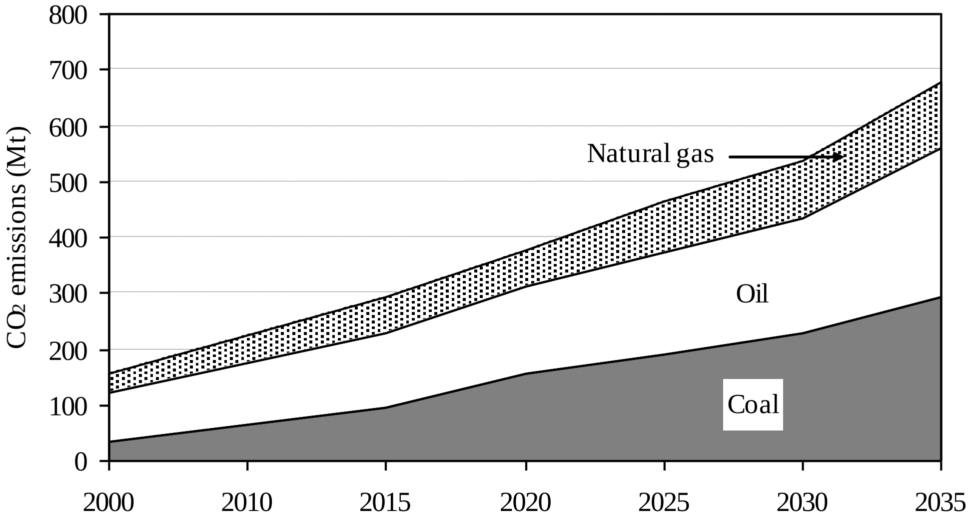

Figure 5.2: CO_2 emissions from direct combustion given by fuel type.

Table 5.8: CO_2 emissions by sector (kt)

Sector	2000	2015	2025	2035
Agriculture	6	9	11	13
Commercial	2	7	12	21
Power	58	68	114	168
Industry	33	102	173	269
Residential	3	6	8	10
Transport	56	100	147	195
Total	158	292	465	676

CO_2 emissions from industrial processes

CO_2 emissions resulting from material handling in cement and steel manufacturing together with lime processing as an industrial raw material and construction is considered under this category. Use of lime is the main source of emissions and it accounted for almost two-thirds of emissions in this category in 2000. However, it is expected to play a much lesser role in the future. In 2035, dolomite and other raw materials used for cement manufacturing would have the highest contribution in total fugitive CO_2 emissions from industrial processes. It would account for almost three-fifth of the total CO_2 emissions that year. This would be followed by lime use, which would account for a quarter of the emissions, while the primary steel manufacturing process would contribute by almost one-tenth of the total emissions. The fugitive CO_2 emissions from raw material handling in the industry sector would increase from 34 Mt in 2000 to 217 Mt in 2035 at an AAGR of 5.4%. The estimated fugitive CO_2 emissions from the industry sector during 2000-2035 are given in Table 5.9.

Table 5.9: Fugitive CO_2 emissions from industrial processes (kt)

Industry	2000	2015	2025	2035
Cement	12,712	44,021	79,791	134,058
Steel	-	7,336	13,689	26,507
Lime	21,784	33,939	44,514	56,982
Total	34,496	85,295	137,995	217,548

CO_2 emissions from Land use change and forestry

The CO_2 emissions from the forestry sector would decrease during 2000-2035. The net CO_2 emissions would decrease from 73 Mt in 2000 to 53 Mt in 2035 at a rate of 0.9%. This is largely due to forest conservation and reforestation activities. The CO_2 emissions from the use of forests and grass lands for anthropogenic activities would also be decreasing over the period. The forestry related CO_2 emissions would decrease from 8 Mt in 2000 to 5 Mt in 2035. These emissions are mainly attributed to forest fires associated with land clearing and removal of trees. Compared to other sectors, land use and forestry related activities are expected to play a relatively insignificant role in the future.

5.4.2. Methane Emissions

The future CH_4 emissions are expected to increase at a much slower rate compared to CO_2 emissions. This is mainly due to the limitations in scope in expanding the agriculture and livestock sectors. Most of these emissions will come from enteric fermentation and manure management of livestock and digestion of biological matter in flooded rice fields. Currently, most of land in the country is used for rice cultivation. It is unlikely that the land used for rice will increase significantly in the next few decades. The total CH_4 emissions are expected to increase from 4,011 kt in 2000 to 6,906 kt in 2035 at an AAGR of 1.6%. The CH_4 emission by each source is given in Table 5.10. The shares of energy, land use change and forestry, wastes, rice cultivation, livestock and others in total CH_4 emissions between 2000 and 2035 are given in Figure 5.3. The CH_4 emissions from livestock include both enteric fermentation and manure management, while that from others include field burning of agricultural residues and the emissions from soils used for agricultural purposes.

Table 5.10: Methane Emissions by Source during 2000-2035 (kt)

Source		2000	2015	2025	2035
Energy	Fuel combustion	22	56	88	98
	Fugitive Emissions	480	786	1110	1567
Agriculture	Enteric Fermentation	323	294	297	301
	Manure Management	76	121	150	184
	Rice Cultivation	2346	2436	2504	2573
	Field Burning of agric. Residues	37	39	40	41
Waste	Solid Waste Disposal	312	671	1102	1687
	Wastewater	385	424	434	433
Land use and forestry	Forest and grassland conversion	30	27	24	22
Total		4,011	4,854	5,749	6,906

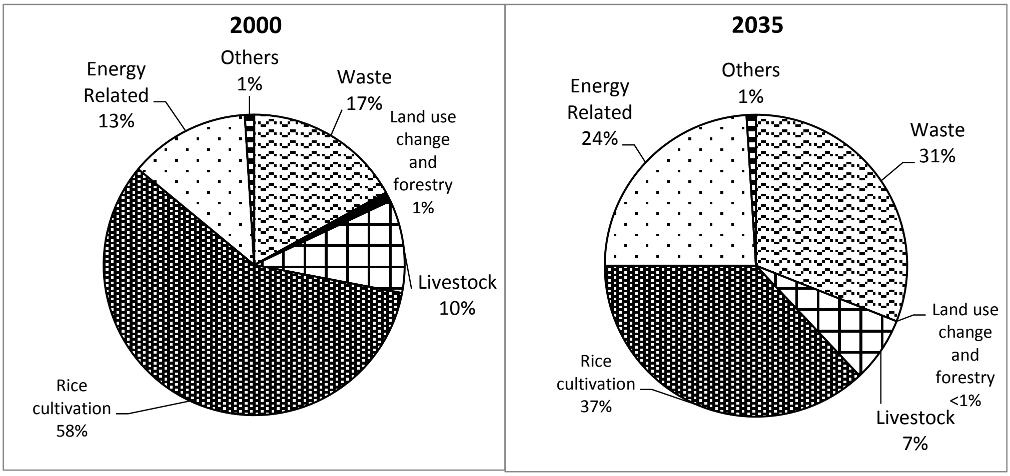

Figure 5.3: Shares of CH_4 emissions by source in 2000 and 2035.

Thailand was the world's seventh largest rice producer in 2013 (FAO, 2015). Rice production has the highest contribution to CH_4 emissions. The rice yield per unit area in the country has been increasing over the years and the area under paddy cultivation is not expected to increase significantly over the next few decades. Therefore, the share of paddy fields in CH_4 emission is expected to decrease from 58% in 2000 to 37% in 2035. The methane emission by each sub category (i.e. major rice and second rice) is given in Table 5.11. The present study finds that rice cultivation in the major season contributes to almost 86% methane emissions. It is estimated that anaerobic digestion of organic matter in the flood prone rain fed low lying areas would contribute to almost 53% of total CH_4 emissions from paddy fields in 2035. According to MOSTE (2000), CH_4 emissions are estimated to rise from 2,110 kt in 1994 to 2,244 kt by 2020.

Ensuring security of energy supply will remain a high priority for Thailand. Hence, a significant increase in mining and extraction of domestic resources, which include coal, oil natural gas, and the leaks during transportation of natural gas by pipelines across the country and gas released during storage are to contribute to the buildup of methane emissions in the atmosphere. In addition, methane released during direct fuel combustion would also contribute to overall emissions. This sharp increase in energy extraction related activities would result in increasing the share of energy using sectors in CH_4 emissions from 12% in 2000 to 23% in 2035.

Livestock products constitute a large portion of the Thai economy. Farms and slaughter houses are scattered across the country. The future livestock population (except buffalo) is estimated to increase over time. However, the share of CH_4 emissions from livestock is estimated to decrease from 10% in 2000 to 7% in 2035, owing to the increased CH_4 emission contribution from energy and waste related emissions. The methane produced by enteric fermentation and manure management of ruminant and non-ruminant animals during the period of 2000-2035 is given in Tables 5.12 and 5.13. CH_4 emission from enteric fermentation is estimated to decrease from 323 kt in 2000 to 301 kt in 2035, while that from manure management is estimated to increase from 76 kt in 2000 to 184 kt in 2035. In comparison, according to MOSTE (2000), CH_4 emissions from enteric fermentation is estimated to decrease from 475 kt in 2000 to 441 kt in 2020 and from manure management it is estimated to increase from 127 kt in 2000 to 250 kt in 2020. In estimating CH_4 emissions in 2000, MOSTE (2000) used a forecast value for the livestock in 2000, while the present study has considered the actual number of livestock in that year. CH_4 emission from enteric fermentation in the present study is estimated to decrease as it is expected that there will be a decline in buffalo population. Non-dairy cattle would contribute to almost 82% of the total enteric fermentation related CH_4 emissions in 2035. The excreta from the swine would account for almost four fifth of the CH_4 emissions from manure management in 2035.

Waste is found to be the second largest contributor to CH_4 emissions. Additionally, increases in production in manufacturing sector would also generate industrial waste water and solid waste. Manufacturing of chemicals and plastic products would result in producing hazardous as well as non-hazardous waste. Both the managed and unmanaged dumping of industrial waste results in releasing CH_4 emissions to the atmosphere. Thailand's large food industry is also a major source of CH_4 emission. A significant amount of CH_4 emissions would be generated by the waste water released during the production of starch, sugar, distillery and monosodium glutamate processes (Prasertsan and Sajjakulnukit, 2006). The results of this study reveal that the share of CH_4 emissions from both the industrial and domestic waste is estimated to increase sharply from 17% in 2000 to 31% in 2035. CH_4 emissions from solid waste would be increasing from 312 kt in 2000 up to 1687 kt in 2035 (AAGR of 4.9%) and liquid waste would be increasing from 385 kt in 2000 up to 433 kt in 2035 (AAGR of 0.3%). The estimated values of CH_4 emissions from the waste during 2000-2035 are given in Table 5.14.

Forest fires are the main source of CH_4 emissions under forest and grassland conversion activates. However, forest and grassland conversion activates are expected to play an insignificant role (i.e., less than 0.5%) in the total CH_4 emissions during the study period.

Table 5.11: Methane Emissions in Paddy Fields (kt)

Category		Sub category	2000	2015	2025	2035
Major rice						
Upland	Rain fed		-	-	-	-
	Irrigated	Continuously flooded + OM	549	570	586	602
		Continuously flooded	233	242	249	256
Lowland	Rain fed	Flood prone + OM	184	191	196	201
		Flood prone	431	448	460	473
		Drought prone + OM	428	444	456	469
		Drought prone	182	189	195	200
	Deepwater	water depth>100cm	7	7	7	7
Second rice	Irrigated	Continuously flooded	333	346	355	365
Total Emissions			2,346	2,436	2,504	2,573

Table 5.12: Methane emissions produced during enteric fermentation of animals (ton)

Type of livestock	2000	2015	2025	2035
Dairy cattle	202	228	238	248
Non dairy cattle	20	22	23	24
Buffalo	94	31	19	9
Swine	7	12	16	20
Total	323	294	297	301

Table 5.13: Methane emissions produced during manure management (ton)

Animal	2000	2015	2025	2035
Dairy cattle	9	10	11	11
Non dairy cattle	10	11	11	12
Buffalo	5	2	1	0
Poultry	46	87	112	142
Swine	6	12	15	18
Total	76	121	150	184

Table 5.14: Methane generation from waste during 2000-2035 (kt)

Source	Sub category	2000	2015	2025	2035
Solid waste	Centralized dump	193	415	682	1044
	Land fill	112	241	396	606
	Open dump	7	15	25	38
Liquid waste	Domestic	383	419	425	419
	Industrial	2	5	9	14
	Total	697	1094	1536	2120

5.4.3. Nitrous oxide Emissions

Agriculture sector activities account for the highest share of N_2O emissions. This study shows that the soils used for agricultural purposes account for almost 85% of the total N_2O emissions in 2000 and 76% in 2035 (Table 5.15). Figure 5.4 shows the share of different sources contributing to total N_2O emissions in years 2000 and 2035. A breakdown of the agricultural soil related N_2O emissions by each type of sub category is given in Table 5.16. Thailand consumed 1.7 Mt of fertilizer in 2002 (FAO, 2005). Among the agricultural soil related N_2O emissions, synthetic fertilizer accounts for almost 60% in 2000 and its share would decrease to 48% in 2035. The level of fertilizer use depends on the area cultivated and local harvesting practices.

Apart from agricultural practices, livestock have a significant contribution to N_2O emissions. It is estimated that grazing animals on pasture land and livestock would account for almost 45% of agricultural soil related N_2O emissions in 2035. The handling of livestock manure also plays an important role in total N_2O emissions; it contributed 11 kt (11%) in 2000 and its emissions would increase up to 21kt (14%) in 2035. There would also be a significant increase in N_2O emissions from direct burning of fossil fuels. Fossil fuel burning will account for almost 9% of the total N_2O emissions in 2035.

Table 5.15: N_2O emissions by source (kt)

	2000	2015	2025	2035
Fuel combustion	3	7	11	13
Manure management	11	15	18	21
Agricultural soils	81	94	102	111
Others*	1	1	1	1
Total	96	117	132	146

* Others include burning of agricultural residue and land use and forestry

Table 5.16: Agricultural soil related N_2O emissions from by source (ton)

Source		2000	2015	2025	2035
Direct Emissions	Synthetic fertilizer	27.6	28.7	29.5	30.3
	Animal waste	8.8	12.4	14.7	16.9
	Total crop residues	7.2	7.5	7.7	7.9
	N-fixing crops	0.4	0.4	0.4	0.4
Indirect Emissions	Synthetic fertilizer	20.8	21.7	22.3	22.9
	Animal waste	8.5	12.1	14.3	16.5
Grazing Animals		8.0	11.6	13.7	16.0
Total		81.4	94.3	102.5	110.8

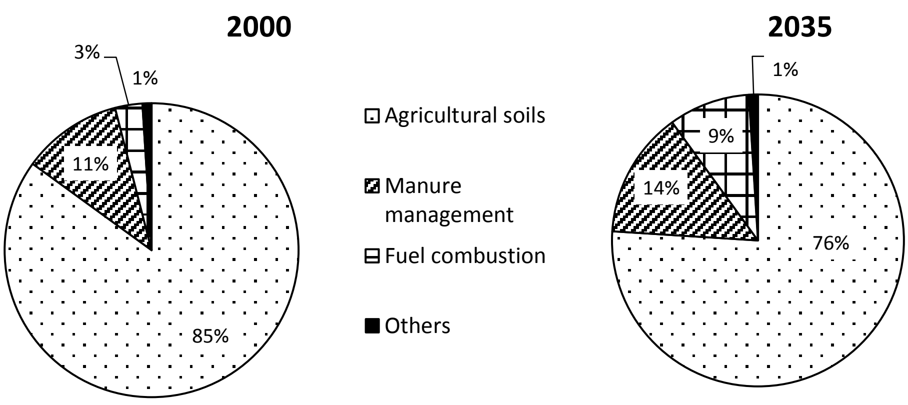

Figure 5.4: Share of N_2O emissions by source in 2000 and 2035.

5.4.4. Thailand's National Greenhouse Gas Emission during 2000-2035

Tables 5.17, 5.18, 5.19 and 5.20 present a summary of annual emissions of CO_2, CH_4, N_2O, NO_x and CO from different emission sources in Thailand, estimated by the present study, for the years 2000, 2015, 2025 and 2035 respectively.

Table 5.17: Thailand's national GHG emissions in the BAU scenario in 2000 (kt)

Greenhouse Gas Source and Sink Categories		CO_2 Emissions	CO_2 Removals	CH_4	N_2O	NO_x	CO
Total Emissions & Removals		280,779	-14,775	5,540	53	968	5,141
1. Energy		157,968	0	501	3	925	4,081
1A.	Fuel Combustion	157,968	0	21	3	925	4,081
	1A1. Energy & Transformation Ind.	57,875		7	1	167	816
	1A2. Industry	33,230		5	1	143	614
	1A3. Transport	55,894		6	1	510	2,125
	1A4. Commercial	1,726		<1	0	4	9
	1A5. Residential	3,288		3	0	37	437
	1A6. Agriculture	5,955		<1	0	64	80
1B.	Fugitive Emissions	0	0	480	0	0	0
	1B1. Solid Fuels			16			
	1B2. Oil and Natural Gas			464			
2. Industrial Processes		34,496				3	8
3. Agriculture		0	0	4312	50	32	786
3A.	Enteric Fermentation			323			
3B.	Manure Management			78	11		
3C.	Rice Cultivation			3,874			
3D.	Agricultural Soils				38		
3E.	Prescribed Burning of Savannas						
3F.	Field Burning of agric. Residues			37	1	32	786
3G.	Others						
4. Land use change and forestry		88315	-14775	30	0	8	266
a. Changes in forests and other woody biomass stocks		80,585	-14,775				
b. Forest & Grassland Conversion		7,730		30	0	8	266
c. Abandonment of Managed Land							
d. Others							
5. Wastes		0	0	697	0	0	0
5A.	Solid Waste Disposal			312			
5B.	Wastewater Treatment			385			

Table 5.18: Thailand's national GHG emissions in the BAU scenario in 2015 (kt)

Greenhouse Gas Source and Sink Categories		CO_2 Emissions	CO_2 Removals	CH_4	N_2O	NO_x	CO
Total Emissions & Removals		454,544	-13,002	4,853	139	1,799	8,495
1. Energy		291,531	0	841	6	1,752	7,413
1A.	Fuel Combustion	291,531	0	56	6	1,752	7,413
	1A1. Energy & Transformation Ind.	68,089		20	3	249	2,437
	1A2. Industry	102,188		11	2	318	1,090
	1A3. Transport	99,633		20	1	1024	3,267
	1A4. Commercial	6,582		<1	0	16	12
	1A5. Residential	6,196		4	0	50	488
	1A6. Agriculture	8,843		1	0	95	119
1B.	Fugitive Emissions	0	0	785	0	0	0
	1B1. Solid Fuels			28			
	1B2. Oil and Natural Gas			757			
2. Industrial Processes		85,295				7	31
3. Agriculture		-	-	2,890	133	33	817
3A.	Enteric Fermentation			294			
3B.	Manure Management			121	15		
3C.	Rice Cultivation			2,436			
3D.	Agricultural Soils				117		
3E.	Prescribed Burning of Savannas						
3F.	Field Burning of agric. Residues			39	1	33	817
3G.	Others						
4. Land use change and forestry		77,718	-13,002	27	-	7	234
a. Changes in forests and other woody biomass stocks		70,915	-13,002				
b. Forest & Grassland Conversion		6,803		27	-	7	234
c. Abandonment of Managed Land							
d. Others							
5. Wastes		-	-	1,095	-	-	-
5A.	Solid Waste Disposal			671			
5B.	Wastewater Treatment			424			

Table 5.19: Thailand's national GHG emissions in the BAU scenario in 2025 (kt)

Greenhouse Gas Source and Sink Categories		CO_2 Emissions	CO_2 Removals	CH_4	N_2O	NO_x	CO
Total Emissions & Removals		673,586	-11,820	5,748	132	2,646	12,034
1. Energy		464,939	0	1,197	11	2,594	10,929
1A.	Fuel Combustion	464,939	0	87	11	2,594	10,929
	1A1. Energy & Transformation Ind.	114,133		41	6	453	5,046
	1A2. Industry	172,655		12	3	513	1,016
	1A3. Transport	146,614		29	2	1,421	4,253
	1A4. Commercial	12,113		<1	0	29	19
	1A5. Residential	7,969		4	0	54	440
	1A6. Agriculture	11,455		1	0	124	155
1B.	Fugitive Emissions	0	0	1110	0	0	0
	1B1. Solid Fuels			52			
	1B2. Oil and Natural Gas			1,058			
2. Industrial Processes		137,995				12	53
3. Agriculture		0	0	2991	121	34	839
3A.	Enteric Fermentation			297			
3B.	Manure Management			150	18		
3C.	Rice Cultivation			2,504			
3D.	Agricultural Soils				102		
3E.	Prescribed Burning of Savannas						
3F.	Field Burning of agric. Residues			40	1	34	839
3G.	Others						
4. Land use change and forestry		70652	-11820	24	0	6	213
a. Changes in forests and other woody biomass stocks		64,468	-11,820				
b. Forest & Grassland Conversion		6,184		24	0	6	213
c. Abandonment of Managed Land							
d. Others							
5. Wastes		0	0	1536	0	0	0
5A.	Solid Waste Disposal			1102			
5B.	Wastewater Treatment			434			

Table 5.20: Thailand's national GHG emissions in the BAU scenario in 2035 (kt)

Greenhouse Gas Source and Sink Categories		CO_2 Emissions	CO_2 Removals	CH_4	N_2O	NO_x	CO
Total Emissions & Removals		957,389	-10,638	6,907	145	3,468	13,319
1. Energy		676,253	0	1,666	12	3,411	12,205
1A.	Fuel Combustion	676,253	0	99	12	3,411	12,205
	1A1. Energy & Transformation Ind.	167,759		48	7	620	5,688
	1A2. Industry	269,447		11	3	774	517
	1A3. Transport	194,793		35	2	1,768	5,466
	1A4. Commercial	21,417		1	0	51	30
	1A5. Residential	9,558		3	0	55	325
	1A6. Agriculture	13,279		1	0	143	179
1B.	Fugitive Emissions	0	0	1567	0	0	0
	1B1. Solid Fuels			69			
	1B2. Oil and Natural Gas			1,498			
2. Industrial Processes		217,548				17	61
3. Agriculture		0	0	3099	133	35	862
3A.	Enteric Fermentation			301			
3B.	Manure Management			184	21		
3C.	Rice Cultivation			2,573			
3D.	Agricultural Soils				111		
3E.	Prescribed Burning of Savannas						
3F.	Field Burning of agric. Residues			41	1	35	862
3G.	Others						
4. Land use change and forestry		63588	-10638	22	0	5	191
a. Changes in forests and other woody biomass stocks		58,022	-10,638				
b. Forest & Grassland Conversion		5,566		22	0	5	191
c. Abandonment of Managed Land							
d. Others							
5. Wastes		0	0	2120	0	0	0
5A.	Solid Waste Disposal			1687			
5B.	Wastewater Treatment			433			

5.4.5. Total Greenhouse Gas Emissions of Thailand in terms of Global Warming Potential

The estimated total greenhouse gas emissions from Thailand expressed in CO_2 equivalent term using their global warming potential for a 100-year period is given in Table 5.21 and Figure 5.5. These emissions have been estimated from GHG source and sink categories that comprise energy using sectors, as well as industrial processes, agriculture, land use, land use change and forestry and waste. The total global warming potential of all greenhouse gas emissions is estimated to increase from 401 $MtCO_2e$ (million tons of CO_2 equivalent) in 2000 to 1,159 $MtCO_2e$ in 2035. According to the MOSTE (2000), global warming potential of all GHG emissions was estimated at 286 $MtCO_2e$ in 1994. CO_2 emissions accounted for almost 70% of the greenhouse gases in 2000 while the rest came from CH_4 and N_2O emissions. The significance of CO_2 emissions tends to increase in the future years owing to the increase in energy using sectors. In 2035, CO_2 emission, which is mostly related to energy using activities, is estimated to account for more than four-fifth of the total GHG emissions. This highlights the importance of the policies that reduce the CO_2 emissions from the energy using sectors, particularly, the industry, transport, residential, commercial and electricity generation sectors. The share of CH_4 emissions will account for only 14% of the total GHG emissions measured in terms of global warming potential of different gases in 2035 owing to the limited future growth in agriculture and livestock sectors. In contrast to CO_2 and CH_4 emissions, the role of N_2O emissions would be very small (4%) in total emissions of GHGs by 2035.

Table 5.21: Emissions of CO_2, CH_4 and N_20 and total GHG emission in Thailand (Mt)

Pollutant	2000	2015	2025	2035
CO_2	281	455	674	957
CH_4	92	112	132	159
N_2O	28	35	39	43
Total GHG emission in $MtCO_2e$	401	601	845	1159

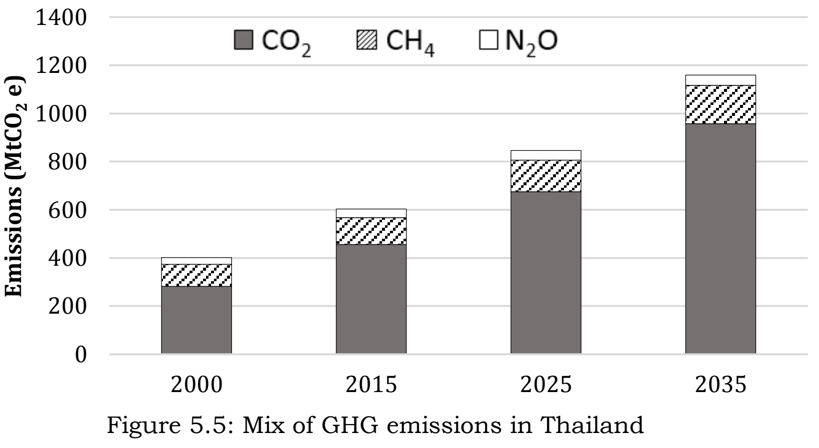

Figure 5.5: Mix of GHG emissions in Thailand

5.5. Conclusion and Final Remarks

The study has estimated the growth in the emission of GHGs in Thailand during 2000-2035. In doing so, it has included major sources of GHG emissions covering both energy using sectors (i.e., agriculture, commercial, industry, residential and transport) and non-energy activities (i.e., industrial processes, agriculture, land use, forestry and waste). Pollutants covered in the study are CO_2, CH_4, N_2O, NO_x and CO emissions.

The results of this study showed that the global warming potential of all GHG emissions would increase from 401 $MtCO_2e$ in 2000 to 1,159 $MtCO_2e$ in 2035 at an AAGR of 3.6%. This is nearly a three-fold increase during the 35 year period. The CO_2, CH_4 and N_2O from energy emissions would increase by 12%, 11% and 6%, respectively from 2000 to 2025. Out of the total CO_2 emissions direct, fuel combustion will account for almost 71% of the CO_2 emissions in 2035. The total CH_4 and N_2O emissions will increase up to 6.9 Mt and 146 kt, respectively by 2035. Out these emissions almost 46% of CH_4 emissions and 91% of N_2O emissions in 2035 are estimated to come from agriculture and livestock sectors. Although the land use and forestry related activities contributed to almost 31% of the CO_2 emissions in 2000, low population growth and forest management and land use practices are estimated to result in decreasing the sector's share to around 7% by 2035.

Out of the total global warming pollutants, CO_2 emissions remain to be the most significant accounting for more than four-fifth of the total in 2035. Industry, transport and electricity generation sectors have been estimated to play an increasingly important role in the context of considering future mitigation options. On the other hand the agriculture and livestock sectors have been estimated to play an insignificant role in global warming in the future.

Basic research, field observations and testing are needed to improve the quality of the data, to reduce uncertainties, and to enhance understanding of the relationship of these emissions with productive activities in order to help determine the needs and limitations of reducing them. One limitation of the study is that since the study was carried out in 2006, the available IPCC (1996) guidelines were used to estimate the GHG emissions in Thailand. The use of the revised IPCC (2006) guidelines could be used in further studies of this kind. Another major limitation of the present study is that some of the short-lived climate forcers such as BC, OC, VOC, etc. have not been included in the emission estimation.

References

Bouwman, A.F., 1990. Soil and the greenhouse effect. John Wiley & Sons, New York.

Center for Applied Economics (CAE), 2000. Thailand's 1994 National Inventory of Greenhouse Gases. A report submitted to OEPP, CAE, Bangkok, Thailand.

Department of Industrial Works (DoIW), 2006. Waste water data. DoIW, Ministry of Industry, Bangkok (Personal communication).

Food and Agriculture Organization (FAO), 2005.. Statistical Databases of FAO of United Nations, New York. Accessed on 15/01/2006 from http://faostat.fao.org/.

Food and Agriculture Organization (FAO), 2015. FAOSTAT. Statistics Databases of FAO of United Nations (UN), New York. Available on http:// http://faostat3.fao.org/, cited 30 November 2015.

International Energy Agency (IEA), 2004. Energy Statistics of Non-OECD Countries, OECD/IEA, Paris, France.

IEA, 2012. CO_2 emission from fuel combustion (2012 edition), IEA, Paris.

Intergovernmental Panel on Cimate Change (IPCC), 1996a. Climate Change 1995. The Science of Climate Change. Technical summary, (eds.) J.T. Houghton, J., Meira Filho, L., Callander, B., Harris, N., Kattenberg, A. and Maskell, K., IPCC, Cambridge University Press, Cambridge.

IPCC, 1996b. Revised IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual, Vol. 3., Bracknell, USA.

Intergovernmental Panel on Climate Change (IPCC), 2001a. Metz, B., Davidson, O., Swart, R. and Pan J. (Eds.), Climate change 2001: Mitigation Contribution of Workshop Group III to the Third Assessment Report of the IPCC, Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC), 2001b. McCarthy, J., Canziani, O., Leary, N., Dokken, D. and White, K. (Eds.), Climate Change 2001: Impacts, Adaptation & Vulnerability Contribution of Working Group II to the Third Assessment Report of IPCC. Cambridge University Press, UK.

Intergovernmental Panel on Climate Change (IPCC), 2006. IPCC (2006) guidelines. Available online at http://www.ipcc-nggip.iges.or.jp/faq/faq.html.

Kainuma, M., Y. Matsuoka and T. Morita (Eds.), 2003. Climate Policy Assessment: Asia-Pacific Integrated Modeling, Springer-Verlag, Tokyo, Japan.

Li, Y. F., Zhang, Y. J., Cao, G. L., Liu, J. H. and Barrie, L. A., 1999, Distribution of Seasonal SO_2 Emission from Fuel Combustion and Industrial

Activities in Shanxi Province, China, With 1/6ox1/4o Longitude/ latitude Resolution". Atmospheric Environment 33: 257-265.

Ministry of Agriculture and Co-operatives (MoAC), 2004. Agricultural Statistics of Thailand 2003. MoAC, Bangkok, Thailand. Available on http://www.oae.go.th/statistic/yearbook/2003/indexe.html, downloaded 15 December 2005.

Ministry of Science and Technology (MoSTE), 2000. Thailand's Initial National Communication under the United Nations Framework Convention on Climate Change. MoSTE, Bangkok.

National Institute of Development Administration (NIDA), 2006. Thailand long–term load forecasts. Report submitted to Energy Policy and Planning Office, NIDA, Bangkok (see http://www.eppo.go.th/load/nida/eng/contents.html).

Office of Industrial Economics (OIE), 2006. Industrial Statistics. OIE, Ministry of Industry, Bangkok. Accessed online from http://www.oie.go.th/IndStatistic/statistics.asp.

Prasertsan, S., Sajjakulnukit, B., 2006. Biomass and biogas energy in Thailand: potential, opportunity and barriers. Renewable Energy 31, 599–610.

Royal Forest Department (RFD), 2006. Forestry statistics. RFD in Thailand, Bangkok. Available on http://www.forest.go.th/default_e.asp and www.forest.go.th/stat/stat44/tab1.pdf.

Shrestha, R.M., Kumar S. and Visvanathan C., 2006. CDM potential of Municipal Solid Waste Projects in Thailand, Asian Institute of technology, Pathumthani (unpublished report).

Shukla, P.R. Rana, A. Garg, A. Kapshe, M. Nair, R., 2004. Climate Policy Assessment for India: Applications of Asia-Pacific Integrated Model (AIM), University Press, Hyderabad.

Thailand Development and Research Institute (TDRI), 2004, Impacts of Thailand Electricity Tariff Reform Project, Report submitted to Electricity Generating Authority of Thailand, TDRI, Provincial Electricity Authority and Metropolitan Electricity Authority, Bangkok (in Thai).

United Nations Framework Convention on Climate Change (UNFCCC), 2007. Climate Change: Impact Vulnerabilities and Adaptation in Developing Countries. Climate Change Secretariat, UNFCCC, Bonn. Accessed online on 11/25/2015 https://unfccc.int/resource/docs/publications/impacts.pdf.

United Nations (UN), 2004. World Population Prospects: The 2004 Revision and World Urbanization Prospects: The 2003 Revision. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, UN, New York.

World Bank (WB), 2015. World development indicators, WB.

Yevich R. and Logan J. A. 2002. An assessment of biofuel use and burning of agricultural waste in the developing world. Harvard University, Massachusetts. Submitted to Global Biogeochemical Cycles. Also available on http://www-as.harvard.edu/chemistry/trop/publications/yevich2002.abs.html, downloaded 05 January 2006.

Chapter 6

Implications of Post-Kyoto CO_2 Emission Reduction Targets on Energy and Environment in Thailand

Abstract

This study examines energy system development and its associated greenhouse gas and local air pollutant emissions under base case and three different CO_2 emission reduction targets in Thailand during 2000-2035. The base case results show that fossil fuels would continue to dominate the total energy supply and that the corresponding CO_2 emissions would increase by more than three-folds between years 2000 and 2035. Power-, transportation- and industry- sector together would contribute 93% of total CO_2 emission by 2035. With limited availability of economically viable new and renewable energy sources and indigenous fossil fuels, the country's energy import dependency under the base case would increase from 50% in 2000 to 77% in 2035.

With the CO_2 emission reduction targets set from 2013, the results of the study show a fall in the share of coal and an increase in the share of natural gas in the total primary energy mix during 2013-2035. However, the renewable energy sources would play a limited role in primary energy mix. The power sector would play a greater role in reducing CO_2 emissions than the other sectors especially at high ER targets. In the scenario with the emission reduction (ER) target of 15%, up to 41% of SO_2 and 10% of NO_x emissions could be reduced as co-benefits. Furthermore, new technologies such as carbon capture and storage and solar for electricity generation; and hydrogen-based fuel cell vehicles and hybrid vehicles for road transportation would become cost-effective under the scenario. The incremental CO_2 abatement cost would vary from 36 US$ per tCO_2 under ER target of 5% to 49 US$ per tCO_2 under ER target of 15% during 2013-2035.

6.1. Introduction

In the face of growing national and international concerns for mitigation of GHG emissions and increasing pressure on developing countries (DCs) to participate in the post-Kyoto climate regime, it is important to identify sustainable energy pathways that lead to low carbon economy in DCs in the future. This requires identification of various options for mainstreaming climate concerns developmental policies and strategies of individual DCs. Thus, it is of interest for policy makers to analyze the implications of post-Kyoto CO_2 emission reduction (ER) targets on energy development and environment in DCs. A number of studies have systematically analyzed several options of emission reduction requirements and time of participation in the international climate regime (Jacoby et al., 1999; Berk and den Elzen, 2001; Criqui et al., 2003; Den Elzen et al., 2005; Groenenberg et al., 2004; Höhne et al., 2002; Kawase et al., 2006; WBGU, 2003; WWF, 2005).

However, most of these studies are concentrated either at the global or at the Annex I[1] level. There are only limited studies on implications of ER on energy system and the environment in DCs. A recent study by IGES (2005) highlighted concerns, interests and priorities from Asian perspectives on climate regime beyond 2012 but limited reference were made on ER targets and their implications on energy systems in developing countries. In the present study, we first analyze energy system development and its implications on environment in the context of Thailand without any constraint on ER during 2000-2035. Then an assessment of post-Kyoto ER targets on energy systems and environment is made over the study period starting from 2013 through 2035. In particular, this study assesses implications of CO_2 emission reduction targets on changes on primary fuel mix, sector-wise energy mix, use of renewable energy technologies, sector-wise GHG emissions and other local pollutants, as well as energy system costs during 2013-2035.

This chapter is divided into six sections. Section 6.2 briefly describes the methodology used in the study. Section 6.3 provides the scenario description including a brief description of data used and their sources. Analyses of results and key findings are presented in Section 6.4. The concluding section presents key findings and final remarks.

6.2. Methodology and Scenario Description

The Thailand AIM/Enduse model is used as the tool for analysis in this chapter. The details of the model are presented in Chapter 2.

Four scenarios are considered in this study; i.e., a base case and three alternative cases each of which considers different CO_2 emission reduction target. Year 2000 is considered as the base year as and the end year of the planning horizon is 2035. The data on economic and demographic parameters, service demand, technology characteristics, energy price, domestic resources availability, emission factors (for CO_2, SO_2 and NO_x), appliance stock in the base year (i.e., 2000) and the information on maximum share (or penetration level) of different technologies are collected from several sources as described in Appendix 3.B in Chapter 3.

The base case scenario in this chapter is the business-as-usual (BAU) scenario. It considers continuation of current economic, demographic and energy sector trends and policies, and there is no mitigation policy. The GDP is considered to grow at a rate of 6% per year during 2000-2020 and 5% per year during 2021-2035. The population is considered to grow at 0.74% per year during 2000-2035. The detailed description of the BAU scenario is

[1] Annex I Parties include the industrialized countries that were members of the OECD (Organization for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States.

presented in Section 3.2 (see Chapter 3). The discount rate considered is 10%. All costs are expressed in constant 1995 US$.

In the three emission reduction cases, targets for CO_2 emission reduction are set at 5%, 10% and 15% of the CO_2 emission during the post-Kyoto period of 2013-2035 in the base case. Hereafter, these three cases are referred to as ER5, ER10 and ER15.

6.3. Results and discussions

In this section, the results of the analysis of energy pathways and their associated environmental and cost implications in Thailand are presented under the base case and three ER target cases.

6.3.1. Base case

Energy development implications

The changes in the structure of total primary energy supply (TPES), energy import dependency and the sector-wise energy demand during 2000-2035 are discussed in Sections 3.3 to 3.5 in Chapter 3.

CO_2 and local air pollutant emissions

The CO_2 and local air pollutant emissions during 2000-2035 in the base case are described in Section 3.6 in Chapter 3.

6.3.2. CO_2 emission reduction target cases

Effects on primary energy mix and final energy demand

With ER targets set from 2013, the results indicate substantial changes in the primary energy mix during 2013-2035. As seen from Figure 6.1, coal share in TPES would fall during the period: It would decrease by 6% under ER5 case and by 12% under ER10 and ER15 as compared to the base case. The reason for only 12% fall in the coal share under ER15 is due to increasing use of CCS based electricity generation (primarily using coal and natural gas) with the increasing ER targets. On the other hand, natural gas share in TPES would increase steadily by 2%, 7% and 10% under ER5, ER10 and ER15 cases respectively. The reason for rise in the share of natural gas in TPES over the study period is its increasing use in electricity generation and industries. Likewise, the share of others (biomass, hydro and new renewable energy sources) in TPES would increase steadily by 1%, 4% and 10% under ER5, ER10 and ER15 cases respectively. In contrast, changes in oil share under all ER cases are rather less significant. The share of oil in TPES over the study period would increase by 0.3% and 0.6% under ER5 and ER10 cases respectively, while it would fall by 2% under ER15 case as compared to the base case. Most of the additional oil requirements to meet growing travel demand would be met by increasing the use of biofuels (ethanol and biodiesel). While no biofuels was used in road transportation in 2000, its share in TPES for transportation would reach 6% (3.3 Mtoe) under ER15 by 2035.

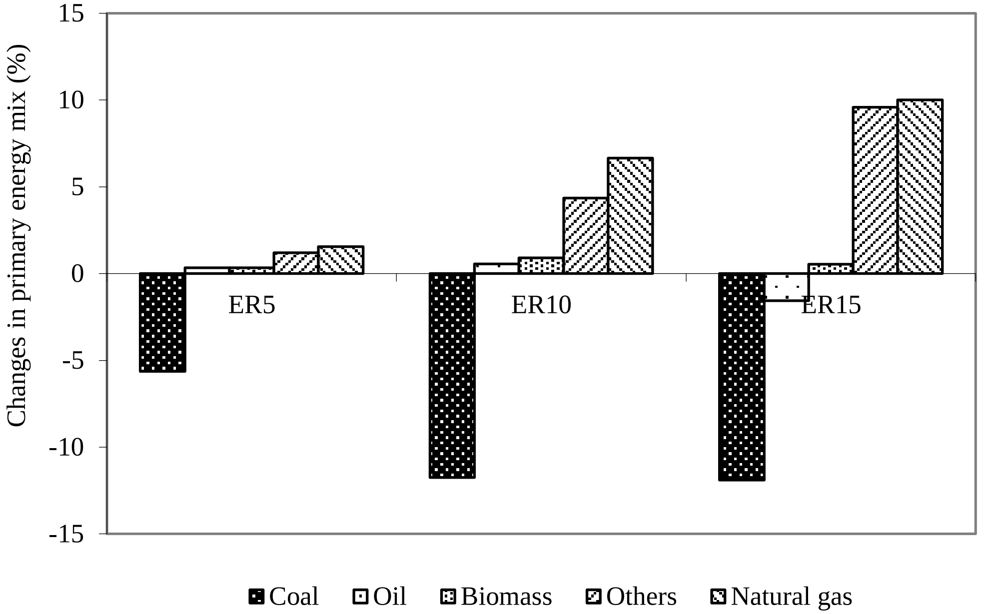

Figure 6.1: Changes in primary energy supply mix under CO_2 emission reduction cases during 2013-2035.

The study shows that renewable energy sources would play a role in primary energy mix under ER targets. Among the renewable sources, the use of biomass (excluding biofuels), wind and solar is found to increase with increasing ER emission targets (Figure 6.2).Solar power (PV and thermal) would be economical only under ER10 and ER15 cases while biomass (excluding biofuels) and wind power would be attractive under all ER cases. However, the increase in the use of hydro, geothermal, biogas and MSW resources with increasing ER targets would remain limited under all ER cases. The total share of renewable sources is estimated towould increase to reach 18.6% under ER15 case as compared to bfromase case value of 17.518.2% in the base case during 2013-2035.

With increasing ER targets, the final energy demand (FED) in the industrial sector would decrease in an increasing order during 2013-2035, i.e., by 1.8% (61 Mtoe), 2.4% (82 Mtoe) and 3.8% (130 Mtoe) under ER5, ER10 and ER15 cases respectively. As can be seen from Figure 6.3, the FED of transport sector would decrease by 3.1% under ER5 to 6.7% under ER15 during 2013-2035. The FED of industry sector would decrease by 1.6% under ER5 to 3.2% under ER15 and FED of residential sector would decrease by 0.2% under ER5 to 0.5% under ER15 during the same period. The reduction of the total FED from agriculture and commercial sectors are found to be negligible.

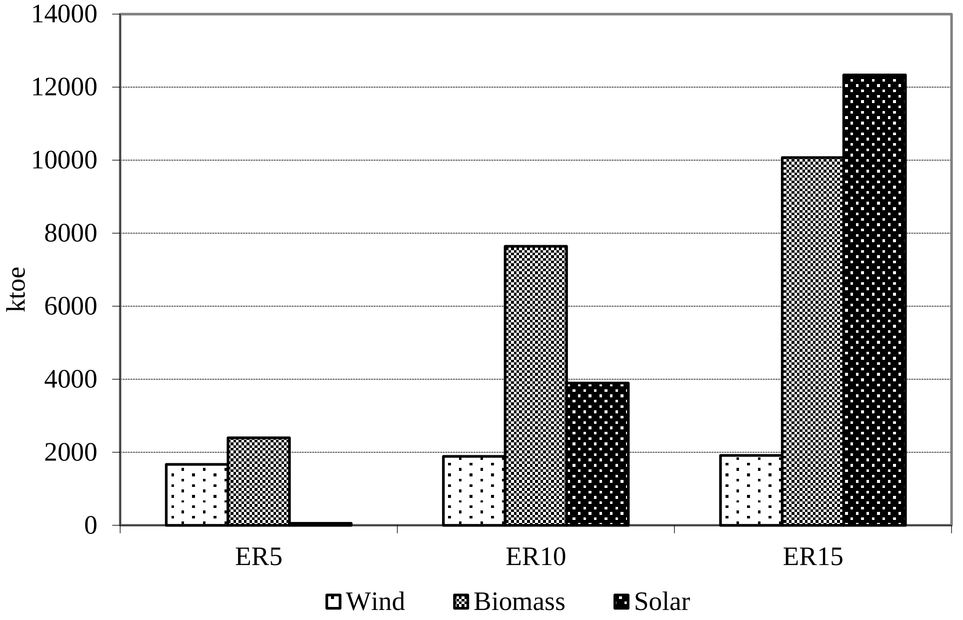

Figure 6.2: Increase in renewable energy sources under CO_2 emission reduction cases during 2013-2035 when compared to the base case.

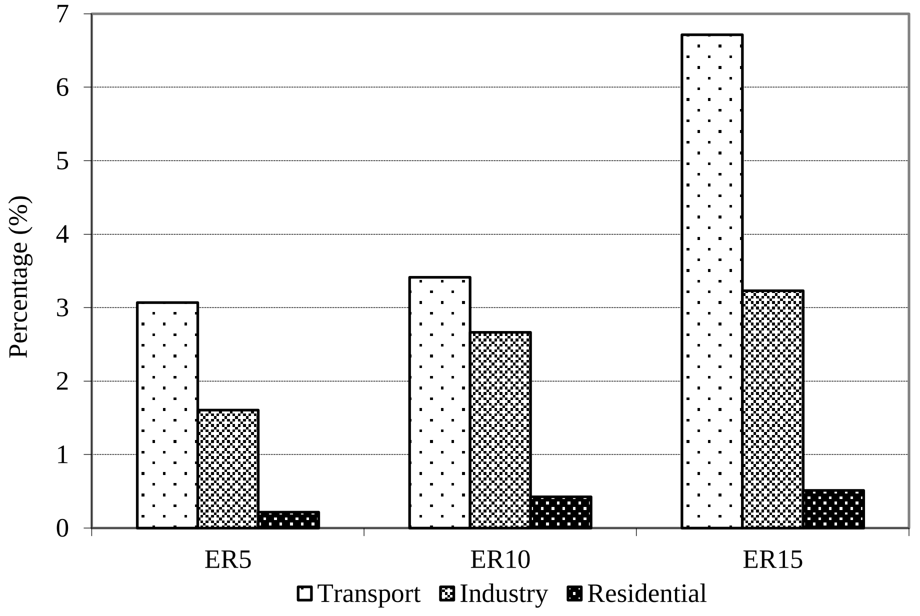

Figure 6.3: Sector-wise reduction in cumulative final energy demand under CO_2 emission reduction target cases during 2013-2035 (%).

Changes in sectoral CO_2 emissions

With ER targets, most of the CO_2 emission reduction would take place in the power, industry and transportation sectors as these sectors would consume more than 90% of the TPES in the country. As shown in Figure 6.4, the power sector be the largest contributor to the CO_2 emission reduction with its share varying from 44% under ER5 to as high as 58% under ER15 during 2013-2035. This is because the power sector provides the highest flexibility to fuel switching (coal to natural gas); it is also because of the adoption of new technologies (integrated gasification combined cycle (IGCC) with CCS) under ER targets. The industry sector would be the second largest contributor accounting for more than 33% and 22% of total CO_2 emission reduction under ER5 and ER15 cases respectively during 2013-2035. The reduction in this sector would come primarily from fuel switching, i.e., from coal to natural gas. The transport sector would be the third largest sector contributor accounting for 23% and 20% of the total CO_2 emission reduction under ER5 and ER15 cases respectively during 2013-2035. The reduction of CO_2 emission in the transport sector would come mainly from the use of more efficient vehicle technologies.

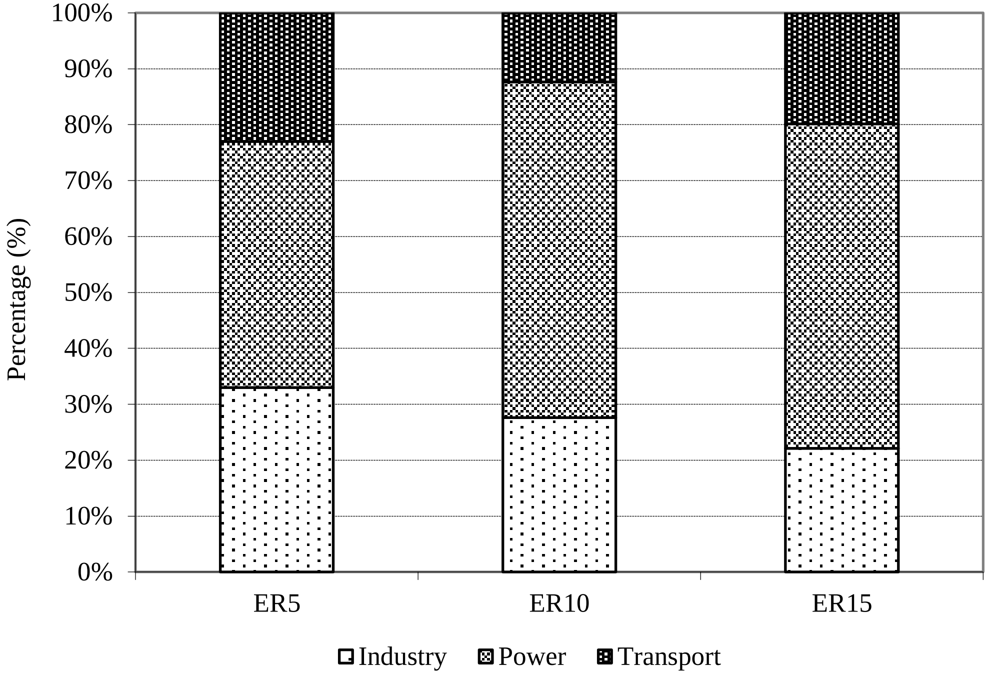

Figure 6.4: Sector-wise contribution to CO_2 emission reduction under ER cases during 2013-2035.

Effects on changes in energy mix and technologies for electricity generation

During the period 1990-2005, the total electricity generation in Thailand grew much faster (8% per year) than the GDP (5% per year) (NIDA, 2006; NESDB, 2006). The present study shows that electricity generation in the base case would increase at a much lower rate (4.5% per year) during 2000-2035.

As shown in Table 6.1, total electricity generation in the base case is estimated to increase from 93 TWh in 2000 to about 433 TWh in 2035. With the ER targets, the total electricity generation in 2035 would be slightly lower (i.e., 433 TWh) under ER5 case, while it would be slightly higher at 445 TWh under ER10 and ER15 cases as compared to the base case. The reason for lower total electricity generation under ER5 as compared to the base case is that more efficient and advance electricity generation technologies (such as advanced natural gas combined cycle) would be used in that case, while the reason for higher total electricity generation under ER10 and ER15 cases is due to increasing use of CCS technologies (which are less efficient than advance combined cycle) with increasing ER targets. Figure 6.5 shows the energy mix in electricity generation under the base and three ER target cases during 2013-2035. The share of natural gas would increase in the energy mix under ER targets, while the share of coal would decrease. The share of natural gas in total energy requirements in the power sector would increase from 32.4% in base case to 36.5% under ER15, while coal share would fall from 37.0% in base case to 31.8% under ER15 during 2013-2035. The fall of coal share in ER15 is due to a shift from conventional coal-based thermal plants to pressurized fluidized bed combustion (PFBC) and IGCC plants with CCS technologies. There is no significant change in the share of hydro and biomass on energy mix, however, the share of renewable increased from 6.8% in base case to 7.9% in ER15. Although there is not much increase in renewable energy sources in energy mix the emission reduction from power sector is significant due to use of CCS technologies in coal- and natural gas-based power plants. The results of this study indicate that under ER15, electricity generation from coal- and natural gas- plants with CCS technology would require 23% and 5% of total fuel requirement during 2013-2035. With ER targets the solar and wind based generation is expected to play an increasing role. The primary energy requirement for solar and wind based electricity generation will increase from 1.3 Mtoe in base case to 3.0 Mtoe in ER5, 7.1 Mtoe in ER10 and 22.8 Mtoe in ER15 during 2013-2035.

The present study shows substantial changes in terms of technology mix for electricity generation under the ER targets. As can be seen from Table 6.1, integrated gasification combined cycle (IGCC) with CCS technology and advanced natural gas combined cycle plants would become economically viable options for electricity generation under ER targets. In 2035, about 11% of total electricity generation would be based on CCS based electricity generation technologies under the base case, whereas the share is estimated to increase up to 17%, 25% and 35% under ER5, ER10 and ER15 cases respectively. Although relatively small, the share of advanced natural gas combined cycle with CCS technology plants would increase from 3% under ER10 to about 7% under ER15 in 2035.

Table 6.1: Total electricity generation by plant type (TWh)

Technology type	Energy type	2000	2035			
			Base case	ER5	ER10	ER15
Fossil fuel and biomass based technologies						
Conventional steam	Lignite	16	20	20	21	-
	Natural gas	10	-	-	-	-
	Fuel oil	10	-	-	-	-
	Biomass	-	30	30	29	29
Integrated gasification combined cycle (IGCC)	Lignite	-	22	21	7	-
	Bituminous coal	-	35	34	35	33
Pressurized fluidized bed combustion (PFBC)	Lignite	-	12	10	-	-
	Bituminous coal	-	45	44	46	18
Combined cycle	Natural gas	39	-	-	-	-
	Fuel oil	-	-	-	-	-
Combined cycle–advanced	Natural gas	-	134	108	93	78
Gas turbine	Natural gas	-	-	-	-	-
	Fuel oil	-	-	-	-	-
Biomass integrated gasification combined cycle (BIGCC)	Biomass	-	39	39	40	40
Carbon capture and storage (CCS)		-	-	-	-	-
Integrated gasification combined cycle (IGCC)	Lignite	-	-	25	31	31
	Bituminous coal	-	30	30	31	31
Pressurized fluidized bed combustion (PFBC)	Lignite	-	-	2	17	31
	Bituminous coal	-	17	17	17	31
Advanced combined cycle	Natural gas	-	-	1	15	31
Renewables based technologies		-	-	-	-	-
Hydro		8	31	31	31	31
Wind		-	2	2	2	13
Solar PV		-	-	-	-	2
Solar thermal		-	-	1	12	11
Geothermal		-	6	6	6	6
MSW		-	6	6	6	6
Biogas		-	3	3	3	3
Co-generation	Coal	3	-	-	-	-
	Natural gas	6	-	-	-	-
Total		93	433	431	445	445

Non-fossil fuel based power generation will increase from 27% in base case to 36% in ER15 in 2035. The total installed capacity of renewable energy in 2013 was 3,788 MW. According to Alternative Energy Development Plan (2012-2021), renewable energy target in power generation is set to be 9,201 MW by 2021 (DEDE, 2012). The share of renewable energy sources excluding hydro in power generation increased from less than 1% in 2004 to 9.2% in 2013 (DEDE, n.d.). Renewable sources such as hydro, geothermal, MSW and biogas play a negligible role in emissions reduction in ER cases. The role of biomass is also found to be negligible in ER cases. Wind based generation will play a role in ER15. It will increase from 2 GWh in all cases except ER15 to 13 GWh in ER15 in 2035. Solar power will become economically viable with ER targets and it would increase to 1 GWh in ER5, 12 GWh in ER10 and 32 GWh in ER15. Total renewable based power generation will increase from 11% in base case to 20% in ER15 in 2035. The change in electricity demand in ER5 is negligible as compared to the base case in 2035. However, there is an increase in electricity requirement from 431 GWh in ER5 to 445 GWh in ER10 in 2035. It will remain at 445 GWh in ER15 in 2035.

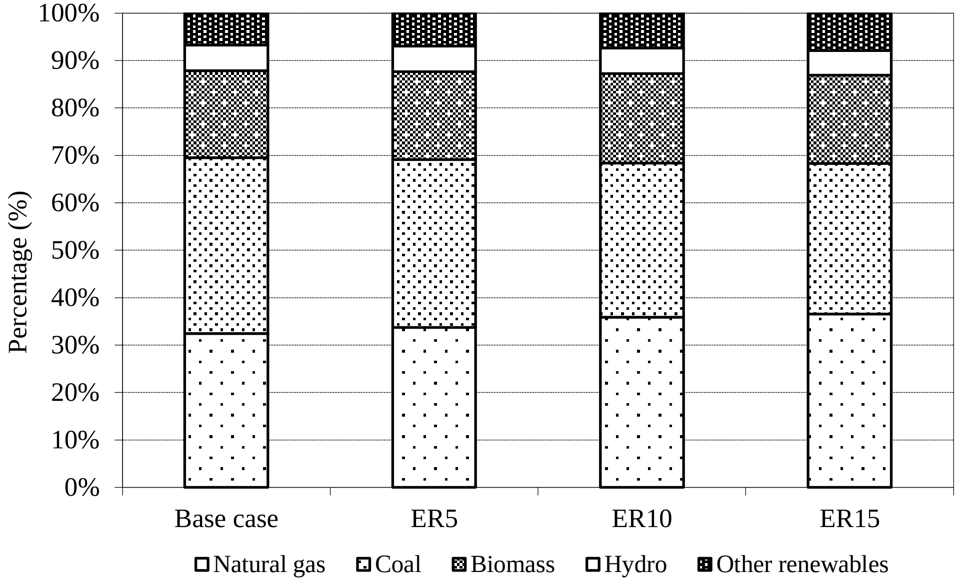

Figure 6.5: Energy mix in electricity generation under the base and ER target cases during 2013-2035.

Effects on road transport fuels and technologies

This study considered conventional gasoline, diesel, LPG and natural gas vehicles as existing technologies. Latest models of existing vehicle types, hybrid vehicles, biodiesel direct injection and urban electric train were considered as efficient technologies. The vehicle technology mix in road transportation under the base and ER target cases is shown in Figure 6.6.

With the ER targets, this study finds that the conventional vehicles would be replaced by hybrid and fuel cell vehicles in road transportation. The share of hybrid vehicles would increase from 49% under the base case to 55% under ER15 in 2035. Likewise, the share of fuel cell vehicles would increase from about 20% under the base case to 22% under ER15 in 2035. The new and advanced vehicle technologies could reduce the total road transportation energy requirements by 4% under ER5 and by 8% under ER15.

This study estimated that biofuels and natural gas together could meet only about 6.5% of total energy requirements in road transportation in 2009. By 2035, the share of alternative fuels would increase up to 24% (i.e., 10% from hydrogen, 6% from biofuels and 8% from natural gas) in the base case. On the contrary, there would be a reduction in natural gas requirements in road transportation under ER targets. This is due to the substitution of low operating efficiency natural gas vehicles with more efficient new and hybrid vehicles. Indeed, only about 6% of total energy requirements in road transportation would come from natural gas while about 7% each would come from hydrogen and biofuels under ER15 during 2013-2035.

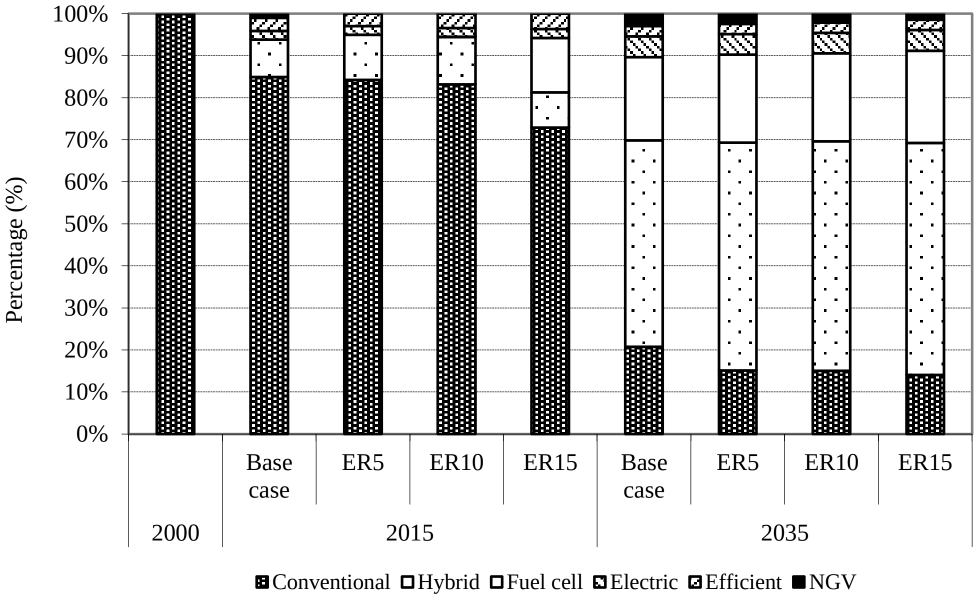

Figure 6.6: Vehicle technology mix in road transportation under base and ER cases in 2000, 2015 and 2035.

Co-benefits of CO_2 emission reduction

The CO_2 ER targets result in reduced SO_2 and NO_x emissions as co-benefits. Figure 6.7 shows the percentage reduction of SO_2 and NO_x emissions in the ER target cases from the emissions in the base case during 2013-2035. As seen from the figure, ER targets would be more effective in reducing SO_2 emissions than NO_x emissions. This is because relatively high sulfur coal would be substituted by natural gas under ER cases resulting in higher percentage of reduction in the emissions of SO_2 than that of NO_x. Total SO_2 emission during 2013-2035 would be reduced by 12.9% (12.5 Mt), 30.9% (30 Mt) and 41.4% (40 Mt) under ER5, ER10 and ER15 cases respectively from the base case emissions. Likewise, the percentage reduction in total NO_x emission during 2013-2035 would be 2% (1 Mt), 5% (3 Mt) and 10.4% (6 Mt) under ER5, ER10 and ER15 cases respectively. The reduction in NO_x emissions under ER targets could be attributed to partial substitution of coal and oil by natural gas in the power and industry sectors and increasing use of natural gas vehicles in road transportation.

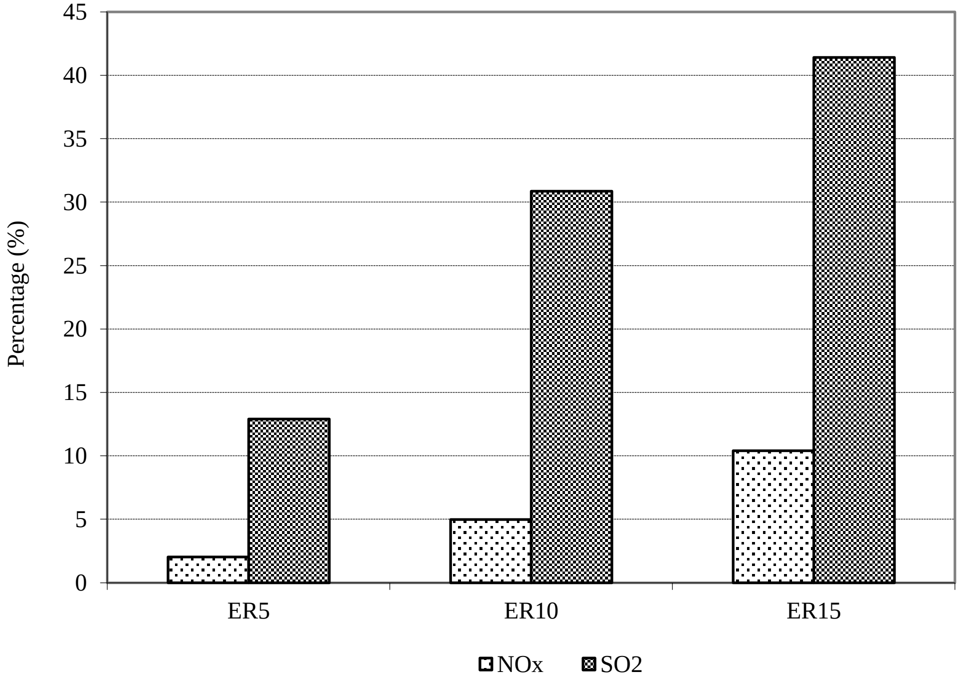

Figure 6.7: Percentage reduction of SO_2 and NO_x emissions under ER target cases compared to base case during 2013-2035

As can be seen from Figure 6.8, the industry and power sectors together would account for about 97%, 94% and 63% of total NO_x emission reduction during 2013-2035 under ER5, ER10 and ER15 respectively, while the transport sector would account for 3%, 6% and 38% of total NO_x emission reduction under ER5, ER10 and ER15 respectively. Likewise, power and industry sectors together would account for 84% and 86% of total SO_2 emission reduction during 2013-2035 under ER10 and ER15 cases. However, under ER5, the results show that there would be an increase of 54% in SO_2 emission from power sector due to more use of lignite for electricity generation.

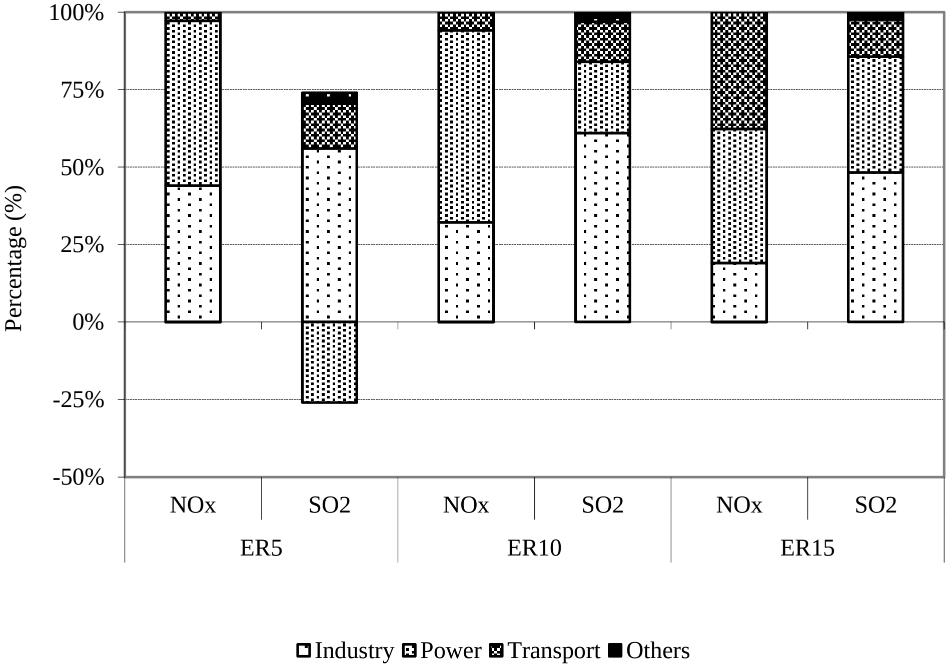

Figure 6.8: Sector-wise percentage reduction of SO_2 and NO_x emissions under ER target cases compared to base case during 2013-2035

The cost of CO_2 emission abatement

The cumulative CO_2 emissions and the corresponding incremental abatement cost (IAC)[2] of mitigating CO_2 emissions in ER5, ER10 and ER15 cases are shown in Figure 6.9. As can be seen from the figure, under ER5, ER10 and ER15 there would be cumulative CO_2 emission reductions of 459, 965 and 1,486 $MtCO_2$ during 2013-2035 under ER5, ER10 and ER15 respectively and the corresponding incremental abatement cost per ton of CO_2 (tCO_2) would be 63 US$, 66 US$ and 125 US$.

[2] IAC of CO_2 emissions is calculated as follows:

$$IAC = TC^e - TC^0 \Bigg/ \left\{ \sum_{t=1}^{T} (E_t^0 - E_t^e)/(1+r)^t \right\}$$

where, TC^e = present value of total cost corresponds to the least cost generation expansion plan with emission constraints, TC^0=present value of total cost corresponds to the least cost generation expansion plan without emission constraints, E_t^0 = pollutant emission in year t corresponds to the least cost generation expansion plan without emission constraints, E_t^e = pollutant emission in year t corresponds to the least cost generation expansion plan with emission constraints, r=discount rate, T=planning horizon.

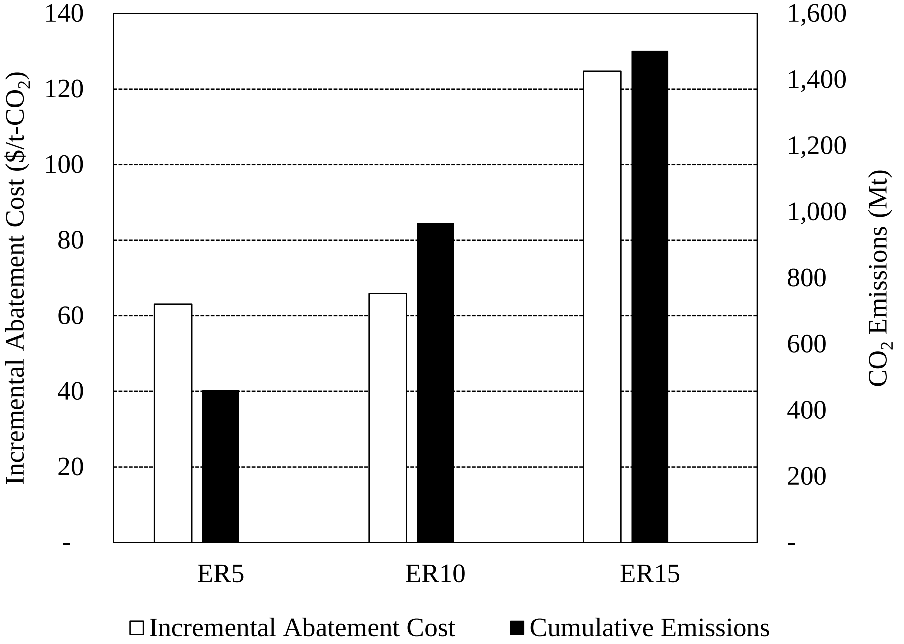

Figure 6.9: Cumulative CO_2 emission reduction and incremental cost of CO_2 emission abatement and during 2013-2035 under ER cases.

6.4. Conclusion and final remarks

Thailand is a heavily fossil fuel intensive economy and is highly dependent on imported energy. Energy security is high on Thai government's agenda. Indeed, 48% of the total primary energy requirement was met through import in 2000 and this study shows that the energy import dependency of the country would reach 78% by 2035. Thailand contributed only about 0.8% of the total energy related CO_2 emission at the global level in 2010. However, if the current trend continues without any mitigation measure, CO_2 emission from the country would increase by more than three-folds by 2035 as compared to the 2000 value. The power sector, which is predominantly fossil-fuel based, would contribute the most in total CO_2 emission, followed by the transport and industry sectors. These three sectors together would contribute more than 93% of the total CO_2 emission from the country during 2013-2035.

There are significant implications of introducing emission reduction targets for the structure of energy system as well as CO_2 and other local air pollutant emissions. With the increase in ER targets, coal share in TPES would fall, while natural gas and renewable energy shares would increase during 2013-2035. However, the decrease in coal consumption in TPES (i.e., 12%) would remain the same under ER10 and ER15 cases due to increasing use of coal based CCS technologies for electricity generation under ER15. Indeed, the share of coal- and natural gas- based CCS technologies would increase to 17%, 25% and 35% under ER5, ER10 and ER15 cases respectively as compared to only about 11% under the base case during

2013-2035. Among the renewable sources, the use of biomass, wind and solar is found to increase with the increase in ER targets during 2013-2035. The share of biofuel in TPES for road transportation would grow to 6% (i.e., 3.3 Mtoe) under ER15 by 2035.

The power sector would play a greater role in reducing CO_2 emissions than the other sectors especially at high ER targets: Its share would be varying from 44% under ER5 to as high as 58% under ER15 during 2013-2035. The industry and transport sectors are the second and the third largest after the power sector accounting for 22% and 20% of total CO_2 emission reduction respectively under ER15 by 2035. As to the environmental co-benefits, ER targets would be more effective in reducing SO_2 emissions than NO_x emissions due to the substitution of high sulfur content lignite by natural gas, which would result in larger percentage of reduction in the emission of SO_2 than NO_x.

The incremental CO_2 mitigation cost is estimated to vary from 63 US$ per tCO_2 under ER5 to 125 US$ per tCO_2 under ER15 during 2013-2035.

The Thailand AIM/Enduse model is a static year by year optimization model. Thus, results presented in this study could be different from end-use models that consider dynamic optimization over the planning horizon. In addition, economic-wide implications of changes in energy prices and costs due to emission reduction targets are not considered in the present analysis, which is based on a bottom-up partial equilibrium energy system model. Furthermore, some of the features of the electricity generation sector such as the lumpiness of investments, discrete nature of power generation capacities and variations in daily load curve are not considered in the selection of power generation plants in the model. Also it is to be noted that the nuclear power generation option is not included in this study. It would be interesting to find out if the consideration of the nuclear power generation option would significantly affect the results of the present analysis.

References

Berk, M.M., den Elzen, M.G.J., 2001. Options for differentiation of future commitments in climate policy: how to realise timely participation to meet stringent climate goals? Climate Policy 1(4), 465-480.

Criqui, P., Kitous, A., Berk, M.M., den Elzen, M.G.J., Eickhout, B., Lucas, P., van Vuuren, D.P., Kouvaritakis, N., Vanregemorter, D., 2003. Greenhouse gas reduction pathways in the UNFCCC process up to 2025. Technical Report, B4-3040/2001/325703/MAR/E.1 for the DG Environment, CNRS-IEPE, Grenoble, France.

Department of Alternative Energy Development and Efficiency (DEDE), n.d. Energy in Thailand: Facts & Figure 2013. DEDE, Ministry of Energy, Bangkok. (Accessed online on 12/06/2015 from http://weben.dede.go.th/webmax/content/energy-thailand-facts-figures-2013)

DEDE, 2012. Alternative Energy Development Plan (2012-2021). DEDE, Ministry of Energy, Bangkok.

Den Elzen, M.G.J., Lucas, P., van Vuuren, D.P., 2005. Abatement costs of post-Kyoto climate regimes. Energy Policy 33, 2138-2151.

Groenenberg, H., Blok, K., Sluijs, J., 2004. Global triptych: a bottom-up approach for the differentiation of commitments under the climate convention. Climate Policy 4, 153–175.

Höhne, N., Harnisch, J., Phylipsen, G.J.M., Blok, K., Galleguillos, C., 2002. Evolution of commitments under the UNFCCC: Involving newly industrialized economies and developing countries. Research report (FKZ 201 41 255) prepared for German Federal Environmental Agency by Ecofys, Cologne.

Institute for Global Environmental Strategies (IGES), 2005. Asian perspectives on climate regime beyond 2012: Concerns, interests and priorities. IGES, Hayama.

Jacoby, H.D., Schmalensee, R., Wing, I.S., 1999. Toward a useful architecture for climate change negotiations. Report no. 49, MIT Joint Program on the Science and Policy of Global Change, MIT, Cambridge, Massachusetts.

Kawase, R., Matsuoka, Y., Fujino, J., 2006. Decomposition analysis of CO_2 emission in long-term climate stabilization scenarios. Energy Policy 34, 2113-2122.

National Institute of Development Administration (NIDA), 2006. Thailand Long-Term Load Forecasts. Final report, NIDA, Bangkok (Accessed online from http://www.eppo.go.th/load/nida/eng /contents.html).

National Energy Policy Office (NEPO), 1999. Thailand's energy strategy and policy. Final report, NEPO, Bangkok.

National Economic and Social Development Board (NESDB), 2006. Gross domestic product: 1994-2006. NESDB, National Accounts Office, Bangkok (Accessed online from http://www.nesdb.go.th/econSocial/macro/NAD/1_qgdp/data2_06/menu.html).

German Advisory Council on Global Change (WBGU), 2003. Climate protection strategies for the 21st century: Kyoto and Beyond. Special report, WBGU, Berlin.

World Wide Fund for Nature (WWF), 2005. Types of future commitments under the UNFCCC and the Kyoto Protocol post 2012. Briefing paper, WWF, Gland.

Chapter 7

Energy and Environmental Implications of Using Biofuels in Thailand's Road Transport

Abstract

This chapter assesses the energy and environmental implications of liquid biofuels promotion and use in Thailand's road transport sector under four scenarios. These scenarios include a reference scenario and three biofuel scenarios that involve different biofuel resource limitations and price, and future development of biofuels as a potential transportation fuel. Changes in the energy supply mix, biofuel requirements, penetration of new technologies as well as implications for energy security and emissions of CO_2, SO_2 and NO_x emissions are assessed for each scenario in this chapter.

7.1. Introduction

Thailand has abundant agricultural resources that are suitable as raw materials for biofuels. The Thai government has been considering the use of biofuels for more than two decades. Two possible options that have been considered are gasohol and biodiesel. Utilization of agricultural product-based energy would not only help stabilize energy prices, but also decrease the nation's dependency on foreign energy (DEDE, 2012). The Thai government has launched programs creating awareness and promoting the use of gasohol and biodiesel.

The National Ethanol Committee (NEC) selected three types of raw materials which would be suitable for ethanol production. These raw materials are sugarcane, molasses and fresh cassava. His Majesty the King of Thailand inaugurated the gasohol project in 1985 with his vision that the kingdom would experience oil shortage and low prices for agriculture products. However, it was in October 2003 that the first successful commercial production of ethanol began.

In Thailand, in initial years, pure biodiesel used to be blended with conventional diesel at ratios from 2% to 20% (DEDE, 2004b). A mixture of 10% pure biodiesel and 90% diesel oil was the most commonly used biodiesel in Thailand (PTT, 2005). The blend provides the same quality and properties as diesel oil and meets the specifications required by the Ministry of Commerce for high-speed diesel (HSD) oil. However, due to palm oil shortage in the country, the ratio of pure biodiesel and HSD blend has been readjusted several times. The blend of pure biodiesel was limited up to only 5% in 2011. The blend of 2% pure biodiesel and 98% HSD blend was the most common mixture in 2011 (EPPO, 2015).

The analysis in this chapter, especially from section 7.3 to 7.5 was carried out during 2005-2007. The main objective of this chapter is to assess the energy and environmental implications of using biofuels in the road transport sector using a least cost energy systems expansion model for

Thailand. Four different scenarios, one reference scenario and three biofuel scenarios are considered for analysis in this study.

This chapter is organized as follows: in the next section, the national policy on biofuels as well as their production targets and consumption are discussed. In Section 7.3, a brief description of the methodology and assumptions is given. This is followed by scenario description in Section 7.4. Section 7.5 discusses the results of the model. Key findings of the chapter and final remarks are presented in Section 7.6.

7.2. National Policy on Biofuels

The Thai Cabinet passed a resolution on renewable energy policy on 2 September 2003. The use of renewable energy resources particularly in the power generation and industrial sectors was emphasized by the policy in order to increase the share of renewable energy in total energy consumption. Since then, the Thai government is actively involved in biofuels promotion as well. According to the Alternative Energy Development Plan (AEDP) (2008-2022), the 15 year target for the consumption of ethanol was set at 3.5, 6.2 and 9.0 million liters/day in 2012, 2016 and 2022, respectively (MoE, 2009). Likewise, the 15 year target for biodiesel was set at 3.14, 3.64 and 4.5 million liters/day in 2012, 2016 and 2021, respectively.

In 2011, the Thai government modified the 15 year AEDP (2008-2022) with 10 year AEDP (2012-2021). The main purpose of this plan was to increase the share of renewable and alternative energy from 20% to 25% by 2021. The AEDP (2012-2021) sets almost the same target of 9.0 million liters/day production of ethanol by 2021 (DEDE, 2012). In order to achieve this target, the government is planning to increase the production of cassava and sugarcane, and promotion of other alternative crops commercially, such as sweet sorghum, on the supply-side. On the demand-side, the government promotes gasohol in the market by providing a subsidy. In 2011, the average prices of E10, E20 and E85 were 37.96, 34.35 and 22.23 Baht[1]/liter, respectively, compared to 46.42 Baht/liter for regular gasoline (EPPO, 2015). In addition, the government has reduced the excise tax to 8% on flexible-fuel vehicles (FFV) using E10 and 3% on FFV using E20 in order to promote the use of biofuels (ADB, 2015).

The AEDP (2012-2021) sets the 2021 target of 5.97 million liters/day of biodiesel production by 2021 (DEDE, 2012). To achieve this target, the Thai government is promoting palm trees plantation in areas where staple crops are not grown, on the supply-side. On the demand-side, the government plans to manage the proportion of biodiesel blending relevant to the domestic palm oil production, carry out the pilot fueling of B10 or B20 in fleet trucks or fishery boats, and prepare to develop the biodiesel standard of Fatty Acid Methyl Ester (FAME) to gain the blending share up to 7% in diesel oil. The

[1] In 2011, 1 US$ = 30.5 Baht (MoF, 2015)

government also promotes biodiesel in the market by providing a subsidy. In 2011, the biodiesel (B5) was 0.50 Baht cheaper per liter than the regular high speed diesel (EPPO, 2015).

In 2015, the government revised the AEDP plan with 20 year AEDP (2015-2036) plan. In AEDP (2015-2036), the production target for ethanol is 7 million liters/day by 2026 and 11.3 million liters/day by 2036. Similarly, the production target for biodiesel is 5 million liters/day by 2026 and 14 million liters/day by 2036 (DEDE, 2015). In 2013, about 905 million liters of biodiesel and 707 million liters of ethanol were consumed in the country's transport sector (DEDE, 2015).

7.3. Methodology and assumptions

To assess energy and environmental effects of using biofuels in the road transport sector, the Thailand AIM/Enduse model has been used in this study. The structure and the mathematical formulation of the model is discussed in detail in Chapter 2. The output of the Thailand AIM/Enduse model provides a least cost energy mix to meet the service demands in different sectors during 2000-2035. However, only the road transport related outputs from the model are analyzed in this chapter. The present study assumes that the total biofuel requirement would be domestically produced. Furthermore, it was also assumed that the natural gas supply in the country would come only from domestic sources. It was considered that the availability of domestic natural gas will increase to 19.2 Mtoe by 2015; it would decrease to 10.2 Mtoe by 2030 and remain at that level till 2035 (NEPO, 1999). The natural gas has competing uses in power generation, road transport and other sectors. There was no subsidy considered for natural gas used in the road transport.

The conventional vehicle options include vehicles that use fuels such as gasoline, diesel and LPG. In this study, advanced vehicle options such as efficient, hybrid, CNG, electric and fuel cell vehicles have been considered. The efficient vehicle options include vehicles that have advanced options such direct injection, low weight, variable valve displacement, variable valve timing and turbochargers intended for energy saving. The hybrid vehicles are mainly of hybrid electric types that have an internal combustion engine and an electric propulsion system. The electric powertrain is intended to achieve a better fuel economy. Although these vehicles have a rechargeable battery it does not need external charging. It was considered that all conventional, efficient and hybrid vehicles types will use biofuels. It was assumed that the prices of advanced vehicles would decrease over time in the future. Future prices of different vehicle types were based on Tseng et al., 2005.

The rest of the model inputs and scenarios considered in this chapter are described below.

7.3.1. Maximum limit on biofuels production

The maximum production target set by the government in 2004 for ethanol and biodiesel are given in Table 7.1. These targets were used in the Thailand AIM/Enduse model as inputs on biofuel availability.

Table 7.1: Targeted daily pure biodiesel and ethanol production in Thailand

Year	Pure Biodiesel Production (Million liters/day)	Ethanol Production (Million liters/day)
2005	5.8	0.7
2006	6.2	1.0
2007	6.6	1.4
2008	7.0	1.8
2009	7.4	2.2
2010	7.7	2.6
2011	8.1	2.8
2012	8.5	3.0

Source: DEDE, 2004b

7.3.2. Fuel prices

The fuel prices in constant 1995 US dollars are used in the Thailand AIM/Enduse model. The biofuels prices are related to the prices of B10 (a blend of 10% pure biodiesel and 90% biodiesel) and E10 (a blend of 10% bio-ethanol).

Prediction of future energy prices is sensitive to several factors, including discovery of new resources, geo-political situation around resource rich areas and world economic situation. In this study, prices of transport fuels used for 2000 and 2005 are actual values. The prices of different energy sources during 2005-2035 are assumed to follow the historical trends during 1980-2005. Further, the prices of biofuels are assumed to remain the same during the period.

7.4. Description of scenarios

In this study, one reference scenario and three biofuel scenarios are considered. These scenarios consider the constraints on resource availability, role of different technological options and the effects of increased biofuels prices. It is assumed that in all four scenarios, the GDP would grow at an average rate of 6% per year during 2000-2020 and it would slow down to 5% per year for the remaining years until 2035 like in the BAU scenario in Chapter 3 (NESDB, 2003). Likewise, the population is assumed to grow at an average rate of 0.74% per year over the study period again like in the BAU scenario in Chapter 3 (UN, 2004). The four scenarios specifically focus on the structural changes in the road transport sector in the near to medium terms during 2000-2035.

Reference scenario (hereafter called "Ref"):

The reference scenario considers an extreme case. It assumes that there would be no technological developments in road transport sector during 2000-2035. Hence, it is considered that biofuels will not be a feasible option during the study period. It also considers that the cost of efficient technologies will not decrease over time. The demand for road transport will be met by conventional fuels (i.e., gasoline, diesel and LPG) and vehicles that run on such fuels. These vehicles include both conventional and efficient motor vehicles but exclude vehicles that are based on advanced technologies, such as hybrid, CNG and electric vehicles. However, in the BAU scenario as discussed in Chapter 3, other fuel options such as CNG and hydrogen are also considered during 2000-2035 and they are also found cost-effective.

Biofuel Scenario 1 (hereafter called "S1"):

This scenario considers that the biodiesel would be produced with a blend of 10% palm oil and 90% diesel. Gasohol would be produced as a blend of 10% ethanol and 90% gasoline. It is considered that the production limit of pure biodiesel would reach 8.5 million liters/day and gasohol would reach 30 million liters/day by 2012. It is also assumed that the biofuel production would reach maximum potential by that year. In addition, the scenario assumes that the cost of advanced vehicle options would decrease over time.

Biofuel Scenario 2 (hereafter called "S2"):

In this scenario, it is assumed that all the conditions described in scenario 1 will prevail, except for the production limits for biodiesel and gasohol. This scenario assumes that all the biodiesel and ethanol requirements can be met through either domestic production or imports from other countries. Cleaner technology options and other factors considered are the same as in Scenario 1.

Biofuel Scenario 3 (hereafter called "S3"):

This scenario considers a blend that is different from the other cases. The biodiesel produced will have 15% pure biodiesel and 85% diesel, while gasohol is produced with 15% ethanol and 85% gasoline. It is assumed that there will be a greater availability of the biofuel resources. The production capacity of biofuels will be twice as large as that of Scenario 1. All other considerations will remain the same as in Scenario1.

7.5. Results

This section discusses the effects on energy mix in road transport, environmental emissions, penetration of new vehicle technologies, energy security and biofuel requirements during 2000-2035 under different scenarios.

7.5.1. Changes in energy mix in road transport

There would be significant changes in the energy consumption in road transport in each case during 2000-2035. The changes in energy mix in each scenario for three selected years (2015, 2025 and 2035) are shown in Figures 7.1, 7.2 and 7.3.

In the reference scenario, diesel would account for almost two-thirds of the total road transport final energy requirements and its share would remain unchanged during the years 2015, 2025 and 2035. However, the share of gasoline would decrease from 24% in 2015 to 17% in 2035. The decreasing share of gasoline is mainly due to increasing share of LPG in road transport (the share of LPG would increase from 11% in 2015 to 17% in 2035).

In 2015, diesel and gasoline (with a share of 65% and 24% respectively) represent the two largest shares for meeting the road transport energy requirement in the reference scenario. However, in the biofuel scenarios, diesel and gasoline fuels are replaced by the liquid biofuels (biodiesel and gasohol). The share of pure biodiesel in the final energy mix would vary from 5% in S2 to 7% in S3. Likewise, the shares of ethanol in total energy requirements vary from 3% in S2 to 4% in S3. The role of CNG in the road transport would be limited as it represents about 2% in all scenarios except in the reference scenario.

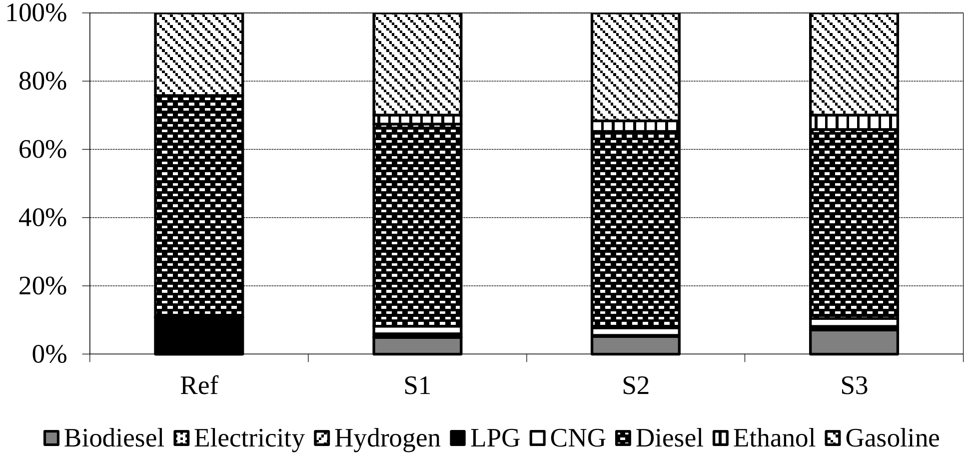

Figure 7.1: Energy mix in road transport in different scenarios in 2015

In 2025, following a similar trend as in 2015, biofuels would replace the use of gasoline and diesel. The share of diesel would decrease from 65% in the reference scenario to 59% in S3. On contrary, the gasoline share would increase from 19% in both reference scenario and S1 scenarios to 1% in both S2 and S3. The pure biodiesel and ethanol use would increase to 9% and 4% respectively in S3. LPG would play a negligible role in all the scenarios. CNG would become cost effective in S1 and S2. The share of CNG would be 13% in S1 and 8% in S2 in 2025.

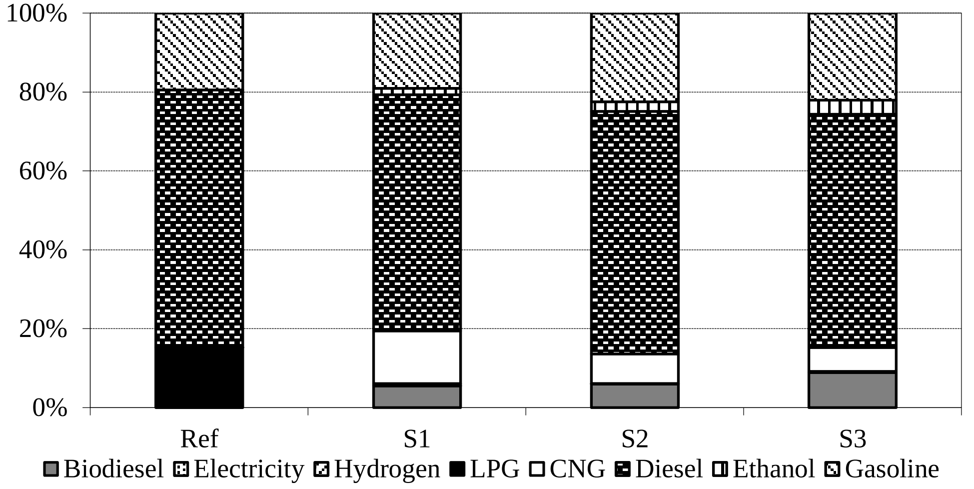

Figure 7.2: Energy mix in road transport in different scenarios in 2025

In 2035, a significant proportion of the total road transport energy requirement would be met by biofuels in S2 and S3 owing to the biofuel availability. Combined together, pure biodiesel and ethanol would have a share of almost 5% in S1, 9% in S2 and 13%% in S3 in the road transport total energy consumption. LPG would have a negligible role. CNG would have a higher share when there are limitations in biofuel supply. Therefore, CNG would be 8% in S1 in 2035. However, during the period from 2005 to 2035, the role of CNG is relatively small. This is mainly because of two reasons: (i) natural gas supply was considered available only from domestic sources and (ii) only a limited amount of gas would be available for use in the transport sector as the gas was found more cost effective to use for power generation. Thus only a relatively small amount of gas would be available for transportation use after meeting the requirement of the power sector.

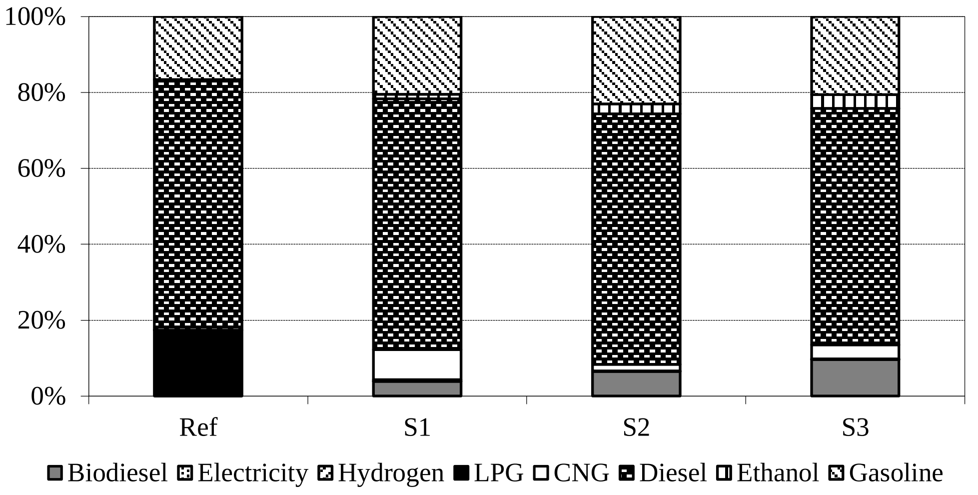

Figure 7.3: Energy mix in road transport in different scenarios in 2035

7.5.2. Biofuel production requirement

The amount of pure biodiesel and ethanol production required under different scenarios are shown in Figures 7.4 and 7.5. The pure biodiesel requirement would reach 21.3 million liters/day by 2035 in S3, as a higher biofuel blend (15%) is considered. In S2, where a 10% blend is considered, the corresponding amount would be 14.3 million liters/day in 2035. In S1, biodiesel production would reach the targeted production level by 2025 and would remain at about the same level till 2035.

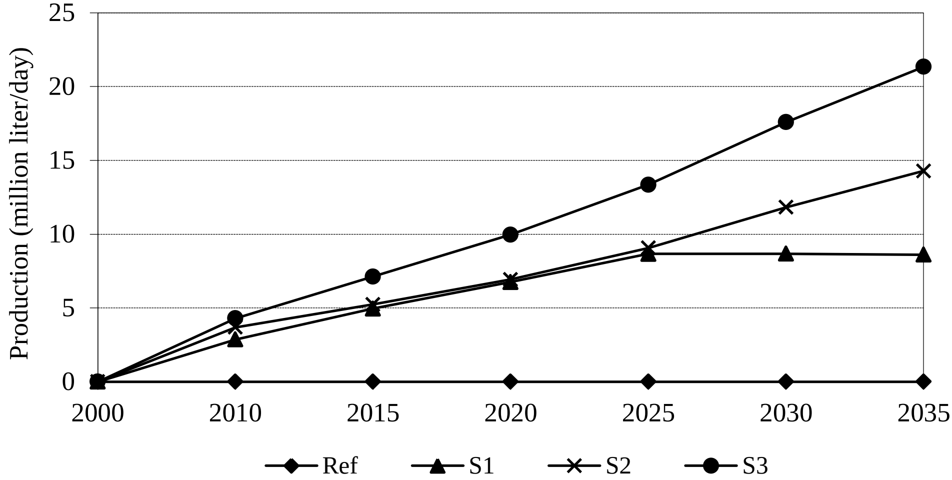

Figure 7.4: Biodiesel production requirement in different scenarios during 2000-2035

The demand for ethanol would be the highest in S3. It would require 8.8 million liters of ethanol per day by 2035 in S3. The ethanol requirement would be the lowest in S1.

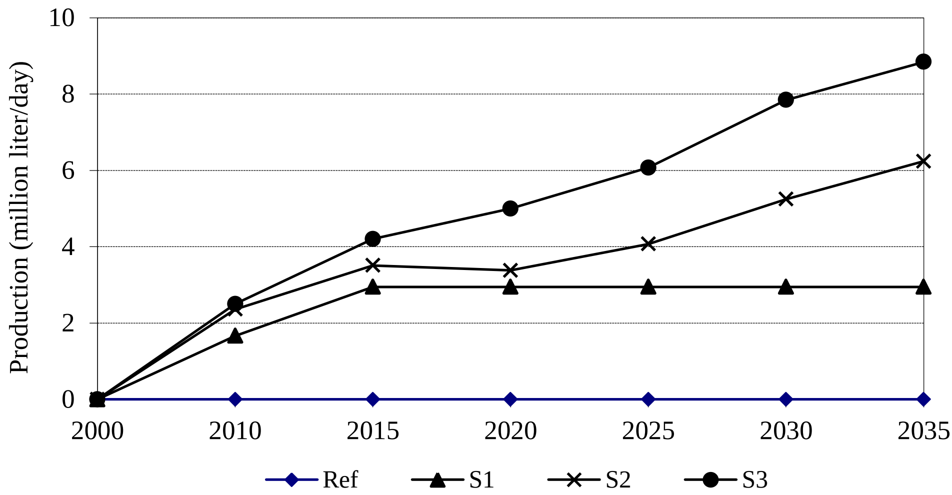

Figure 7.5: Ethanol production requirement in different scenarios during 2000-2035

7.5.3. Vehicle technology mix in road transport

The mix of both conventional and advanced vehicles in road transport is shown in Figures 7.6, 7.7 and 7.8 for 2015, 2025 and 2035, respectively.

In 2015, hybrid vehicles have the highest penetration in the advanced vehicle options. Under the three biofuel scenarios considered, hybrid vehicles would account for 12% of the vehicle fleet used in road transport. The share of efficient vehicles would be between 4% in S1 and S3 and 7% in S2. The electric vehicles would play a negligible role in the future.

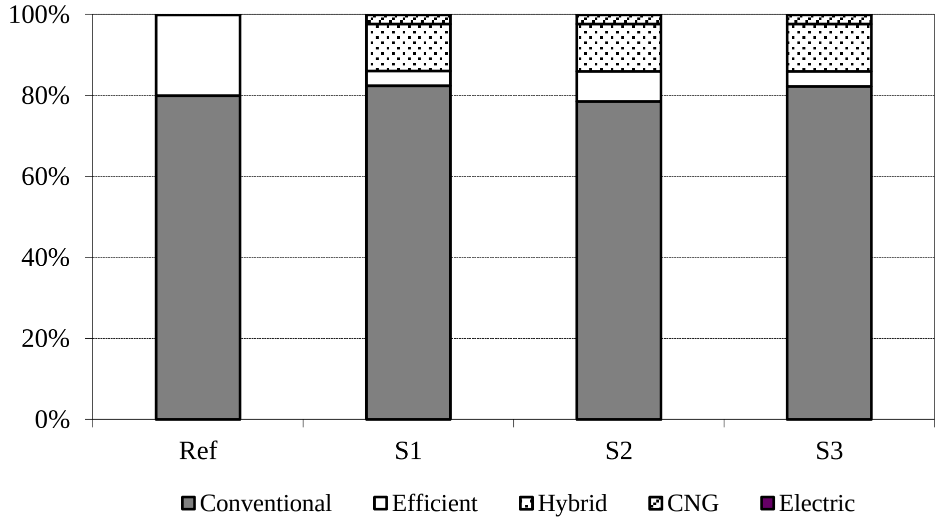

Figure 7.6: Shares of conventional and advanced vehicle technologies in different scenarios in 2015

In 2025, there will be a further penetration of hybrid vehicles. This is because the fixed cost of these vehicles is expected to decrease further, making them to be more economical as compared to conventional vehicle options. In the biofuel scenarios, hybrid vehicles comprise almost one third of the vehicles used in road transport. The share of hybrid vehicles will be highest in S3 scenario with 37% of the vehicle fleet. When biofuels are in limited supply CNG vehicles are found to be economical. CNG vehicles will have its highest share of 13% in S1 scenario. The electric vehicles are not found to be economically viable under the price of that was considered for biofuels.

In 2035, the share of efficient and hybrid vehicles would increase further in the biofuel scenarios. Combined together, efficient and hybrid vehicles would increase from 16% in 2015 to 70% in 2035. The share of hybrid vehicles would increase when biofuels are abundantly available. The share of hybrid vehicles would increase between 43% in S1 scenario and 46% in S2 scenario in 2035. On the contrary, owing to the limitations in domestic natural gas availability, the share of CNG vehicles would decrease. CNG vehicles would comprise 8%, 2% and 4% in S1, S2 and S3, respectively. Electric vehicles would not be cost-effective. The share of efficient conventional vehicles would be highest with 28% in S1.

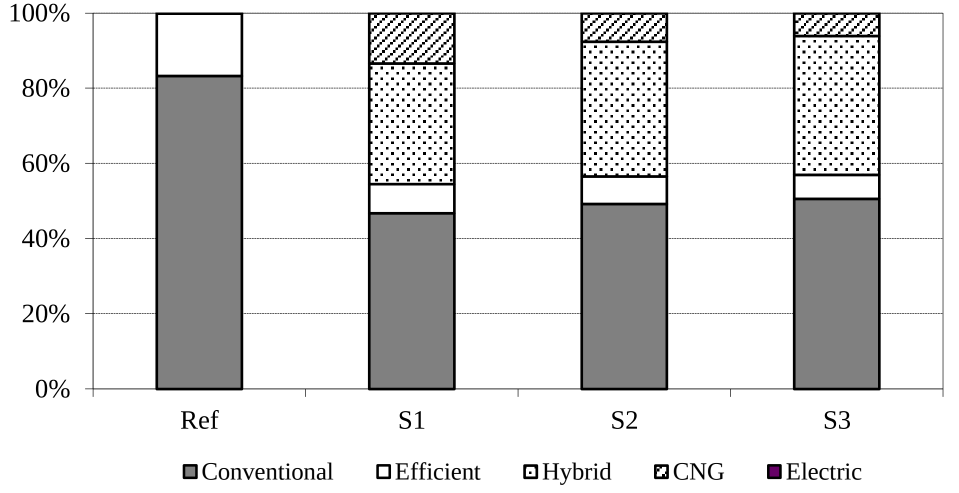

Figure 7.7: Shares of conventional and advanced vehicle technologies in different scenarios in 2025

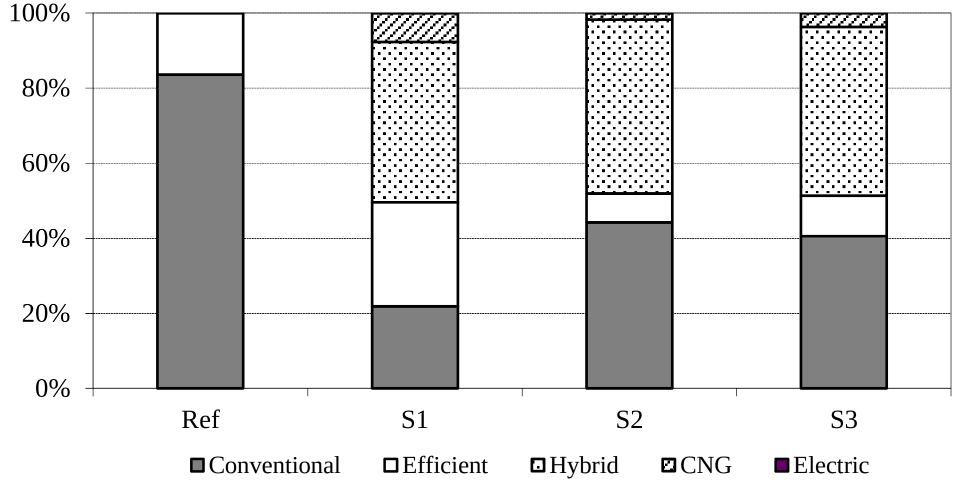

Figure 7.8: Shares of conventional and advanced vehicle technologies in different scenarios in 2035

7.5.4. Environmental Implications

Emissions of greenhouse gases and local pollutants in the selected scenarios are shown in Figure 7.9 and Table 7.2. The introduction of biofuels along with efficient vehicle technologies would change the emission profiles in each scenario to some extent. The reference scenario gives an indication of the emissions profile if there are no further improvements with respect to the development of vehicular technology or use of alternative fuels in the transport sector. As can be seen from Figure 7.9, the emissions would gradually decrease in the biofuel scenarios.

It was estimated that, the reduction in CO_2 emissions in 2015 would be relatively small due to the limited penetration of biofuels and efficient technology options. Due to high biofuel blend (15%) in S3, it is estimated that there would be almost 14% less CO_2 emissions as compared to the reference scenario in that year. In S1 and S2, the reduction of CO_2 emissions would be close to 10% less as compared to the reference scenario. However, biofuels would have an increased contribution to CO_2 emissions reduction over time. The biofuel use in S3 would reduce the CO_2 emissions by almost a quarter as compared to the reference scenario in 2025 and 2035. Among the three biofuel scenarios, the CO_2 emission reduction would be the lowest in S1 due to limited biofuel use. In S1, the reduction in CO_2 emissions would be 15% in 2025 and 19% in 2035.

In the reference scenario (i.e., with no biofuel use and with no efficient vehicle technologies), the CO_2 emissions in the transport sector would increase from 95 Mt in 2015 to 239 Mt in 2035. However, in S1 with limited biofuels usage, the CO_2 emissions from the road transport would decrease to 194 Mt in 2035. However, if abundant biofuel resources are available and a higher blend of biofuels is considered, the CO_2 emissions would decrease to 177 Mt in 2035 in S3.

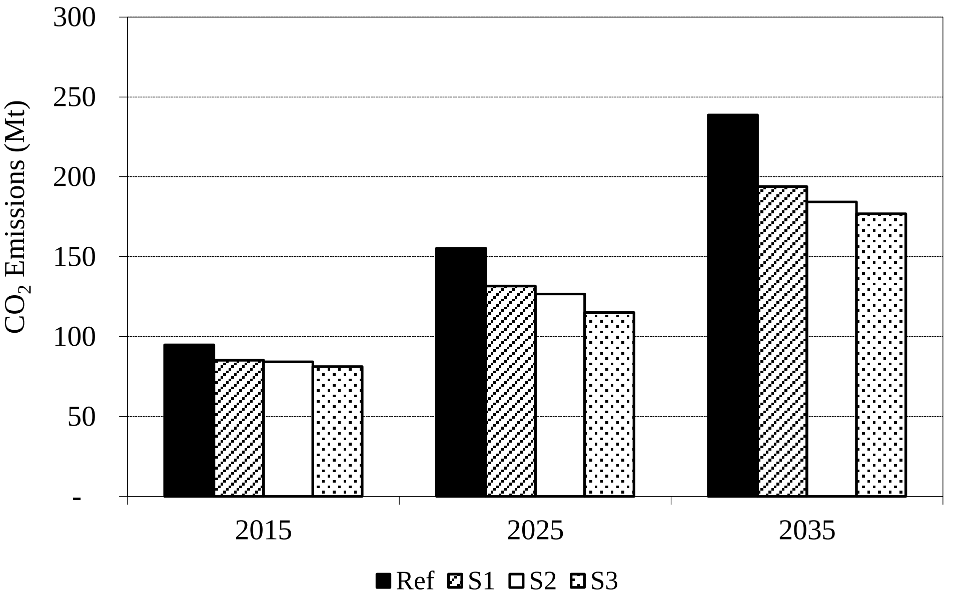

Figure 7.9: CO_2 emissions in different scenarios

In the biofuel scenarios, SO_2 emissions would be the highest in S1 (348 Mt) and the lowest in S3 (321 Mt) in 2015. This is because a 15% blend is considered for biofuels in S3. The SO_2 emissions in S1 and S2 would be higher due to limitations in ethanol production in these scenarios. In 2025, the SO_2 emissions in S1, S2 and S3 would be 549 kt, 543 kt and 512 kt, respectively. Similarly, SO_2 emissions would be the highest in S1 (860 Mt) and the lowest in S3 (796 Mt) in 2035.

The use of biofuels would contribute to reducing SO_2 emissions in the road transport. As shown in Table 7.2, higher biofuel use would result in lower SO_2 emissions. With limited biofuel use in S1, SO_2 emissions would be reduced by almost 15% in 2035. In S3, the scenario that has a higher biofuel use, SO_2 emissions would be reduced by more than one-fifth as compared to that in the reference scenario from 2025 onwards. This is a considerable co-benefit of using biofuels.

Table 7.2: SO_2 and NO_x (as NO_2) under each scenario during 2015-2035

Scenario	NO_x emission(kt)			SO_2 emission (kt)		
	2015	2025	2035	2015	2025	2035
	900	1,436	2,187	394	650	1,013
S1	925	1,396	2,058	348	549	860
S2	914	1,396	2,139	336	543	843
S3	912	1,414	2,166	321	512	796

The changes in NO_x emission would not be considerable as compared to SO_2 emissions. This is because gasohol and biodiesel play an opposite role in terms of NO_x emissions. The use of gasohol produces less NO_x emissions as compared to gasoline. On the contrary, biodiesel results in releasing more NO_x emissions as compared to diesel. Due to this reason, it is seen from Table 7.2, that the change in NO_x emissions is reltively small during 2015-2035.

In 2015, there is an increase in NO_x emissions in all the biofuel scenarios. The NO_x emission would be the highest in S1. This is largely due to the increase in biodiesel use and the decrease in LPG using vehicles. The NO_x emission would increase by 3% from 900 kt in the reference scenario to 925 kt in S1 in 2015.

In 2025 and 2035, the NO_x emissions would be lower in all the biofuel scenarios than that in the reference scenario. In 2025, the NO_x emissions would be the lowest in both S1 and S2 (1396 kt) and the highest in S3 (1414 kt). The NO_x emissions in S1 and S2 would be about 3% lower than that in the reference scenario. In 2035, the NO_x emissions would be the lowest in S1 (2058 kt) and the highest in S3 (2166 kt). The NO_x emissions in S1 would be almost 6% lower than that in the reference scenario in 2035.

7.5.5. Effects on Energy Security

Energy security has been a growing concern in Thailand. The government has taken an initiative to promote biofuels and natural gas in the transport sector as a measure to improve the energy security (EPPO, 2005). Most of the raw materials that is used for biofuel production will be produced in Thailand (ADB, 2015). In the current study, it was assumed that all the biofuels would be produced domestically. This section discusses how total energy import dependency (EID) of the country would be affected in the biofuel scenarios that have been considered.

The EID in each scenario is shown in Figure 7.10. As can be seen, the EID in the biofuel scenarios would be less than that in the reference scenario. Throughout the study period, EID would be the lowest in S3, where a 15% blend of both pure biodiesel and ethanol are considered. It is estimated that in 2015, EID in the reference scenario would be 60%. In S3, the EID would decrease to 56%. However, there are minor differences in the EID between the biofuel scenarios in 2015. This is because of the limited penetration of biofuels in the road transport sector. In 2025, EID varied between 69% in reference scenario and 65% in S3. In 2035, the EID would be between 79% in the reference scenario and 75% in S3.

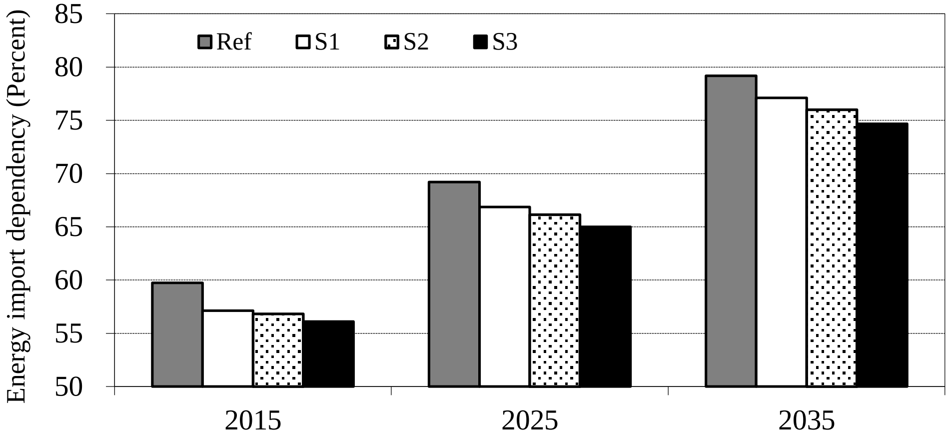

Figure 7.10: Energy import dependency in each scenario

7.6. Conclusions and Final Remarks

The analysis in this chapter shows that biodiesel and gasohol would play a significant role in the road transport sector. Under S1, the maximum production potential would have to be utilized in meeting the total biofuel demand. The ethanol production would reach its capacity by 2014 and pure biodiesel production would reach its maximum capacity by 2025.

In 2035, the share of biofuels would be the highest in S3 (9%) and the lowest in S1 (5%). CNG as an option for road transport would have the highest share in S1 with 13% in 2025. However, it is seen that the share of CNG would decrease owing to the limited availability in domestic natural gas. Among different technology options, hybrid vehicles would be cost-effective in the future years. In the biofuel scenarios, hybrid vehicles would account for more than 43% of the total energy used in road transport by 2035.

This study also shows that the biofuel use in the transport sector could bring significant benefits to Thailand. One of the key benefits is an improvement in national energy security. The energy import dependency in

Thailand would be reduced by almost a quarter in S3 in 2035 if a 15% blend is considered for biodiesel and gasohol. The CO_2 emissions would also be reduced by almost a quarter in S3 from 2025 onwards. In S2 and S3, fossil fuel use would be 9% lower than that in the reference scenario in 2035. There would also be significant reductions in SO_2 emissions with biofuels. SO_2 emissions would be reduced by almost one-fifth in S3. However, there would only be a relatively smaller reductions in NO_x emissions with the use of biofuels: NO_x emissions would be almost 6% lower in S1 as compared to that in the reference scenario in 2035.

This research study was conducted during 2005-2007. One of the limitations in the present study is the assumption on availability of natural gas. At the time this study was carried out, it was considered that natural gas supply would be limited to the amount available from domestic production sources and no possibility of import for gas was considered. As the use of gas was found to be more attractive for power generation, the amount of the gas remaining for other uses 9including transportation was rather small. This is the main reason for low shares of CNG vehicles in road transport. The results would be different if the constraint on gas availability is relaxed (e.g., by including gas imports). There was also no subsidy on cleaner vehicles (i.e., hybrid and natural gas and CNG vehicles) considered in the model at the time of this study.

Furthermore, the results presented in the study do not capture the effects of changes in government regulations (such as AEDP (2012-2021) plan) and recent changes in prices of transportation fuels including biofuels, and new vehicle technologies (flexible-fuel vehicles) due to change in taxes. This study focused only on the fuel and technology options in the road transport sector. Issues such as effects of increasing public transport including expansion of Mass Rapid Transport (MRT) systems were not considered as a part of this study. Inclusion of the price incentives and issues mentioned above would produce different results than what are found in this study. Such issues would be interesting to consider in a future study.

References

Asian Development Bank (ADB), 2015. Renewable Energy Developments and Potential in the Greater Mekong Subregion. ADB, Manila.

Department of Alternative Energy Development and Efficiency (DEDE), 2004a. Ethanol and Biodiesel Research Situation and Renewable Energy in Thailand. DEDE, Paper presented in the Conference on Ethanol and Biodiesel Integrated Research Project, July 2004, Bangkok (in Thai).

DEDE, 2004b. Renewable Energy in Thailand: Ethanol and Biodiesel. DEDE, Original Thai language edition by The Standing Committee on Energy, House of Representatives, National Assembly of Thailand, BIOFUEL 2004, Thailand.

DEDE, 2006a. Thailand energy situation: 2000 - 2005. Annual reports, DEDE, Ministry of Energy, Bangkok.

DEDE, 2006b. Electricity in Thailand: 2000 - 2005. Annual reports, DEDE, Ministry of Energy, Bangkok

DEDE, 2006c. Oil in Thailand: 2000 - 2005. Annual reports, DEDE, Ministry of Energy, Bangkok

DEDE, 2012. Alternative Energy Development Plan (AEDP 2012–2021). DEDE, Bangkok.

DEDE, 2015. Biofuel Status and Policy. DEDE, Bangkok. Accessed online on 12/09/2015 from https://www.mtec.or.th/files/chanpen/1_DEDE.pdf

Energy Policy and Planning Office (EPPO), 2005. Energy Strategy: Energy for Thailand's Competitiveness. Ministry of Energy, Bangkok. Accessed online on 05/20/2005 from http://www.eppo.go.th/doc/strategy2546/strategy.html. Date Down loaded:.

EPPO, 2014. Energy Statistics of Thailand 2012. EPPO, Ministry of Energy, Bangkok.

EPPO, 2015. Energy Statistics of Thailand 2013. EPPO, Ministry of Energy, Bangkok.

Ministry of Energy (MoE), 2009. Ministry of Energy. Thailand's Renewable Energy and its Energy Future: Opportunities and Challenges. Final Draft report. MOE, Bangkok.

Ministry of Finance (MoF), 2015. Economic data. Monetary data. Foreign exchange rate. MOF, Thailand. Accessed online on 06/06/2015 from http://www2.mof.go.th/economic_data.htm#monetory_data

National Energy Policy Office (NEPO), 1999. Thailand's energy strategy and policy. Final Report, NEPO, Bangkok.

National Economic and Social Development Board (NESDB), 2003. National Income of Thailand, 1980-2001 ed. Office of the NESDB, Bangkok.

PTT Public Company Limited (PTT), 2005. Palm Diesel in Thailand. Bangkok. Accessed online on 05/14/2005 from http://www.pttplc.com/en/ptt_core.asp?page=ps_pr_fu_ds_01.

Tseng, P., Lee J., Friley P., 2005. A hydrogen economy: opportunities and challenges. Energy 30, 2703-2720.

United Nations (UN), 2004. World population prospects: The 2004 Revision. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, UN, New York.

Chapter 8

Co-benefits of CO_2 Reduction in a Developing Country[1]

Abstract:

In this paper, we examine the co-benefits of reducing CO_2 emissions in Thailand during 2005–2050 in terms of local pollutant emissions as well as the role of renewable-, biomass- and nuclear-energy. It also examines the implications of CO_2 emission reduction policy on energy security of the country. The analyses are based on a long term energy system model of Thailand using the MARKAL framework. The study shows that the power sector would account for the largest share (over 60%) in total CO_2 emission reduction followed by the industrial and transport sectors. Under the CO_2 emission reduction target of 30%, there would be a reduction in SO_2 emission by 43% from the base case level. With the CO_2 emission reduction target of 10–30%, the cumulative net energy imports in the country during 2005–2050 would be reduced in the range of over 16 thousand PJ to 26 thousand PJ from the base case emission level. Under the CO_2 emission reduction targets, the primary energy supply system would be diversified towards lower use of coal and higher use of natural gas, biomass and nuclear fuels.

8.1. Introduction

Climate change policies are, although primarily intended to reduce Greenhouse gas (GHG) emissions, often have other benefits, usually named as co-benefits and ancillary effects[2] (IPCC, 2007, 2001). The fact that there is a linkage between mitigation of GHGs and local air pollution is already accepted (IPCC, 2007). That the climate friendly technologies and resources reduce not only GHGs but also the local pollutant emissions provide impetus for adoption of cleaner fuels and advanced technologies. Thus, inclusion of the co-benefits can have significant impacts on the cost effectiveness of the climate policy. Likewise, the cost of controlling local or regional air pollutants might be reduced if these are combined with GHG mitigation policies (Van Harmelen et al., 2002). Caspary and O'Connor (2002) suggested that the co-

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[2] The term "co-benefit" is referred as intentional benefits of policies, e.g. reduction of conventional air pollutants as a result of a climate change mitigation policy. The term "Ancillary effect" is referred ancillary physical effects evaluated in terms of monetary values. See IPCC (2001), O'Connor (2000) and Davis et al. (2000).

benefits in developing countries are probably more significant than those in developed countries and emphasized on the requirement of such study for making informed decisions.

Most studies on co-benefits and ancillary effects of GHG mitigation policies are conducted for developed countries, particularly the US and Europe (Barker and Rosendahl, 2000; Davis et al., 2000). Since developing countries are not obliged to reduce GHG emissions, studies in evaluating co-benefits of GHG mitigation policies in developing countries are lacking (Creutzig and He, 2008). For the fast developing countries like Thailand, the evaluation of the co-benefits of GHG mitigation policies would provide a basis for a more comprehensive economic and environmental analysis. Such an evaluation would also assist in integrating climate change mitigation policies with the sustain-able development strategies of the country.

Thailand is the second largest economy among the countries in the Association of South East Asian Nations (ASEAN) (IMF, 2008) as well as the second largest emitter of CO_2. The country is heavily dependent on imported energy in that the imported energy accounts for about 55% of the total primary energy supply in the country in year 2005 (DEDE, 2006a). With the economy growing at over 5% per annum and increasing urbanization, the CO_2 emission in the country is expected to grow significantly in the future.

There are some studies on GHG emissions in the case of Thailand, (Shrestha and Pradhan, 2008a; Shrestha et al., 1998, 2007, 2008b; Limmeechokchai and Suksuntornsiri, 2007a, 2007b; Tanatvanit et al., 2003, 2004; NEPO, 1999). Santisirisomboon et al. (2001) analyze the effects of carbon tax in the power generation sector of Thailand. Timilsina and Shrestha, 2002 and Malla and Shrestha (2005) analyze the effects of carbon tax on the Thai economy using a general equilibrium framework for the period of 2000–2030. Shrestha and Pradhan (2008a) and Shrestha et al. (2008b) analyze the effect of carbon tax for the period of 2000– 2050. However, these studies did not examine the co-benefits of CO_2 reduction comprehensively for a period of 2005–2050.

In the present study, we examine the prospects for CO_2 reduction from the Thai economy during 2005–2050 under three CO_2 emission reduction targets taking two analysis periods (i.e., 2005–2030 and 2005–2050). We analyze the co-benefits of the emission reduction targets in terms of the reduction of local air pollutants (NO_x and SO_2) and energy security of the country. We also examine the effect of the CO_2 emission reduction targets on the development of renewable energy and use of nuclear energy. A bottom–up least-cost energy system optimization model of Thailand was developed based on the Market Allocation (MAR-KAL) modeling framework (ETSAP, 2007).

The paper is organized as follows: Section 8.2 describes the methodology used in the study. Section 8.3 provides descriptions of the reference (or base) and emission reduction scenarios. The description of the reference case analysis is presented in Section 8.4 followed by an analysis of the effects of CO_2 emission reduction targets on energy security and air pollutant emission reductions and other co-benefits i.e., introduction of cleaner energy use in the power and transport sectors, improvement in efficiency of power generation, and adoption of efficient appliances in residential sectors is presented in Section 8.5. The final section presents the key conclusions and final remarks as well as policy implications of the study.

8.2. Methodological Approach

The study uses a bottom–up least cost optimization energy system model of Thailand that was developed for the study using the MARKAL framework. The model computes an inter-temporal partial equilibrium on energy markets, i.e., it ensures that the supply meets the given demand at a given set of prices of all energy forms at each time period with an assumption of possessing complete foresight in a competitive market (Loulou et al., 2004). This type of model is used in several studies on energy and CO_2 emission analysis at country and global levels (Rajesh et al., 2003; Strachan and Kanan, 2008; Seebregts et al., 2005; Smekens-Ramirez Morales, 2004; Remme and Blesl, 2008).

The model selects both the supply- and demand- technology mix that minimizes the discounted cost of the energy system under a set of resource and demand constraints. The energy system includes primary energy resources (includes mining, extraction, etc.), secondary fuels (refining, power generation, etc.), final energy and energy services. The primary energy resource component includes coal mining, natural gas extraction, crude oil extraction and import and export of these fuels. The conversion of primary fuels to secondary fuels takes place through refinery and power generation. For power generation, 80 existing and 36 new technology options are considered. Among the new technology options considered, there are coal-, lignite- and natural gas-based carbon capture and storage (CCS) technologies. Other emerging technology options includes clean coal technologies (such as IGCC, PFBC), fuel cell vehicles, hybrid electric vehicles and plug-in hybrid electric vehicles besides conventional technology options in different sectors. It also includes bio-fuel (10% bio-ethanol mixed with 90% gasoline and 10–20% bio-diesel mixed with 90–80% diesel) as an energy resource option in the transport sector. Flex-fuel vehicles using up to 85% ethanol are also considered in the present analysis. We have considered nuclear energy as an energy option for power generation and six potential nuclear power generation technologies in the future are considered in the present analysis.

In the demand-side, we have divided the Thai economy in five main sectors, namely, agriculture, commercial, industrial, residential and transport (NEPO, 1999). DEDE (2006b) has treated energy consumption in mining, manufacturing and construction as separate sectors; however, in this paper, we have categorized them as sub-sectors of the industrial sector. The industrial sector has been sub-divided into various sub-sectors, i.e., cement, steel, sugar, paper, chemicals, food, equipment, textile and others. Similarly, transportation is sub-divided into passenger and freight transportation. The passenger transportation is further divided into road, rail, air and water transport. All trading enterprises, hotels, restaurants, financial and telecommunication establishments are included in the commercial sector. The residential sector has been divided into urban and rural categories. Altogether 248 existing and candidate technology options are considered for meeting end-use service demands. The future projections of service demands in agriculture, commercial, industrial and freight transport sectors are based on sub-sectoral value added, while the projection of service demands in the residential sector is based on number of households and appliance ownership per household. The service demand for passenger transport is projected based on the population growth. Thailand's GDP projection during 2005–2016 is based on TDRI (2004), according to which the GDP would be growing at 6.4% by 2016. Thereafter, it is assumed that the GDP will grow at the rates of 6.4%, 5.3% and 4.5% per annum during 2016–2030, 2030–2040 and 2040–2050, respectively. On population, the medium variant forecast of the UN (2004) is considered in the model. Although there is a possibility of decoupling of economic development and service demands over a long run, we have assumed that the service demand in a given year is linearly proportional to the value added in the year due to lack of studies as to the possible timing of such decoupling.

8.3. Scenario Description

In the study, four scenarios are considered: the base case and three alternative scenarios. The base case in the present study is the scenario based on the presently available information and future plans and policies (e.g. government policies in energy, environment and economy) that may influence the energy demand and supply in Thailand. It includes the energy carriers and technology options, which are presently being used in Thailand. The cost parameters of these technologies are based on CGER-NIES (2007). Also, different emerging technology options like bio-fuel, hybrid fuel vehicles and carbon capture and storage (CCS) and possible future energy carriers like nuclear and fuel cell are considered in the base case. The costs of the CCS type of power generation technologies used in this study are based on IEA-OECD (2004), while the costs for other power generation technologies are based on IEA (2001, 2005a, 2005b) and IAEA (2001). Likewise, the costs of hybrid vehicles are based on Lipman and Delucchi (2003). No greenhouse gas (GHG) mitigation policy intervention is considered in the base case.

The maximum availability of domestic fossil-fuel resources (coal, oil and natural gas) and renewable energy resources during 2005–2050 under the base case is based on DEDE (2006a, 2006b). Both exports and imports of the fossil fuel resources and electricity are considered in the model and there is no limit imposed on imports of the fossil-fuel resources. The export and import energy prices are taken from DEDE (2006a, 2006b).

According to the first revised Power Development Plan (PDP) 2007 (EGAT, 2007), 4000 MW of nuclear-based power generation was planned to be introduced from 2020 and this study took this into account. However, we find that the plan has been modified recently and the nuclear power generation capacity has been proposed to be reduced to 2000 MW (EGAT, 2009). In EGAT (2007), the Electricity Generation Authority of Thailand (EGAT) has proposed nuclear fuel as an option to replace old fossil fuel-fired power plants on their retirement. Thus, in the present study, the nuclear power generation technology option is included from 2020 onwards. The maximum exploitable level of agricultural residues (sugar cane residues (i.e., bagasse), paddy husk, corncob and others) is assumed to be 590 PJ (Santisirisomboon et al., 2001; Prasertsan and Sajjakulnukit, 2006; DEDE, 2006c). The maximum level of plantation based biomass is assumed to be 745 PJ (DEDE, 2006b). It is assumed that the plantation based biomass is produced on a sustainable basis and therefore there would be no net CO_2 emission involved. The Thai Government has some environmentally friendly strategies and plans in the transport sector, which include substitution of existing diesel-run trains with electric trains, developing mass rapid transit to substitute private vehicles (813 km long double track trains) and intercity trains to reduce private vehicles within city areas. Likewise, the government has a bio-fuel promotion plan in the transport sector, which aims to substitute 10% of diesel use with bio-diesel by 2012. This plan requires the utilization of 85 million liters of blended biodiesel (10% biodiesel mixed with 90% diesel) per day and production of 8.5 million liter per day of pure bio-diesel production by 2012. Also the government has the Gasohol Strategic Plan, which would increase the utilization of E10 Gasohol (10% ethanol mixed with 90% gasoline) from one million liters per day in 2006 to 3 million liters of ethanol per day by 2011. Thus, in accordance with these plans, we have considered the transport fuel consumption in future and as a result there would be an increase in the use of bio-fuels till 2025. Some hybrid and flex fuel vehicles are already in the market, which shows that these vehicles have good potential in future. Thus, the emerging technologies like hybrid vehicles (HEV20 and HEV60) are considered to be available from 2015 onward; fuel cell, fuel flex, plug-in hybrid vehicles and power generation with carbon capture and storage technologies are considered to be available from 2020 onward. The planning horizon of the study is 2005– 2050 (45 years) and the model is calibrated for year 2005, the base year. Further, the results are analyzed for two analysis periods i.e., 2005–2030 and 2005–2050. We have used 10% discount rate in the study.[3] All costs are expressed at the constant US dollar prices of year 2000.

Besides the base case, the three emission reduction target scenarios are considered:

(1) 10% Emission reduction target (hereafter called as “ERT10” Case)
(2) 20% Emission reduction target (hereafter called as “ERT20” Case)
(3) 30% Emission reduction target (hereafter called as “ERT30” Case)

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[3] Asian Development Bank (ADB, 1998) states citing National Economic Social Development Board (NESDB) of Thailand that the Government of Thailand uses 10% discount rate.

The ERT10 case is the 'what if' scenario, in which a cumulative reduction of not less than 10% of the cumulative CO_2 emission during the planning horizon in the base case is desired, all other things remaining the same as in the base case. The ERT20 and ERT30 cases are defined similarly for cumulative reductions in CO_2 emissions of not less than 20% and 30%, respectively, from the base case emission.

8.4. Base Case Analysis

8.4.1. CO_2 Emission

The total CO_2 emission increases by more than 7 folds to 1,934 million tCO_2 in 2050 as compared to 208 million tCO_2 in 2005, whereas the total primary energy supply (TPES) grows by over 5 folds in the same period. The final demand for energy increases by over 6 folds in the same period. Therefore, in the base case, the CO_2 intensity would increase along with the increase in the efficiency in energy use. As a result, there would be cumulative CO_2 emissions during the 45 year period of 36,403 million tCO_2. The transport sector accounts for the largest share (37%) of emissions in 2005 followed by the power sector (32%), industrial sector (24%) and the other sectors (i.e., agricultural, residential and commercial) (7%) (see Figure 8.1). In the base case, the share of the transport sector would decrease from 37% in 2005 to 33% in 2050. However, there would be a small increment in the share of the power sector (32% in 2005 to 34% in 2050). Likewise, the share of the industrial sector would also increase from 24% in 2005 to 29% in 2050. The share of the other sectors have small share (7%) in 2005, which would decrease to 4% by 2050. The three sectors (i.e., power, transport and industrial sectors) would be the major contributors (over 93%) in the total CO_2 emission from the country throughout the planning horizon.

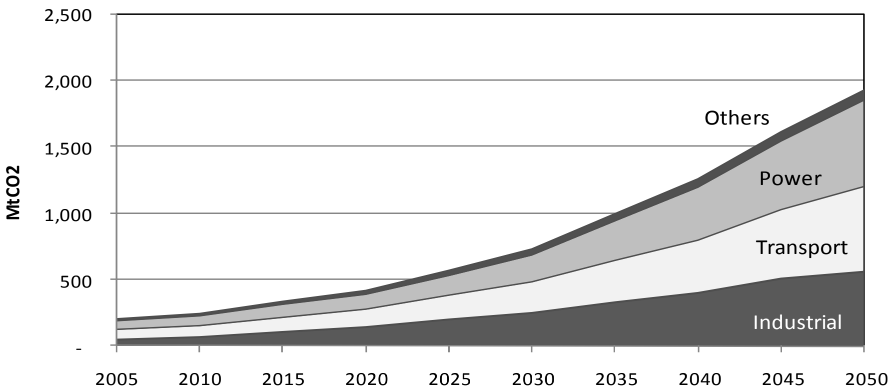

Figure 8.1: CO_2 emissions in the base case (million tCO_2)

8.4.2. Energy Supply Mix

Energy mix is found to change towards the decreasing shares of oil, natural gas and biomass energy and towards an increasing share of coal during

2005–2050. The combined share of natural gas and oil would decrease from 71% in 2005 to 46% in 2050, whereas the share of coal would increase from 15% to 46% in the same period. The share of biomass would also decrease from 12% in 2005 to 3% in 2050. Introducing the nuclear-based power generation in 2020 the share of the nuclear-based electricity in the TPES would reach 3% in 2050. This shows that coal would be the major fuel supply by the end of the planning horizon (see Figure 8.2).

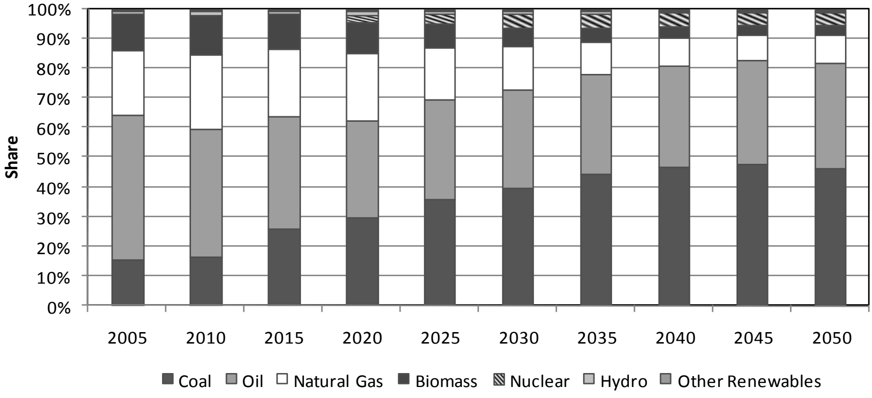

Figure 8.2: Energy supply mix in the base case during 2005-2050.

8.4.3. Final Energy Demand (FED)

The total final energy demand (FED) would increase from 2,699 to 21,370 PJ during 2005–2050. The result shows that the transport sector would continue being the largest final energy using sector maintaining its share of around 40–41% in FED during the planning period, followed by the industrial sector, with its share slightly increasing from 36% in 2005 to 39% in 2050. During the same period, the share of the commercial sector would increase from 5% in 2005 to 10% in 2050. However, the share of the residential and agriculture sectors would decrease from 14% and 5% respectively to 8% and 2% during 2005–2050 (see Figure 8.3).

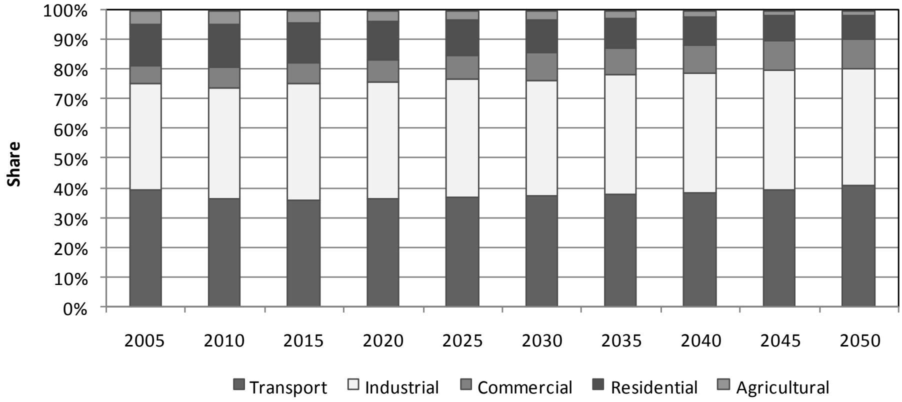

Figure 8.3: Sectoral share in total final energy consumption in the base case

8.5. Effect of CO_2 Emission Reduction Targets

8.5.1. CO_2 emission intensity of energy use

The energy system would be more carbon intensive over time during the planning horizon in the base case in that CO_2 emission per unit of total primary energy supply (hereafter "CO_2 intensity of energy use") would increase from 51 kg/GJ in 2005 to 75 kg/GJ in 2050[4]. Our results show that the CO_2 intensity of energy use in 2050 would be reduced to 65, 57 and 55 kg/GJ under ERT10, ERT20 and ERT30 cases, respectively. Interestingly, significant reduction in CO_2 intensity of energy use begins around 2025 under ERT10 and ERT20, while it starts much earlier (i.e., before 2015) under ERT30 (see Figure 8.4).

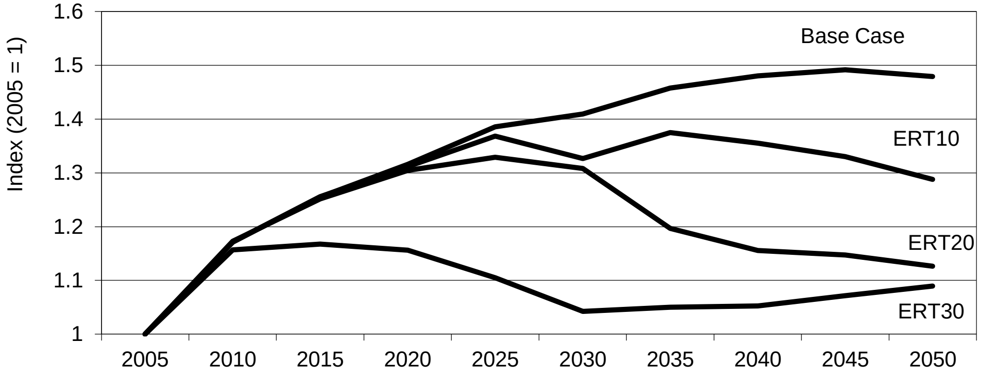

Figure 8.4: CO_2 emission per unit primary energy requirement in the selected ERT cases

8.5.1.1 Cost implications

As can be seen from Figure 8.5, the difference between marginal costs of CO_2 reduction under ERT10 and ERT20 is relatively small, while the marginal cost of CO_2 reduction in ERT30 is significantly higher than that in ERT20. The marginal abatement cost would rise from 6.5 to 476.4 US$/t$CO_2$ during 2005–2050 in ERT30, while the cost would increase from 1.4 to 102.4 US$/t$CO_2$ in ERT20 and from 0.4 to 27.6 US$/t$CO_2$ in ERT10 during the period. It is interesting to note here that the CO_2 abatement cost in 2050 under ERT20 is similar to the carbon price of $100/t$CO_2$ in 2050 as has been reported to be necessary for the stabilization target of 450 ppmv CO_2e

[4] Recently (i.e., during 2007–2008) the CO_2 intensity of energy use has been observed to have declined; however, such a decline is not pre-specified in the base case.

by some studies[5] (Edmond et al. as cited in Shukla et al., 2008; Edmond et al., 2008). The marginal CO_2 abatement cost in ERT30 is, however, significantly higher than the carbon price needed to achieve the stabilization target of 450 ppmv CO_2e in 2050. This analysis shows that it could be possible to cost-effectively reduce cumulative CO_2 emission by up to 20% from that in the base case in a rapidly industrializing developing country like Thailand at the carbon price that grows exponentially from \$1.4 to \$102.4/tCO_2 during 2005–2050. More importantly, even the carbon price of \$100/tCO_2 by 2050 (i.e., needed globally for the stabilization target of 450 ppmv) may not be sufficient to achieve the cumulative CO_2 emission reduction by more than 20% during 2005–2050 in a country like Thailand.

The total discounted system cost would increase only nominally in the selected ERT cases as compared to that in the base case; i.e., by less than 0.01% in ERT10, 0.02% in ERT20 and 0.13%, in ERT30. Note however, that the increment in total discounted system cost is significantly higher in ERT30 than that in ERT20 (see Figure 8.5).

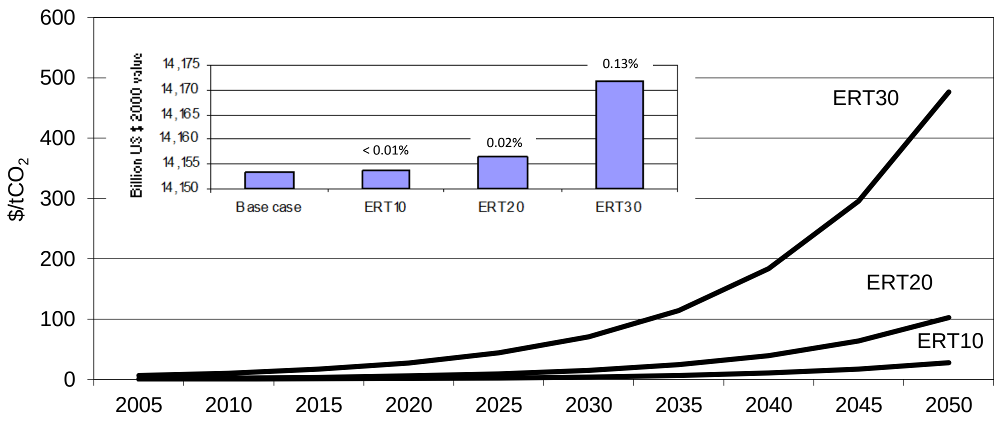

Figure 8.5: Marginal cost of CO_2 abatement in the selected ERT cases

Note: Percentage figures denote increase in the system cost as compared to that of the base case

8.5.1.2 Sectoral contributions in CO_2 reduction

The power sector has the highest share in total CO_2 emission reduction during 2005–2050 (accounting for 84%, 74% and 60% of the reduction in ERT10, ERT20 and ERT30, respectively) followed by the industrial and transport sectors (see Table 8.1). On the contrary, there would be an increase in CO_2 emission from the residential sector. There would be no change in CO_2 emission from the agriculture sector; similarly, there would

[5] Personal communication with Jae Edmonds: The values (in US\$ at 2000 prices) are based on the MiniCAM model output for India and the other South and East Asian countries (Edmond et al., 2008).

be almost no change in the emission from the commercial sector. The power sector contributes most in CO_2 reduction, which is also the case during a shorter time horizon of 2005–2030. As shown in the table, almost the entire CO_2 reduction in ERT10 would come from the power sector during 2005–2030. If the emission reduction targets are increased, the industrial and transport sectors would also play an increasing role in emission reduction (e.g., nearly 50% of the total CO_2 emission reduction in ERT30 case would come from the industrial sector during 2005–2030, while the transport sector would contribute to a reduction of about 1% only). Further, our results show that it would be possible to attain a target of reducing the cumulative CO_2 emissions during 2005–2050 by up to 52%; however, the marginal cost of abatement at that level would be exorbitantly high (rising exponentially up to \$138,832/tCO_2 by 2050).

The reduction in CO_2 emission would be achieved through the reduction in the use of coal in power generation and mainly with the use of natural gas-based advanced combined cycle and nuclear power generation technologies. There would also be an increase in biomass and other renewable energy- (i.e., municipal solid waste, geothermal, wind and solar) based power generation contributing to the reduction in CO_2 emission.

The industrial sector plays an almost negligible role in the cumulative CO_2 emission reduction in ERT10 during 2005–2030, while it would account for over 23% of the cumulative reduction in CO_2 emission during 2005–2050. At the higher CO_2 reduction cases of ERT20 and ERT30, the present study shows that the industrial sector would account for over 9% and nearly 51% of the total cumulative CO_2 emission reduction during 2005–2030. During 2005–2050, the industrial sector would contribute to 30% and 33% of the total CO_2 emission reduction in ERT20 and ERT30 cases, respectively. The CO_2 emission reduction in the industrial sector would take place mainly with the use of natural gas-based advanced efficient boilers in place of mostly the conventional coal boilers and dryers in chemical industries and the conventional lignite boilers in food and textile industries.

As can be seen from Table 8.1, the transport sector would have no role in attaining the cumulative CO_2 emission reduction target of 10% (i.e., ERT10) during the study period. At higher targets, the sector would account for below 1% and around 9% of the total CO_2 reduction in ERT20 and ERT30 cases, respectively. The present analysis shows that, the CO_2 emission reduction from the transport sector in ERT20 and ERT30 would require the use of biodiesel passenger buses, biodiesel van and pickups, ships, gasohol 3-wheelers and gasohol van and pickups. Further, it also shows that B20 buses (i.e., buses using 20% biodiesel and 80% diesel) and plug-in hybrid electric vehicles (HEV) would be cost-effective in ERT30 and that they would replace the conventional diesel buses, vans and pickups and LPG 3-wheelers.

In the residential sector, there would be a small increase in CO_2 emission under all ERT cases (see Table 8.1). This is partly due to the sectoral CO_2 accounting convention used in that any reduction in electricity use from the residential sector through the replacement of electrical appliances with non-electric devices would be considered to cause a reduction in CO_2 emission from the power sector although such reductions are basically due to changes in choices made in the residential sector. However, any replacement of electric cooking devices with more energy efficient LPG stoves would appear to increase the CO_2 emission from the residential sector although there could be a bigger reduction in CO_2 emission from the power sector resulting from the electricity use avoided in cooking. The present analysis shows that florescent tube lamps (FTLs) and compact fluorescent lamps (CFLs) would replace all incandescent lamps in the base case, whereas CFLs would replace all FTLs under ERT20 and ERT30. Moreover, efficient air conditioners would replace their conventional counterparts in ERT30. Electric cookers are replaced by conventional LPG cookers in ERT10 and ERT20 whereas, efficient LPG cookers would replace the electric cookers in ERT30 hence the apparent increase in CO_2 emission from the residential sector.

There would be only a slight reduction in CO_2 emission from the commercial sector in the ERT cases (see Table 8.1). This occurs mainly due to replacement of fuel oil boilers with LPG boilers in meeting the heating service demand. Although conventional refrigerators would be replaced by efficient refrigerators in ERT30, the associated CO_2 reduction would, however, be accounted in the power sector.

The agriculture sector would not contribute to the CO_2 abatement as efficient options, i.e., efficient electric motors, diesel tractors and gasoline water pumps would all be used in the base case and thus leaving no further scope for CO_2 reduction in the ERT cases.

Table 8.1: Base case cumulative emission and CO_2 emission reduction from demand sectors in the selected emission targets during 2005-2030 and 2005-2050 (10^6 tCO_2)

Sectors	Base case emissions	CO_2 reduction in 2005-2030			Base case emissions	CO_2 reduction in 2005-2050		
		ERT10	ERT20	ERT30		ERT10	ERT20	ERT30
Industrial	3,385.3	0.2	28.7	843.2	11,652.2	782.2	2,075.4	3,579.6
Power	2,877.8	161.4	306.0	843.8	11,122.2	2,840.6	5,146.2	6,530.0
Transport	3,337.2	0.0	1.5	18.3	11,711.7	0.0	13.9	948.5
Others*	691.4	0.0	(10.5)	(49.2)	1,917.2	(227.9)	(258.7)	(242.5)
Total	10,291.8	161.6	325.6	1,656.1	36,403.3	3,395.0	6,976.8	10,815.5

* comprises agriculture, residential and commercial sectors.

8.5.2. Analyzing Co-benefits of ERTs

Any strategy to reduce the CO_2 emission is likely to have an effect on the emission of local and regional level pollutants and energy security of the country. These will be discussed next.

8.5.2.1. SO_2 and NO_x emission reduction

The present study shows that the least cost strategy to attain the CO_2 emission targets will also generate benefits in the form of lower cumulative SO_2 emission during the planning horizon by 9.1%, 28.6% and 43.2% in

ERT10, ERT20 and ERT30 cases, respectively, as compared to that in the base case (see Table 8.2). The highest reduction in cumulative SO_2 emission would take place in the industrial sector followed by the power sector. About 57%, 46% and 44% of the SO_2 reduction would come from the industrial sector in ERT10, ERT20 and ERT30 cases during 2005–2050 mainly through replacement of the conventional fuel oil (residual oil) kiln burners with natural gas and fuel oil-based efficient kiln burners. It is also found that a relatively larger reduction in SO_2 emission would take place during 2031–2050 than that during 2005–2030 under all ERT cases. Although there would be a small increment in SO_2 emission from the residential sector because of the substitution of electric cookers with LPG cookers, we find that the sector has the lowest share in the total SO_2 emission. Thus, the emission reduction targets are not found to have significant effect in SO_2 emission from the sector.

The cumulative NO_x emission during 2005–2050 would decrease by 3.27%, 5.25%, 5.35% from the base case in ERT10, ERT20 and ERT30 cases, respectively (see Table 8.2). The highest reduction in NO_x emission would take place in the power sector followed by the industrial sector during the period. However, the increase in the use of biodiesel vehicles would increase the NO_x emission and as a result, would negatively affect the net NO_x reduction. Note that the cumulative reduction in NO_x emission during 2005–2030 in ERT30 is lower than that in ERT20 (see Table 8.2). This would occur due to the increase in the use of biodiesel vehicles in the transport sector (which involves a higher NO_x emission) in ERT30 during 2005–2030 (see Table 8.2). Like in the case of SO_2 emission, the CO_2 emission reduction target would not have a significant effect on NO_x emissions from the residential sector since the sector has the lowest share in the total NO_x emission.

Table 8.2: SO_2 and NO_x emission in the base case and cumulative SO_2 and NO_x reduction in the selected emission reduction target cases during 2005-2030 and 2005-2050 (10^6 tons)

Emission Type	2005-2030				2005-2050			
	Base case emission	Reduction			Base case emission	Reduction		
		ERT10	ERT20	ERT30		ERT10	ERT20	ERT30
SO_2	71.7	1.7	5.2	20.8	225.3	20.48	64.4	97.4
NO_x	109.9	0.7	1.1	0.1	375.0	12.3	19.7	20.1

8.5.2.2 Improvement in energy efficiency in the end-use sectors

It is found that the level of sectoral energy use in all ERT cases would be lower than that in the base case in all sectors except the residential sector. Overall, the total final energy consumption would decrease by over 5000, 11,000 and 23,000 PJ in ERT10, ERT20 and ERT30 cases during 2005–2050, respectively (see Table 8.3). As the service demands under each case are the same, this means that the emission reduction targets would improve the sectoral end-use energy efficiency. Among the end-use sectors, the industrial sector would gain most in terms of energy efficiency improvements during 2005–2050 in all ERT cases considered. In the residential sector, energy consumption would increase because of the higher use of charcoal stoves, which are less energy efficient but are zero-carbon emitting (as biomass is assumed to be produced on a sustainable manner).

Table 8.3: Reduction in total final energy use (FED) in the end-use sectors in the selected emission target cases during 2005-2030 and 2005-2050 (PJ)*

Sector	2005-2030			2005-2050		
	ERT10	ERT20	ERT30	ERT10	ERT20	ERT30
Agricultural	-	-	-	-	-	-
Commercial	-	-	139	-	95	859
Industrial	153	360	2,418	5,814	13,285	17,769
Residential	-	(14)	(860)	(572)	(1,838)	(2,171)
Transport	0	29	(15)	(0)	38	7,321
Total	153	375	1,681	5,242	11,580	23,778

* Figures in the parentheses indicate an increase in the energy use.

8.5.2.3 Effects on energy security

Will CO_2 emission reduction targets have positive impacts on energy security of the country? This issue is analyzed in terms of changes in net energy import dependency and diversification of energy resources resulting from least cost strategies to attain the selected CO_2 emission reduction targets.

Net energy import dependency

There would be a mixed effect of the emission reduction targets on net energy import dependency (defined as net energy import as a percentage of total primary energy supply) and cumulative net energy imports during 2005–2050. The net energy import dependency (NEID) would decrease by 2.1% under ERT10 during the period, whereas it would increase by 0.1% and 0.7% in ERT20 and ERT30 cases, respectively. However, the total net energy imports during the period under each of the ERT cases considered in this study would be lower than that in the base case (i.e., lower by over 19 thousand PJ, 16 thousands PJ and 26 thousand PJ in ERT10, ERT20 and ERT30, respectively; see Table 4). Import of coal would decrease, while natural gas and nuclear fuel imports would increase. Thailand is already importing electricity from Laos, which has a large hydroelectric power generation potential in the region. More electricity imports are likely in the future as per the recent electricity imports agreements between Thailand and neighboring countries like Myanmar and People's Republic of China. Although these developments may give an optimistic scenario for increasing electricity trade in the region, there are geo-political issues that might slow down the trade. We have, therefore, assumed that the electricity imports limit would increase gradually from 15 PJ in 2005 to 109 PJ in 2050. Our base case results show that the electricity imports would go up to the limits imposed. This would also be the case under the ERT cases. Thus, the effect on electricity imports due to emission reduction targets is limited in the study. Oil remains the dominant fuel in the transport sector in the base as well as ERT cases showing an insignificant effect on its import during 2005–2050. During 2005– 2030, NEID would increase marginally under ERT cases (except ERT10); however, the level of net energy import in absolute term would be lower (except in ERT20) than that in the base case.

Also the present analysis shows that the net energy import as a percentage of the total primary energy requirement in the base case would decrease with the level of CO_2 reduction considered under the ERT cases (Tables 8.4 and 8.5). That means the total imported energy expenditure in the ERT cases would be less than that in the base case.

Table 8.4: Cumulative total net energy imports in the selected cases during 2005-2030 and 2005-2050 (10^3 PJ)

Fuel types	2005-2030				2005-2050			
	Base case	ERT10	ERT20	ERT30	Base case	ERT10	ERT20	ERT30
Coal	28.7	27.0	26.1	17.2	165.7	115.4	79.4	45.8
Natural Gas	7.3	8.6	10.7	16.0	30.3	51.7	82.4	104.7
Oil	55.0	54.0	55.1	55.5	175.6	177.7	179.8	177.0
Electricity	0.5	0.5	0.6	0.6	1.9	1.9	2.0	2.0
Nuclear	3.3	3.7	3.7	4.8	19.4	26.5	34.1	37.3
Total Net Energy Import	94.8	93.7	96.2	94.1	393.0	373.3	377.6	366.8
NEID[a]	60.8%	60.2%	61.9%	61.7%	77.9%	75.8%	78.0%	78.6%
NEID[b]	60.8%	60.1%	61.7%	60.4%	77.9%	74.0%	74.8%	72.7%

NEID[a]: Net Energy Import Dependency with respect to the TPES in the corresponding case.
NEID[b]: Net Energy Import Dependency compared to the TPES in the base case.

Diversification in the total primary energy requirement

The diversification of TPES is better represented by the Shannon– Wiener index (SWI) (Grubb et al., 2006). The SWI is expressed by:

$$SWI = -\sum_i X_i ln X_i \quad (1)$$

where X_i is the share of fuel type 'i'. The higher the value of SWI, the more diversified would be the energy supply mix.

Table 8.5: Selected annual net energy imports in the selected cases during 2005–2050 (10^3 PJ).

Different cases	2005	2030	2050	Total
Base case	2.2	7.3	24.4	393.0
ERT10	2.2	7.1	22.4	373.3
ERT20	2.2	7.5	22.3	377.6
ERT30	2.2	7.1	20.8	366.8

The results show that the diversification of total primary energy requirement (TPES) would increase during the planning horizon. As can be seen from Figure 8.6, the value of the SWI in all the ERT cases would be higher than that in the base case. Moreover, the value of the index is found to increase with the emission reduction target except in ERT30 during 2005–2050. This is because the share of coal in the cumulative TPES during the period would further decrease and that of the natural gas would increase in ERT30 as compared to that in ERT20. As can be seen from Table 8.6, during 2005–

2050, the share of coal would decrease from 41% in the base case to 32%, 21% and 11% in ERT10, ERT20 and ERT30, respectively. The share of natural gas would increase from 13% in the base case to 18%, 24% and 29% in ERT10, ERT20 and ERT30 cases, respectively, while the share of oil is not significantly affected in the selected emission reduction target cases. The share of the nuclear power generation would increase from 4% in the base case to 5%, 7% and 8% in ERT10, ERT20 and ERT30, respectively, in the same period. Also, the share of biomass would increase from 6% in the base case to 7%, 9% and 11% in ERT10, ERT20 and ERT30, respectively, in the same period. Renewables having less than 1% share in TPES in the base case would have over 1% share in ERT20 and ERT30; no significant difference would be there in ERT10. This shows that, as a result of the ERTs, the coal dominated energy supply would be diversified to promote larger shares of natural gas, oil, biomass and nuclear energy in TPES during the planning horizon. It is also found that unlike during 2005–2050, there would not be significant diversification of energy resources with ERT during 2005–2030 except in ERT30 (see Figure 8.6).

The present study also shows that there would be a higher degree of diversification in net energy imports with ERT (see Figure 8.7) like in the case of TPES. Also like in the case of TPES, the diversification of net energy imports would increase with the level of CO_2 emission reduction target (except in ERT30 during 2005–2050). The share of the imported coal would decrease with ERT, whereas the share of the imported natural gas would increase and the share of oil would not be affected.

Reduction of total primary energy supply

A reduction in the total primary energy requirement is another co-benefit of the emission reduction targets. It is found that the TPES would be reduced by about 2.4%, 4.1% and 7.5% in ERT10, ERT20 and ERT30 cases, respectively, during 2005–2050 as compared to the TPES in the base case (see Table 8.6).

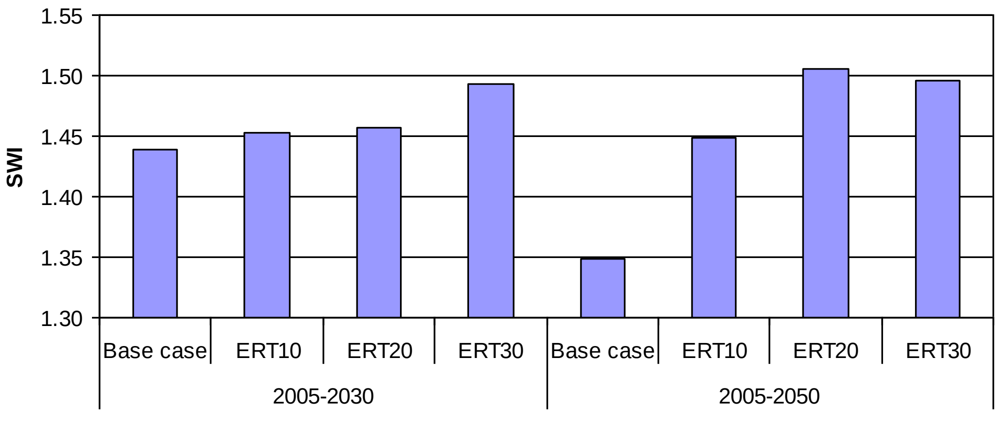

Figure 8.6: Shannon-Wienier Index (SWI) showing the degree of diversification of total primary energy requirement in the selected cases.

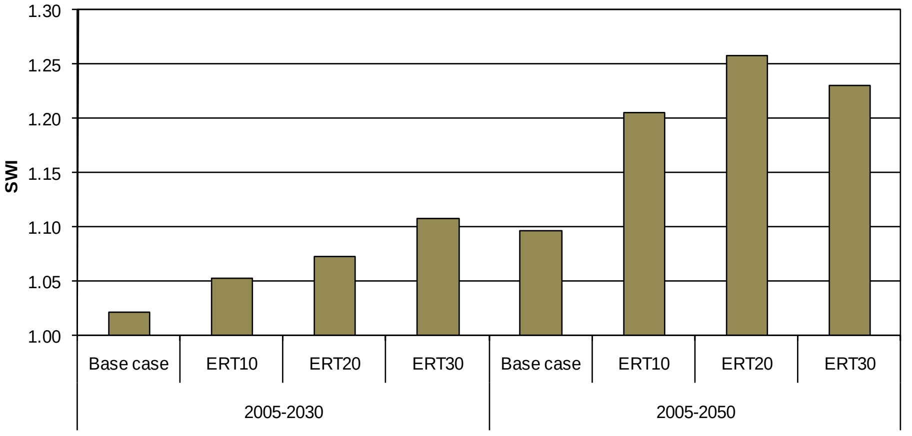

Figure 8.7: Shannon-Wienier Index (SWI) for net energy imports in the selected cases

Table 8.4: Cumulative primary supply energy requirement in the selected cases during 2005-2030 and 2005-2050 (10^3 PJ)

Fuel type	2005-2030				2005-2050			
	Base case	ERT10	ERT20	ERT30	Base case	ERT10	ERT20	ERT30
Coal	46	44	41	24	207	156	101	53
Natural Gas	32	33	35	40	66	87	118	138
Oil	57	57	57	57	177	181	181	179
Hydro	2	2	2	2	4	4	4	4
Nuclear	3	4	4	5	19	27	34	37
Biomass	15	16	16	23	29	36	43	53
Other Renewables	1	1	1	1	2	2	3	3
Total	156	156	155	153	505	493	484	467

8.5.2.4 Cleaner fuel use and efficiency improvement in the power sector

As the result of the emission reduction targets show, the power sector efficiency would improve and the total energy use in the power sector would decrease by 6.3%, 8.4% and 10.8% in ERT10, ERT20 and ERT30 cases, respectively, as compared to that in the base case (see Table 8.7).

As discussed in Section 8.5.1, the power sector would contribute the most to attain the ERTs, which would take place through the relatively smaller coal-based power generation and increased natural gas, biomass and nuclear-based power generation during 2005–2050.

The nuclear energy-based power generation has been included in the government's recommended power development plan from 2020 onward. But the implementation of nuclear power generation in the country requires public acceptance. Another uncertainty about the technology is the disposal of the nuclear waste. Therefore, the government is planning to have a wider awareness raising program about the nuclear technology and its safety to the general public. Our results show that the nuclear-based power generation would increase gradually with the increase in the emission targets in the case of unrestricted nuclear fuel supply during 2005–2050 (see Figure 8.8). In the case of restricted nuclear fuel supply, natural gas-based carbon capture and storage technology would gradually increase in the same period.

Table 8.7: Base case final energy use and the changes in the final energy use in the power sector in the selected emission target cases during 2005–2030 and 2005–2050 (10^3 PJ)[a].

Fuel types	2005-2030				2005-2050			
	Base case energy use	Changes in total final energy use			Base case energy use	Changes in total final energy use		
		ERT10	ERT20	ERT30		ERT10	ERT20	ERT30
Coal	17.8	(2.4)	(5.1)	(10.6)	100.6	(39.4)	(73.7)	(93.4)
Natural gas	18.7	1.2	3.4	3.1	25.7	15.3	33.1	41.6
Oil	1.5	0.0	0.0	0.0	1.5	0.0	0.0	0.0
Hydro	1.1	0.0	0.0	0.1	1.7	0.0	0.0	0.1
Nuclear	3.3	0.4	0.4	1.5	19.4	7.1	14.6	17.9
Biomass	3.5	0.6	0.8	2.5	7.5	6.5	11.1	14.0
Other renewables	0.0	0.0	0.0	0.6	0.0	0.7	1.7	2.7
Total	45.8	(0.1)	(0.6)	(2.9)	156.4	(9.9)	(13.1)	(17.0)

[a]Note: Figures in the parentheses indicate decrease in the energy use.

As a result of the emission targets, power generation-based on renewable energy (i.e., wind, geothermal and municipal solid waste) would also gradually increase during 2005–2050 (Table 8.7). Further, the emission targets would introduce the renewable energy-based power generation (i.e., municipal waste- and wind-based power generation) earlier than that in the base case during 2005–2050 (Figure 8.9). These would be introduced by year 2040, 2030 and 2020 in ERT10, ERT20 and ERT30 cases, respectively. Likewise, biomass-based power generation would also gradually reach to its available limit in the base case. However, the ERTs would result in the use of these power generation options in an earlier year than that in the base case (Figure 8.10).

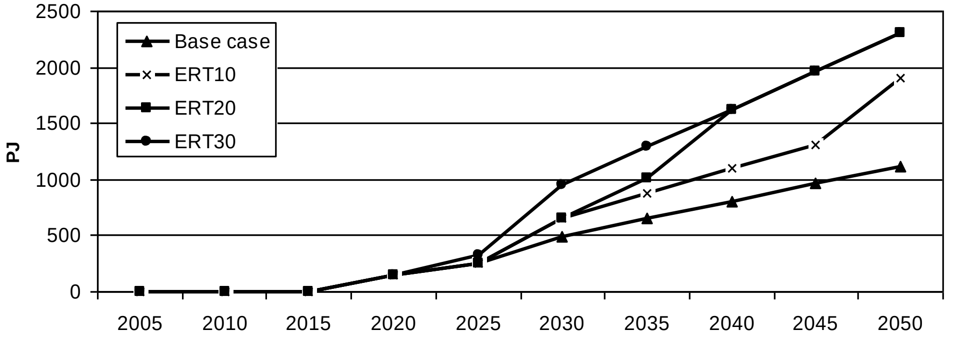

Figure 8.8: Nuclear energy use in the power sector (PJ)

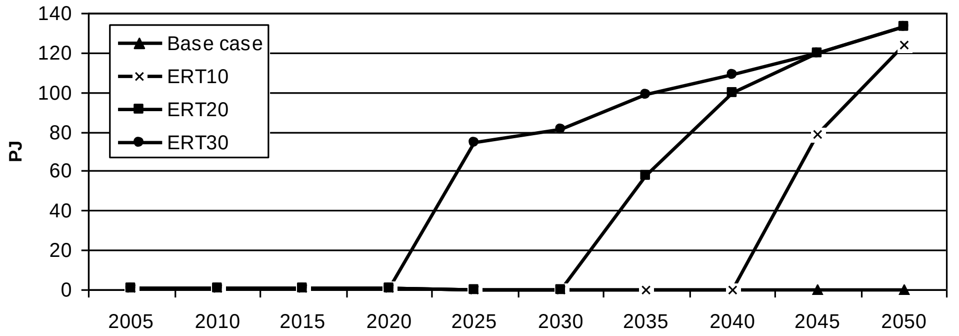

Figure 8.9: Renewable energy use in the power sector (PJ)

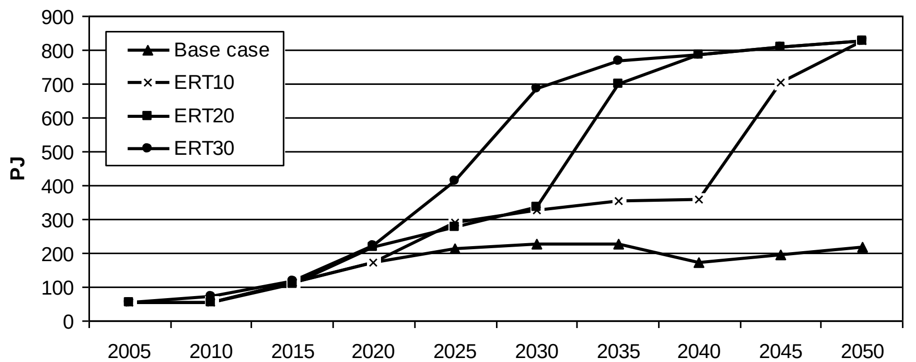

Figure 8.10: Solid biomass use in power generation (PJ)

8.5.2.5 Cleaner fuel use in the transport sector

The results show that the CO_2 emission targets would gradually increase the use of bio-fuels in the transport sector. ERT10 and ERT20 are not found effective in increasing the use of bio-fuels above the level in the base case, whereas there would be significant increase in the use of bio-fuel in ERT30 (Figure 8.11). Most of the bio-fuel use would come from bio-ethanol in the transport sector. Our analysis shows that flex fuel vehicles (up to 85% bio-ethanol blend with gasoline) would not be cost-effective in the selected emission reduction targets. Plug-in hybrid electrical vehicles would be introduced from year 2040 onward in ERT30 case. As a result, significant increase in electricity use would take place in the transport sector during 2040–2050 in ERT30.

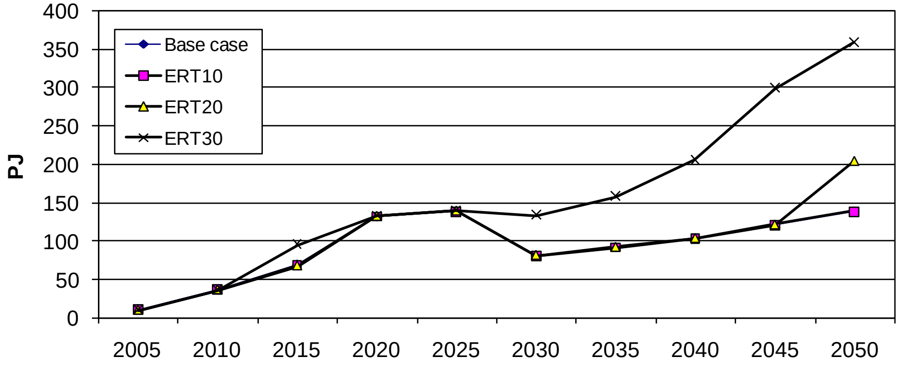

Figure 8.11: Bio-fuel (bio-ethanol and bio-diesel) fuel use in the transport sector (PJ)

8.5.2.6 Diffusion of energy efficient appliances in the residential sector

The present shows that, although the total final energy demand in the residential sector would increase as explained in Section 8.5.2.2, electricity consumption in the residential sector would decrease in the selected CO_2 emission reduction target cases during 2005–2050. This is due to the gradual increase in the use of energy efficient appliances in the residential sectors. As shown in Figure 8.12, the adoption of these energy efficient appliances (CFLs, fans and air conditioning devices) would have to start from year 2035, 2025 and 2015 in ERT10, ERT20 and ERT30 cases, respectively.

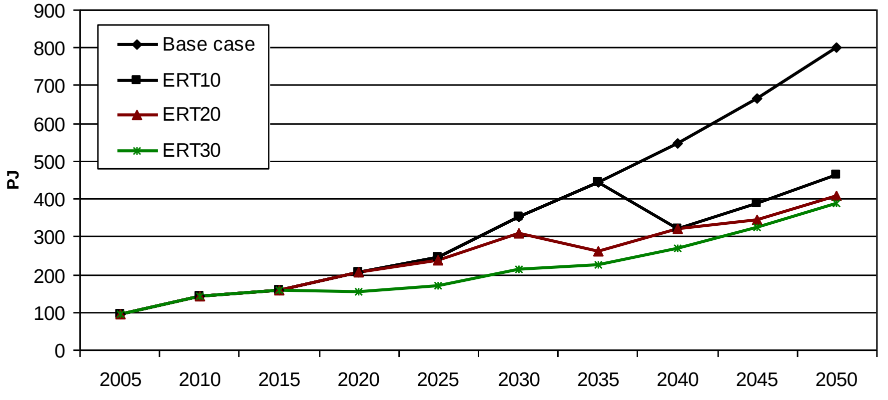

Figure 8.12: Reduction in electricity use in the residential sector

8.6. Conclusion and Final Remarks

This paper has analyzed the effects of selected CO_2 emission reduction targets on environmental emissions as well as energy technology and resource mix using the Thailand country MARKAL model. It has also discussed the energy security implications of the CO_2 emission reduction targets. In the base case, we find that the total CO_2 emission would increase by more than 7 folds during 2005–2050. As a result, the CO_2/TPES would increase from 51 kg/GJ in 2005 to 75 kg/GJ in 2050, whereas the CO_2/TPES would be about 55 kg/GJ by the year 2050 under ERT30.

The marginal cost of CO_2 reduction in the case of ERT30 is significantly higher than that in ERT20. The marginal cost would rise from 6.5 to 476.4 US\$/tCO_2 during 2005–2050 under ERT30. It should be noted that the marginal cost of CO_2 reduction in ERT20 (i.e., 102.4 US\$/tCO_2) in year 2050 is similar to the carbon price in 2050 for the stabilization target of 450 ppmv CO_2e. This analysis shows that it could be possible to cost-effectively reduce the cumulative CO_2 emission during 2005–2050 by up to 20% of that in the base case in a rapidly industrializing developing country like Thailand if the carbon price grows exponentially from \$1.4 to \$102.4/tCO_2 during 2005–2050. Similarly, it also shows that a reduction in cumulative CO_2 emission by at least 10% (i.e., ERT10) would be possible during the planning period, if the carbon price is to grow from 0.4 to 27.6 US\$/ tCO_2. The implementation of several climate friendly projects should thus be possible during the period under the clean development mechanism (CDM) even at that modest carbon price growth scenario.

The power sector would play a major role to achieve the selected CO_2 reduction targets. The sector would account for CO_2 reduction over 84% in ERT10, 74% in ERT20 and 60% in ERT30. The CO_2 reduction in the power sector would mainly come through the use of natural gas-based power generation, as well as biomass and nuclear-based power generation.

As a consequence of the CO_2 emission targets, the SO_2 emission would decrease in the range 9.1–43.2% from the base case emission level during 2005–2050. The highest level of SO_2 emission reduction would take place in the industrial sector followed by the power sector. Unlike SO_2, there would be a relatively small percentage reduction in NO_x emission under the CO_2 reduction targets (i.e., 3.3–5.4%).

The CO_2 emission targets would result in a reduction in final energy demand. The final energy demand would decrease in the range of over 5 thousands PJ to 23 thousands PJ in the selected emission reduction target cases during 2005–2050. This shows that there would be an improvement in efficiency in the final energy use. The industrial sector would gain the most in terms of energy efficiency improvements.

The CO_2 emission targets would have mixed effects in the NEID of the country. The low CO_2 emission reduction target (ERT10) would decrease the NEID, whereas the NEID would increase in the case of higher CO_2 emission reduction target cases (i.e., ERT20 and ERT30). However, the total net energy imports would decrease in all the ERT cases (in the range of over 16 thousand PJ to 26 thousand PJ).

The analysis also shows that the degree of diversification in the total energy requirement would increase with the CO_2 emission reduction target. The primary energy supply system would diversify from the one dominated by coal to that involving a greater use of natural gas, biomass and nuclear fuels under the selected emission reduction targets. Also the primary energy requirement would decrease in the selected emission targets. This would enhance the country's energy security.

In order to meet the CO_2 emission reduction targets, cleaner fuels would have to be introduced in the energy systems. In the power sector, the level of nuclear power generation would increase with the CO_2 emission reduction targets. Power generation based on renewable energy (i.e., municipal waste- and wind-based power generation) would have to be adopted in an earlier year than that in the base case. Although biomass-based power generation reaches its maximum limit in the base case, it would be introduced in an earlier year in the planning horizon in all the selected CO_2 emission target cases. In the transport sector, there would be almost no difference between the base case and ERT10 and ERT20 cases in terms of the bio-fuel use. The situation would be different under ERT30, in which a higher amount of bio-fuels and plug-in hybrid vehicles would be used cost-effectively. In the residential sector, electricity consumption would be reduced as a result of the increased use of energy efficient appliances under the emission target cases.

It should be noted here that due to lack of necessary data to develop rigorous econometric models for estimations of the service demands, we have assumed the service demand to be directly related to either the GDP or sectoral value added. This, however, ignores the potential for decoupling of economic growth and service demand (and hence energy consumption) over a long-term. This is indeed one of the limitations of the present study. Further studies to establish necessary database and to estimate service demands more accurately would greatly help to overcome such a limitation.

References

ADB, 1998, Asia least-cost greenhouse gas abatement strategy: Thailand, Asian Development Bank, Global Environment Facility, United Nations Development Programme, Manila, Philippines.

Barker, T. and Rosendahl, K. E., 2000, Ancillary benefits of GHG mitigation in Europe: SO_2, NO_x and PM_{10} reductions from policies to meet Kyoto targets using the E3ME model and externe valuations, presented in Workshop on "Assessing the Ancillary Benefits and Costs of Greenhouse Gas Mitigation Strategies, Washington DC, 27–29 March 2000.

Caspary, G., O'Connor, D., 2002. Beyond Johannesburg: Policies and Finance For Climate-Friendly Development, Policy Brief No. 21. OECD Development Center, Paris.

CGER-NIES, 2007, Aligning climate change and sustainability – scenarios, modeling and policy analysis, Asia Pacific Integrated Modeling Team, Center for Global Environment Research, National Institute for Environmental Studies, Tokyo.

Creutzig, F., He, D., 2008. Climate change mitigation and co-benefits of feasible transport demand policies in Beijing, Article. Transportation Research Part D in Press.

Davis, D.L., Krupnick, A. and McGlynn, G., 2000, Ancillary benefits and costs of greenhouse gas mitigation – an overview, presented in Workshop on "Assessing the Ancillary Benefits and Costs of Greenhouse Gas Mitigation Strategies, Washington DC, 27–29 March 2000.

DEDE 2006a, Thailand Energy Situation 2005, Department of Alternative Energy Development and Efficiency, Ministry of Energy, Bangkok.

DEDE 2006b, Thailand Alternative Energy Situation 2005, Department of Alternative Energy Development and Efficiency, Ministry of Energy, Bangkok.

DEDE, 2006c, Biomass Potentials in Thailand. Department of Alternative Energy Development and Efficiency, Ministry of Energy, Bangkok /http://www.dede.
go.th/dede/fileadmin/usr/berc/energysave/BiomassPotentialsinThailand.P dfS.

Edmond, J., Clarke, L., Wise, M., Pitcher, H., Smith, S., 2008. Implications for the USA of stabilization of radiative forcing at 3.4 W/m2. Climate Policy 8, 76–S92.

EGAT, 2007, Thailand Power Development Plan (PDP 2007: Revision 1), Electricity Generating Authority of Thailand, Bangkok.

EGAT, 2009, Thailand Power Development Plan 2008–2021 (PDP 2007: Revision 2), Electricity Generating Authority of Thailand, Bangkok.

ETSAP, 2007, Models and Applications: Global, Energy Technology Systems Analysis Programme (ETSAP), USA /http://www.estap.orgS.

Grubb, M., Butlerb, L., Twomeyb, P., 2006. Diversity and security in UK electricity generation: the influence of low-carbon objectives. Energy Policy 34, 4050–4062.

IAEA, 2001. Greenhouse Gas Mitigation Analysis using ENPEP: A Modeling Guide. International Atomic Energy Agency (IAEA), Vienna.

IEA, 2001. Annual Energy Outlook 2001: Electricity Market Module. International Energy Agency, USA [available at.

IEA, 2005a. Prospects for Hydrogen and Fuel Cells. International Energy Agency (IEA) and Organisation for Economic Co-operation and Development (OECD), Paris.

IEA, 2005b. Projected Costs of Generating Electricity. International Energy Agency (IEA), Paris.

IEA-OECD, 2004. Prospects for CO2 Capture and Storage: Energy Technology Analysis. International Energy Agency (IEA) and Organisation for Economic Co-operation and Development (OECD), Paris.

IMF, 2008, World Economic Outlook Database, April 2008, International Monetary Fund.

IPCC, 2001, IPCC Third Assessment Report: Climate Change 2001, Cambridge University Press, Cambridge, London.

IPCC, 2007. Climate change 2007: mitigation. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Limmeechokchai, B., Suksuntornsiri, P., 2007a. Assessment of cleaner electricity generation technologies for Net CO2 mitigation in Thailand. Renewable and Sustainable Energy Reviews 11, 315–330.

Limmeechokchai, B., Suksuntornsiri, P., 2007b. Embedded energy and total greenhouse gas emissions in final consumptions within Thailand. Renewable and Sustainable Energy Reviews 11, 259–281.

Lipman, T.E., Delucchi, M.A., 2003. Hybrid-Electric Vehicle Design Retail and Lifecycle Cost Analysis, UCD-ITS-RR-03-01. Institute of Transportation Studies, University of California, California.

Loulou, R., Goldstein, G. and Noble, K., 2004, Documentation for the MARKAL Family of Models, Energy Technology Systems Analysis Programme (ETSAP), Paris.

Malla, S and Shrestha, R. M., 2005, Implications of carbon tax and energy efficiency improvement on Thai economy, The Sixth IHDP Open Meeting 2005 Conference Paper, Bonn.

NEPO, 1999. Thailand Energy Strategy and Policy, Final Report for Phase 1, Phase 2 and Phase 3. National Energy Policy Office, Bangkok, Thailand.

O'Connor, D., 2000, Ancillary benefits estimation in developing countries: a comparative assessment, presented in Workshop on "Assessing the Ancillary Benefits and Costs of Greenhouse Gas Mitigation Strategies, Washington DC, 27–29 March 2000.

Prasertsan, S., Sajjakulnukit, B., 2006. Biomass and biogas energy in Thailand: potential, opportunity and barriers. Renewable Energy 31, 599–610.

Rajesh, N., Shukla, P.R., Kapshe, M., Garg, A., Rana, A., 2003. Analysis of long-term energy and carbon emission scenarios for India. Mitigation and Adaptation Strategies for Global Change 8, 53–69.

Remme, U., Blesl, M., 2008. A global perspective to achieve a low-carbon society (LCS): scenario analysis with the ETSAP-TIAM model. Climate Policy 8, 60–75.

Santisirisomboon, J., Limmeechokchai, B., Chungpaibulpatana, S., 2001. Impacts of biomass power generation and CO2 taxation on electricity generation expansion planning and environmental emissions. Energy Policy 29, 975–985.

Seebregts, A.J., Goldstein, G.A., Smekens, K., 2005. Energy/Environmental Modeling with the MARKAL Family of Models. Energy Research Centre of the Nether-lands (ECN), the Netherlands.

Shrestha, R. M. and Pradhan, S., 2008, Effects of carbon tax on greenhouse gas emission and use of emerging technologies in Thailand, the 31st IAEE International Conference: Bridging Energy Supply and Demand: Logistics, Competition, and Environment, Istanbul.

Shrestha, R.M., Khummonkol, P., Biswas, W.K., Timilsina, G.R., Sinbanchongjit, S., 1998. CO2 mitigation potential of efficient demand-side technologies: The case of Thailand. Energy Sources 20, 310–316.

Shrestha, R.M., Malla, S., Liyanage, M.H., 2007. Scenario-based analyses of energy system development and its environmental implications in Thailand. Energy Policy 35, 3179–3193.

Shrestha, R.M., Pradhan, S., Liyanage, M.H., 2008. Effects of carbon tax on greenhouse gas mitigation in Thailand. Climate Policy 8, 140–155.

Shukla, P.R., Dhar, S., Mahapatra, D., 2008. Low-carbon society scenarios for India. Climate Policy 8, 156–176.

Smekens-Ramirez Morales, K.E.L., 2004. Response from a MARKAL technology model to the EMF scenario assumptions. Energy Economics 26, 655–674.

Strachan, N., Kanan, R., 2008. Hybrid modeling of long-term carbon reduction scenarios for the UK. Energy Economics 30, 2947–2963.

Tanatvanit, S., Limmeechokchai, B., Chungpaibulpatana, S., 2003. Sustainable energy development strategies: implications of energy demand management and renew-able energy in Thailand. Renewable and Sustainable Energy Reviews 7, 367–395.

Tanatvanit, S., Limmeechokchai, B., Shrestha, R.M., 2004. CO2 mitigation and power generation implications of clean supply-side and demand-side technologies in Thailand. Energy Policy 32, 83–90.

Timilsina, G.R., Shrestha, R.M., 2002. General equilibrium analysis of economic and environmental effects of carbon tax in a developing country: case of Thailand. Environmental Economics and Policy Studies 5, 179–211.

TDRI, 2004. GDP Forecast 2000–2016. Thailand Development and Research Institute (TDRI), Bangkok.

UN, 2004. World Population Prospects: The 2004 Revision. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, New York (Av).

Van Harmelen, T., Bakker, J., Vries, B.d., Van Vuuren, D., Elzen, M.D., Mayerhofer, P., 2002. Long-term reductions in costs of controlling regional air pollution in Europe due to climate policy, Environmental Science & Policy 5, 349–365.

Chapter 9

Thailand's Low-Carbon Scenario 2050: The AIM/CGE Analyses of CO_2 Mitigation Measures[1]

Abstract:

Climate change and CO_2 mitigation have become increasingly important environmental issues. Recently Thailand has proposed policies on GHG mitigation such as Thailand's Nationally Appropriate Mitigation Action (NAMA), which aims at GHG mitigation in the energy sector. This study used the computable general equilibrium (CGE) model, called "AIM/CGE" model, to analyse GHG mitigation measures under emission trading and carbon capture and storage (CCS) technology in Thailand. Results show that the international free emission trading policy can drive more GHG reduction by decreasing energy supply and demand, and increasing prices of emissions. The CCS technologies would balance emission reduction but they would reduce energy efficiency improvement and renewable energy utilization. In the energy security aspect, the policy options in this study would improve energy security, energy import dependency, and co-benefits of GHG mitigation in forms of improving local air quality. Results are also helpful to GHG mitigation policy in developing countries.

9.1. Introduction

The increasing global energy demand results in increasing GHG emissions to the biosphere which impact climate change as well as humanity. We are facing challenges in energy-environment-economy development in the context of limited energy resources availability and global climate change. Many countries have attempted to reduce petroleum-based energy use through energy efficiency improvement, biomass consumption promotion, etc. The low carbon society (LCS) concept is one of the tools implemented in many countries in order to alleviate these problems. The idea of a low-carbon society or low-fossil fuel economy has been promoted in order to minimize output of GHG emissions into the biosphere and it represents the low-carbonization in all aspects of the society including economy, culture and life (Yuan et al, 2011). The European Union (EU) is building a low carbon society by establishing a mandatory target of

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20% renewable energy by 2020. Research on hydrogen extraction from biomass is being done in order to maintain stability of renewable energy supplier and smart grids from home and enterprises are being encouraged (Carvalho et al, 2011). Japan and the United States are attempting to become low-carbon societies through the target of 80% reduction in CO_2 emissions by 2050 which was committed to in a Japan-U.S. Summit Meeting (2009). There are a number of studies on pathways to achieve this target, e.g. modeling development (Kainuma et al., 2012) and roadmap towards a low-carbon society (Fujino et al., 2009), (Ashina et al., 2012). For developing Asian countries, such as India and China, the proposed 2.6 W/m^2 scenarios for a low-carbon society were analyzed through the Asian Modeling Exercise (AME) by the integrated assessment models (Calvin et al., 2012). The Asian countries have diverse geographic features, political regimes, industrial competitiveness, and states of economic development, as well as energy resource endowments; thus, the roadmaps to low-carbon societies of this region may vary among their conditions (Kainuma et al., 2012).

However, the LCS concepts would be different in developing countries such as Thailand, having lower per capita emissions and lower emissions per GDP when compared to developed countries (Winyuchakrit et al., 2011). Thailand is also facing challenges in energy-environment-economy development in the context of limited energy resources availability and global climate change. One of the approaches to meet this challenge is the adoption of a sustainable development paradigm that promotes low-carbon society. Policies to achieve low-carbon society targets affect not only the national energy mix but also the national economy as a whole, and these effects need to be assessed. The city level low-carbon development in Bangkok was studied by Phdungsilp (2010) in regard to energy and carbon towards 2025 using the Long-range Energy Alternatives Planning System (LEAP) model. At the national level, Winyuchakrit et al. (2011) studied the possibility for Thailand to become a low-carbon society in 2030 through efficiency improvement in all economic sectors by using demand-side analysis. Recent studies have examined the effect of energy and GHG mitigation targets on the economy and energy systems in Thailand using the Computable General Equilibrium (CGE) model. The CGE model is a top-down model for analysis of short-term and long-term economic implications of climate change, where price is an important signal that drives agents in an economy (Peace and Weyant, 2008; Shukla et al., 2008; Hosoe et al., 2010). Several CGE models have been used to analyze the effect of climate policy on the economic impacts in many countries, e.g. in the EU (Kretschmer, et al., 2009), Switzerland (Bretschger et al., 2011), China (Lin and Jiang, 2011), etc. Furthermore the CGE models can be used to analyze the effect of carbon tax policy in order to achieve the GHG mitigation policy (Kumbaroglu, 2003; Liang et al., 2007; Timilsina et al., 2011).

This study uses a computable general equilibrium (CGE) model called the AIM/CGE model, which has been developed by the Asia- Pacific Integrated Model (AIM) team (Fujimori et al., 2011) to analyse the effect of the GHG mitigation policy under Thailand's Nationally Appropriate Mitigation Action

(NAMA). The AIM/CGE model has been developed for analyses at global level (Matsumoto and Masui, 2010; Okagawa et al., 2012) as well as at country level (Xu and Masui, 2009; Dai et al., 2011). In this study, the AIM/CGE model is used to investigate the effect of selected CO_2 counter- measures including emission trading and carbon capture and storage (CCS) technologies on economic and energy aspects during 2005–2050. GHG emission policies do not only have influences on climate change (Shrestha and Pradhan, 2010), but they also generate co-benefits and ancillary effects. Therefore this study also considers the energy security aspect of GHG mitigation for the period of 2005–2050.

9.2. Methodology

9.2.1. AIM/CGE model

The Asia-Pacific Integrated Model (AIM) team has developed the AIM/CGE model which is a recursive dynamic model in order to analyze climate policy in both global (Masui et al., 2011; Okagawa et al., 2012) and country levels, e.g. China (Xu and Masui, 2009; Dai et al., 2011). Thailand's AIM/CGE model includes the socioeconomic assumptions of IPCC SRES-B2 (Special Report on Emissions Scenarios – SRES). Future developments in the global environment with special reference to the production of greenhouse gases and aerosol precursor emissions were constructed in SRES scenarios. The SRES-B2 emphasizes sustainability and regional equity and has been described by IPCC as "The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability" (IPCC, 2000). The mitigation scenario of the rest of the world is under very strong climate mitigation policy consistent with a 2 degree target. This study considers the equilibrium of Thailand and the rest of the world among Thailand's GHG mitigation targets (see Fujimori et al., 2011). The model deals with all payments recorded in the Social Accounting Matrix (SAM), which has been modified from 2005 Thailand's input-output table and relevant data. The model structure consists of four blocks, i.e. production, income distribution, expenditure, and market (see Figure 9.1).

The first block, the production block, represents the structure of the production function in which a nested CES (Constant elasticity of substitution) function is applied. Each activity produces one or more commodities according to fixed yield coefficients and is assumed to maximize profits, defined as the difference between revenue earned and the cost of factors and intermediate inputs. Profits are maximized subject to a production technology. The difference in activity cost for energy and non-energy transformation sectors is energy and value added treatment. For each activity, total revenue net of taxes is fully exhausted by payments for value-added and intermediate inputs.

Secondly, the income or institution block, consists of enterprise, government and household sectors. In the household sector, the consumption covers market commodities with market prices that include commodity tax. An enterprise or corporation is a legal entity, created for the purpose of producing goods or services for the market, that may be a source of profit or other financial gain to its owner. It is collectively owned by shareholders who have the authority to appoint directors responsible for its general management. Corporations are classified into two types; non-financial and financial corporations. This block describes the income allocation and distribution to the institutional sectors. The main sources of the income are from production factor supply and tax on products and production. There is also transfer among the sectors. The income of institutional factor demand is split among domestic institutions in fixed shares after payment of direct factor taxes and transfers to the rest of the world. The payment transfers are fixed in foreign currency and transformed into domestic currency by multiplying by the exchange rate which makes reference to the set of domestic institutions, i.e. households, enterprise, and the government, a subset of the set of institutions, which also includes rest of the world.

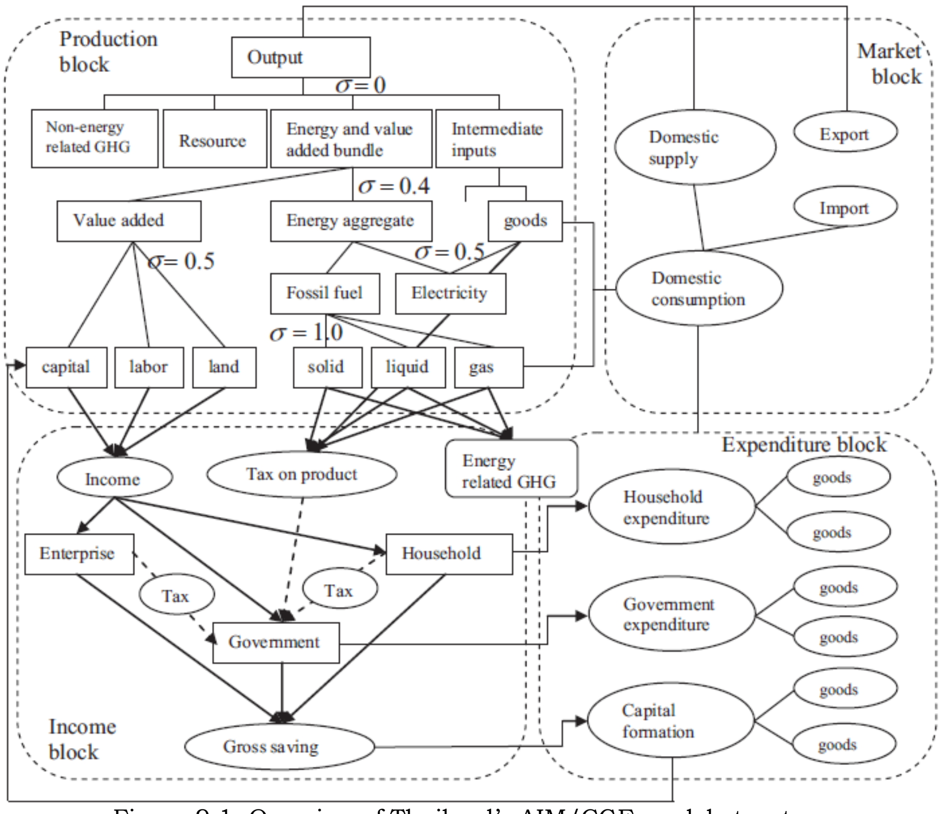

Figure 9.1: Overview of Thailand's AIM/CGE model structure

The third block is the expenditure block which describes household expenditure, government consumption and capital formation which institutions consume goods as final consumption. In the household expenditure, it is assumed that each household maximizes a Stone-Geary utility function to a consumption expenditure constraint. Its results are referred to as an LES (Linear Expenditure System) function since spending on individual commodities is a linear function of total consumption spending. Government expenditure and capital formation are defined as a constant coefficient function. The government consumption demand is the services provided by the government labor force. It is defined as the base-year quantity multiplied by an adjustment factor. This factor is also exogeneous and, hence, the quantity of government consumption is fixed.

Lastly, the market block describes three main aspects of market. First is the output collection including stock change. Second is the disaggregation of domestically produced commodities to domestic market and export. The last is the aggregation of domestically produced and imported commodity. Aggregate marketed production of any commodity, excluding energy commodity, is defined as a CES aggregate of the marketed output levels of the different activities producing the commodity. The optimal quantity of the commodity from each activity source is inversely related to the activity-specific price.

The sector classifications are disaggregated to 17 non-energy sectors and 14 energy sectors. The energy sectors are classified into three groups: energy mining and refinery, power generation from various technologies, and gas manufacturing distribution (see Table 9.1). The data of each sector are based on Thailand's input-output table 2005 (NESDB, 2005). In addition, the energy balances are used for the energy data (DEDE, 2005).

Table 9.1: Description of sector classification

	Non-energy sectors		Energy sectors
1	Agriculture	1	Coal mining
2	Forestry	2	Oil mining
3	Mineral mining and other quarrying	3	Gas mining
4	Food products	4	Petroleum and coal refinery
5	Textiles and apparel and leather	5	Coal-fired generation
6	Wood products	6	Oil-fired generation
7	Paper, paper products and pulp	7	Gas-fired generation
8	Chemical, plastic and rubber products	8	Hydroelectric power generation
9	Mineral products	9	Nuclear electric power generation
10	Iron and steel	10	Photovoltaic power generation
11	Non ferrous products	11	Wind-power generation
12	Machinery	12	Biomass-power generation
13	Transport equipment	13	Other renewable energy power generation
14	Other manufacturing	14	Gas manufacture distribution
15	Construction		
16	Transportation and communications		
17	Service sector		

The emission gases treated in this study are CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide), NH_3 (ammonia), NMVOC (non-methane volatile organic compounds), NO_x (nitrogen oxide), SO_2 (sulphur dioxide), BC (black carbon), OC (organic compound), and CO (carbon monoxide). The emission sources are classified into two groups. The first is related to fuel combustion and its emission is proportional to energy consumption, and the second is related to the activity level.

9.2.2. Model dynamics

The AIM/CGE model can be categorized as a recursive dynamic model. The model assesses capital, labor and technology improvement through TFP (Total Factor Productivity) and AEEI (Autonomous Energy Efficiency Improvement) factors.

The capital stock is determined by the previous year's capital stock, capital formation and capital depreciation. In the model, the capital stock is calculated except for the base year which is prepared by using the World Bank's physical capital stock database (The World Bank, 1995).

The labor is also dynamically determined as its quantity is assumed growing after the population growth rates (UN, 2008).

Total Factor Productivity (TFP) is determined with the assumption that capital and labor stocks are already estimated. The adjusted efficiency parameter in the CES value-added function stands for TFP.

The energy demand is controlled by calibration of the Autonomous Energy Efficiency Improvement (AEEI). The annual AEEI improvement rate is set. The intermediate input coefficients and household energy commodity consumption are set along with the improvement rate.

9.2.3. Input data

The input data used in this study are based on 2005 input-output table (NESDB, 2010), 2005 energy balance (DEDE, 2005), CO_2 emission factors of fossil fuels from IPCC (2006). Gross domestic product (GDP) and population in the base year 2005 are given by NESDB, 2010 and NSO (2010). The total GDP has been projected with the help of growth rates in Power Development Plan, PDP 2010 (EPPO, 2012) referring to the trajectory by NESDB and the population forecasted follows government agencies (see Table 9.2).

The model disaggregates power generation into eight groups: three fossil-based plant groups (i.e. coal, oil and gas), and five alternative energy-based plant group (i.e. hydro, wind, solar, biomass and nuclear). In the case of Thailand, installed power plants during 2005–2030 follow Thailand's power development plan 2010, PDP2010 (EPPO, 2012) in which the forecasted demand is approximately 52,890 MW in 2030 (EGAT, 2010). In order to achieve the demand of power in 2030, new power plants will be installed by the Electricity Generating Authority of Thailand (EGAT) for conventional power plants as well as new technologies such as nuclear power. The first nuclear power plant will be commissioned in 2020 with a capacity of 1,000 MW and will be increased to 5,000 MW by 2030. Power from renewable energy, i.e. small hydro, solar and wind power plants, are generated from EGAT and power producers which are IPP (Independent Power Producer), SPP (Small Power Producer) and VSPP (Very Small Power Producer). The summary of Thailand power development plan during 2010–2030 is shown in Table 9.3.

Table 9.2: GDP and population growth

Year	GDP1		Population2	
2005 (base year)	billion US	176.3	million person	66.7
2006-2010	Growth rate	3.4%	Growth rate	1.0%
2011-2020		4.3%		0.6%
2021-2030		4.0%		0.5%
2031-2040		3.9%		0.3%
2041-2050		3.9%		0.2%

[1]*Source*: Office of the National Economic and Social Development Board (2010).
[2]*Source*: National Statistical Office (2010).

Table 9.3: Summary of Thailand power development plan during 2010-2030

Power plant	Capacity (MW)
EGAT power plant	22,182
Power purchased from IPP	4,400
Power purchased from SPP & VSPP	11,307
Co-generation power plants	6,423
Small hydro power plants	69
Solar power plants	1,097
Wind power plants	1,192
Municipal solid waste power plants	157
Biomass	2,369
Power purchased from neighbouring countries	11,669
Nuclear	5,000

Source: EGAT 2010

In the BAU scenario, the demand and supply in the power sector follow PDP 2010 until 2030, and projected to 2050, except that nuclear power plant capacity is maintained at 5,000 MW during 2030–2050 due to an uncertain future nuclear situation since the accident at the Fukushima nuclear power plants. Hydro power plants, which include electricity purchased from neighbouring countries and power producers, will be 3,424 MW in 2050. The capacity of wind and solar power plants from SPP and VSPP will be 1,321 and 1,107 MW in 2050, respectively. These capacities are applied for the BAU and all scenarios whereas the consumption of other energy supplies for power plants will be varied due to factors of countermeasures.

The Kyoto protocol (KP) is a legal agreement which was negotiated in December 1997 about GHG emissions mitigation in industrialized or Annex I countries (UNFCC, 1998). The KP prescribed three mechanisms in order to assist the countries in achieving the emission mitigation targets, i.e. Emission Trading (ET), Joint Implementation (JI), and Clean Development Mechanism (CDM) (TGO, 2012). As Thailand is a Non-Annex I country, CDM has been introduced. The current CDM projects in Thailand, consist of 5 issuance projects which have capacity of only 0.9 Mt-CO_2 GHG emission reduction (TGO, 2011), thus the CDM projects are neglected in this study. For this reason, the GHG reduction policy after the NAMAs project and emission trading are the key mechanisms considered in this study.

The emission trading permission rates considered in this study are no trade, 50% trade and 100% trade or free trade in 2050. The free trading policy has no ceiling for emissions exported. The quantity of emissions would depend on market price and customer demand. The third is carbon capture and storage (CCS) technologies in electricity generation. Carbon capture storage (CCS) technology involves capturing emissions from combustion or conversion of fuel or industrial processes and storing CO_2 underground or at deep sea level, away from the atmosphere for a very long period of time. The prices of CCS technologies adopted in this study are shown in Table 9.4.

Table 9.4: Prices of CCS technologies adopted in the study

	Sector	Price (US$/tCO2)
Manufacturing	Petroleum refinery coal transformation	100
	Non-metal and mineral	200
	Paper and pulp	150
	Chemical	150
Power	Coal fired	50
	Oil fired	50
	Gas fired	70
	Biomass fired	70

Sources: AIM, 2011.

9.2.4. Energy security and co-benefits

The energy security parameters which are considered in this study are Shannon-Wiener index (SWI)1 which is a measure for the degree of diversification, Oil Intensity (OI), Oil Share (OS), Energy Intensity (EI), Carbon Emission Intensity (CEInt), and Carbon Emission per capita (CECap). Co-benefits and ancillary effects of GHG mitigation are sulphur oxide (SO_x), and nitrogen oxide (NO_x), whose emission factors are obtained from EEA (2009).

9.3. Thailand's GHG Mitigation Target

In 2000 Thailand emitted about 70% of its carbon dioxide emissions from the energy sector, about 23% from the agricultural sector, and about 7% from industrial processes. The trend of GHG emissions in Thailand has been increasing; however, Thailand is categorized in Non-Annex I countries and has no commitment to any quantitative objectives under the Kyoto Protocol. There are many projects which show an intention of being the main supporter for climate change reduction and GHG mitigation in South-East Asia including the proposed Nationally Appropriate Mitigation Actions (NAMAs). Thailand's NAMAs are classified into two types: domestic NAMAs and internationally supported NAMAs. Domestic NAMAs or domestically supported mitigation actions are the unilateral NAMAs whose financing and implementation are supported by Thailand's government as the counter-measures in these NAMAs generally have low investment cost and can be implemented, e.g. energy management and energy efficiency improvement. The international NAMAs or international supported mitigation actions involve high investment cost and advanced technology countermeasures. Therefore the international NAMAs have to seek international support to facilitate financial assistance on countermeasures. In 2020, the amount of forecasted GHG emissions is 331.6 Mt-CO_2 and the NAMAs project reported that Thailand has potential to reduce GHG emissions about 29.5 Mt-CO_2 for domestic NAMAs and 35.5 Mt-CO_2 for internationally supported NAMAs. The total of GHG mitigation from the NAMAs project is 65.0 Mt-CO_2 and accounted for 19.6% of total emissions. Therefore, the GHG mitigation levels in 2020, which are considered in this study, are analyzed at two levels: 10% and 20%, and increased to 30% and 50% in 2050, respectively.

9.4. Scenario of CO_2 Mitigation

In order to study the influence of three key policy measures and technological options, 13 scenarios including the BAU scenario are analysed by using AIM/CGE model. The BAU scenario assumes that there are no GHG mitigation measures or policies introduced during the studied period. The 12 scenarios of counter-measures are defined as the CM30 and CM50 scenarios which consider two levels of GHG mitigation targets in 2050, i.e., 30% and 50% reduction of GHG emission from the BAU scenario. The emissions achieved from GHG mitigation are traded under the emission trading policy. The no trade policy is considered in the CM30, CM30C, CM50 and CM50C scenarios. The emission limitation policies are considered to be less than 50% trade and 100% trade or free trade of mitigated emissions in 2050, which are called as T50 and T100, respectively. The 'C' in the end of scenario names means that the carbon capture storage technology (CCS) is considered. The characteristics of all scenarios are shown in Table 9.5.

Table 9.5: GHG countermeasures in all scenarios

Scenario	GHG reduction level (%)		Emission trading		CCS Technology
	30	50	T50	T100	
BAU	-	-	-	-	-
CM30	X	-	-	-	-
CM30C	X	-	-	-	X
CM30T50	X	-	X	-	-
CM30T100	X	-	-	X	-
CM30T50C	X	-	X	-	X
CM30T100C	X	-	-	X	X
CM50	-	X	-	-	-
CM50C	-	X	-	-	X
CM50T50	-	X	X	-	-
CM50T100	-	X	-	X	-
CM50T50C	-	X	X	-	X
CM50T100C	-	X	-	X	X

9.5. Results and Discussion

9.5.1. Economic output and GHG reduction

Procedures of GHG emissions mitigation mostly are involved with reduction of resources and energy consumption. Generally, the procedure will start from simple and non-investment activities, such as housekeeping and efficiency improvement, and then move forward to high investment activities, such as major changes in technologies. GHG mitigation policies strongly influence both monetary and technology changes. In the BAU scenario, growth of population and GDP obtained from NSO and NESDB are used to estimate the output of energy situation and emission towards 2050 as shown in Table 9.6.

Table 9.6: Estimated socio-economic indicators in 2050

	2005	2050	2050/2005
Population (million persons)	66.7	82.0	1.2
GDP (billion US$)	176.3	952.4	5.4
GDP per capita (US$/capita)	2,643.2	11,614.6	4.4
Total primary energy supply (Mtoe)	85.2	438.6	5.1
Total final consumption (Mtoe)	64.0	261.7	4.1
Industrial sector	24.4	129.2	5.3
Transport sector	17.2	73.4	4.3
Residential sector	10.2	20.0	2.0
Service sector	4.0	26.9	6.8
Agriculture sector	3.0	4.6	1.6
Others	5.3	7.7	1.4
Power generation (Mtoe)	11.2	77.7	6.9
CO_2 emissions (Mt-CO_2)	293.9	1,597.8	5.4

The effect of GHG mitigation and emission trading policy on GDP per capita is illustrated in Figure 9.2. Average annual GDP growth rate during 2005–2050 in the BAU scenario is 3.8%. Compared to the BAU scenario, GDPs in scenarios of 30% GHG mitigation (CM30 and CM30C) have roughly the same growth rate as these scenarios have no motivation on emission trading policies. The emission trading policies allow carbon trading as goods which results in increasing GDPs as shown in the CM30T50, CM30T50C and CM30T100C scenarios (average annual GDP growth rates are 3.8 - 4.1%). But free emission trade gives a negative result on the CM30T100 scenario. Its annual average GDP growth rate is 3.7% and 2050's GDP is obviously lower than the BAU's. The trend of GDP growth rates are similar in scenarios of 50% GHG mitigation, except the changing of GDP growths are more extreme than in the 30% GHG mitigation target scenarios (see Figure 10.2).

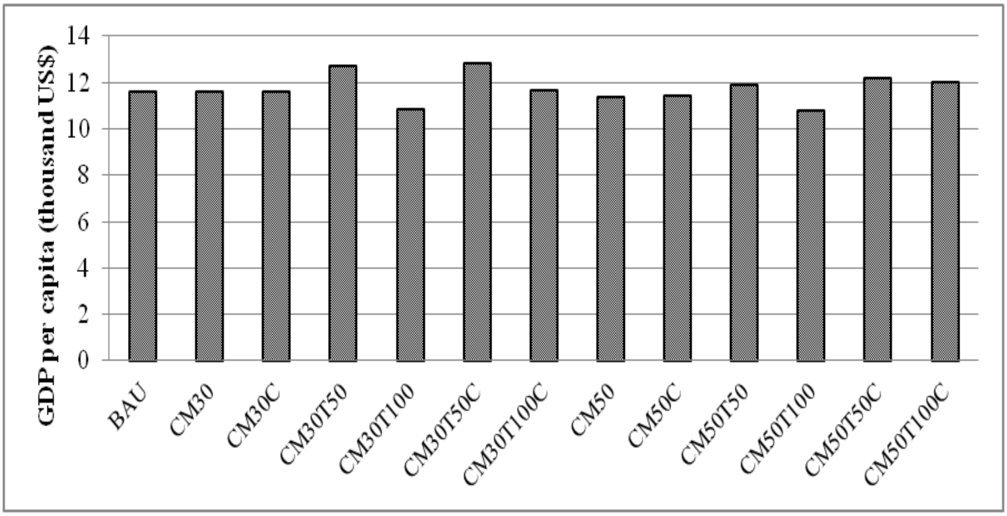

Figure 9.2: GDP per capita due to GHG mitigation policies

In order to achieve the GHG mitigation targets and the free trade of emission, the relevant technologies investment, e.g. green technology, will be introduced. The higher mitigation levels need higher investment. The CCS technology is one of the alternative technologies to achieve higher GHG reduction levels. The GDP in the scenarios which include CCS will increase when compared to the scenarios without CCS; therefore, CCS will become cheaper than other mitigation technologies by 2050. For this reasons, GDPs of the CM30T100 and CM50T100 scenarios are lower than the others.

9.5.2. GHG emission reduction and GHG prices

Results of GHG mitigation and its price as compared with the corresponding values in the BAU scenario are presented in Table 9.7. In the CM30 and CM50 scenarios, GHG emissions will be reduced to the level of reduction targets, 30% and 50%, respectively. These GHG emissions reduction levels also occurred in the scenarios which included the CCS technology, i.e. the CM30C and CM50C scenarios, since there is no motivation from emission trading allowance. GHG emissions from the AIM model are assumed to come from the energy supplier; therefore, the price of GHG is the most important driving force of GHG mitigation. On the other hand results from emission trading has significant effects on GHG mitigation, especially in the free trade scenarios (the CM30T100, CM30T100C, CM50T100 and CM50T100C) because the higher prices of emissions will push producers to reduce GHG to lower levels than the targets.

The GHG prices in 2050 are consistent with the value of GHG mitigation, i.e. higher prices drive higher GHG reduction levels. The highest price is in the CM30T100 and CM50T100 scenarios which considers unlimited emission trading policy. The higher prices are the consequence of the higher cost of GHG mitigation procedures beside CCS technology. The cost of GHG mitigation procedure by CCS technology is lower; thus, GHG prices in their scenarios (CM30T100C and CM50T100C) are lower.

Table 9.7: GHG mitigation and prices in all scenarios

Scenarios	GHG mitigation (%)	GHG price (US$/t-$CO_2$)
CM30	30.0	29.3
CM30C	30.0	29.3
CM30T50	58.2	152.3
CM30T100	73.2	358.1
CM30T50C	58.2	120.6
CM30T100C	76.9	284.2
CM50	50.0	198.1
CM50C	50.0	130.4
CM50T50	66.2	270.7
CM50T100	76.9	334.2
CM50T50C	66.2	169.9
CM50T100C	76.9	202.1

Targeted at 30% reduction of GHG emission level, Thailand will be a carbon credit exporter after 2022. In the higher reduction target of 50%, the emission export ability will be postponed to 2025. During 2022–2050 under the GHG reduction target of 30%, the cumulative carbon credit to be exported will be about 4,600 Mt-CO_2 and 8,798 Mt-CO_2 for 50% and free emission trading options, respectively. Under the GHG reduction target of 50%, the cumulative carbon credits of 2,657 Mt-CO_2 and 5,299 Mt-CO_2 will be exported during 2025–2050 for 50% and free emission trading policies. The extreme GHG mitigation target of 50% results in delay of carbon export and decreasing CO_2 reduction and its prices.

9.5.3. Total primary energy supply and total final consumption

Total primary energy supply (TPES) in all scenarios in 2050 is illustrated in Figure 9.3. GHG mitigation measures with allowance on carbon trading and CCS technology option result in lower levels of total primary energy supply, especially in the case of 50% GHG reduction level i.e. the CM50T100. TPES in the CM30 and CM30C scenarios are reduced from the BAU by 20.9% and the CM50 and CM50C scenarios are reduced by 37.6% and 35.9%, respectively. The emission trading policy in the CM30T100 and CM50T100 scenarios will bring down TPES by 51.7% and 57.7% from the BAU, respectively.

Cumulative TPES during 2005–2050 shows that energy supply from fossil is 8,521 Mtoe and alternative energy is 1,077 Mtoe or represented by proportion of alternative and fossil supplies about

12.6% in the BAU scenario. In the CM30, CM30C, CM50, and CM50C scenarios, TPES from fossil is slightly decreased and alternative energy supply is slightly increased as shown by the proportions being increased from 15.0 -18.0%. As fossil fuels are the main source of GHG emissions, the reduction of fossil supply and replacement by alternative energy are important tools for achieving GHG mitigation targets in these scenarios, apart from overall energy supply reduction. In the scenarios including emission trading and CCS technology, the alternative energy used during 2005–2050 is significantly increased from 18.0–21.3% in the 50% emission trading option and from 24.9–26.6% in the free emission trading. Comparing the TPES from fossil energy, the amount of fossil energy in the scenarios with CCS technology are higher than the scenarios without CCS technology in the same emission trading allowance. It is 5,613.9 Mtoe in the CM30T100C scenario whereas it is only 5,329.7 Mtoe in the CM30T100 scenario.

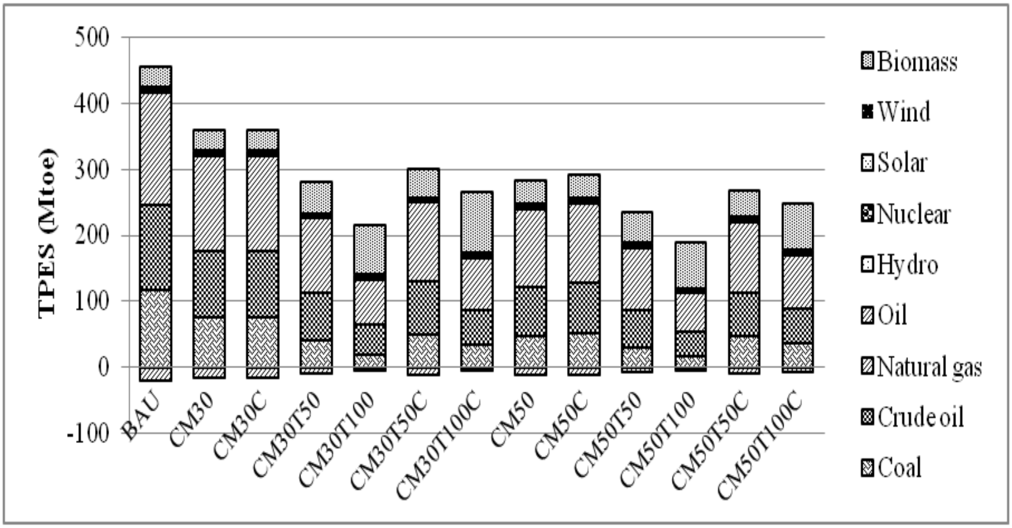

Figure 9.3: Total primary energy supply in 2030

Results show GHG mitigation policies on reduction in TPES. Emission trading allowances are an important motivation for TPESs reduction. The CCS technology is one of the important tools to achieve the GHG mitigation through capturing CO_2 from processes, thus reducing GHG emissions without requiring other procedures. Therefore, the scenarios with CCS technology give the lowest GHG emissions, whereas TPESs are higher in scenarios such as CM30T100 and CM30T100C.

Results of total final energy consumption (TFEC) by sector and by type in 2050 are illustrated in Figures 9.4 and 9.5, respectively. In the BAU scenario, TFEC is about 261.7 Mtoe and the highest energy consuming sectors are the industrial and transport sectors. Energy consumption in the CM30 and CM30C scenarios will be reduced by 23.8% from the BAU scenario, and the share of energy consumption by sector and by type would remain the same as in the BAU scenario. In the scenarios with free emission trading and CCS, i.e. the CM30T100C and CM50T100C scenarios, TFECs are found to be 124.4 and 120.3 Mtoe or decreased by 52.5% and 54.0% from the BAU scenario, respectively. In the CM30T100 and CM50T100 scenarios, the free emission trading will drive TFEC down to 104.5 and 91.1 Mtoe or reduced by 60.1% and 65.2% from the BAU scenario in 2050, respectively. Furthermore, shares of energy consumption in the industrial and transport sectors will decrease when compared to the BAU scenario (see Figure 9.4).

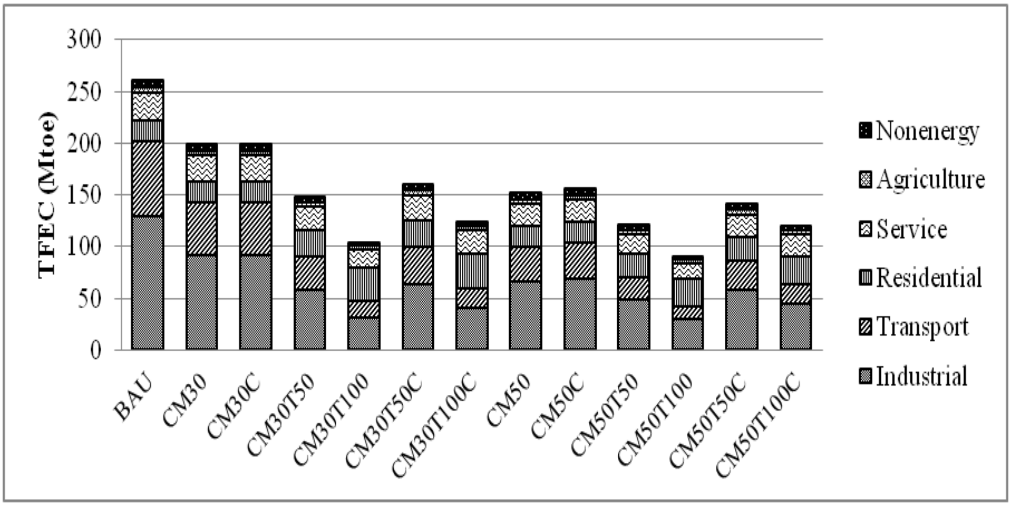

Figure 9.4: Total final consumption by sectors in 2050

Shares of TFEC by types in other scenarios are similar to the BAU scenario. Oil is mostly consumed, followed by electricity and coal. It is obvious that energy consumption of fossil based fuels will decrease in the free emission trading scenarios while biomass will significantly increase. In the counter-measures with CCS, the consumption of fossil-based fuels will increase as a result of corresponding CO_2 emissions captured by CCS.

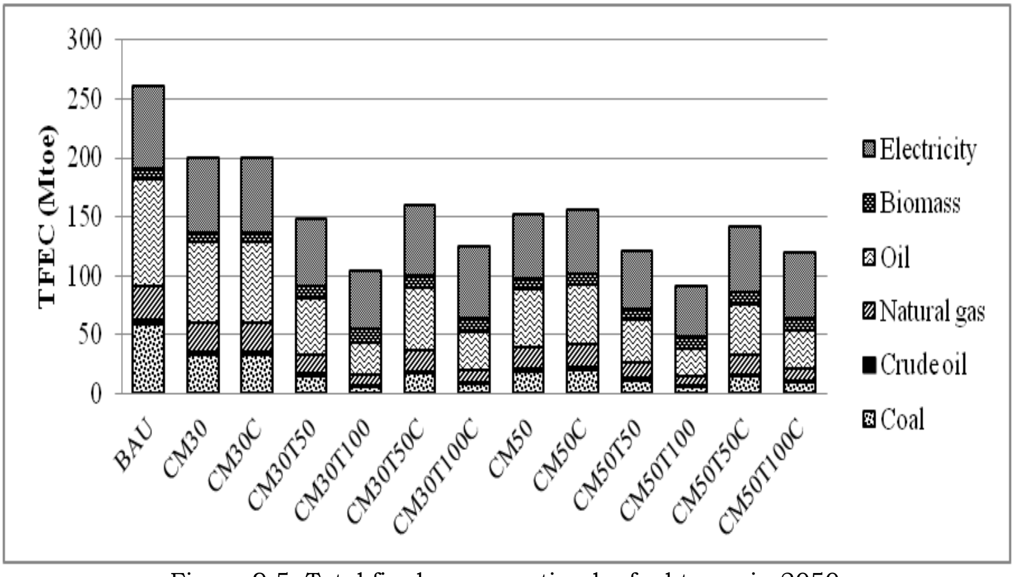

Figure 9.5: Total final consumption by fuel types in 2050

Apart from lower amounts of TFEC in all scenarios, the proportion of energy consumption in industrial and transport sectors is lower than others, especially in the free emission trading scenarios. These results arise from the motivation of the emission merchandise opportunity and they are in accord with the proportion fuel type of TFEC. Fossil consumptions are decreased, especially coal, which generated high level of GHG emissions whereas lower sources of GHG emissions, biomass and electricity, are increased.

9.5.4. Electricity generation

Results of total electricity generation in all scenarios in 2050 are illustrated in Figure 9.6. In the BAU scenario, the power generation value is 77.7 Mtoe which mainly comes from gas, coal and oil. The power sector in the CM50T100 and CM30T100 scenarios will consume only 52.7 and 45.8 Mtoe, respectively due to free emission trading. In addition, consumption of fossil fuels is significantly reduced whereas biomass use is increased. In the scenarios with CCS technology, half of power plants that used fossil fuels become plants with CCS. Although GHG emissions are the lowest of all scenarios, the CM30T100C and CM50T100C scenarios with CCS technology give higher electricity generation values than the free emission trading policy without CCS, i.e the CM30T100 and CM50T100 scenarios. Therefore, in the scenarios with CCS technology, i.e. fossil-based plants with CCS technology and biomass based plants with CCS, CCS technologies play an important role in balancing emission reduction with demand growth. GHG reduction targets will be achieved by biomass and alternative energy resources in free emission trading scenarios.

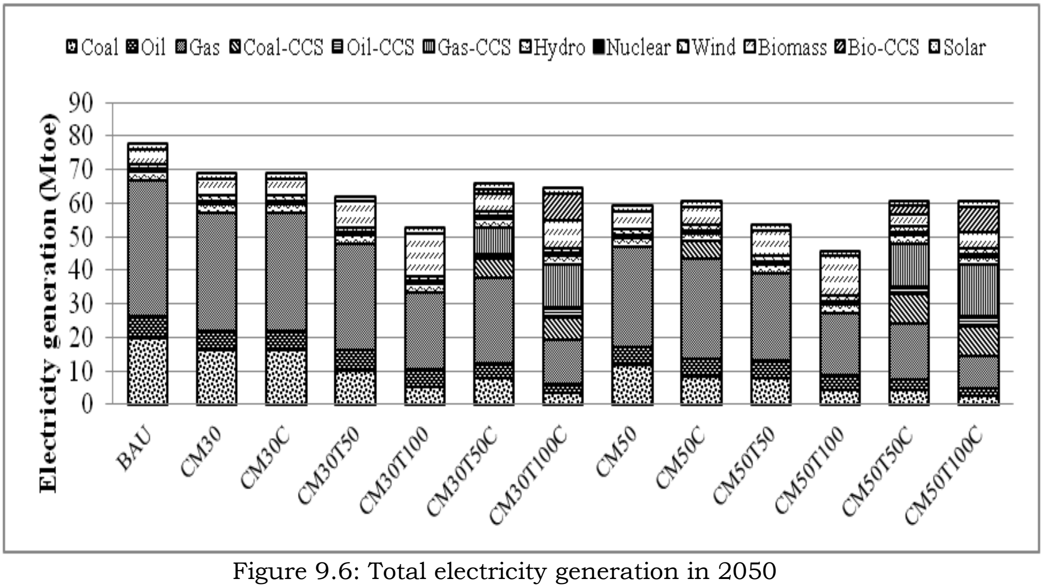

Figure 9.6: Total electricity generation in 2050

9.5.5. GHG mitigation

The GHG mitigation measures in all scenarios are illustrated in Figure 9.7. In the CM30, CM30C, CM50, and CM50C scenarios, GHG emissions will be mostly reduced by non-energy activities, about 34.7% to 40.4%. In the scenarios with emission trading, the energy efficiency improvement is the key measure of GHG mitigation which contributes in share of GHG mitigation higher than 40%. Renewable energy resources also play an important role in GHG mitigation, with shares of about 6.8%, 6.6% and 7.4% in the CM30T100, CM30T100C, and CM50T100 scenarios, respectively. However its share will be decreased to 5.5% in the CM50T100C scenario as a result of carbon capture storage.

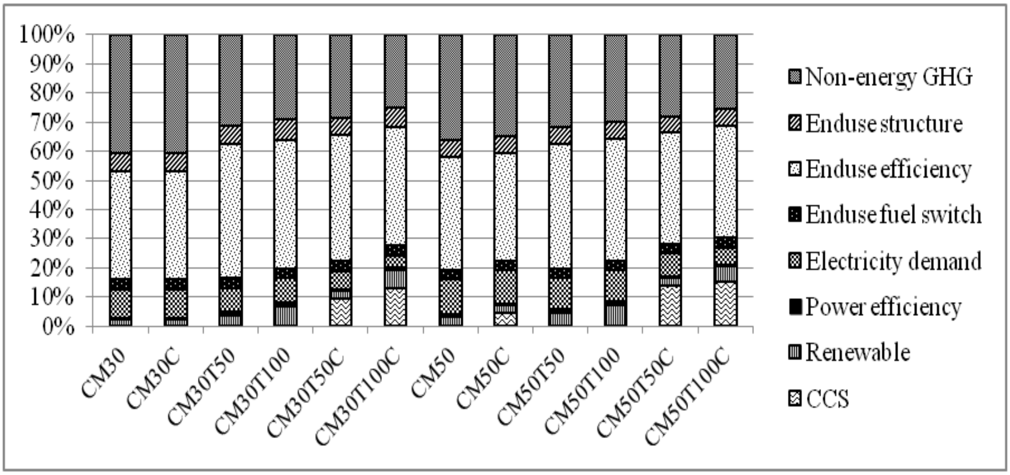

Figure 9.7: GHG reduction measures in all scenarios

In the GHG reduction target of 30%, the CCS technology will reduce GHG emissions by 9.47% and 12.9% in the CM30T50C and CM30T100C scenarios, respectively. The CCS technology would not influence the CM30C scenario but it plays a role in the CM50C of more than 4%. The CCS technology will further reduce GHG emissions in the CM50T50C and CM50T100C scenarios by 14.1% and 15.1%, respectively. This obviously shows that emission trading policies will increase renewable energy utilization.

These findings are consistent with previous results as emission trading, especially full allowance, is an important motivation for GHG emission reduction. In the scenarios without CCS technology as an option, the energy efficiency improvement and renewable energy consumption becomes an important role to achieve the GHG emission mitigation targets. The important role is dominated by the CCS technology when it occurs.

9.5.6. Energy security and co-benefits

9.5.6.1. Diversification of primary energy demand

The levels of Shannon-Wiener index (SWI) for all scenarios are illustrated in Figure 9.8. Results show that the diversities of primary energy for all scenarios are higher than the BAU scenario. The emission trading policy would increase the diversities of primary energy as shown in the CM30T100, CM30T100C, CM50T100, and CM50T100C scenarios. The CCS will increase SWI when compared with the cases of without CCS when other things are the same. The diversity of primary energy mix in the BAU scenario and counter-measure scenarios are not significantly changed which implies that these GHG reduction levels do not have an effect on the diversity of primary energy mix. However, SWI will be improved in all GHG counter-measures in 2050.

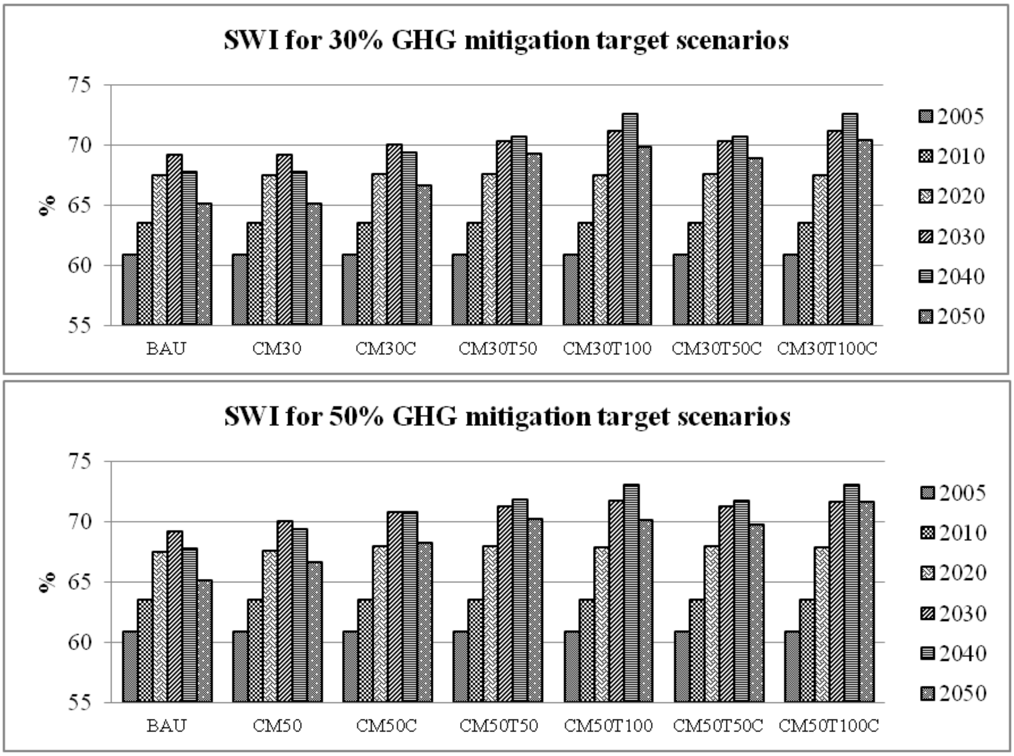

Figure 9.8: Diversification of primary energy resources

9.5.6.2. Oil intensity and oil share

Results of the oil intensity (OI) for all scenarios are illustrated in Figure 9.9. The OI in all scenarios is lower than the BAU scenario which implies that GHG mitigation policy will reduce oil consumption. The emission trading policy will reduce more oil consumption than the CCS policy. Thus, the CCS technology could be used to reduce CO_2 emissions rather than oil consumption.

The share of oil consumption (OS) in the BAU scenario will slightly decrease during 2005–2050. In 2050, OS in the BAU scenario will be reduced by 17.0%. The largest reduction of OS in 2050 will be found in four free emission trading scenarios, particularly in the CM50T100 scenario in which OS will be reduced by 58.1% from the BAU scenario. The effects of the emission trading and the CCS technology on GHG mitigation are similar to OI.

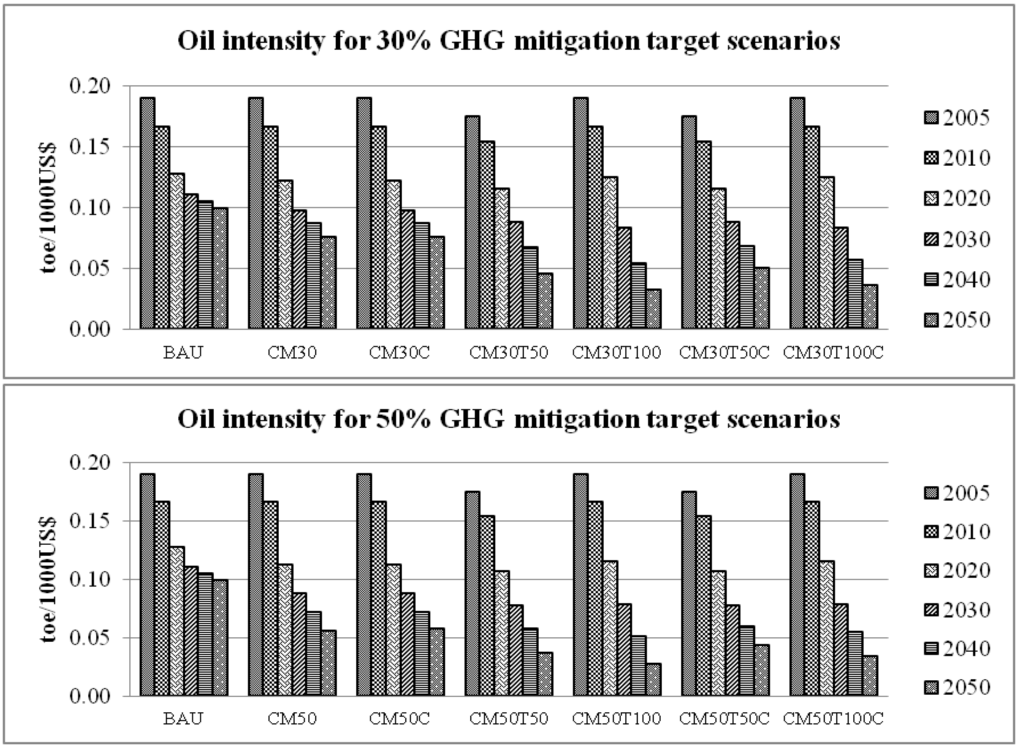

Figure 9.9: The oil intensity in all scenarios

9.5.6.3. Energy intensity

The energy intensity (EI) in all scenarios, which is defined as primary energy consumption per GDP, is illustrated in Figure 10.10. The scenarios without emission trading show that GHG mitigation policies will decrease energy intensity. The EI in 2050 will be reduced by 24.4% for the CM30 and CM30C scenarios and 39.1% and 37.6% for the CM50 and CM50C scenarios, respectively. The EI will be decreased more by emission trading. The EI will be reduced by 55.8% in the CM50T100 when compared to the BAU scenario. In the scenarios with CCS, energy intensities under emission trading are higher than those in the scenarios without CCS. It was found that both GHG reduction targets and emission trading policy will reduce EI. GHG mitigation with CCS will increase by using CCS rather than energy consumption reduction.

The CO_2 emissions per GDP or the Carbon Emission Intensity (CEInt) in all scenarios are illustrated in Figure 9.11. In the BAU scenario, the CEInt was about 1.7 kgCO_2/US$ in 2005 and it will slightly decrease to 1.4 kgCO_2/US$ in 2030, before it rebounds to 1.7 kgCO_2/US$ in 2050. Other scenarios have lower CEInt in 2050 than 2005. The emission trading policy will reduce the CEInt in the CM30T50, CM30T100, CM50T50 and CM50T100 scenarios about 58.3%, 73.9%, 65.9%, and 77.9%, respectively, from the base year. Furthermore, the CEInt will be reduced even more in the CM30T100C and CM50T100C scenarios, about 80.2% and 80.6%, respectively.

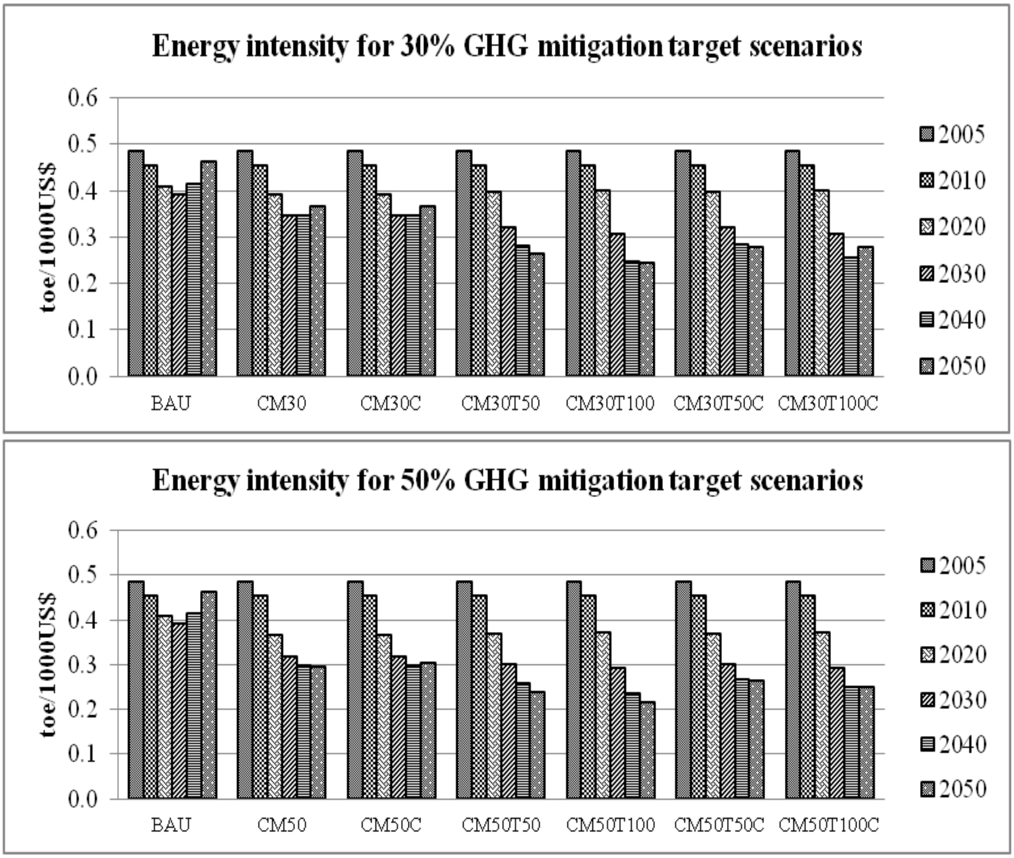

Figure 9.10: Energy intensity in all GHG mitigation scenarios

9.5.6.4. Carbon emission intensity and carbon emission per capita

In the aspect of CO_2 emission per capita (CECap), the values of CECap in all scenarios in 2005 are 4.4 kg-CO_2/person and it will increase to 19.5 kg-CO_2/person in the BAU scenario in 2050. In the CM30 and CM50 scenarios, the CECap in 2050 will decrease to 13.6 and 9.5 kg-CO_2/person, respectively. The CECap will significantly decrease in the scenarios with free emission trading. In the GHG reduction target of 30%, the CECap in the CM30T100C decreases by 12.6% from the base year. Results of the GHG reduction target of 50% are similar to the 30% target as the emission trading and CCS give positive effects on the CECap.

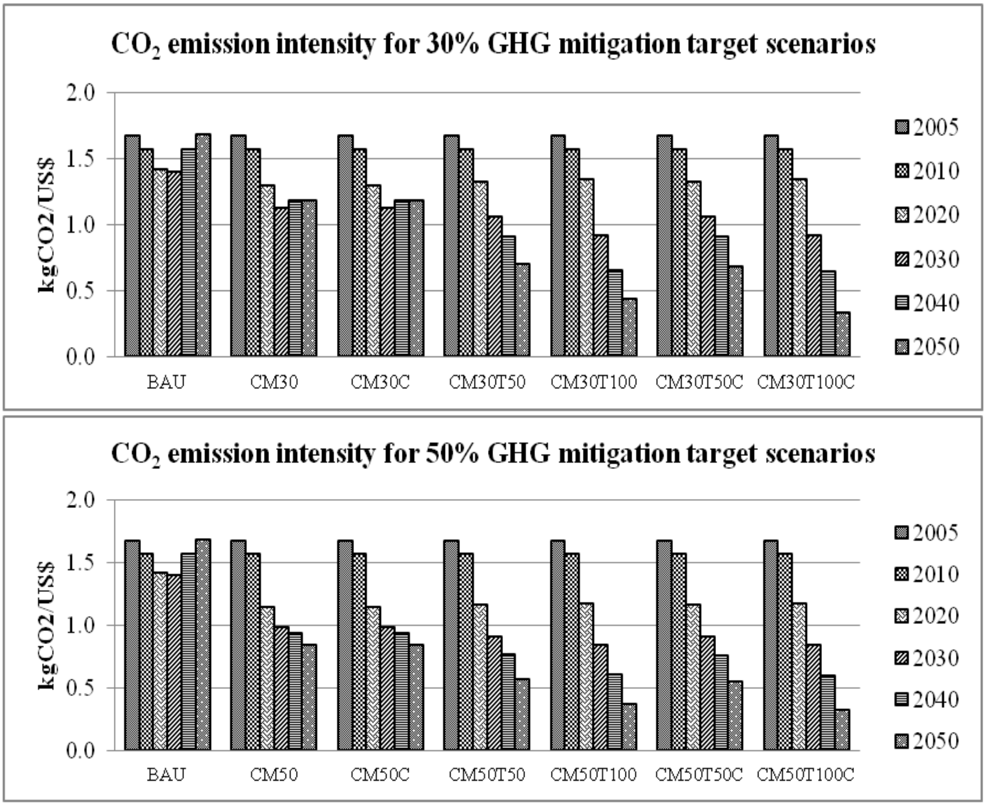

Figure 9.11: CO_2 emission intensity in all GHG mitigation scenarios

9.5.6.5. Energy import dependency

Thailand's imported energies include coal, crude oil, natural gas, petroleum product or oil and electricity. The energy import dependency index is represented by the net energy import dependency (NEID), which is defined as net energy imports as a percentage of TPES during 2005–2050. In the base year the import crude oil is 41.3 Mtoe, representing the largest share of imported energies. In the BAU scenario, imported energy accounts for more than half of all TPES. The NEID of the CM scenarios slightly decreases when they respect to the TPES in the corresponding case (NEIDa). While the NEID which compared to the TPES in the BAU (NEIDb) are further decreased (see Table 9.8). GHG mitigation policies bring down the imported energy in all scenarios when compared with the BAU scenario. The percentages of imported energy to TPES in the scenarios with GHG mitigation policy are 45.2–48.1% in 2030 and drop to 33.7–46.4% in 2050.

Compared with the BAU scenario, the GHG mitigation policies under free emission trading would reduce the import of energies except electricity. Electricity is imported from neighbouring countries and the trend of import is increasing, which agree with Shrestha and Pradhan (2010). Since the imported energies are fossil fuels, low GHG emissions energy like electricity and biomass, which are domestic energy resources, would be increasingly consumed.

Table 9.8: Cumulative total net energy imports during 2005-2050

Scenario	Imported energy (Mtoe)						NEID[a] (%)	NEID[b] (%)
	Coal	Crude oil	Natural gas	Oil	Electricity	Total		
BAU	1,229.6	2,386.9	776.7	228.8	50.5	4,672.5	67.1	67.1
CM30	858.8	2,097.8	702.1	200.7	50.8	3,910.2	62.8	56.2
CM30C	614.2	1,832.5	631.3	175.2	51.6	3,304.9	60.1	47.5
CM30T50	858.2	2,097.8	702.1	200.7	50.8	3,910.2	62.8	56.2
CM30T100	628.1	1,842.3	633.2	176.2	51.5	3,331.3	60.3	47.9
CM30T50C	636.1	1,912.5	702.1	182.5	56.9	3,490.1	58.5	47.6
CM30T100C	491.4	1,694.6	633.2	163.3	55.9	3,038.4	60.1	43.7
CM50	447.4	1,652.6	601.7	168.8	69.6	2,940.2	54.0	39.9
CM50C	394.3	1,546.2	556.2	150.5	62.7	2,709.8	56.9	38.9
CM50T50	666.6	1,934.7	668.4	187.0	53.8	3,510.4	61.1	50.4
CM50T100	561.3	1,746.2	612.1	168.1	54.9	3,142.5	59.7	45.2
CM50T50C	522.1	1,710.0	621.6	167.2	64.7	3,085.6	55.1	44.3
CM50T100C	489.4	1,623.5	585.4	157.5	58.5	2,914.3	56.1	41.9

[a]NIED: net energy import dependency with respect to the TPES in the corresponding case.
[b]NIED: net energy import dependency with respect to the TPES in the base case.

9.5.6.6. Co-benefits

In this study, co-benefits of GHG mitigation are presented in terms of SO_x and NO_x migitation. The cumulative SO_x and NO_x emissions in all scenarios during 2005–2050 are presented in Table 9.9. Most SO_x emissions are emitted from coal and oil combustion while most NO_x emissions are emitted from oil combustion. Results show that the GHG emissions under emission trading without CCS (CM30T100 and CM50T100 scenarios) will be dramatically decreased. The CCS technologies capture only CO_2, but not SO_x and NO_x emissions. The emission trading would result in lower emissions than CCS because power generation under emission trading policy deploys alternative technologies such as nuclear and biomass, which do not account for SO_x and NO_x emissions.

Table 9.9: Cumulative SO_x and NO_x

Emission type	2005-2050						
	BAU emission	Emission reduction under scenarios					
		CM30	CM30C	CM30 T50	CM30 T100	CM30 T50C	CM30 T100C
SO_x	210.46	10.4	10.4	23.4	39.9	20.0	30.0
NO_x	431.25	8.7	8.7	17.0	30.2	15.1	24.0
Emission type	2005-2050						
	BAU emission	Emission reduction under scenarios					
		CM50	CM50C	CM50 T50	CM50 T100	CM50 T50C	CM50 T100C
SO_x	210.46	23.1	21.7	33.2	43.7	24.7	30.4
NO_x	431.25	18.7	18.0	25.7	34.4	20.7	25.8

9.6. Conclusions

Results of CO_2 counter-measures show that policy on emission trading plays an important role in GHG mitigation. The carbon prices are dramatically high in the scenarios with emission trading. At the target at 30% reduction of GHG emission level, Thailand will be a carbon credit exporter after 2022. In the higher reduction target of 50%, the emission export ability will be postponed to 2025. GDPs in the higher GHG reduction levels will decrease when compared to the BAU, especially without CCS technology scenarios. Since higher mitigation levels need higher investment, without CCS technology more expensive technologies would be needed in order to achieve the GHG mitigation target instead of CCS technology. The CCS technology is one of the alternative technologies to achieve higher GHG reduction levels and the GDP in the scenarios which include CCS will increase when compared to the scenarios without CCS. In the energy aspect, emission trading policy will play an important role in decreasing fossil consumption and increasing renewable energy utilization. It was found that CCS technologies can contribute in emission reduction; but shares of renewable energy and energy efficiency improvement will decrease. Apart from economic and energy aspects, the GHG mitigation polices positively influence primary energy supply, reducing oil consumption as well as carbon emission, and promoting renewable energy consumption. In addition, low carbon technologies and energy supply in power generation would increase co-benefits in terms of reduction in SO_x and NO_x emissions. The 50% GHG mitigation targets along with CCS and the free emission trading policy will help Thailand to achieve GHG emissions reduction targets and energy security. It was found that these results are also beneficial to the policy makers in other developing countries for consideration to a become low-carbon society.

Acknowledgments

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References

Asia-Integrated Model Team (AIM), 2011. How to introduce mitigation measures, AIM training workshop 2011, June 13, 2011.

Ashina, S., Fujino, J., Masui, T., Ehara, T., Hibino, G., 2012. A roadmap towards a low- carbon society in Japan using backcasting methodology: Feasible pathways for achieving an 80% reduction in CO_2 emissions by 2050. Energy Policy 41, 584–598.

Bretschger, L., Ramer, R., Schwark, F., 2011. Growth effects of carbon policies: Applying a fully dynamic CGE model with heterogeneous capital. Resource and Energy Economics 33, 963–980.

Calvin, K., Clarke, L., Krey, V., Blanford., Jiang, K., Kainuma, M., Kriegler, E., Luderer, G., Shukla, P.R., 2012. The role of Asia in mitigating climate change: Results from the Asia modelling exercise. Energy Economics 34, S251–S260.

Carvalho, M.G., Bonifacio, M., Dechamps, P., 2011. Building a low carbon society. Energy 36, 1842–1847.

Dai, H., Masui, T., Matsuoka, Y., Fujimori, S., 2011. Assessment of China's climate commitment and non-fossil energy plan towards 2020 using hybrid AIM/CGE model. Energy Policy 39, 2875–2887.

DEDE, 2005. Thailand Energy Situation 2005. Department of Alternative Energy Department and Efficiency. Ministry of Energy, Bangkok.

Energy Policy and Planning Office (EPPO), 2012. Summary of Thailand power development plan 2012-2030 (PDP2010). Ministry of Energy. Bangkok, Thailand.

EEA, 2009. EMEP/EEA air pollutant emission inventory guidebook 2009. European Environment Agency, Copenhagen.

Fujino, J., Hibino, G., Ehara, T., Matsuoka, Y., Masui, T., Kainuma, M., 2009. Back- casting analysis for 70% emission reduction in Japan by 2050. Climate Policy 8, S108–S124.

Fujimori, S., Tu, T.T., Masui, T., Matsuoka, Y., 2011. AIM/CGE [basic] manual. National Institute for Environmental Studies, Tsukuba.

Hosoe, N., Gasawa, K., Hashimoto, H., 2010. Textbook of Computable General Equilibrium Modelling: Programming and Simulations. Palgrave Macmillan, New York.

IPCC, 2000. IPCC Special Report: Emissions Scenarios. Intergovernmental Panel on Climate Change.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change, Hayama.

Japan-U.S. Summit Meeting, 2009. Japan-U.S. Joint Message on Climate Change Negotiations, Available at: ⟨http:/www.mofa.go.jp/region/n-america/us/ pv0911/summit.html⟩ [accessed: 10 August 2010].

Kretschmer, B., Narita, D., Peterson, S., 2009. The economic effects of the EU biofuel target. Energy Economics 31, S285–S294.

Kumbaroglu, G.S., 2003. Environmental taxation and economic effects: a computable general equilibrium analysis for turkey. Journal of Policy Modeling 25, 795–810.

Liang, Q.M., Fan, Y., Wei, Y.M., 2007. Carbon taxation policy in China: How to protect energy- and trade-intensive sectors? Journal of Policy Modeling 29, 311–333.

Lin, B., Jiang, Z., 2011. Estimates of energy subsidies in China and impact of energy subsidy reform. Energy Economics 33, 273–283.

Masui, T., Matsumoto, K., Hijioka, Y., Kinoshita, T., Nozawa, T., Ishiwatari, S., Kato, E., Skukla, P.R., Yamagata, Y., Kainuma, M., 2011. An emission pathway for stabilization at 6 Wm^2 radiative forcing. Climate Change 109, 59–76.

Matsumoto, K., Masui, T., 2010. Economic impacts to avoid dangerous climate change using the AIM/CGE model. Procedia Environmental Sciences 6, 162–168. National Economic and Social Development Board (NESDB), 2010. 2005 Input-output table. Available at: ⟨http:/www.nesdb.go.th/Default.aspx?tabid=97⟩. [accessed: 7 January 2012].

National Statistical Office (NSO). Thailand population projection, 2000-2030. Available at: ⟨http:/portal.nso.go.th⟩. [accessed: 18 August 2010].

Okagawa, A., Masui, T., Akashi, O., Hijioka, Y., Matsumoto, K., Kainuma, M., 2012.

Assessment of GHG emission reduction pathways in a society without carbon capture and nuclear technologies. Energy Economics 34, S391–S398.

Peace, J., Weyant, J., 2008. Insights not numbers: the appropriate use of economic models. White paper of Pew Center on Global Climate Change.

Phdungsilp, A., 2010. Integrated energy and carbon modelling with a decision support system: Policy scenarios for low-carbon city development in Bangkok. Energy Policy 38, 4808–4817.

Shrestha, R.M., Pradhan, S., 2010. Co-benefits of CO_2 emission reduction in developing country. Energy Policy 38, 2586–2597.

Shukla, P.R., Dhar, S, Mahapatra, D., 2008. Low-carbon society scenarios for India. Climate Policy 8, s156–s176.

Thailand Greenhouse Gas Management Organization (TGO), 2011. Status of CDM projects in Thailand. Available at: ⟨http:/www.tgo.or.th⟩. [accessed: 20 September 2011].

Thailand Greenhouse Gas Management Organization (TGO), 2012. Carbon market and emission allowances. Seminar of "How does carbon market kelp climate change in industrial sector?". February 28, 2012. Bangkok. Thailand. (in Thai). Timilsina, G., Csordas, S., Mevel, S., 2011. When does a carbon tax on fossil fuels stimulate biofuels? Ecological Economics 70, 2400–2415.

The World Bank, 1995. Physical Capital Stock: Sources, Methodology and Results Dataset. Available at: ⟨http:/econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/0,,contentMDK:20699846 page%20PK:64214825 piPK:64214943 theSitePK:469382,00.html⟩. [accessed: 12 May 2012].

United Nations, 2008. World Population Prospects, The 2008 Revision Population Database.

United Nations Framework Convention on Climate Change (UNFCC), 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change. United Nations. Available at: ⟨http:/unfccc.int/resource/docs/convkp/kpeng.pdf⟩.[accessed: 3 March 2012].

Winyuchakrit, P., Limmeechockchai, B., Matsuoka, Y., Gomi, K., Kainuma, M., Fujino, J., Suda, M., 2011. Thailand's low-carbon scenario 2030: Analyses of demand side CO_2 mitigation options. Energy for Sustainable Development 15, 460–466.

Xu, Y., Masui, T., 2009. Local air pollutant emission reduction and ancillary carbon benefits of SO_2 control policies: Application of AIM/CGE model to China. European Journal of Operational Research 198, 315–325.

Yuan, H., Zhou, P., Zhou, D., 2011. What is low-carbon development? A conceptual analysis. Energy Procedia 5, 1706–1712.

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CLIMATE POLICY AND ENERGY DEVELOPMENT IN THAILAND AN ASSESSMENT

This book examines the long-term implications of various climate-friendly policies on energy system development, associated greenhouse gases (GHG) and other environmental emissions in Thailand. It presents a current overview of energy and environmental trends and climate-friendly policies in Thailand. It then analyzes specific issues such as GHG emission reduction targets and their co-benefits; promotion of biofuels in the transport sector; multi-gas emissions; and energy development and environmental emissions under different socioeconomic scenarios. The book also includes an analysis of the economy-wide effects of low carbon measures with emission trading, carbon capture and storage technology during 2005 - 2050. Most of the analyses use a long-term energy system model of Thailand (i.e., Thailand AIM/Enduse model), whereas two chapters utilize a MARKAL based energy system model and AIM/CGE model.

This book will be of interest to policy makers, researchers and other individuals or organizations involved in energy, environmental and climate change policy issues in developing countries in general and Thailand in particular.

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