A DESIGN OF LOW CARBON DEVELOPMENT ACTION TOWARDS 2050 IN CAMBODIA

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A thesis submitted in partial fulfillment for the degree of
Doctor of Engineering in the
Department of Environmental Engineering
Graduate School of Engineering
Kyoto University

2015

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Cambodia has made all of her utmost effort to develop the national economy to be recognized as one of the most rapid economic growth countries among the developing world. The Government has set the target to shift to an upper-middle income country by 2030 and a high-income level by 2050. With the projected increase of energy demand, the Government set two main energy development targets -- the first is to achieve the 100% level of village electrification by 2020, while the second is to achieve 70% level of household electrification by 2030. The forest cover had decreased from around 73% in 1960 to 57% in 2010, which was below the target to maintain the forest cover of 60% by 2015. The Government is implementing the National Forest Programme (2010-2029) in order to ensure sustainable forest protection and management and to increase forest cover accordingly. Cambodia's GHG emissions are regionally and globally insignificant; however, Cambodia has an obligation to voluntarily join with the world to stabilize the GHG concentration into the atmosphere with her own capacity and affordability. This study proposed a scenario to design a low carbon development action towards 2050 in Cambodia, focused on energy and Agriculture, Forestry and other Land-Use (AFOLU) policies. Two quantitative models are applied including, the Extended Snapshot (ExSS) tool and the AFOLU Bottom-up (AFOLU-B) model. The first estimates socioeconomic activity level, energy demand, CO_2 emissions and reduction potentials through low-carbon measures in the energy sector, while the latter estimates GHG emissions and reduction potentials based on assumed socioeconomic indicators and on ongoing policies from the AFOLU sector through taking several constraints under mitigation measures and costs into account.

In the energy sector, CO_2 emissions are projected to increase to about 23,277ktCO_2/year and 91,327ktCO_2/year, about 6 times and 22 times in 2030BaU and 2050BaU, respectively, compared to around 4,221ktCO_2/year in 2010. Under low carbon measures, CO_2 emissions are expected to reduce by about 12,826ktCO_2/year and 52,153ktCO_2/year in 2030CM and 2050CM, respectively. About 68% and 77% of total CO_2 emissions reduction can be achieved by improving energy efficiency in 2030CM and 2050CM, respectively. About 14% and 6% in 2030CM and 2050CM, respectively, can be achieved by adopting a modal shift, while energy saving behavior and conservation is expected to reduce CO_2 emissions of around 12% and 9% in 2030CM and 2050CM, respectively.

In the AFOLU sector, GHG emissions are projected to change from a net carbon sink of approximately 940ktCO_2eq./year and 8,764ktCO_2eq./year in 2010 and 2030BaU, respectively, to a net emitter of around 13,982ktCO_2eq./year in 2050BaU. Under low carbon measures, total GHG emissions of approximately 24,461ktCO_2eq./year and 29,435ktCO_2eq./year in 2030CM and 2050CM, respectively, are expected to reduce. In the agricultural sector, about 64% and 70% of total GHG emissions are expected to reduce in 2030CM and 2050CM, respectively, and they are applied with the cost of less than 10USD/tCO_2, while in the Land Use, Land Use Change and Forestry (LULUCF) sector, the most plausible mitigation measures are applied with the cost of less than 50USD/tCO_2 and around 36% and 30% of total GHG emissions are expected to reduce in 2030CM and 2050CM, respectively.

Furthermore, total GHG emissions in Cambodia in energy and AFOLU sectors are projected to increase from around 3,281ktCO_2eq./year in 2010 to 14,514ktCO_2eq./year (around 4 times) and 105,307ktCO_2eq./year (around 32 times) in 2030BaU and 2050BaU, respectively. Under low carbon measures, GHG emissions of about 37,287ktCO_2eq./year and 81,588ktCO_2eq./year are expected to reduce in 2030CM and 2050CM, respectively. GHG emissions per capita are projected to increase from 0.24tCO_2eq./year in 2010 to 0.79tCO_2eq./year and 4.79tCO_2eq./year in 2030BaU and 2050BaU, respectively; however, they are expected to decrease to a negative value of around -1.24tCO_2eq./year in 2030CM and to 1.08tCO_2eq./year in 2050CM. In order to reach the GHG emissions reduction goal, this study proposed eight low carbon development strategies towards 2050.

The effective implementation of these strategies, Cambodia is expected to become a net carbon sink, offsetting about 22,774ktCO_2eq./year in 2030CM, while about 77% of total GHG emissions are expected to reduce in 2050CM. The strategy on green agriculture management and sustainable forest management are expected to attribute to the largest share of total GHG emissions reduction (about 38% and 24%) in 2030CM, respectively, followed by green transportation (about 13%). However, green transportation and green agriculture management attribute to the biggest share of GHG emissions reduction of about 31% and 22% in 2050CM, respectively, followed by green energy (around 21%).

In order to ensure the effective implementation of these strategies, the country has to make sure sufficient financial resources and human capacity. Besides, the participation and cooperation from different stakeholders is a must. Furthermore, the establishment of a low-carbon research network is another impetus to help bridge the gap between researchers and decision-makers on the low carbon development through making a mutual and cordial dialogue. Given the limited research on climate change mitigation in Cambodia, the results of this study are expected to be used to formulate a concrete and feasible climate change mitigation and low carbon development policy in the future.

ABBREVIATIONS

ADB	Asian Development Bank
AFOLU	Agriculture, Forestry and Other Land-Use
AFOLU-A	Agriculture, Forestry and Other Land-Use Activity Model
AFOLU-B	Agriculture, Forestry and Other Land-Use Bottom-up Model
AG	AGriculture
AGF	AGro-Forestry
ASEANs	Association of Southeast Asian Nations
BAU	Business as Usual
CM	CounterMeasure
CMDGs	Cambodia Millennium Development Goals
CCCSP	Cambodia Climate Change Strategic Plan
CFSP	Cambodia Fuelwood Saving Project
CDM	Clean Development Mechanism
CCTT	Climate Change Technical Team
CO_2	Carbon Dioxide
CHP	Combined Heat and Power Plants
CH_4	Methane
DNA	Designated National Authority
EAC	Electricity Authority of Cambodia
ExSS	Extended Snap Shot
EDC	Electricite Du Cambodge (Electricity of Cambodia)
EU	European Union
ESVG	Energy Service Demand Per Driving Force
ELCs	Economic Land Concessions
FA	Forestry Administration
FTD	Freight Transportation Demand
FTG	Freight Transportation Generation
FTS	Freight Transportation Share (Modal share)
FTAD	Freight Transportation Average Distance
FTM	Freight Transportation Mode
GAMS	General Algebraic Modelling System
GDP	Gross Domestic Product
GG	Green Growth

GHG	Green House Gas
GMS	Greater Mekong Sub-region
HFO	Heavy Fuel Oil
HH	HouseHold
IEA	International Energy Agency
IGES	Institute for Global Environmental Strategies
INC	Initial National Communication
IO Table	Input-Output Table
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producers
IUCN	International Union for Conservation of Nature and Natural Resources
JICA	Japan International Cooperation Agency
LCS	Low Carbon Society
LCD	Low Carbon Development
LoCAR-Net	Low Carbon Research Network
LULUCF	Land Use, Land-Use Change and Forestry
LUCF	Land Use Change and Forestry
MAFF	Ministry of Agriculture, Forestry and Fisheries
MIME	Ministry of Industry, Mines, and Energy
MME	Ministry of Mines and Energy
MPWT	Ministry of Public Works and Transport
MoE	Ministry of Environment
MoP	Ministry of Planning
MoT	Ministry of Tourism
MLMUPC	Ministry of Land Management Urban Planning and Construction
MoU	Memorandum of Understanding
NAPA	National Adaptation Programme of Action
NEEPSAP	National Energy Efficiency Policy, Strategy and Action Plan
NFP	National Forest Programme
NGL	Natural Gas Liquids
NBP	National Bio-digester Programme
NIES	National Institute for Environmental Studies
NIS	National Institute of Statistics
NGOs	Non-Governmental Organizations
NCCC	National Climate Change Committee

NSDP	National Strategic Development Plan
N_2O	Nitrous Oxide
NPRD	National Programme to Rehabilitate and Develop Cambodia
NPRS	National Poverty Reduction Strategy
NTFP	Non-Timber Forest Product
PAs	Protected Areas
PD	Output by Industry
PFE	Permanent Forest Estate
POP	Population
PPP	Purchasing Power Parity
PASS.KM	PASSenger KiloMeter
PTD	Passenger Transportation Demand
PTG	Passenger Transportation Generation
PTS	Passenger Transportation Share (Modal share)
PTAD	Passenger Transportation Average Distance
PTM	Passenger Transportation Mode
RGC	Royal Government of Cambodia
REDD	Reduce Emission from Deforestation and Forest Degradation
RIL	Reduced Impact Logging
RFS	Reforestation-Fast Growing Species
SNEC	Supreme National Economic Council
SAGE	System for the Analysis of Global Energy Market
SMEs	Small and Medium Enterprises
SNC	Second National Communication
SOB	Strategic Objective
SSCA	State Secretariat of Civil Aviation of Cambodia
SEDP	Socio-Economic Development Plan
TPES	Total Primary Energy Supply
TFC	Total Final Consumption
TV	Television
TWG	Technical Working Group
UK	United Kingdom
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
USAID	United States Agency for International Development

USA	United States of America
U.S.EPA	United States Environmental Protection Agency
USD	United States Dollar
UNFCCC	United Nations Framework Convention on Climate Change
VERs	Voluntary Emission Reductions
WB	World Bank

UNIT:

GWh	Gigawatt Hour
Gg	Gigagram
$GtCO_2$	Gigatonne of Carbon Dioxide
ha	Hectare
kgoe	Kilogram of Oil Equivalent
kWh	Kilowatt hour
$ktCO_2$	Kilotonne of Carbon Dioxide
$ktCO_2$eq.	Kilotonne of Carbon Dioxide Equivalent
ktoe	Kilotonne of Oil Equivalent
KM	Kilometer
Mtoe	Megatonne of Oil Equivalent
MWh	Megawatt-hour
T	Tonne
GWh	10^3 MWh
MWh	10^3 KWh
Gg	10^9 Grams
Gg	10^3 t
Mtoe	10^3 ktoe
ktoe	10^3 toe
toe	10^3 Kgoe
$GtCO_2$	10^3 $MtCO_2$
$MtCO_2$	10^3 $ktCO_2$
$ktCO_2$	10^3 tCO_2
tCO_2	10^3 $kgCO_2$
$KgCO_2$	10^3 gCO_2

CHAPTER 1 INTRODUCTION

1.1 Country background and problem statement

Cambodia is an agricultural country, occupying 181,035km^2 and shares her 2,428km land border with Thailand to the northwest, Lao PDR to the northeast and Vietnam to the east and the south (see Figure 1.1). The country has the coastline of 435km along the Gulf of Thailand. The country is influenced by the tropical monsoons with distinct rainy and dry seasons. The rainy season extends from May to October, while the dry season starts from November to April. The average annual rainfall is about 1,400mm on the central plain and increases to as much as 3,800mm in the mountains and along the coast. The average annual temperature is about 27°C with the maximum mean temperature of about 28°C and the minimum mean temperature of about 22°C.

Figure 1.1: Map of Cambodia

The Cambodian population had increased from about 11.44 million in 1998 to about 13.95 million in 2010 (NIS, 2012) and increased to about 14.70 million in 2013 (RGC, 2014). The total number of households had increased from about 2.16 million in 1998 to about 2.92 million in 2010 in which the urban areas were about 0.55 million, while the rural areas were around 2.37 million (NIS, 2012). The population dominated by Khmer (90.0%), Chinese and Vietnamese (5.0% of each), small numbers of Chams, Burmese and hill tribes. The predominant religion is Theravada Buddhism, virtually all Khmers are Buddhists.

The Royal Government of Cambodia (RGC) has made an utmost effort to rebuild the society, economy and infrastructure and subsequently open a market framework and the country is gradually advancing the economic development and social stability. Cambodia has seen the agricultural sector as one of the crucial parts for the national economy and this sector had sustained a strong annual growth of about 4.6% over the last decade (Vuthy *et al*., 2014). It was observed that GDP per capita exceeded 1,000 USD in 2013 (RGC, 2014). In this regard, the country might be moving out of the least-developed country status in the near future. Similarly, it was recorded that energy demand had increased dramatically whereby the annual per capita energy consumption increased from 54kWh in 2005 to 268kWh in 2013. At the time of enjoying the economic growth, Cambodia has severely affected by the adverse impacts of climate change. The country has witnessed floods and droughts resulting in considerable economic losses, infrastructure damage and fatalities; for example, the natural disaster in 2011 resulted in economic losses about 4.3% of the total GDP (MoE, 2013).

The Government realized that addressing economic and social development by taking climate change into account will assist the country in reducing vulnerability to potential climate risks, improving air quality and mitigating GHG emissions. Having understood the necessity of climate change, the Government mainstreamed climate change into the National Strategic Development Plan (NSDP) Update (2009- 2013) aiming to build the capacity of the RGC's institutions and to develop a strategy dealing with the anticipated impacts of climate change, and strengthening disaster management capabilities. Based on this priority, the country approved the first ever climate change strategy namely Cambodia Climate Change Strategic Plan (CCCSP) (2014-2023) in 2013 with the goals to reduce vulnerability to climate change impacts, in particular the most vulnerable, and critical systems; to shift toward a green development path by promoting low-carbon development and technologies; and to promote public awareness and participation in climate change response actions. Furthermore, the NSDP (2014-2018) pointed out that managing environment and climate change has become another challenge for the sustainability of Cambodia's economic growth and social development (RGC, 2014). It also gives the priority on implementing the CCCSP in order to reduce the adverse impacts of climate change by strengthening the adaptation capacity and resiliency to climate change.

GHG emissions in Cambodia are currently extremely low compared to regional and global averages. The country was a net sink in 1994 with a net total carbon removal of around 5,142Gg of CO_2eq./year and became a net emitter in 2000 with total national GHG emissions of about 219Gg of CO_2eq./year (MoE, 2013a). It was indicated that due to the Government's commitment to robust the economic development to reach the advanced level, the energy sector is projected to contribute the highest share of GHG emissions in the long term, followed by the Agriculture, Forestry and Other Land-Use (AFOLU), which mainly result from the intensification of paddy rice cultivation, livestock production, fertilizer consumption and land use change. However, it is expected that the forestry sector will become a net carbon sink if the REDD-plus scheme can successfully and effectively be implemented.

As for GHG emissions reduction measures, the country has developed several policies and strategies related to climate change mitigation such as energy efficiency improvement and conservation, sustainable transportation, sustainable agricultural management, national forest programme, and livestock strategic plan, etc. Besides, a number of GHG mitigation projects and activities have been undertaking such as forest management and conservation through the implementation of community forestry, bio-digester programme, energy efficient cook stoves, energy efficiency improvement, transportation management (*e.g.* the introduction of public buses in Phnom Penh and electric vehicles for tourists in Siemreap), etc. On top of that, the Government has realized that Low-Carbon Development (LCD) is a very important approach in the context of not only for GHG emissions reduction, but also for sustaining the economic development and environmental sustainability. On this, the Government has conducted several capacity building training workshops on low carbon related matters and signed a few agreements such as the low emission development strategy and the low carbon growth partnership, etc. However, Cambodia has not formulated a clear direction or plan for an LCD in the country. It was noted that there are a number of studies and researches on climate change in Cambodia; however, they are mainly focused on climate change vulnerability assessments and adaptation measures; whereas, there is no study or research on climate change mitigation or low carbon growth.

As indicated above, there is a need to conduct a comprehensive research on the assessment of GHG emissions and reduction potentials and to develop a scenario for a systematic and quantitative design for an LCD in Cambodia. Therefore, this study will propose a scenario to design a low carbon development action towards 2050 in Cambodia, focused on energy and AFOLU policies. Two quantitative models are applied in this study including the Extended Snapshot (ExSS) tool and the AFOLU Bottom-up (AFOLU-B) model. The first estimates socio-economic activity levels, energy demand, CO_2 emissions and reduction potentials through low-carbon measures, while the latter estimates GHG emissions and mitigation potentials based on assumed socioeconomic indicators and on ongoing policies from the AFOLU sector through taking several constraints under mitigation measures and costs into account.

1.2 Objectives and scope of the study

In order to reflect the above-mentioned challenges in the problem statement, this study proposed six major objectives as follows:

1) To propose appropriate low carbon development strategies on energy and AFOLU policies for Cambodia;
2) To conduct a systematic and quantitative estimation of GHG emissions reduction of the proposed strategies by using quantitative methodologies;
3) To quantify the socioeconomic parameters and to project CO_2 emissions as well as to identify the appropriate reduction measures towards 2050 from the energy sector by using the ExSS tool;
4) To estimate GHG emissions and mitigation potentials based on the assumed socioeconomic indicators and on ongoing policies by using the AFOLU-B model;
5) To initiate, coordinate, and enhance communication and dialogue among policy-makers, researchers, academia, and the public on climate change mitigation and low-carbon development; and
6) To encourage the translation of the proposed strategies into the real implementation in Cambodia.

This study focuses on:

1) A design of the low carbon development action in Cambodia, focused mainly on energy and AFOLU policies. Two scenarios are carried out, business as usual (BaU) and countermeasure (CM), for GHG emissions and reduction potentials;
2) GHG emission sources of the energy sector cover residential, commercial, industrial, transportation, and power sectors, while the AFOLU sector is dominated by land use change, livestock requirement, harvested areas, and fertilizer consumption, etc.;
3) The target GHG emissions and reduction potentials are Carbon Dioxide (CO_2), Methane (CH_4), and Nitrous Oxide (N_2O). The energy sector considered only CO_2 emissions, while the AFOLU sector covered all GHG emissions; and
4) Year 2010 is set as the base year, 2030 as the intermediate target year, and 2050 as the final target year for GHG emissions and reduction potentials calculation.

1.3 Research framework

The holistic and sequential arrangement is made to acquire the above-mentioned objectives and scope of the study. The thesis covers six chapters as shown in Figure 1.2, while the detail descriptions of the organization are as follows:

Chapter 1 gives the overall background of the research and observes strengths and weaknesses of the current low carbon study and implementation plan so that we can identify and propose a study on the low carbon development action in Cambodia as well as figure out objectives and scope, and research framework accordingly.

Chapter 2 focuses on the overview of Cambodian situation related to the existing climate change mitigation strategies and policies and the current status of low carbon development. This chapter indicates how and to what extend Cambodia is implementing climate change mitigation related policies, strategies and activities and investigates the sectors of the economy which considered as the potential impacts of GHG emissions and mitigation.

Chapter 3 gives the overview of a quantitative tool used to quantify socioeconomic indicators and to estimate CO_2 emissions and reduction potentials of the energy sector. This chapter describes energy demand and CO_2 emissions as well as CO_2 emissions reduction potential under low carbon measures. In this chapter, I also discuss socioeconomic assumptions; such as economic growth, transportation demand, and energy demand to illustrate how the assumptions go in line with some other countries' experiences in Asian as well as the results of CO_2 emissions and reduction potentials by sectors and by categories of low carbon measures.

Chapter 4 gives the overview of a quantitative tool used to estimate GHG emissions and reduction potentials from the AFOLU sector based on the assumed socioeconomic indicators and on ongoing policies in the AFOLU sector. This chapter indicates the estimation of GHG emissions reduction potentials through taking several constraints such as mitigation measures and costs. In this chapter, the results of GHG emissions and reduction potentials are discussed by comparing to the Second National Communication (SNC).

Chapter 5 summarizes the results of GHG emissions and reduction potentials of energy and AFOLU sectors and illustrates the change of per capita GHG emissions based socioeconomic development. This chapter describes quantitative GHG emissions reduction potential based the proposed eight low carbon development strategies towards 2050 in Cambodia and identifies appropriate low carbon actions. Furthermore, this chapter illustrates a proposal for low carbon research network for Cambodia aiming to facilitate, enhance, and expand communication, cooperation, and participation from different stakeholders as well as to bridge the gap between researchers and decision-makers.

In the last chapter, **Chapter 6** concludes the above findings and proposes a recommendation for the Government and other stakeholders to improve data acquiring, management and accessibility as well as suggestion of more studies on climate change mitigation and low carbon development in Cambodia so that it can provide good insights for the Government to design climate change mitigation policies and the low carbon development plan.

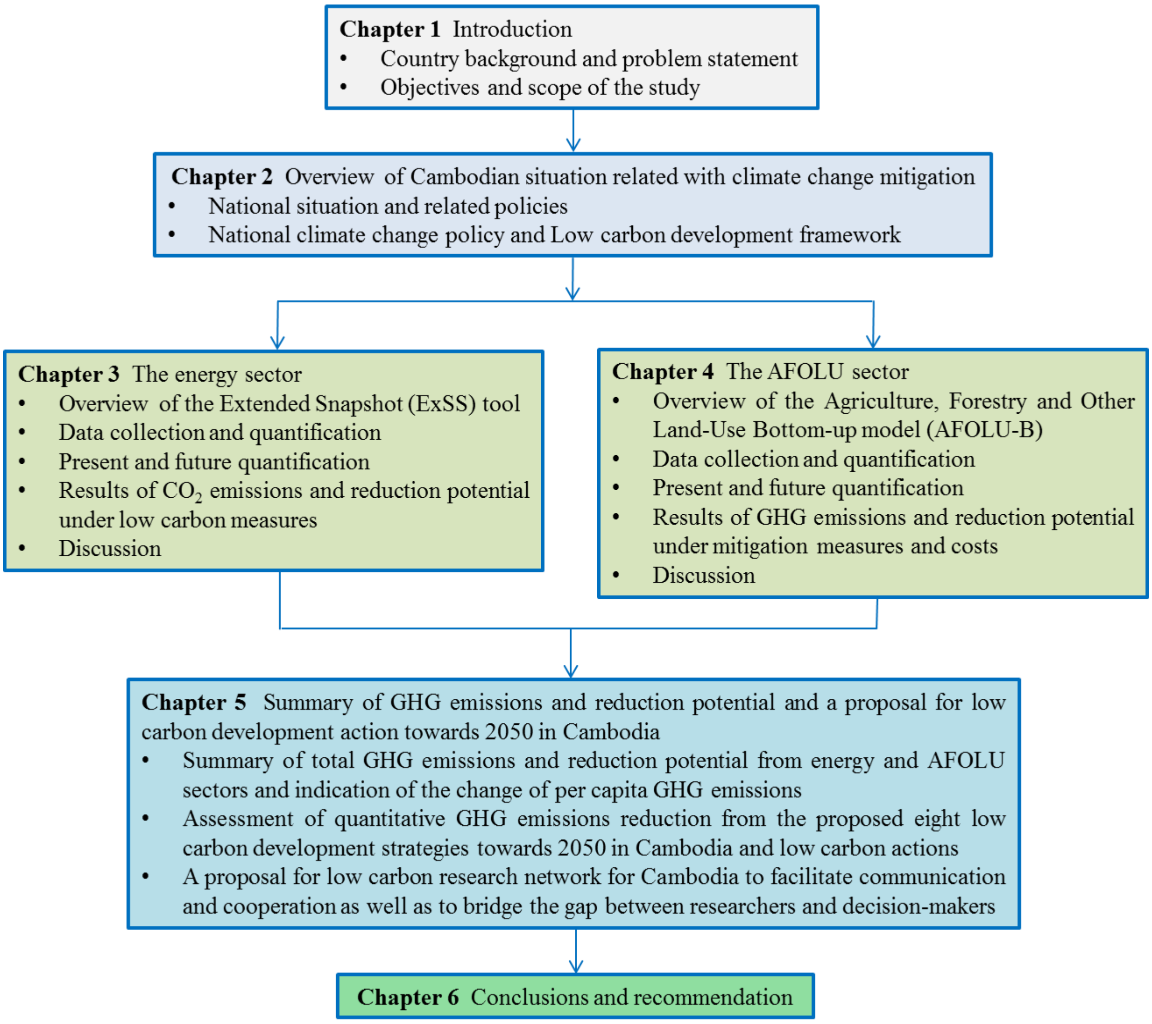

Figure 1.2: Structure of the research framework

CHAPTER 2 OVERVIEW OF CAMBODIAN SITUATION RELATED WITH CLIMATE CHANGE MITIGATION

2.1 Status of economic growth and development

After the full national reconciliation in 1999, the RGC set a **"Win-Win"** policy to unify all the national forces for socioeconomic rehabilitation and development where the priority policy was the **"War against Poverty"** (RGC, 2002). Furthermore, in order to sustain the socioeconomic growth and environmental sustainability, the Government has formulated the National Strategic Development Plan (NSDP), which focused on improving natural resources management, building peace, political and social stability, and promoting socioeconomic development (RGC, 2005, 2009 and 2014). Cambodia has made a great effort and stepped on the right tracks to restore and promote economic prosperity by moving from a night mare country to a rapid economic development one. As a result, Cambodia was ranked as one of the most rapid economic growth countries among the developing world (RGC, 2012).

Cambodia's economy relies on four main sectors: agriculture, industry, tourism, and construction. The highest contributor to the GDP was service (39.7%) with the tourism sector as the main contributor, followed by agriculture (29.6%) and industry, mainly contributed by the construction (23.9%) in 2010 (NIS, 2011). Although the industrial sector was smallest contributor for the GDP, it experienced the strongest average annual growth rate of around 13.6%, followed by agriculture (4.0%) and service (3.3%) during that year. Concerning the employment, the agricultural sector accounted for 54.2% of total workers, while industrial and service sectors provided 16.2% and 29.6%, respectively, in 2010 (NIS, 2012). Cambodia had experienced an average annual economic growth rate of around 7.7% from 1994 to 2011, while the GDP per capita had quadrupled, increasing from 216USD in 1992 to more than 1,000USD in 2013 and is expected to reach 1,579USD in 2018 (RGC, 2012 and 2014). Furthermore, several studies optimistically predicted that Cambodia's average annual GDP growth rate of around 7.0%, which will retain in years to come. JICA (2006) projected the average annual economic growth of around 7.0% towards 2020. And the Government recently set an economic development target to reach the status of an upper-middle income country by 2030 and a high-income level by 2050 (RGC, 2013). On this, the country must keep a strong and constant average annual economic growth rate of around 7.0% and this growth should be sustainable, inclusive, equitable and resilient to shocks through diversifying the economic base to achieve a more broad-based and competitive structure with low and manageable inflation, stable exchange rate and steady growth in international reserves.

The Government indicated that in any circumstances, the country still realizes that the stable and steady growth is largely attributed to the good performance of the agricultural sector coupled with other sectors. The Government, for instance, is increasing the value added in the agricultural sector, in particular through enhancing the value added of milled rice production and export as well as other high value agriculture products (RGC, 2013). Moreover, the country will promote the diversification of her secondary industrial base through encouraging investments in new high value added, more creative and competitive industries and expanding industrial development zones into the rural areas to boost economic growth, job creation, and the incomes of people. The Government will also upgrade the diversification of manufacturing base and promote further development of Small and Medium Enterprises (SMEs).

2.2 Agriculture and its policy

Most Cambodian households are depending on agriculture and livestock, fisheries and Non-Timber Forest Product (NTFP) extraction for their livings. The increased agricultural productivity improves farmers' incomes, enhances consumption of high quality nutritious food and helps people escape from poverty (Vuthy *et al.*, 2014). It was also observed that the crop production growth over the last decade was driven largely by higher yields, which were attributable to the increased use of fertilizers, improved seeds and available irrigation systems. It was indicated that a 1.0% increase in fertilizer use could increase wet season rice yield by 0.1% and dry season rice yield by 0.2% (Yu and Fan, 2009). However, the use of chemical fertilizer in Cambodia was still much lower than some countries in Southeast Asian Nations (ASEANs) (Yu and Diao, 2011) and the intensification of rice cultivation is needed to increase agricultural output to meet the accelerating food demand by increasing the efficient application of appropriate fertilizers (Yu and Fan, 2009).

The Government shaped its policy toward enhancing rice production through developing a policy paper on the Promotion of Paddy Production and Rice Export with a vision to transform Cambodia into a **"rice basket"** and a key milled rice exporting country in the global market and set a target to export of at least one million ton of milled rice by 2015 (RGC, 2010). Therefore, there is a need to transform the traditional agricultural practice into a modern and diversified one in order to increase rice production. The Government has also improved other crop productions such as corn, cassava, mung bean, and soy bean, etc. for feeds, food and processing. Livestock is also a key part of rural livelihoods and sources of incomes and food (RGC, 2013). Since the launch of the rice policy, milled rice exports have grown at a rapid pace, boasting a tenfold increase to 200,000 tons in 2012; however, this goal might not be reached due to constraints in the rice sector such as primary farm production, post-harvest handling and processing, export logistics, and physical infrastructure (Vuthy *et al*., 2014).

The Government has paid further attention to increase agriculture production by shifting from the extension of cultivated areas to intensive farming on the existing land (Jeremy and Rebeca, 2010). And it is expected to achieve through an integrated approach including the proper use of improved agricultural inputs, agricultural extension, research and development, construction and maintenance of the rural infrastructure, especially irrigation network, expansion of rural credit and microfinance, agricultural market development, organization of farmer communities and better management of the agricultural land. The Government has put more focus on rehabilitating existing and constructing more irrigation networks to solve the water needs of the agricultural sector. In fact, the capacity of water reservoirs has been expanded and the ability to provide water for cultivation has increased (RGC, 2014).

2.3 Land use and its policy

The RGC holds about 14.5 million hectares (around 80% of the total land area) as **"state land"**, while around 3.6 million hectares (20%) are owned by private entities (RGC, 2012 and USAID, 2011). Cambodia has faced strong and chronological land disputes due to the lack of land use planning and the application of relevant policies and procedures is not sufficient for the effective land use management. Cambodia developed a Land Law in 2001, aiming to establish a national system of land classification and land ownership rights and set provisions on social and economic land concessions (ELCs), which refers to a mechanism to grant private state land through a specific economic land concession contract to a concessionaire to use for agricultural and industrial-agricultural exploitation (RGC, 2005), indigenous land rights, land registration, and land dispute resolution. The law distinguished between the state land in the public domain, such as forests and protected areas (PAs), and the state land in the private domain, which is used to provide land for economic and social development (RGC, 2001). The law stipulated that the granting of concessions in several locations, jointly exceeding the 10 thousand hectares, for the same person(s) or different legal entities controlled by the same person(s) is prohibited.

The Sub-degree on ELCs was approved in 2005 with the objective to grant private state land through a specific and long-term ELC contract to use for agriculture and industrial development such as cultivation of food crops or industrial crops, raising animals and aquaculture, and construction such as plants or factories (RGC, 2005). The ELCs would help increase employment in the rural areas within the framework of intensification and diversification of livelihood opportunities and to generate state revenues through economic land use fees, taxation and related services charges. It was reported that RGC provided around two million hectares of degraded forest land for ELCs to some private companies to cultivate agro-industries; among them, the MAFF granted around 1.3 million hectares within forest concession areas (MAFF, 2013) and around 0.7 million hectares granted by the MoE within the PAs, which is named sustainable economic development zones (Mareth, 2014).

The Government also declared that the land reform is a crucial tool to increase agricultural production by providing titles and security of land tenure to the poor. The land reform is vital to enhance social stability, development of an efficient land market, and environmental sustainability. The Government developed land policy in 2009 with the objective to strengthen land tenure security and land markets, and prevent or resolve land disputes, manage land and natural resources in an equitable, sustainable and efficient manner, and promote land distribution with equity. The RGC has issued more than 3 million land titles to Cambodian people, and granted social land concessions to 31,000 families of the poor, soldiers, and veterans (RGC, 2013). It has also provided the allocated land to about 500,000 families under the **"Old Policy-New Action"** framework (RGC, 2013).

2.4 Forestry and its policy

The RGC considers the ecologically, socially and economically viable conservation and management of forest resources as a major pillar of public welfare directly contributing to environmental protection, poverty reduction and socioeconomic development. Cambodia's forest has declined in recent decades due to logging, forest fires, land-grabbing (the contentious issue of large-scale land acquisitions, either buying or leasing), encroachment (unlawful entering, gradually and without permission, into the forest land) and intensified shifting cultivation. A logging concession system was introduced between 1994 and 1997 and the Government granted 36 forest concessions covering around 7 million hectares (70.0% of forest areas) (according to Cambodia's National Forest Progamme Background Document). Destructive, legal and illegal logging and over-capacity of processing facilities, combined with weak law enforcement and monitoring, jeopardized attempts toward sustainable forest management (ITTO, 2005). Besides, Mangroves have also been destroyed by urbanization, resort development or expansion of aquaculture, while the inundated forest around Tonle Sap Lake has been severely damaged by agricultural expansion and wood cutting for consumption. It was emphasized that the increasing population, high rates of internal migration and rural poverty are the key factors. Forest resources accounted for, on average, 10-20% of household consumption and income sources for around one third of Cambodians (Turton, 2004). Forest resources have been extracted for firewood and charcoal, which are the main sources of energy for households and many SMEs such as palm sugar producers, noodle factories, brick and tile industries.

To reverse the trend of forest degradation, a logging moratorium, which was a circulation issued by the Government to suspend granting forest concession to concession companies for timber export purpose, was introduced in 2002. Besides, an institutional reform was also initiated with a forest policy statement and a new forestry law. The Forestry Law was passed in 2002 stipulating that the Permanent Forest Estate (PFE) has to be managed in a sustainable way in order to maximize the social, economic and environmental benefits and cultural values. It was observed that illegal logging and other human pressures on forest resources have noticeably decreased or stopped in many areas after the law came into force. There are two main Government institutions which manage forest resources including the MoE and the MAFF. The first is managing the 23 PAs, which were declared by the Royal Degree in 1993, while the latter is managing commercial and reproductive forests. In 2010, forest cover was about 57.1% of the total land area decreased from around 73.0% in 1960 (RGC, 2011), which was below the target of maintaining the forest cover of 60.0% by 2015 (the target set for Cambodia Millennium Development Goals (CMDGs)). And to meet the determined target, the Government is implementing measures to reinforce the protection and management of forest resources, to decrease the pressure on forests by improving farming techniques, to reduce dependence on fuel-wood, and to engage in an active programme of forest rehabilitation and reforestation.

The RGC has issued a number of policies, orders and proclamations in order to eliminate the forest anarchy and to move toward sustainable forest management and one approach for achieving a sustainable forestry sector was community forestry management (RGC, 2009). The Government has also embedded reform of the forestry sector into the NSDP and some other Government's strategies. In this regard, the Forestry Administration (FA) of the MAFF has a strong commitment to implement the Forestry Law, relevant regulations, policy frameworks and other related Government orders and more specifically the National Forest Programme (NFP) (2010 to 2029) (RGC, 2011). The main activity under the NFP is the implementation of REDD-plus scheme (reducing emissions from deforestation and forest degradation, forest conservation, sustainable forest management, and enhancement of carbon sinks) (Ty *et al*., 2011). In fact, two REDD-plus projects have been piloting, one in Oddar Meanchey province was awarded Dual Gold Validation by the Climate, Community and Biodiversity Standard and the Verified Carbon Standard, while the other in Keo Seima Protected Forests, Mondulkiri province was prepared Project Design Document and submitted to a carbon standard for validation.

2.5 Energy and its policy

Cambodia's rapid economic growth was accompanied by a steady increase in energy demand, with peak demand rising by an annual average of over 20.0% between 2003 and 2008 (JICA, 2012). There is, thus, a clear need for the formulation and effective implementation of power development plan to cope with the growing energy demand. It was reported that only 29.7% of total households were connected with the national power grid in 2010, almost 100% of all households in the urban areas and around 12.3% of the rural households (MIME, 2010). It was indicated that the access to sustainable energy service was included in the CMDGs and the NSDP and it has been seen as an important element to reduce fuel-wood dependency and poverty.

The electricity sent-out by the Independent Power Producers (IPP), Electricity of Cambodia (EDC), and Consolidated Licensees comprised 93.0% of diesel/HFO (heavy fuel oil), 3.0% of hydropower, 3.0% of coal, and 1.0% of biomass in 2010 (EAC, 2010). Due to the increase of energy demand, energy imports were almost trebled from 2008 to 2010 and in 2011, 45.0% of total national electricity demand was imported from

Thailand, Vietnam and Lao PDR. Per capita consumption of electricity had increased from 15Kwhs/year in 1993 to 268Kwhs/year in 2013 (RGC, 2014). Cambodia adopted the "Law on Electricity" in 2000, which covered all activities related to the supply, provision of services and use of electricity, and other associated activities of the power sector. The law helps reform the current electricity sector, and was endorsed to boost private investors in the power sector in a fair, just, and efficient manner for the benefit of the Cambodian society. Besides, the RGC also specified the development of the energy sector in the NSDP with the prioritized aims of increasing electricity supply capacity and reducing tariff rates to an appropriate level, while strengthening institutional mechanism and management capacity. Hydropower is a cornerstone of Cambodia's energy policy with potential capacities of more than 10,000MW. The use of solar power in the country was very low with total installed capacity between 1997 and 2002 of 205kW and reached over 300kW in 2004. The dependence on firewood had been reduced by 12.0% from 1998 to 2010 (from 90.4 % in 1998 to 79.5% in 2010); however, it remains far from the 52.0% target for 2015 (RGC, 2012).

To meet the increasing energy demand, the Government set two main energy development targets --the first is to achieve the 100% level of village electrification (47.0% level as an intermediate target of household electrification) by 2020; and the second is to achieve 70.0% level of household electrification with grid quality electricity by 2030 (JICA, 2006). Moreover, the Government disclosed that the fuel mix of power generation in 2030 will comprise natural gas (40.0%), hydropower (35.0%), coal (15.0%), import (6.0%), oil (3.0%), and renewable energy (1.0%) (MME, 2014). Besides, the Government identified the best alternative options to introduce more constant, reliable, and affordable sources of energy where hydropower is prioritized after natural gas. And the RGC strongly confirmed the country's available capacity and facilities to build hydropower dams. Table 2.1 shows the detail list of power development plan in Cambodia, including coal power plants.

It has been investigated that in order to reduce energy demand and CO_2 emissions in the future and simultaneously to provide reliable and affordable energy services to all of the end users in the most sustainable manner, the Government declared a circular on the "Implementation of Electricity Saving Measures" that required all Government ministries and public institutions to participate in a programme on "Electricity Saving Consumption" in 2008 so as to save the national budget and to ensure the effective and efficient use of electricity. Moreover, the Government developed national policy, strategy and action plan (NEEPSAP) on energy efficiency in 2013, which covered five priority areas, including: Energy efficiency in industry, Energy efficiency of end-user products, Energy efficiency in buildings, Energy efficiency of rural electricity generation and distribution, and Efficient use of biomass resources for residential and industrial purposes (MME, 2013).

Table 2.1: Power development plan in Cambodia

No.	Generation Expansion Plan	Fuel	MW	Year
1	Kamchay Hydro Power Plant	Hydro	193.2	2011
2	200 MW Coal Power Plant (I) in Sihanouk Ville -Phase 1	Coal	100	2011
3	Kirirom III Hydro power Plant	Hydro	18	2012
4	Atay Hydro Power Plant	Hydro	110	2012
5	200 MW Coal Power Plant (I) in Sihanouk Ville -Phase 2	Coal	100	2012
6	Tatay Hydro Power Plant	Hydro	246	2013
7	Lower Stung Rusey Chhrum Hydro Power Plant	Hydro	338	2013
8	700 MW Coal Power Plant (II) in Sihanouk Ville -Phase 1	Coal	100	2013
9	700 MW Coal Power Plant (II) in Sihanouk Ville -Phase 2	Coal	100	2014
10	700 MW Coal Power Plant (II) in Sihanouk Ville -Phase 3	Coal	100	2015
11	700 MW Coal Power Plant (II) in Sihanouk Ville -Phase 4	Coal	100	2016
12	Lower Sesan II + Lower Srepok II	Hydro	400	2016
13	Stung Chay Areng Hydro Power Plant	Hydro	108	2017
14	700 MW Coal Power Plant (II) in Sihanouk Ville -Phase 5	Coal	100	2017
15	700 MW Coal Power Plant (II) in Sihanouk Ville -Phase 6	Coal	200	2018
16	Steung Treng Power Plant	Hydro	980	2018
17	Sambor Hydro Power Plant	Hydro	2600	2019
18	Coal Power Plant (III) or Gas Power Plant	Coal/NG	450	2020

2.6 Transportation and its policy

Cambodia's road infrastructure was almost completely destroyed after more than 20 years of civil strife and, it has recently been restored and built due to the essence of accelerating the economic development and transportation demand. There are four types of transportation mode including, road (80.0%), rail (1.0%), maritime (15.0%), and aviation (4.0%) (MPWT, 2013). It has been noted that the rapid urbanization presents tremendous challenges to the transportation systems; both the capital and urban areas are experiencing serious problems caused by inadequate transportation facilities and management system set against the rapid growth of population and socioeconomic activities. Many cities are enlarging the capacity of the road network, but often at the expense of the safety of the vulnerable road users. Many people died and injured in road crashes, causing social, economic, and health consequences.

The rail transportation sector in Cambodia was destroyed during the civil war of the 1970s, and now requires the replacement. Once they are re-functioning, both of Cambodia's rail lines are expected to become part of the GMS southern economic corridor and help Cambodia become more competitive by offering faster and less expensive transportation. The passenger train service ceased to operate since 2009, while freight service had begun to decrease after reaching 557,000 tons in 2002 and currently only Southern Line remains in service and it carried only cement with the cargo volume of 3,000 tons (36,000 (tons.km)/year) in 2010 (MPWT, 2010 and 2012). The rail transportation mode is expected to grow by 7.0-12.0% per year by 2030, with a projected increase in locomotives (ADB, 2011).

Inland waterway also plays very important role for both passenger and freight demand. It has a total navigable length of 1,750km of which only 580km are navigable all year round. The Mekong River accounts for about 30.0% of the length of navigable inland waterways, Tonle Sap 15.0%, Tonle Bassac 5.0% and the remaining waterways 50.0%. The inland waterway has declined in recent years as cargoes were switched to road transportation. However, it is expected to increase in the future due to the waterway improvements, including dredging to maintain the navigable length and providing safety markers. Regarding the air transportation mode, the State Secretariat of Civil Aviation of Cambodia (SSCA) undertook the operational management of Phnom Penh International Airport since 1995, Siem Reap International Airport since 2001, and Preah Sihanouk Airport since 2006. Since the Government policy to attract seven million foreign tourists annually by 2020 (MoT, 2012), Cambodia will improve international airports and rehabilitate the local ones located in several provinces to support the eco-tourism.

At the time of the increasing traffic demand, the RGC does not ignore environmental stresses, and the strategy on Environmental Sustainable Transportation Development was formulated to ensure stable economic growth and environmental sustainability. The strategy focused on the establishment of transportation networks in accordance with land use planning; the introduction of a modern public transportation system to respond to future traffic demand; the development of efficient, comfortable, and safe transportation system to reduce traffic congestion; and the establishment of an efficient traffic control system with the provision of traffic signals in urbanized areas to reduce traffic accidents and congestion through effective traffic law enforcement.

2.7 National climate change policy

Climate change has become one of the greatest risks facing humanity and a high priority of global concern in the 21st century. As the earth continues to heat up, the severity of climate change impacts on global socioeconomic development and environmental sustainability continue to intensify and amplify, prompting the need to seek urgent solutions. A recent assessment report discovered that warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of Greenhouse Gases (GHGs) have increased (IPCC, 2013). Among the total world GHG emissions of 49GtCO_2eq./year in 2010, the energy sector contributed by 35.0%, the AFOLU sector by 24.0%, industry by 21.0%, transportation by 14.0%, and buildings by 6.4%. The report suggested that the anthropogenic GHG emissions from the AFOLU sector, which attributed mainly from deforestation and agricultural emissions from livestock, soil and nutrient management had decreased from 31.0% in 2004 to 24.0% in 2010 (IPCC, 2007 and Smith *et al.*, 2014). Even so, the total amount of GHG emissions from this sector remained similar and the share to the world emissions had decreased largely due to increases in emissions in the energy sector.

It was also observed that Southeast Asia has faced increasing threats from climate change, with increasing loss of human lives and significant damage to economic development and natural resources. We have all observed the alarming trends of more frequent and intensified floods, droughts, saline intrusion and extreme weather events, especially over the last decades. As for Cambodia, it was observed that the temperature has increased and this trend is predicted to continue with mean temperatures increase by 2099 from between 0.013^{o}C to 0.036^{o}C per year (MoE, 2013a). In terms of GHG emissions, Cambodia is regionally and globally insignificant with emissions per capita of 0.23tCO_2/year in 2000. The highest contributor was Land Use Change and Forestry (LUCF), which accounted for 51.0%, followed by agriculture 45.0%, energy (4.0%), and waste (less than 1.0%). However, the country had changed from a net carbon sink in 1994 to a net emitter in 2000 and it continues to increase in the future.

Climate change mitigation is a human intervention to reduce the sources or enhance the sinks of GHGs. There is a need to stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, and such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner (IPCC, 2014). Additionally, the Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities (Article 3 of the UNFCCC) (UN, 1992).

Cambodia is aware that climate change is caused by intensive human industrial activities and past unsustainable economic development. The country has witnessed floods and droughts resulting in considerable economic losses, infrastructure damages and fatalities. And to address this catastrophe, Cambodia is working very closely and actively with the world community by ratifying the UNFCCC on 18 December 1995 and acceding to the Kyoto Protocol on 04 July 2002. In 2006, Cambodia developed the National Adaptation Programme of Action (NAPA) by proposing 39 adaptation projects, including agriculture development, water supply, irrigation, health care, fighting malaria, malaria education, agro-forestry development, and coastal zones. Cambodia has established the National Climate Change Committee (NCCC) as the policy and decision making body with the mandate to prepare, coordinate, and monitor the implementation of policies, strategies, legal instruments, plans and programmes to address climate change issues. The NCCC is chaired by the Minister of the Environment and honorary chair by the Prime Minister. Besides, a Climate Change Technical Team (CCTT) was established as an inter-ministerial body to provide technical support to the NCCC in fulfilling its mandate. The MoE was appointed as the national focal point for the UNFCCC and its Kyoto Protocol, and the secretariat for the Cambodian Designated National Authority (DNA) for the Clean Development Mechanism (CDM). Cambodia has approved 10 CDM projects, nine of which have been registered by the UN CDM Executive Board, and can reduce approximately two million tons of GHG emissions (MoE, 2013). In addition, Cambodia has put a strong commitment on managing forests under the REDD-plus scheme (Ty *et al.*, 2011).

Cambodia has mainstreamed climate change into the NSDP and other development activities. In addition, some local organizations have implemented voluntary carbon standards as viable alternatives to the CDM. There are two Voluntary Emission Reductions (VERs) projects, including National Bio-digester Programme (NBP) and Fuel-wood Saving Project (CFSP). The NBP covered 10,000 family-sized bio-digesters with the expected annual emissions reduction of around 59ktCO_2 eq./year, while the CFSP is working on the improvement of cook stoves that consumed about 20.0% less charcoal than traditional ones, and could reduce GHG emissions by about 160ktCO_2eq./year over the period of 2003-2012 (RGC, 2013a). In addition, Cambodia launched National Strategic Plan on Green Growth (2013-2030) in March 2013 aiming to promote national economy with growth stability, reduction and prevention of environmental pollution, safe ecosystem, poverty reduction, and promotion of public health service, educational quality, natural resource management, sustainable land use, and water resource management to increase energy efficiency, ensuring food safety and glorifying the national culture (RGC, 2013b). Besides, in November 2013, the country launched Cambodia Climate Change Strategic Plan (CCCSP) (2014-2023) (MoE, 2013), covering 8 strategic objectives (SOBs), including:

(1) SOB-1: Promote climate resilience through improving food, water and energy security;
(2) SOB-2: Reduce sectoral, regional, gender vulnerability and health risks to climate change impacts;
(3) SOB-3: Ensure climate resilience of critical ecosystems (Tonle Sap Lake, Mekong River, coastal ecosystems, highlands, etc.), biodiversity, protected areas, and cultural heritage sites;
(4) SOB-4: Promote low-carbon planning and technologies to support sustainable development;
(5) SOB-5: Improve capacities, knowledge, and awareness for climate change responses;
(6) SOB-6: Promote adaptive social protection and participatory approaches in reducing loss and damage due to climate change;
(7) SOB-7: Strengthen institutions and coordination frameworks for national climate change responses; and
(8) SOB-8: Strengthen collaboration and active participation in regional and global climate change processes.

It can be noted that the SOB-4 indicated the Government effort to apply the low carbon development plan to achieve a sustainable development framework, which covered the following activities:

- Conducting sectoral analyses on low emission options and sources of emissions (in agriculture, land-use and forest management, energy, industry, and waste management);

- Preparing low-carbon development policies, legal frameworks, and action plans in conformity with national development priorities;
- Promoting an appropriate technology transfer for low-carbon development (*e.g.* improving energy efficiency, renewable energy, etc.) and facilitating their diffusion through guidelines, technical assistance and establishment of partnerships, financial and fiscal incentives, carbon market mechanisms, and mobilizing public-private partnerships (PPP);
- Promoting low-carbon, climate-resilient city development planning and developing city level coordination mechanisms (*e.g.* capital and provincial effective mass transportation, modernization of wastewater treatment facility and landfill);
- Establishing a system of registration for GHG mitigation projects and programmes; and
- Establishing a high quality national system for GHG inventory.

2.8 Low carbon development framework in Cambodia

The LCD or Low Carbon Society (LCS) is no longer a new concept for Cambodia as it has born in this country for several years and this spirit will be captured to ensure a sound economic development with environmental sustainability. The initial concept of the LCS was introduced into Cambodia during the first workshop on the LCS in 2010 in Phnom Penh, Cambodia with the support from the Institute for Global Environmental Strategies (IGES). To enhance and expand the collaboration and cooperation on this matter, IGES awarded a short-term LCS related training programme to an officer of the MoE in the following year. Having realized the importance of the LCS and to sustain the research network in Cambodia, a proposed Low Carbon Research Network (LoCAR-Net) was raised. This network provides substantial advantages for data collection and discussion and helps distribute LCS related activities and brings together different key stakeholders.

The LCD refers to the development of an economy, which has a minimal output of GHG emissions into the atmosphere. In Cambodia, LCD means not only to reduce GHG emissions, but also to ensure better resource efficient consumption and energy efficiency as well as to improve economic growth. The LCD implementation will significantly contribute to the achievement of the CMDGs and other Government's development plans; it has been considered as the important economic development tool for socioeconomic development. The RGC has mainstreamed the LCD concept into relevant Government institutions, academia, and research institutes as well as other key stakeholders through workshops and trainings. It was obviously proposed in the SOB-4 of the CCCSP (2014-2023) that is "to promote low-carbon planning and technologies to support sustainable development". Moreover, Cambodia signed a low carbon growth partnership with Japan in April 2014, aiming to ensure the achievement of sustainable development and to address climate change.

Cambodia is an energy poor country and uses little modern energy due to limited resources and energy technologies. The country needs to improve the energy consumption pattern by developing an energy system in an efficient and sustainable way to ensure sufficient energy distribution and simultaneously to reduce CO_2 emissions. The country also needs to improve the energy intensity status, promote end-use device efficiency, adopt some behavioral and consumption styles, and fuel switching from conventional to low-carbon energy. Cambodia requires developing a methodology for projecting the future scenario to achieve a sustainable and LCD. A possible low carbon development framework can be seen in Figure 2.1.

Renewable energy is considered as the best option to reduce CO_2 emissions. As for concrete low carbon measures, the Government considers hydropower as one of the main sources of energy supply in the future, not only from the point of meeting the increasing energy demand, but also toward the LCD. Another important option for LCD is an improvement of energy efficiency. On this, Cambodia developed national policy, strategy, and action plan on energy efficiency in 2013 to reduce energy demand and CO_2 emissions in the future and at the same time to provide reliable and affordable energy services to all of the end users in the most sustainable manner (MME, 2013). The Government also established a national transportation implementation plan in 2012 to address the issues through implementing vehicle inspection, regulation of second hand vehicles, eco-driving, road management, and infrastructure improvement (MPWT, 2013). The Government has also encouraged the use of public transportation system such as buses and trains, especially in the urban areas, with a low-cost and efficient service (RGC, 2014). The country also sees technology development, transfer, and diffusion as a necessary prerequisite for a meaningful response to climate change as well as to promote low carbon social and economic development (RGC, 2013a).

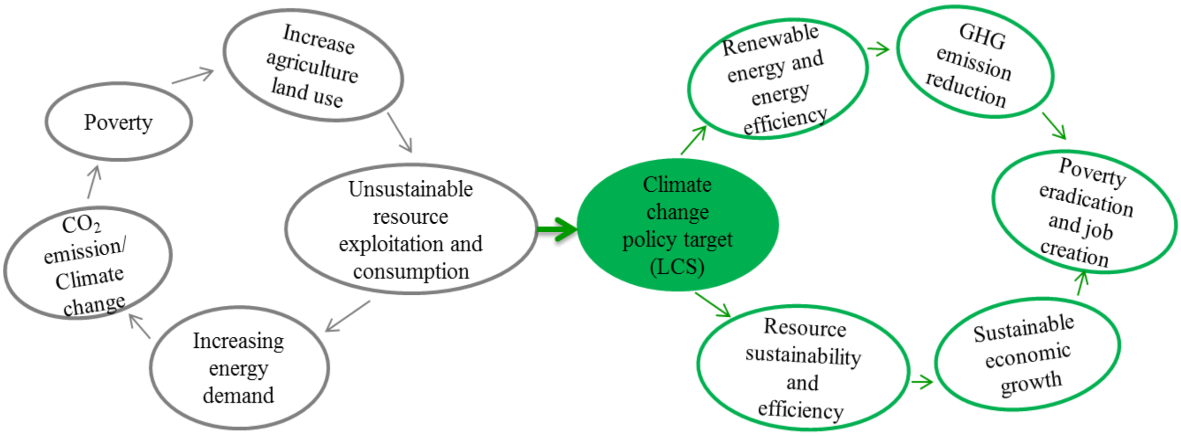

Figure 2.1: The shift from unsustainable development to a sustainable manner

CHAPTER 3 THE ENERGY SECTOR

3.1 Overview of the Extended Snapshot (ExSS) tool

The ExSS tool is a system of simultaneous equations. It is a designing tool of a future society rather than a projection or prediction of likely future. To formulate quantitative information about macro-socioeconomic and environmental variables for developing LCD scenario, the ExSS tool is applied (Figure 3.1).

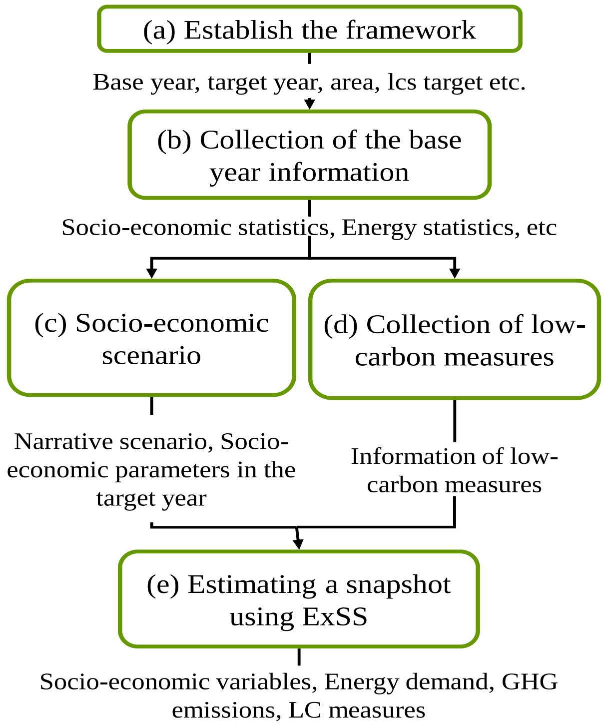

Figure 3.1: The procedure of the ExSS tool

Establish the framework

The framework of the whole LCD scenario is determined. It comprises the base year, target year, target activities, environmental targets and the number of scenarios, etc.

Collection of base year information:

Prior to performing quantitative estimation, a qualitative future image is described. It is an image about future lifestyle, economy, industry, land use, and so forth. Some of the below listed descriptions are the ways to describe the qualitative future image 1) a concept, a plan, or a target for each sector of the country, 2) listens to professionals or hold a workshop, etc., 3) extend or fix current trend, and 4) literature review about the future of a country. In consideration of an actual measure, it is necessary to choose a method of being more meaningful in the deployment of a subsequent policy. The assumption of society and economy is considered the "premise" of the LCD scenario.

Quantification of socioeconomic assumptions:

To estimate a future snapshot of a society based on the future image of the base year, values of exogenous variables and parameters are estimated. Using those inputs, the ExSS tool calculates socioeconomic indices of the target year such as composition of GDP, output by industry, transportation demand, and so forth (Table 3.1).

Table 3.1: Input parameters of socioeconomic assumption in the ExSS tool

Data	**Unit**
Demography	
Population by household type and age cohort	number
Persons per household by household type	number
Transportation demand	
Model share of passenger transportation	ratio
Average trip distance of passenger transportation	km
Trip per person per day	number
Freight generation per industrial output	monetary
Model share of freight transportation	ratio
Average distance of passenger transportation	km
Economy	
Final demand by final demand sector	monetary
Input coefficient	ratio
Import ratio	ratio
Energy demand	
Energy service demand per driving force	*
CO_2 emission factor	
CO_2 emission factor by primary fuel	tCO_2/toe

* Energy service demand per driving force, the unit depends on the service and sectors. Units of sector are number of household (residential), square km (commercial), monetary (industry)

Collection of low-carbon measures:

Measures considered feasible to be introduced by the target year are collected. They include high energy-efficiency devices, public transportation, the use of renewable energy, and energy saving behavior and conservation, and so on. Technical data are required to estimate their effect to reduce GHG emissions. Low carbon measures applied in this study are shown in Table 3.2, while lists of detail countermeasures with quantitative emissions reduction used in this study are shown in the Appendix 1.

Table 3.2: Lists of low carbon measures

Sectors	Low carbon measures
Residential	Energy efficiency improvement of electrical and non-electrical equipment (eg. Cook stoves, lighting, refrigerators, hot water, heating, other equipment), fuel switch, and energy saving behavior
Commercial	Efficiency improvement in electric devices (eg. Lighting, refrigerators, hot water, heating, other equipment), insulation buildings (passive house), and energy saving behavior
Industrial	Energy efficiency improvement (eg. Steam boilors, furnaces, motors, and other equipment), fuel switch, and energy saving technology
Transportation	Fuel efficient vehicles, fuel switch (eg. Gasoline to natural gas, electric and biofuel), and modal shift (eg. Private cars and motorbikes to buses and trains), and eco-driving
Power	Reduction of transmission loss, fuel efficiency improvement (oil, coal and gas), and fuel switch from non-renewable to renewable energy (solar/wind)

Setting introduction of measures by the target year:

Technological parameters related to energy demand and CO_2 emissions, energy efficiency, and so on are listed.

Estimating a snapshot using the ExSS tool:

Based on socioeconomic indices and assumptions of measures introduced, GHG emissions are calculated.

Proposal of policies:

Proposed policy sets to introduce the measures introduced. The selection of low carbon policies in this study was carried out in two stages. First, a list of low carbon policies was listed and discussed with some relevant senior officers and decision-makers in the country. Second, a workshop was organized to collect comments and inputs from the participants from Government's agencies and research institutes and academia to improve the proposed policies. The ExSS tool can show a reduction potential of each low-carbon measure as well as the decomposition of reduction factors. It can identify measures, which have high reduction potentials and important (Gomi and Fukuda, 2010).

3.2 Quantitative estimation tool "ExSS"

Figure 3.2 shows the structure of the ExSS tool with input parameters, exogenous variables and variables. The ExSS tool is formulated as a system of simultaneous equations. Given a set of exogenous variables and parameters, solution is uniquely defined. Only CO_2 emissions from energy consumption are calculated, even though the ExSS tool can be used to estimate other GHG emissions and environmental loads such as air pollution. To determine output of industries, input-output approach is applied. For the future estimation, the assumption of export value is especially important if the target region is thought to (or, desired to) develop some particular industries, such as automotive manufacturing or sightseeing.

Passenger transportation demand is estimated from the population and freight transportation demand is a function of output by manufacturing industries. Floor area of commerce is determined from the output of tertiary industries. Other than driving force, activity level of each sector, energy demand by fuels determined by three parameters. They are energy service demand per driving force, energy efficiency, and fuel share. Diffusion of countermeasures changes the value of these parameters, and so GHG emissions do.

Based on the prescribed changes in the population and the number of households, gross domestic production (GDP), industrial structure, employment, passenger and freight transportation demand, and energy consumption, the ExSS tool can project CO_2 emissions at present and in the future in a consistent way to assess the impact of low-carbon measures in Cambodia. Given the limited country information, additional calculations and assumptions were made to apply the model, for instance, estimation of the transportation demand and structural quantification of detailed energy demand, projection of demography and economy, and so on. The estimation and assumption based on available data, historical trend, and author's professional insight and also some discussions made with the national experts in the respective fields in the country.

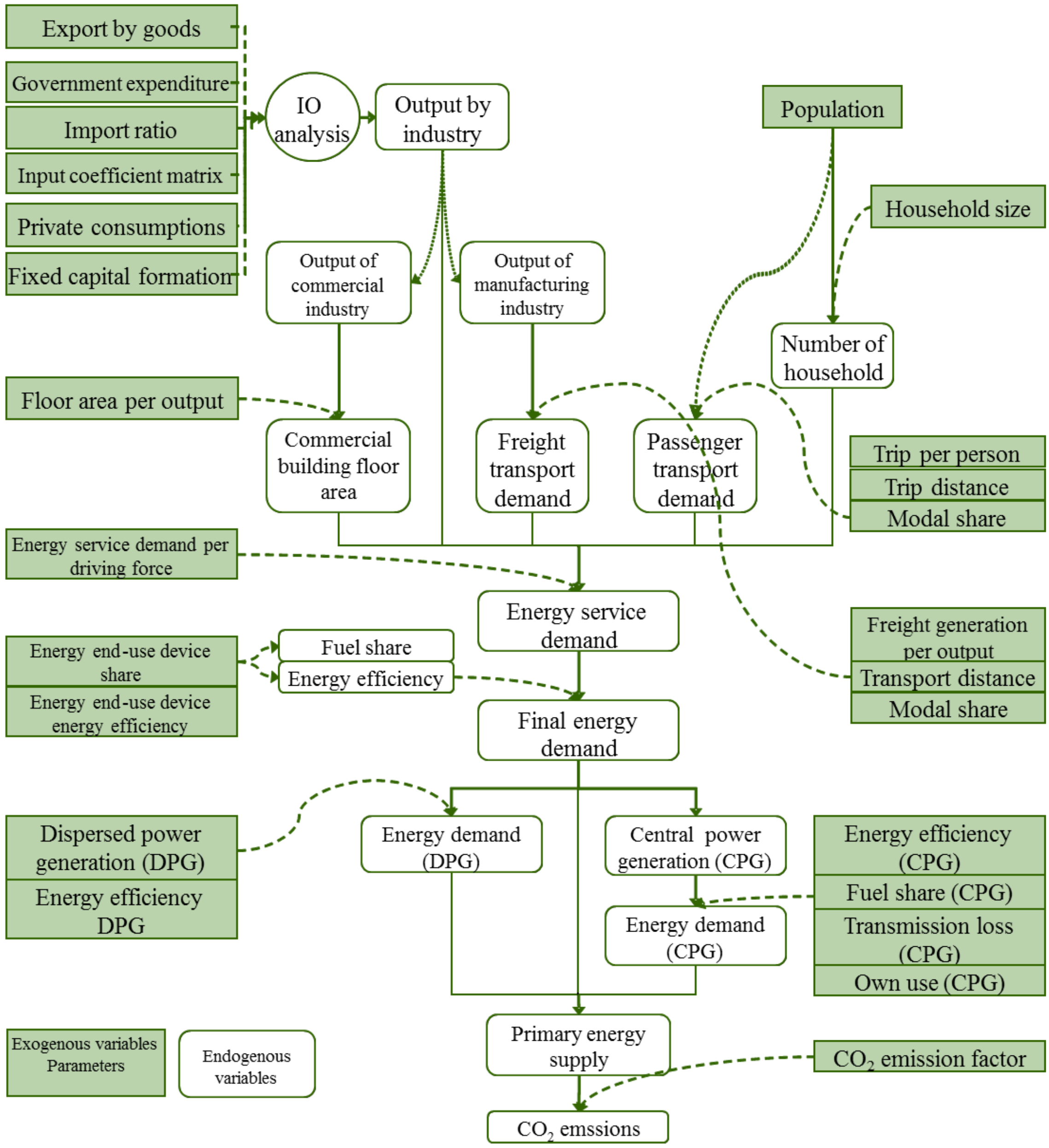

Figure 3.2: The structure of the ExSS tool

3.3 Data collection and quantification

The data estimations and assumptions in this study were primarily based the relevant Government documents and a series of discussions with key Government officers and involved institutions to make the estimations and assumptions more reliable and acceptable for envisioning the country future development pathway. The procedures to acquire these assumptions were made in three steps.

First, relevant documents were collected and discussed with the involved persons to ensure the validity and applicability of the collected information.

Second, workshops were organized to disclose a preliminary estimation and to collect further comments and inputs from the participants to improve the assumptions and estimations.

Third, intensive interviews with relevant Government officials and experts were conducted. Table 3.3 shows lists of some collected documents and the interviewees, while Table 3.4 indicates a series of workshops held for collecting inputs and comments as well as for disclosing the adjusted results to design an LCD in Cambodia.

Table 3.3: Lists of data collection and interviewees in Cambodia

Sectors	Documents	Interviewees	Explanation
Demography	Statistical Year Book of Cambodia 2011; Cambodia Socioeconomic Survey 2010 of National Institute of Statistics of the Ministry of Planning (MoP)	H.E Mom Marady, Advisor to MoP	Discussed about demographic data and future population projection
Economy	Economic Statistics (main macroeconomic indicators) of Supreme National Economic Council (SNEC); IO table 2008 provided by Dr. Oum Sothea; Rectangular strategy phase III; National Strategic Development Plan (2014-2018)	H.E Ung Luyna, Head of Social Policy Devision, (SNEC); Dr. Oum Sothea, Economist of Economic Research Institute for ASEAN and East Asia in Indonesia	Discussed about the IO table and its validity; Government development strategy; long term economic development target (to be an upper middle-income level by 2030 and a high-income one by 2050), etc.
Energy	Energy balance table (1995-2010) provided by Mr. Heng Kun Leang; Analysis on Energy Saving Potential in East Asia by Mr. Lieng Vuthy; National Policy, Strategy and Action Plan on Energy Efficiency in Cambodia in 2013; Power Development Master Plan towards 2030 in 2014 of the Ministry of Mines and Energy (MME)	Mr. Hang Seiha, Vice Chief of Office of Energy Efficiency; Mr. Heang Bora, Deputy Director; Mr. Touch Sovanna, Director of Energy Technique Department, MME; Mr. Heng Kunleang, Director of Department of Energy Development, MME; Mr. Por Nimol, Deputy Director General, MME	Discussed about energy efficiency development plan; long term energy demand projection; power Development plan and master target. Clarified about the information used to construct energy balance table and the cooperation with International Energy Agency (IEA), etc.
Transportation	Data on vehicle fleet of Cambodia in 2009; Overview on Transportation Infrastructure Sectors; Annual Transportation Sector Report; National Implementation Plan on Environmental Improvement in Transportation Sector of the Ministry of Public Works and Transport (MPWT)	Mr. Bong Vuthy, Director of Inland Water Transport Department, MPWT; Mr. Chhreng Phollak, Director of Department of Planning, MPWT; Mr. Taing Peou, Chief of Office of Land Transport; Mr. Preab Chanvibol, Director of Land Transport Department, MPWT	Discussed about the registered vehicles; vehicle fleet data for the second national communication; transportation development strategy and action plan; and long term perspective, inland, air, and railway transportation sector, etc.
Cross sector	Draft Second National Communication; Technology Needs Assessment and Technology Action Plans for Climate Change Mitigation; Cambodia Climate Change Strategic Plan (2014-2023) of the Ministry of Environement (MoE)	H.E Dr. Tin Ponlok, Secretary General of Green Growth, MoE; Mr. Sum Thy, Director of Climate Change Department, MoE	Discussed about the data used for the second national communication as some parts used for this study and technology improvement for energy and transportation, etc.

Table 3.4: Lists of workshops in Cambodia

Titles	Date	Venue	Participants
Workshop on a Systematic and Quantitative Design of Low Carbon Development Plan for Cambodia	22-Apr-13	Phnom Penh, Cambodia	Around 60 participants participated the workshop from line ministries, research institutes, academia, NGOs and Development Partners as well as research institutes and academia from Japan
Capacity Building Workshop on Low Carbon Development Policies for Cambodia, Lao RDR, and Myanmar	25-26-Feb-14	Phnom Penh, Cambodia	Around 70 participants from Institute for Global Environmental Strategies, National Institute for Environmental Studies, and Kyoto University, Japan; Representative of Research Institute from Myanmar; Representatives of Government agencies, research institutes and academia of Cambodia
The Advancement and Enhancement on Low Carbon Development Researches and Policies among Cambodia, Lao PDR, and Myanmar	26-Feb-15	Phnom Penh, Cambodia	Around 70 participants from Institute for Global Environmental Strategies, National Institute for Environmental Studies, and Kyoto University, Japan; Representative of Research Institute from Myanmar; Representatives of Government, research institutes and academia of Cambodia

3.4 Present quantification

The information on socioeconomic development and energy of the base year (2010) was collected. The detailed list of socioeconomic indicators is shown in Appendix 2.

3.4.1 Population

In 2010, the total population of Cambodia was about 13.96 million, which was about 2.3% of the Southeast Asian population (NIS, 2012). At that time, 19.5% and 80.5% of the total population of Cambodia were living in the urban and rural areas, respectively, (Table 3.5).

Table 3.5: Classification by age group and sex in 2010 [1,000 persons]

Sex	Age classification	Urban	Rural	Total
Male	Age group 00-14	322	1,866	2,188
	Age group 15-64	969	3,369	4,338
	Age group 65+	51	262	313
Female				
	Age group 00-14	336	1,943	2,279
	Age group 15-64	1,009	3,506	4,515
	Age group 65+	54	272	326
Total		2,741	11,218	13,959

Source: NIS (2012)

3.4.2 Households

The number of households in the base year was collected from the socioeconomic survey 2010 conducted by the National Institute of Statistics (NIS) of the Ministry of Planning (MoP). The total number of households was about 3.0 million-- 0.6 million were in the urban areas and 2.4 million were in the rural areas. In this study, two types of households were classified. The short forms of households are "hh1 and hh2", which "hh1" referred to households in the urban areas, while "hh2" meant households in the rural areas. The population census in 2008 defined the urban areas as any commune meeting the following criteria:

- Population density exceeds 200 per km^2;
- Percentage of male employment in agriculture below 50.0%; and
- The total population of the commune should exceed 2,000.

The average person per household in 2010 was 4.8 (NIS, 2012). The average person per household for urban and rural areas was very similar (4.8 persons) in that year. Table 3.6 shows the average persons per household in 2010.

Table 3.6: Average persons per household in 2010

Household type	Average persons per household (persons)
Urban	4.8
Rural	4.8

3.4.3 Macro economy

This study used the data of the macro economy of the base year (2010) such as GDP, Gross output of industry, and Final demand sectors, which is shown in Table 3.7. These indicators were taken from the estimated IO table in 2010 which was the combination of the adjusted values of the IO table in 2008 and the economic data in 2010, including value added, gross domestic fixed capital formation, export, import, and private and Government consumption and expenditure from the national accounts statistics. The Cambodian IO table in 2010 was not acquired at the time of the study; it was converted from the IO table in 2008 by using an IO conversion tool. The following section explains the procedure for the estimation.

Table 3.7: Macroeconomic indicators in 2010 [Million USD at 2000 constant price]

Indicators	2010
GDP	7,518
Primary industry (share %)	30
Secondary industry (share %)	29
Tertiary industry (share %)	42
GDP/Capita (USD at 2010 price)	833
Gross outputs	17,699
Primary industry	3,136
Secondary industry	8,910
Tertiary industry	5,653
Final demand sectors	
Private consumption	6,169
Government consumption	654
Gross fixed capital formation	1,650
Exports	6,256
Imports	7,210

IO table estimation

Since the IO table in 2010 in Cambodia was not acquired, it was converted from the IO table in 2008 which was constructed by Sophal and Sothea (2011), by using an IO table conversion tool. The IO table in 2008 comprised 22 sectors and aggregated into a competitive import type of 10 sectors (Appendix 3: IO Table 2008). In order to convert the IO table in 2008 to 2010, some economic data of the new IO table such as "value added, gross domestic fixed capital formation, export, import, and private and Government consumption and expenditure", which could be collected from NIS (2011), were required as controlled totals. The outline of the estimation procedure is shown in Figure 3.3.

i) The input-output table of Cambodia in 2008 was collected and processed; and
ii) The Cambodia IO table in 2010 was estimated from (i) and economic information in 2010 by cross-entropy method.

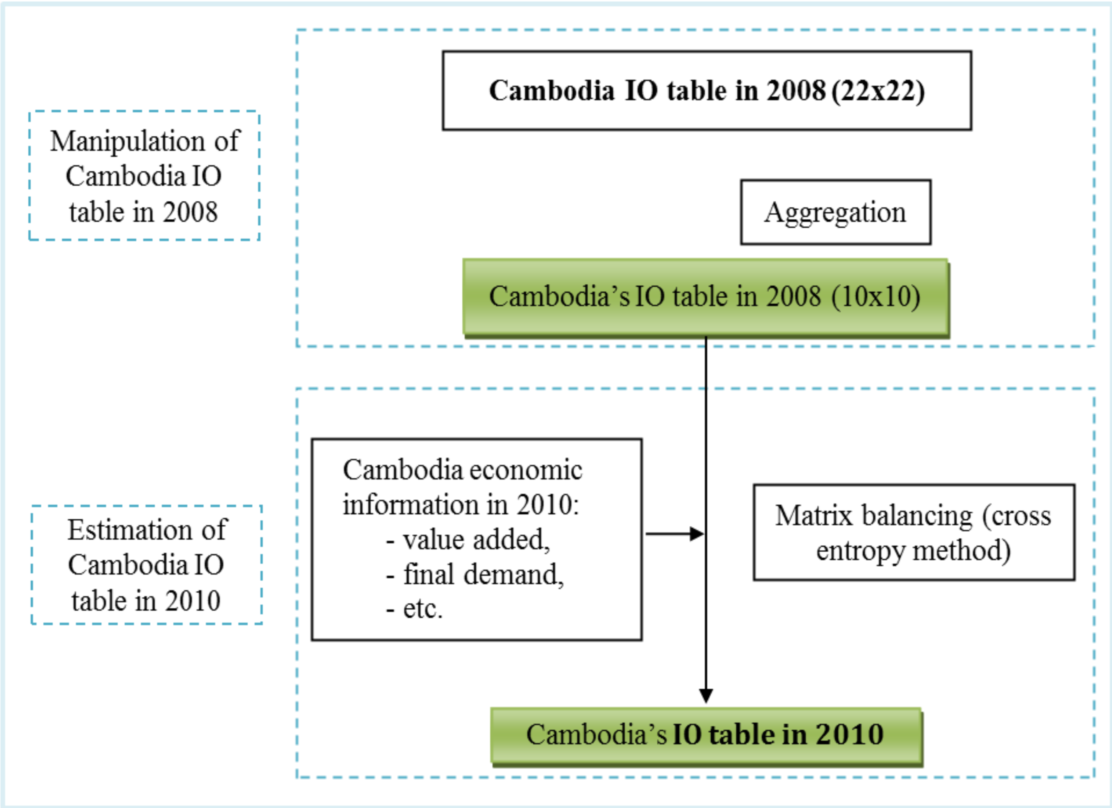

Figure 3.3: Procedure to convert the IO table from 2008 to 2010

Source: Tahsin (2013)

Processing of the Cambodia 2008 IO table:

The IO table of Cambodia in 2008 (a non-competitive import type, 22 sectors) was processed into a competitive import type and aggregated into 10 sectors to make it easier to analyze (Appendix 4: The aggregated IO Table 2008).

Aggregating the sectors:

The aggregation was made with reference to the industrial classification classified in the National Accounts Statistics of the NIS of Cambodia. The aggregation was done by GAMS programme (General Algebraic Modeling System). The aggregated sectors are shown in Table 3.8, while the definition of each sector is presented in Appendix 5.

Table 3.8: The aggregated IO table

11-sector classification in aggregated IO table 2008		22-sector classification in original table 2008	
Code	**Sector**	**Code**	**Description**
1	Agriculture, fishery and forestry	1	Paddy
		2	Other crops
		3	Livestock
		4	Forestry
		5	Fishery
2	Mining and Quarrying	6	Mining
3	Manufacturing	7	Food, beverage & tobacco
		8	Textile & garment
		9	Wood, paper & publishing
		10	Chemical, rubber & plastic
		11	Non-metallic mineral
		12	Basic metals
		13	Other manufacturing
4	Electricity, gas & water	14	Electricity and water
5	Construction	15	Construction
6	Trade	16	Trade services
7	Transport	18	Transport and Communication
8	Finance	19	Finance
9	Government services	21	Public administration
10	Other private services	17	Hotels, restaurants
		20	Real Estate and Business
		22	Other services

Source: Sophal and Sothea (2011)

Estimation of the IO Table in 2010

The Cambodian IO table in 2010 was estimated by using the aggregated IO table in 2008 and some economic data in 2010 such as “value added, gross domestic fixed capital formation, export, import, and private and Government consumption and expenditure” which were collected from NIS (2011). The estimation was done by using a GAMS programme. Figure 3.4 shows the procedure to estimate the IO table in 2010.

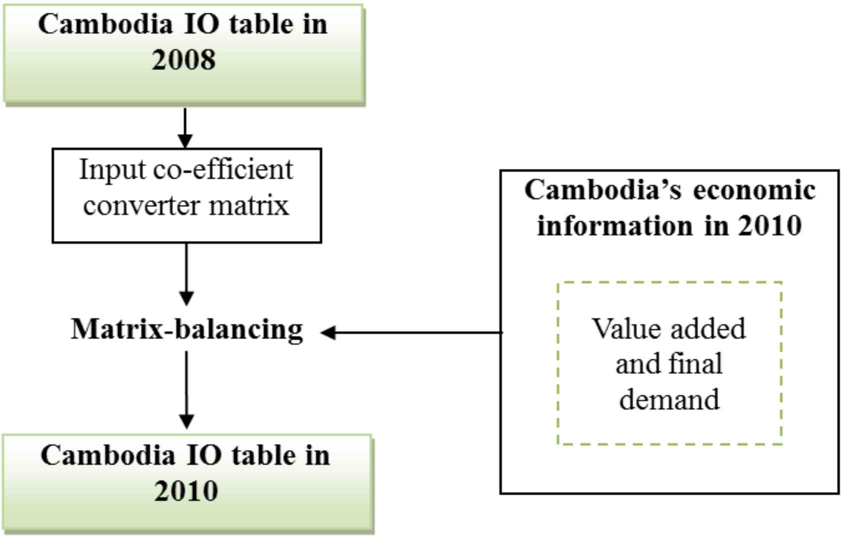

Figure 3.4: The procedure to estimate the IO table in 2010

Used value added:

The value added sectors in 2010 (at 2000 constant price) were collected from NIS (2011) and it was considered as the initial value. The unit was expressed in Cambodian Riel and converted into USD (1 USD = 4,044 Riel in 2010). The value added sectors in 2010 used for this conversion is shown in Table 3.9.

Table 3.9: Value added in 2010 [Million USD at 2000 constant price]

Sectors	2010
Agriculture, fishery and forestry	2,233
Minning and Quarrying	50
Manufacturing	1,642
Electricity, gas & water	52
Construction	407
Trade	723
Transport	509
Finance	150
Government services	97
Other private services	1,655
Total	**7,518**

Used domestic product (control total):

The value of domestic product containing intermediate input in 2010 was not acquired from the national accounts statistics. Thus, it was estimated from the value added and the rate of value added and domestic product of each industry of the IO table in 2008.

Used final demand:

The values of final demand sectors such as private and Government consumption and expenditure, gross domestic fixed capital formation, import, and export in 2010 were collected from NIS (2011). The unit was expressed in Cambodian Riel and converted into USD (1 USD = 4,044 Riel in 2010). Final demand sectors in 2010 used for this conversion are shown in Table 3.10.

Table 3.10: Final demand sectors [Million USD at 2000 constant price]

Final demand sector	2010
Private Consumption	6,169
Government Consumption	654
Gross domestic fixed capital formation	1,650
Exports	6,256
Imports	7,210
Total	**7,518**

The items of intermediate inputs and final demand sector:

The intermediate input was computed by multiplying above mentioned domestic product by the input coefficient in the IO table in 2008. The amount of goods of final demand sectors was computed by multiplying the total amount of each final demand sector by the share distribution of goods in the IO table 2008.

Adjustment of the IO table in 2010:

Since the supply and demand are not balanced in the IO table in 2010 above, it is necessary to correct by adjustment calculation. A cross-entropy method was used under input values and constraints, it was formulized as a nonlinear programming problem, which makes an objective function the minimum. The following formulas show the constraints and the objective function of the method.

Constraints:

- The sum total of a row and the sum total of a column (demand and supply) are in agreement.

$$\sum_i x_{i,k} = \sum_j x_{k,j} \times n_{k,j} \tag{3.1}$$

$x_{i,j}$: IO table (estimated),

$n_{k,j}$: A matrix which is -1 in the columns of imports and 1 in others,

i : Row elements of IO table,

j : Column elements of IO table,

k : Industry $(k \in i)$.

- The maximum of import (import does not exceed domestic demand)

$$IM_k < \sum_l x_{k,l} + \sum_{df} x_{k,df} \tag{3.2}$$

IM_k : Imports of goods k,

df : Domestic final demand sectors $(df \in j)$,

l : Industrial sector $(l \in i)$.

- The maximum of exports (exports do not exceed domestic product)

$$EX_k < \sum_j x_{k,j} \tag{3.3}$$

EX_k: Exports of goods k

<u>Objective function:</u>

- The sum total of deviation from the distribution of the column element of the IO table in 2008, deviation from the distribution of the final demand item of the table, and deviation from an input value shall be made into the minimum. An objective function is shown below. $\omega_1 \sim \omega_4$ is the weight of each term.

$$\min \ \omega_1 \sum_i \sum_j p_{i,j} \ln \frac{p_{i,j}}{q_{i,j}} + \omega_2 \sum_f u_f \ln \frac{u_f}{v_f} + \omega_3 \sum_l \varepsilon_l^{\ 2} + \omega_4 \sum_f \varepsilon_f^{\ 2} \tag{3.4}$$

- The contents of each term are explained below.
- The cross-entropy of the percentage distribution in the column of each element in each column.

$$\sum_i \sum_j p_{i,j} \ln \frac{p_{i,j}}{q_{i,j}} \tag{3.5}$$

$$p_{i,j} = \frac{x_{i,j}}{\sum_i x_{i,j}} \tag{3.6}$$

$$q_{i,j} = \frac{z_{i,j}}{\sum_i z_{i,j}} \tag{3.7}$$

$p_{i,j}$: Percentage distribution of the column element of the estimated IO table,
$q_{i,j}$: Percentage distribution of the column element of IO table in 2008,
$z_{i,j}$: IO table in 2008.

- The cross-entropy of the percentage distribution of each final demand sector to the whole final demand sector

$$\sum_f u_f \ln \frac{u_f}{v_f} \tag{3.8}$$

$$u_f = \frac{\sum_i x_{i,f}}{\sum_i \sum_f x_{i,f}} \tag{3.9}$$

$$v_f = \frac{\sum_i z_{i,f}}{\sum_i \sum_f z_{i,f}} \tag{3.10}$$

$u_{i,j}$: Percentage distribution of final demand sector of the estimated IO table,
$v_{i,j}$: Percentage distribution of final demand sector of the IO table in 2008.

- The rate of change from an initial value (statistic)
  ε is raised to the power of two because it may become a negative value.

$$\sum_l {\varepsilon_l}^2 \tag{3.11}$$

$$\sum_f {\varepsilon_f}^2 \tag{3.12}$$

$$\sum_{av} x_{av,l} = d_l (1 + \varepsilon_l) \quad (3.13)$$

$$\sum_{j} x_{f,j} = d_f (1 + \varepsilon_f) \quad (3.14)$$

d_l : The statistic of value added,

ε_l : The rate of change of an estimated value of the input value,

d_f : The statistic of final demand sectors,

ε_f : The rate of change of an estimated value from the input value,

av : Value added sectors $(av \in i)$.

Estimated result of IO table in 2010

The estimated result of the IO table in 2010 is shown in Appendix 6.

3.4.4 Transportation demand

Transportation sector was reported to be the second-largest sector in terms of CO_2 emissions from fuel combustion in 2010 in the world, emitting about 6,756MtCO_2 (22.3%) of total CO_2 emissions (IEA, 2012). This sector in Cambodia, however, contributed very little to the world's CO_2 emissions due to her limited transportation infrastructure and low economic incomes. The Government has set a plan to invest in transportation infrastructures and to improve trade facilitation through the development of a multi-modal transportation network to ensure connectivity within the country and the whole region (RGC, 2013).

In this study, two types of transportation system (passenger and freight) are described. Since the detailed information about transportation demand in Cambodia was not fully acquired, some assumptions were made based on the professional judgment of the author and personal communication with the country's experts. In this context, Cambodia must improve the data recording, collection, monitoring, and management in order to advance the transportation statistical data in the long run. Table 3.11 shows a comparison of the classification of transportation modes used in this study and in the country and Appendix 7 shows the characteristic of motorized vehicles used in this study.

Table 3.11: Classification of transportation modes

This study classification	Country classification	Explanation
Passenger transportation modes		
Motorbike	Motorcycle, motorcycle trailer, and 3-wheel motorized cycle	Motorbike includes motorcycle trailer and 3-wheel motorized cycle
Tourist Car	Car 4 WD/Pick Up Jeep Van	Tourist car includes Car, 4 WD/Pick-up, Jeep, and Van, and this aggregation used to estimate an average trip distance and number of trip per vehicle
Bus	Mini Bus Big Bus	Bus includes Mini bus and big bus and this aggregation used to estimate an average trip distance and number of trip per vehicle
Walk	-	
Bicycle	-	
Train	-	Only for domestic travel
Ship	-	Ship and speedboat
Air	-	Only for domestic travel while helicopters and
Freight transportation modes		
Small cargo truck	Light Commercial 2 Axial Truck	Small cargo truck includes light commercial and 2 Axial truck and this aggregation used to estimate an average trip distance and freight demand per vehicle
Big cargo truck	3 Axial Truck 4 Axial Truck Trailer 5 Axial Track Multi Trailer Truck	Big cargo truck includes 3 Axial truck, 4 Axial truck trailer, 5Axial track, and Multi trailer truck, and this aggregation used to estimate an average trip distance and freight demand per vehicle
Train	-	Only for domestic travel
Ship	-	Ship

Passenger transportation

The passenger transportation modes comprise land, railways, inland waterways and air. The land transportation mode included motorized vehicles (motorbike, tourist cars, and buses), bicycles and walk, while the railways transportation mode is on trains and the inland waterways transportation mode comprises ships and speedboats. The data about passenger demand in Cambodia was collected from MPWT (2009), NIS (2011), MPWT (2012), and MPWT (2010-2012). Since the detail information was not fully acquired, some of the data were estimated by the author in consultation with the Cambodian experts and some other key stakeholders.

Formulation of the passenger transportation model:

The annual passenger transportation demand (Million pass.km/year) is estimated by multiplying "population (person) by the trip generation per person per day (trip/(person.day)), modal share (%*100), average trip distance (km/trip), and the days in a year (365.25 days for this study)". The main objective of this section is to estimate the value of all the parameters in the base year (2010) of the following formula.

$$PTD_{ptm}=Pop \,.\, PTG \,.\, PTS_{ptm} \,.\, PTAD_{ptm} \,.\, (365.25) \,.\, (1/10^6) \quad (3.15)$$

Where:

- PTD_{ptm} : Passenger transportation demand (Million (pass.km)/year)
- Pop : Population (person)
- PTG : Trip generation per person per day (trip/(person.day))
- PTS_{ptm} : Modal share (%*100)
- $PTAD_{ptm}$: Average trip distance by mode (passenger) (km/trip)
- ptm : Passenger transportation mode

In this study, we used the data in Table 3.12 to estimate PTD_{ptm} (Million (pass.km)/year) in 2010.

Table 3.12: Passenger transportation demand indicators in 2010

Mode (ptm)	Model share (PTS_{ptm}) (%)	Average distance ($PTAD_{ptm}$) (km/trip)	Passenger transportation demand (PTD_{ptm}) (Million pass.km/year)
Motorbike	8.40	10	8,562
Tourist Car	2.45	68	17,073
Bus	1.79	82	14,988
Train	0.00	0	0
Ship	0.00	36	2
Air	0.00	237	32
Walk	45.56	1	4,646
Bicycle	41.81	2	8,526
Total	100		**53,829**

Note:

- Population (Pop) was 13,959 thousand persons; and
- Trip generation per person per day was 2 trips/(person.day).

The following sections explained the procedures to acquire these data.

Population (POP):

The population in 2010 was 13,959 thousand persons (NIS, 2011).

Trip generation per person per day (PTG) (trip/(person.day)):

This study assumed the trip generation (PTG) was 2 trips /(person.day).

Model share (PTS_{ptm}) (%/100):

The information on the model share of each passenger transportation mode was not acquired in Cambodia. The following formula was used for the estimation.

[Model share of each mode (%)] = [No. of trip per year by each mode (trip/year)] / [Total No. of trip per year (trip/year)] * 100 (3.16)

[Total No. of trip per year (trip/year)] = [Pop (persons)]*[PTG (trip/(person.day))] *365.25 (3.17)

Number of trips per year by each mode (trip/year):

Inland waterways:

We used 49,114 trips/year for inland waterways in 2010 which was collected from MPWT (2012).

Railways:

No railway was operated in 2010 in Cambodia.

Air:

We used 0.14 million trips/year for air in 2010 which was collected from NIS (2011).

Land:

Motorized vehicles:

The number of trips per year by motorized vehicles, including motorbikes, tourist cars, and buses was computed with the following formula and some reference data was used for the estimation.

[No. of trip per year by motorized vehicles (trip/year)] = [No. of motorized vehicles (vehicle)] *[Average person per vehicle (trip/(day.person))]*[No. of trip per vehicle per day (trip/(vehicle.day))]*365.25 (3.18)

Where:

- Only one trip per vehicle per day was assumed for this study.
- The number of motorized vehicles (vehicle) was counted by basing on the vehicle lifespan. However, the number of unregistered motorbikes remained significant in Cambodia (no detail information was recorded), especially in the provinces near the neighboring countries and the rural areas as they can be driven without strict traffic control and enforcement. Therefore, this study assumed around 20.0% of the total motorbikes were unregistered, this means that the total number of motorbikes of 1,378,900 were operated in 2010. Meanwhile, all tourist cars and buses were assumed to be strictly registered.

The vehicle fleet data, which was collected from MPWT (2009), used to estimate passenger transportation in Cambodia is shown in Table 3.13.

Table 3.13: Vehicle fleet data in Cambodia

Mode	Motorcycle	Tourist Car				Bus
		Car	4 WD/Pick Up	Van	Mini Bus	Bus
Kilometer driven per year ('000km)	7.2	15.0	30.0	30.0	20.0	40.0
Service life (year)	10.0	10.0	8.0	8.0	8.0	8.0
Number of passengers (person)	1.7	3.9	4.0	8.0	12.0	40.0
Fuel per vehicle kilomemter (liter/km)	0.03	0.10	0.14	0.14	0.17	0.25
No of passenger vehicles ('000 vehicles)	1,378.9			128.9	170.2	2.2

Source: MPWT (2009) and NIS (2011)

Bicycle and walk:

Since the data on the number of trips per year by bicycle and walk was not acquired at the time of the study, the following formula is used for the estimation.

[No. of trips per year by bicycle and walk (trip/year)] = [Total No. of trips per year (trip/year)] - [No. of trips per year by motorized vehicles, inland waterways, railways, and air (trip/year)] (3.19)

As a result, the number of trips of 8,909 million trips/year was obtained in 2010 for bicycle and walk; however, the data on their shares was not acquired. As the bicycle is a common mean of transportation in Cambodia, this study assumed at least two bicycles per household and they were used at least one time per day for each. Furthermore, this study already assumed 2 trips per person per day; therefore, the value of 4,263 (48.0%) million trips/year for bicycle was obtained, while the values of walk was 4,646 (52.0%) million trips/year for the year 2010.

Average trip distance of each passenger transportation mode ($PTAD_{ptm}$) (km/trip):

Since the statistical information about the average trip distance of each passenger transportation mode in Cambodia was not fully acquired at the time of the study, there was a need to complement the unavailable information by using some assumptions.

Passenger transportation demand by each mode (pass.km/year):

Land:

Motorized vehicles (pass.km/year):

The data on the average trip distance of motorized vehicles was collected from MPWT (2009). Based on these data, the average trip distance of motorbike was about 20 km/trip; this value seemed too high and unrealistic for Cambodia. Therefore, we assumed it was only 10km/trip to estimate passenger transportation demand in 2010 for this study. However, the average trip distance of other modes (tourist car and bus) was more realistic and acceptable and used for this study.

Bicycle and walk (pass.km/year):

The average trip distance of bicycle and walk was not acquired. As we observed that in Cambodia the passengers travelled by walk only for a short distance (around 1km), while a longer distance (around 2km), they preferred “bicycle”. Hence, this study assumed the average trip distance of walk is 1 km/trip, while the average trip distance of bicycle is 2km/trip in 2010.

Inland waterways (pass.km/year):

The average trip distance of 36km/trip (including passenger ship and speedboat) was assumed in 2010. This assumption was made in accordance to an interview with Bong Vuthy, Director of Waterways Department of the MPWT of Cambodia in 2013. He stressed that passengers using inland waterways were decreasing and they opted for the land transportation mode as it was more convenient and faster.

Railways (pass.km/year):

No railway was operated in 2010 in Cambodia.

Air (pass.km/year):

Since only two airports are actively operating currently, Phnom Penh and Siemreap International Airport, which are open for both international and domestic flights; however, only domestic flight is considered for this study, the average trip distance was assumed to be in proportion to the distance from Phnom Penh to Siemreap, which is 237km/trip (MPWT, 2010 and 2012).

Freight transportation

The freight transportation modes comprise land, railways, and inland waterways, while the air was not included as it was too small in 2010. The data of freight transportation such as the number of freight, modal share, and average trip distance in Cambodia was computed from the estimated data of vehicle fleet of MPWT (2009), NIS (2011), MPWT (2012), and MPWT (2010 and 2012). Since the detail information was not fully acquired, some of the data were estimated by the author in consultation with the Cambodian experts and other key stakeholders.

Formulation of the freight transportation model:

Freight transportation demand (Million (ton.km)/year) is estimated by multiplying "output of industry (Million USD) by freight generation per industrial output (ton/USD), modal share (%*100), and average trip distance (km/trip)". The primary objective of this section is to estimate the value of all the parameters in the base year (2010) of the following formula.

$$FTD_{ftm} = PD \,.\, Ftg \,.\, Fts_{ftm} \,.\, Ftad_{ftm} \,.\, (1/10^6) \quad (3.20)$$

Where:

FTD_{ftm} : Freight transportation demand (Million ton.km/year)

PD : Output of primary and secondary industry (Million USD)

Ftg : Freight generation per industrial output (ton/USD)

Fts_{ftm} : Modal share of freight transportation (%*100)

$Ftad_{ftm}$: Average trip distance of freight transportation (km/trip)

In this study, we used the data in Table 3.14 to estimate FTD_{ftm} (Million ton.km/year) in 2010.

Table 3.14: Freight transportation demand indicators in 2010

Mode (ftm)	Model share (FTS_{ftm}) (%)	Average distance ($FTAD_{ftm}$) (km/trip)	Freight transportation demand (FTD_{ftm}) (Million ton.km/year)
Small cargo truck	28.86	110	4,731
Big cargo truck	70.31	130	13,688
Train	0.00	12	0
Ship	0.83	115	143
Total	**100**		**18,562**

Note:

- Industrial output was 17,699 million USD in 2010; and
- Freight generation per industrial output was 0.008 ton/USD in 2010.

The following sections explained the procedures to acquire these data.

Industrial output (PD):

The industrial output is the total output of all industries of IO table in 2010, which was 17,699 million USD.

Freight transportation generation per industrial output (FTG_{ftm}) (ton/USD):

This study assumed the same freight transportation generation per output in all industrial sectors and only domestic transportation was considered. Freight transportation generation per output of industry was computed by dividing "the total number of freight (150 Million tons/year) by the total value of industrial output above. The result of 0.008 ton/USD (at 2000 constant price) was obtained.

Modal share (FTS_{ftm}) (%*100):

The data on the model share of each freight transportation mode was not acquired in Cambodia. Hence, the following formula is used to calculate the model share for the purpose of this study.

[Model share of each mode (FTS_{ftm}) (%)] = [Tons of freight demand by each mode (ton/year)] / [Total tons of freight demand (ton/year)]*100 (3.21)

Number of freight transportation demand by each mode (ton/year):

Land (ton/year):

In this study, the land freight mode includes small cargo and big cargo trucks. Due to the limited information in 2010, it was estimated by the following formula by using some assumptions.

[Tons of freight demand (ton/year)] = [Tons of freight vehicles (vehicle)]* [Average loading capacity per vehicle (ton/vehicle)]*365.25 (3.22)

Where:

The number of freight vehicles (vehicle) was counted by basing on the vehicle lifespan. All the freight vehicles were assumed to be strictly registered. The vehicle fleet data, which was collected from MPWT (2009), used to estimate freight transportation in Cambodia is shown in Table 3.15: Freight vehicle fleet data in Cambodia.

Table 3.15: Freight vehicle fleet data in Cambodia

Mode	**Small cargo truck**					**Big cargo truck**
	Light Commercial	2 Axial Truck	3 Axial Truck	4 Axial Truck	5 Axial Track	Multi Trailer Truck
Kilometer driven per year ('000km)	40.0	40.0	40.0	45.0	45.0	60.0
Service life (year)	8.0	8.0	14.0	14.0	14.0	14.0
Average loading capacity per vehicle (ton/vehicle) (assumption)	3.0	4.5	6.0	12.0	12.0	14.0
Fuel per vehicle kilomemter (liter/km)	0.13	0.17	0.20	0.25	0.25	0.33
No. of freight vehicles ('000 vehicles)		31.5				26.2

Source: MPWT (2009) and NIS (2011)

Railways (ton/year):

We used 3000 tons/year for railways in 2010, which was collected from MPWT (2011).

Inland waterways (ton/year):

We used 1.2 million ton/year for inland waterways in 2010, which was collected from NIS (2011).

Average trip distance by each freight mode ($FTAD_{ftm}$) (km/trip):

Since the statistical information about the average trip distance of each freight mode in Cambodia was not fully acquired at the time of the study, there was a need to complement the unavailable information with some assumptions. The average trip distance by each freight mode can be computed by dividing *"freight transportation demand by each freight mode (ton.km/year) by the number of freight by each freight mode (ton/year)"*.

Land (km/trip):

The land transportation mode comprises small cargo and big cargo trucks. The average trip distance of each mode was collected from MPWT (2009).

Inland waterways (km/trip):

The data on the average trip distance of inland waterways was not acquired and it was assumed to be in proportion to the average distance from one port to the other, which was 115km/trip MPWT (2012). This assumption was made in accordance to an interview with Bong Vuthy, Director of Waterways Department of the MPWT of Cambodia in 2013.

Railways (km/trip):

We used 12 km/trip for railways in 2010, which was collected from MPWT (2011).

3.4.5 Energy sector

The total volume of energy demand and supply used in this study was taken from an energy balance table in 2010 by the International Energy Agency (IEA) in the 2012 edition (IEA, 2012) (Appendix 8). The data used to construct this energy balance table was contributed by the Energy Development Department of the Ministry of Industry, Mines and Energy (MIME) and other relevant institutions working in the energy sector in Cambodia (according to a direct interview with Heng Kunleang, Director of Energy Development Department in 2012). In this energy balance table, energy consumption by agriculture, fishery, and forestry was recorded only up to 2009 and during that year, energy consumption in this sector was some 117ktoe/year, while in 2010 was not recorded due to lack of data, added he.

For the purpose of this study, we estimated energy consumption by this sector to be in proportion to the incremental rate of the agricultural machines between 2009 and 2010. Between these years, the agricultural machines increased by 1.06 times Vuthy (2013). Hence, energy consumption in this sector was computed to be some 123.95ktoe/year in 2010. Appendix 9 shows the detail of the adjusted energy balance table in 2010.

Power supply

To estimate power supply in the base year (2010), we used energy balance table in 2010. In 2010, oil products were the highest share of the total power supply (some 91.91%), came after by coal (some 3.11%), hydropower (some 2.61%), while biomass was some 2.01% and renewable energy (solar and wind power) was less than 1.0%. In the same year, around sixty-five per cent of the total national energy supply was imported from neighbouring countries such as Vietnam, Lao PDR, and Thailand (EAC, 2010) (Table 3.16).

Table 3.16: Power supply in 2010 [ktoe/year]

Fuel type	Coal	Petroleum products	Hydropower	Solar/wind	Biofuels and waste	Import	**Total**
Fuel	8.08	241.85	2.24	0.26	6.88	116.70	**376.00**
Power generation	2.67	78.59	2.24	0.30	1.72	116.70	**202.21**
Own use	0.08	2.29	0.07	0.01	0.05	0.00	**2.50**
Transmission loss	0.32	9.33	0.27	0.04	0.20	14.30	**24.45**
Power supply	2.27	66.97	1.91	0.26	1.47	102.40	**175.27**

Energy demand

The energy demand of the energy demand sectors includes *residential, commercial, industrial, and transportation sector.* This study integrated energy consumption in Agriculture, fishery, and forestry into the industrial sector. Energy consumption of each energy demand sector was collected from the energy balance table in 2010;

however, some adjustments were made to correspond to the real country situation. The data of energy consumption by energy demand sectors used in this study is shown in Table 3.17, while the procedure to derive these data explained as followings.

Table 3.17: Energy consumption by energy demand sectors in 2010 [ktoe/year]

Sector/fuel type	Coal	Petroleum products	Biofuels and waste	Electricity	**Total**
Residential	0	129.75	2,322.87	95.89	**2,548.51**
Commercial	0	2.60	122.26	46.78	**171.64**
Industrial	0	331.42	657.18	32.59	**1,021.19**
Passenger transportation	0	321.22	0	0	**321.22**
Freight transportation	0	323.86	0	0	**323.86**
Total	**0**	**1,108.84**	**3,102.30**	**175.27**	**4,386.42**

Residential sector:

Information of energy consumption in the residential sector was collected from the energy balance table in 2010 in which the majority of energy consumption in this sector derived mainly from biofuels and waste. Total energy consumption in this sector was included non-specified (others) and non-energy use in others. This study assumed 5.0% of energy consumption from petroleum products and biofuels in this sector used for the commercial sector (the detail explanation can be found in the commercial sector section). Therefore, total energy demand in the residential sector decreased from 2,673.36ktoe/year to 2,548.51ktoe/year.

Two types of household, including urban and rural, were classified in the residential sector in this study and energy consumption was estimated by the household types accordingly. Energy service demand by energy service sectors in this sector includes cooling, heating, hot water, cooking, lighting, refrigerator, and other household appliances. Because the detail information on energy consumption by each household type was not fully acquired; it was estimated from the socioeconomic survey data conducted by NIS (2012) where energy consumption in the urban areas was estimated around 20.39% (518.02ktoe/year), while in the rural areas was around 79.61% (2,022.36ktoe/year) in 2010. The survey indicated that cooking and lighting was the main sources of energy consumption in Cambodia. It was also observed that other energy service sectors such as cooling, heating, hot water, and refrigerator were commonly used in the urban areas, while in the rural areas were very little.

Since the detail information on energy consumption of each energy service sector was not fully acquired, the System for the Analysis of Global Energy Markets (SAGE) was used to split energy consumption by energy service sector for this study (SAGE, 2003) (Appendix 10). Moreover, some adjustments were made from the calculation by SAGE to reflect the real country situation for both rural and urban households. Table 3.18 shows the estimated result of energy consumption by energy service sector in the urban areas, while Table 3.19 shows the estimated result of energy consumption by energy service sector in the rural areas.

Table 3.18: Energy consumption in the urban areas by energy service [ktoe/year]

Energy service/fuel type	Coal	Petroleum products	Biofuels and waste	Electricity	**Total**
Cooling	0	0	0	5.74	5.74
Heating	0	2.31	21.14	1.06	24.51
Hot water	0	2.31	21.14	1.24	24.69
Kitchen	0	32.14	380.56	2.65	415.35
Refrigerator	0	0	0	6.80	6.80
Lighting	0	9.46	0.00	22.24	31.70
Other electric equipment	0	0	0	13.24	13.24
Total	**0**	**46.22**	**422.85**	**52.95**	**522.02**

Table 3.19: Energy consumption in the rural areas by energy service [ktoe/year]

Energy service/fuel type	Coal	Petroleum products	Biofuels and waste	Electricity	**Total**
Cooling	0	0	0	5.80	5.80
Heating	0	1.67	19.00	0.86	21.53
Hot water	0	1.67	19.00	1.07	21.74
Kitchen	0	57.17	1,862.02	2.15	1,921.34
Refrigerator	0	0	0	4.29	4.29
Lighting	0	23.02	0	18.03	41.05
Other electric equipment	0	0	0	10.73	10.73
Total	**0**	**83.53**	**1,900.02**	**42.94**	**2,026.49**

Commercial sector:

Information on energy consumption in the commercial sector was collected from the energy balance table in 2010. It was observed that the main source of energy in this sector derived solely from electricity; it seems that it didn't reflect the real energy consumption as this sector also covered hotels and restaurants which also consumed a lot of petroleum products and biofuels. Hence, some adjustments were made for the purpose of this study. According to NIS (2011), there were 440 hotels and 1,087 guesthouses in 2010 and most of the hotels served the food service for clients, while only few guesthouses provided this service. Aside from that, there were a lot of restaurants, especially in the most tourist attractive cities such as Phnom Penh, Siemreap, and Sihanoukville (no detail information on the number of restaurants). Those hotels, guesthouses, and restaurants mainly utilized petroleum products and biofuels to cook food for their clients. The amount of energy consumption in these sectors was observed to be smaller than those of households in the residential sector.

Therefore, this study assumed around 5.0% of petroleum products and biofuels consumed in the commercial sector and this value was deducted from the residential one. As a result, energy consumption in this sector increased from 46.78ktoe/year to 171.64ktoe/year. Since the detail information on energy consumption by each industry was not grasped, this study assumed energy consumption to be in proportion to the intermediate input of each industry of the IO table. Furthermore, energy consumption by energy service sectors, such as cooling, heating, hot water, cooking, lighting, refrigerator, and other appliances were not acquired; hence we used SAGE to split energy consumption by energy service sector (Appendix 11). Table 3.20 shows energy consumption by energy service sector by fuel type in the commercial sector.

Table 3.20: Energy consumption by energy service in the commercial sector [ktoe/year]

Energy service/fuel type	Coal	Petroleum products	Biofuels and waste	Electricity	**Total**
Cooling	0	0	0	6.08	6.08
Heating	0	0.13	12.23	1.40	13.76
Hot water	0	0.91	12.23	2.81	15.94
Kitchen	0	1.56	97.81	0.47	99.83
Lighting	0	0	0	16.37	16.37
Refrigerator	0	0	0	9.36	9.36
Other electric equipment	0	0	0	10.29	10.29
Total	**0**	**2.60**	**122.26**	**46.78**	**171.64**

Industry:

Among energy consuming industries, the garment sector was considered as the main driving force, followed by the fabrication of clay bricks, the rice mills for processing paddy into polished rice, the rubber production, and the food sector (MME, 2013).

Energy consumption in this sector was collected from the energy balance table in 2010 and the data of "Other/non-specified industry and Non-energy use industry" were used. Energy consumption in Agriculture, fishery, and forestry was already assumed to be 123.95ktoe/year; however, energy consumption by other industries under this sector was not grasped. This study assumed energy consumption by each industry to be in proportion to the intermediate input of each industry from the IO table. For the purpose of this study, some adjustments were made to reflect the real country situation; for instance "mining and electricity and water" did not consume petroleum products and biofuels and they were included into "manufacturing" accordingly. The estimated energy consumption by each industry is shown in Table 3.21. Since the detail information on the energy service demand by energy service sector (such as direct heating, steam boiler, motor, and other industrial energy services) was not grasped, we used SAGE to split energy service demand by energy service sector (Appendix 12). Table 3.22 shows the energy service demand by energy service sector.

Table 3.21: Energy consumption by fuel type by industries in 2010 [ktoe/year]

Industry/fuel type	Coal	Petroleum products	Biofuels and waste	Electricity	**Total**
Agriculture, fishery, and forestry	0	123.95	0	0	123.95
Mining	0	2.30	0	0	2.30
Manufacturing	0	175.93	617.11	28.00	821.04
Electricity & Water	0	16.59	0	2.61	19.19
Construction	0	12.65	40.07	1.99	54.71
Total	**0**	**331.42**	**657.18**	**32.59**	**1,021.19**

Table 3.22: Energy service demand by energy service sectors in 2010 [ktoe/year]

Energy service/fuel type	Coal	Petroleum products	Biofuels and waste	Electricity	**Total**
Direct heat (furnace)	0	43.08	0	0	43.08
Steam boiler	0	155.77	657.18	2.93	815.88
Motor	0	0	0	25.42	25.42
Other industrial energy service	0	132.57	0	4.24	136.80
Total	**0**	**331.42**	**657.18**	**32.59**	**1,021.19**

Transportation sector:

Energy service sector of passenger and freight transportation are transportation modes. Total energy demand of transportation sector was obtained from the energy balance table in 2010; however, it was not disaggregated energy consumption between passenger and freight mode. Total energy demand of transportation sector was included non-energy use in transportation. Since the energy balance table expressed the value of energy consumption only for road, rail, inland waterways, and air, etc., this study assumed energy consumption of each energy service sector to be in proportion to the average vehicle distance (vehicle.km/year) of each mode and fuel efficiency. Energy service demand of each transportation mode by fuel type is shown in Table 3.23.

Table 3.23: Energy service demand by each transportation mode in 2010

Mode/fuel type		Coal	Petroleum products	Biofuels and waste	Electricity
Passenger transportation	Motorbike	0	64.14	0	0
	Tourist car	0	184.62	0	0
	Bus	0	53.53	0	0
	Train	0	0	0	0
	Ship	0	12.77	0	0
	Air	0	6.16	0	0
Sub-total		**0**	**321.22**	**0**	**0**
Freight transportation	Small cargo truck	0	82.01	0	0
	Big cargo truck	0	143.29	0	0
	Train	0	82.47	0	0
	Ship	0	16.10	0	0
Sub-total		**0**	**323.86**	**0**	**0**
Grand total		**0**	**645.08**	**0**	**0**

3.5 Future quantification

Cambodia has not developed any comprehensive economic development plan until 2050. The future socioeconomic projection primarily based on relevant Government policies and strategies set in the 5th term of the RGC and some other related documents. The values of the exogenous variables and coefficients of the ExSS tool are determined based on the qualitative information on those policies and strategies.

3.5.1 Population and household

The following sections explained the projection of the future population, number of households, and the average person per household.

Population projection

This study used the population projection towards 2030 projected by the NIS of the MoP, which will be about 18.39 million. Since there is no information on the population towards 2050, we used the information from the United Nations Population Projection with high variant, which projected that the population in Cambodia will reach about 21.96 million in 2050 (UN, 2011 and 2013). This study assumed the population projection with the high variant as it was observed that the projection under this scenario in 2030 is very similar to Cambodia's one in the same year, which is about 18.46 million. Concerning the population projection by age cohort, Cambodia currently projected only in 2028 and 2048 (Table 3.24) and this study assumed to be the same in 2030 and 2050, respectively.

Table 3.24: Population projection by age cohort in 2028 and 2048

Age cohort	2028	2048
	Share (%)	Share (%)
a0014*	25.80	20.80
a1564	67.30	67.90
a65+	6.90	11.30

* age group from 0 year to 14 years

Source: MoP (2013)

Moreover, there is no information about the population growth in the urban and rural areas towards 2050 in Cambodia. For the purpose of this study, we extrapolated the population in the urban and rural areas towards 2050 using on the historical trend. NIS (2012) estimated the annual population growth rate between 1998 and 2010 of 2.1% in the urban areas and this study assumed the trend will remain the same in the future. The population in the urban areas is projected to increase to around 29.55% and 44.78% in 2030 and 2050, respectively, (see Table 3.25). The estimated population in the urban areas in Cambodia in 2030 is similar to Vietnam's one in 2010 (31.0%), while the 2050's projection is similar to Thailand's one in 2030 (46.0%) (UNDESA, 2011).

Table 3.25: Population projection by household in 2030 and 2050 [1,000 persons]

Age cohort	2030		2050	
	Urban	Rural	Urban	Rural
a0014	1,402	3,343	2,046	2,523
a1564	3,657	8,720	6,678	8,236
a65+	375	894	1,111	1,371
Sub-total	5,434	12,956	9,835	12,129
Total population		18,391		21,964

Average persons per household by household type

This study assumed the average person per household is 4.2 and 4.5 persons for urban and rural areas in 2030 and 2050, respectively, decreasing from 4.8 in 2010. The assumption was referred to the historical trend where the average persons per household in the urban areas decreased from 5.5 to 4.8, while the rural areas decreased from 5.1 to 4.8 between 1998 and 2010, respectively, (NIS, 2011 and 2012). Table 3.26 shows the average persons per household by household type. It was also investigated that, in terms of decreasing rate, the urban areas decreased faster than the rural areas and this trend is expected to remain constant in the future as they want to move from the extended family (large number of people) to the nuclear one (smaller number of people) for a varieties of reasons such as family management, job competition, and economic development (MoP, 2013).

Table 3.26: Average persons per household by household type

Year	Country	Urban	Rural
1998	5.2	5.5	5.1
2008	4.7	5	4.6
2010	4.78	4.78	4.79
2030 (assumption)	4.4	4.2	4.5
2050 (assumption)	4.4	4.2	4.5

Number of households

The number of households is estimated from the information of the average persons per household above. The total number of households, about 3.0 million in 2010 will increase to about 4.2 million and 5.0 million in 2030 and 2050, respectively.

3.5.2 Macro economy

The projected macroeconomic indicators in the target year used in this study are shown in Table 3.27 and the procedure to derive these values will be explained thereafter.

Table 3.27: Macroeconomic indicators [Million USD at 2000 constant price]

Indicator	2010	2030	2050	2030/2010	2050/2010
GDP	7,518	29,093	112,582	3.87	14.97
Primary industry (share %)	30	22.68	19.03		
Secondary industry (share %)	29	34.33	37.83		
Tertiary industry (share %)	42	42.99	43.14		
GDP/Capita (USD at current price)	833	2,448	7,932	2.94	3.24
Gross outputs	17,699	74,068	298,873	4.18	16.89
Primary industry	3,136	9,265	30,082	2.95	9.59
Secondary industry	8,910	42,155	180,851	4.73	20.30
Tertiary industry	5,653	22,649	87,940	4.01	15.56
Private consumption	6,169	23,871	92,372	3.87	14.97
Government consumption	654	2,530	9,790	3.87	14.97
Gross fixed capital formation	1,650	6,384	24,706	3.87	14.97
Exports	6,256	24,208	93,676	3.87	14.97
Imports	7,210	27,899	107,961	3.87	14.97

Projected GDP growth

Cambodia experienced the average annual GDP growth rate of 7.7% from 1994 to 2011 (RGC, 2012), while the Asian Development Outlook projected the average annual GDP growth of 7.2% is retained between 2013 and 2014 (ADB, 2013). A few studies predicted Cambodia's GDP growth rate at around 7.0% in years to come. Similarly, the RGC recently forecast that the country would reach the status of an upper-middle income country by 2030 and a high-income level by 2050 (RGC, 2013). This commitment encouraged the country to keep a strong and consistent average annual GDP growth rate of around 7.0%. It emphasized that this growth should be sustainable, inclusive, equitable, and resilient to shocks through diversifying the economic base to achieve a more broad-based and competitive structure with low and manageable inflation, stable exchange rate and steady growth in international reserves.

This study assumed the average annual GDP growth rate to be similar to the Government's projection, which is 7.0% between 2010 and 2050. We did expect that the assumed GDP growth rate will be plausible as the Government planned to develop human resources for labor market, to improve infrastructure to facilitate trade, to expand and enhance industrial development, to increase value added from agriculture, and to strengthen governance and public institution to improve the investment climate. In addition, the Government also planned to exploit oil resources from the seabed in the near future (RGC, 2013).

The GDP, which was 7,518 million USD with per capita of 539USD (2000 constant price) or 833USD (2010 current price) in 2010, is projected to increase to 29,093 million USD in 2030 (3.87 times) with per capita of 2,448USD/year, which is similar to that of the Philippines in 2013 (2,496USD/year) and increase to 112,582 million USD (14.97 times) in 2050 with per capita of 7,932USD/year, which is similar to that of Malaysia in 2008 (8,088USD/year) (IMF, 2014). The gross industrial outputs are projected to increase by 4.18 times and 16.89 times in 2030 and 2050, respectively.

Final demand sectors

Since the Cambodian economy is projected to increase significantly in the target year, final demand sectors will also increase accordingly. This study assumed the average annual growth rate of final demand sectors (consumption expenditure, gross fixed capital formation, and export) to be similar to GDP growth rate, which is 7.0% from 2010 to 2050. Table 3.28 shows final demand sectors in Cambodia.

Table 3.28: Final demand sectors [Million USD at 2000 constant price]

Final demand sectors/year	2010	2030	2050	2030/2010	2050/2010
Consumption expenditure	6,822	26,401	102,163	3.87	14.97
Private consumption	6,169	23,871	92,372	3.87	14.97
Government consumption	654	2,530	9,790	3.87	14.97
Gross fixed capital formation	1,650	6,384	24,706	3.87	14.97
Private fixed capital formation	1,051	4,068	15,741	3.87	14.97
Government fixed capital formation	599	2,317	8,965	3.87	14.97
Export	6,256	24,208	93,676	3.87	14.97
Import	7,210	27,899	107,961	3.87	14.97

Economic structure

In terms of the contribution to the GDP, there is no doubt that the primary industry would decrease, while secondary industry and tertiary would increase when a country shifts from a low-income level to a middle- or high-income one. Since the Government of Cambodia has not projected any detail long term economic structure development, this study assumed the economic structure based on the Government development plan and other countries' experiences such as Thailand and Malaysia in which their economies are relying on the secondary and tertiary industry, while the primary industry contributes relatively smaller to the total GDP (Limmeechokchai *et al*., 2010 and Siong *et al*., 2013). As mentioned previously, the RGC is planning to shift from a low income to an upper middle income and a high income level by 2030 and 2050, respectively; it is, therefore, the secondary and tertiary industry is projected to grow substantially in the future. For instance, the Government stressed that it will promote the diversification of the secondary industry base through encouraging investments in new high value added, more creative and more competitive industries and expanding industrial development in the rural areas to boost economic growth, job creation, and the incomes of the people (RGC, 2013). The Government will also upgrade the diversification of manufacturing base and promote further development of small and medium enterprises (SMEs).

Hence, this study assumed that the share of the primary industry in private consumption decreased and substituted by the increase of goods and services of secondary and tertiary industries in both 2030 and 2050. Similarly, the share of the primary industry in export is projected to decrease and substituted by the increase of the secondary industry, while the share of tertiary industry is assumed to remain the same. Meanwhile, the percentage distribution of the Government consumption and expenditure and gross fixed capital formation in both 2030 and 2050 is assumed to remain the same as that of the base year. Table 3.29 shows the percentage distribution of private consumption and expenditure and export in Cambodia in 2030 and 2050.

Table 3.29: Percentage distribution of private consumption expenditure and export

Industry	Share of private consumption and expenditure (%)			Share of export (%)		
	2010	2030	2050	2010	2030	2050
Agriculture, forestry, & fishery	22.91	11.46	6.55	6.78	3.39	1.56
Mining	0	0	0	0	0	0
Manufacturing	36.72	45.18	50.09	71.77	75.16	76.98
Electricity, gas & water	4.61	5.61	5.61	0	0	0
Construction	0	0	0	0	0	0
Trade	1.93	1.93	1.93	0	0	0
Transport	1.79	1.79	1.79	8.71	8.71	8.71
Finance	0.82	0.82	0.82	0	0	0
Government services	1.16	1.16	1.16	0.03	0.03	0.03
Other private services	30.06	32.06	32.06	12.71	12.71	12.71

Projected IO table

The projected IO tables in 2030 and 2050 are shown in Appendices 13 and 14. The projected value added of the primary industry decreased, while the secondary and tertiary industry increased. Table 3.30 shows the value added by main industries and Table 3.31 shows value added by each industry in 2030 and 2050 (2000 constant price).

Table 3.30: Value added of main industries [Million USD at 2000 constant price]

Industry/year	2030	2050	Composition percentage (%)	
			2030	2050
Primary industry	6,598	21,423	22.68	19.03
Secondary industry	9,989	42,590	34.33	37.83
Tertiary industry	12,506	48,570	42.99	43.14
Total	29,093	112,582	100	100

Table 3.31: Value added by each industry [Million USD at 2000 constant price]

Industry/year	2030	2050	Composition percentage (%)	
			2030	2050
Agriculture, forestry, and fishery	6,598	21,423	22.68	19.03
Mining	222	930	0.76	0.83
Manufacturing	7,940	34,554	27.29	30.69
Electricity & Water	239	956	0.82	0.85
Construction	1,587	6,149	5.46	5.46
Trade	2,833	11,055	9.74	9.82
Transport & Communication	1,977	7,663	6.79	6.81
Finance	617	2,440	2.12	2.17
Government Services	376	1,454	1.29	1.29
Other Services	6,704	25,959	23.04	23.06
Total	29,093	112,582	100	100

3.5.3 Transportation demand

Transportation demand is expected to increase significantly in the target year due to the projected growth of the population, incomes, outputs of industry, and the construction and expansion of transportation infrastructures. Since the detail information was not fully acquired, some of the data were estimated by the author based on the professional judgment in consultation with the Cambodian experts and some other relevant stakeholders. The projected transportation demand indicators in both BaU and CM used in this study are shown in Table 3.32 and the detail procedure to derive these values is explained thereafter.

Table 3.32: Main transportation demand indicators in BaU and CM

Transportation mode/year	2030BaU	2030CM	2050BaU	2050CM	2030BaU	2030CM	2050BaU	2050CM
Motorbike	22,560	9,024	67,360	31,089	2.63	1.05	7.87	3.63
Tourist Car	101,544	56,523	378,983	299,184	5.95	3.31	22.20	17.52
Bus	49,283	51,387	183,935	166,215	3.29	3.43	12.27	11.09
Train	90,279	93,100	192,536	206,495	-	-	-	-
Ship	5	7	14	21	2.63	3.95	7.87	11.80
Air	171	171	765	765	5.27	5.27	23.60	23.60
Walk	4,325	4,978	2,695	3,061	0.93	1.07	0.58	0.66
Bicycle	8,651	7,965	5,390	4,576	1.01	0.93	0.63	0.54
Passenger transportation demand (Mil pass.km/year)	**276,819**	**223,155**	**831,678**	**711,406**	**5.14**	**4.15**	**15.45**	**13.22**
Small cargo truck	25,655	22,597	132,517	117,280	5.42	4.78	28.01	24.79
Big cargo truck	77,315	63,170	351,332	285,209	5.65	4.62	25.67	20.84
Train	11,277	15,506	121,341	133,475	-	-	-	-
Ship	1,801	2,702	14,535	21,802	12.55	18.83	101.32	151.98
Freight transportation demand (Mil ton.km/year)	**116,048**	**103,975**	**619,725**	**557,766**	**6.25**	**5.60**	**33.39**	**30.05**

Passenger transportation

In the target year, passenger transportation demand is expected to substantially increase thanks to road construction and expansion, increasing incomes of the people, and population growth. It is projected to increase to 276,819 million (pass.km)/ year (5.14 times) in 2030BaU and 831,678 million (pass.km)/year (15.45 times) in 2050BaU. However, it is expected to decrease to 223,155 million (pass.km)/year (4.15 times) and 711,406 million (pass.km)/year (13.22 times) in 2030CM and 2050CM, respectively. The projected passenger transportation demand indicators used in this study both in BaU and CM are shown in Table 3.33 and the detail procedure to derive these values is explained as followings.

Table 3.33: Passenger transportation demand indicators in BaU and CM

Mode	Average trip distance (km)				Model share (%)				Transportation demand (Mil pass.km/year)			
	2030BaU	2030CM	2050BaU	2050CM	2030BaU	2030CM	2050BaU	2050CM	2030BaU	2030CM	2050BaU	2050CM
Motorbike	10	6	10	6	16.79	11.20	33.59	25.84	22,560	9,024	67,360	31,089
Tourist Car	103	86	103	86	7.34	4.89	18.35	17.35	101,544	56,523	378,983	299,184
Bus	82	57	82	57	4.47	6.71	11.18	14.54	49,283	51,387	183,935	166,215
Train	96	66	96	66	7.00	10.50	10.00	15.60	90,279	93,100	192,536	206,495
Ship	36	36	36	36	0.00	0.00	0.00	0.00	5	7	14	21
Air	474	474	711	711	0.00	0.00	0.01	0.01	171	171	765	765
Walk	1	1	1	1	32.20	37.05	13.44	15.26	4,325	4,978	2,695	3,061
Bicycle	2	2	2	2	32.20	29.64	13.44	11.41	8,651	7,965	5,390	4,576

Trip generation (trip/(person.day)):

The trip generation is assumed to be the same in both BaU and CM. This study assumed the trip generation per person per day in 2030 to be similar to the base year (2 trips/(person.day)); however, it is supposed to increase to 2.5 trips/(person.day) in 2050 due to the projected increase of incomes of the people and more convenient transportation infrastructures. This assumption is similar to Thailand's projection in 2030 where it is 2.6 trips/(person.day) (Limmeechokchai *et al*., 2010).

Modal share (%*100):

Since there is no information on the projection of the modal share of passenger transportation modes, this study projected it by using available information and extrapolated from historical trends as well as the neighboring countries' experiences. The share of motorized vehicles is assumed to be similar to the projected increase of the number of motorized vehicles. It was observed that the number of motorbikes had experienced an average annual growth of around 22.76% (9.54 times) between 2000 and 2010 and during that time the average annual population growth of around 2.45% (1.62 times) (NIS, 2011). The substantial increase of the number of motorbikes was observed from 2005 to 2009; however, it started decreasing from 2010 onward. This trend brought the overall average annual growth rate down. Thus, we assumed that the number of motorbikes will grow slower in the target year than the past, which is similar to the projected population growth. Similarly, it was observed that the number of tourist cars had experienced an average annual growth of around 14.24% (2.90 times) between 2000 and 2010 and it still continued to increase (NIS, 2011). Hence, this study assumed that tourist cars will continue to grow in the target year due to the projected increase of incomes of the people and convenient transportation infrastructures. Meanwhile, the number of buses was observed to experience an average annual growth of around 12.25% (2.52 times) between 2000 and 2010 and it still continued to increase (NIS, 2011). Thus, this study assumed that the number of buses will increase in the target year as the Government is introducing public bus systems in Phnom Penh city and planning to expand to some other major cities (RGC, 2014).

Therefore, this study assumed that the share of motorbike will increase by 2.00 times in 2030BaU from 2010 and it is expected to retain the same growth from 2030BaU to 2050BaU. The share of tourist car is assumed to increase about 3.00 times in 2030BaU and it is expected to decrease to 2.5 times between 2030BaU and

2050BaU. Furthermore, the share of bus is assumed to increase about 2.50 times in 2030BaU from the base year and expected to maintain the same growth in 2050BaU from 2030BaU. Additionally, the share of train, ship, and air is assumed to be mainly based on the Government transportation development plan. Since the Government is planning to improve all means of transportation and expand some other means such as train and air; for instance, the Government is renovating the existing railways and expands several more to connect other parts of the country. The Government is also planning to introduce commuter light trains in some major cities in the future (RGC, 2014). Moreover, ADB (2011) indicated that the railway sector, the smallest mode in 2010, is expected to grow annually by 7.0%-12.0% to 2030. Besides, the Government is planning to renovate several more domestic airports, especially in the tourist destination provinces such as Rattanakiri, Stung Treng, Preah Vihear, and Koh Kong (MPWT, 2012). It was recently indicated that Cambodia will open a new airline company “Cambodia Bayon Airlines” to operate domestic flights at the end of December 2014 (extracted on 17 December 2014: http://www.phnompenhpost.com/business/bayon-air-welcomes-first-aircraft). Similarly, the Government is planning to improve inland waterway infrastructures to facilitate the ship navigation, especially along the Mekong River and Tonle sap lake.

As it is indicated above, we assumed the share of train is expected to contribute to about 7.0% and 10.0% in 2030BaU and 2050BaU, respectively. This sector used to contribute to about 20.0% of total passenger modes before 2005, during that time the road infrastructures were almost completely destroyed by the civil war (JICA, 2006a). This assumption is still slightly lower than Thailand’s projection in 2030 where the share of train is expected to contribute to around 12.0% (Limmeechokchai *et al*., 2010). Moreover, this study assumed the share of air will increase by 2.00 times in 2030BaU from 2010 and retain a similar growth in 2050BaU from 2030BaU. The share of ship is assumed to be double in 2030BaU from 2010 and to remain the same growth in 2050BaU from 2030BaU. The share of bicycle and walk is assumed to decrease in both 2030BaU and 2050BaU.

Under low carbon measures, the share of motorbike and car is assumed to decrease; conversely, the share of bus, ship, and train is assumed to increase in both 2030CM and 2050CM as we expected that the Government will introduce more buses and trains as well as inland waterway improvement. Meanwhile, the share of air is assumed to remain the same as in BaU. The share of walk is assumed to increase, while the share of bicycle is assumed to decrease.

Average trip distance (km/trip):

Since there is no information on the projection of the average trip distance of passenger transportation modes, this study assumed it by using available information, historical records, other countries' experiences, and the professional judgment of the author. We assumed that the average trip distance of motorbike, bus, ship, bicycle, and walk is the same as in the base year in both 2030BaU and 2050BaU; however, the average trip distance of the tourist car is assumed to increase by 1.5 times in both 2030BaU and 2050BaU due to the increase of road constructions and expansions set by the Government and increase incomes of the people. This assumption is very similar to Vietnam and Bangladesh where they assumed the average trip distance of this mode increased in the future due to the increase road infrastructures and incomes (Nguyen, 2012 and Tahsin, 2013). The average trip distance of air is assumed to increase by 2.00 times in 2030BaU from 2010 and another 1.5 times in 2050BaU from 2030BaU because the Government is planning to expand several new domestic airports to attract more tourists. The average trip distance of train in 2030BaU and 2050BaU is assumed to be similar to the past experiences where it was around 100km between 2002 and 2007 (MPWT, 2011). Thus, we assumed the average trip distance of this mode to be 96km in 2030BaU and 2050BaU.

Under low carbon measures, the average trip distance of tourist car, air, ship, bicycle, and walk is assumed to be the same as in the BaU in both 2030CM and 2050CM; however the average trip distance of motorbike and tourist car is assumed to decrease to 6km and 86km in both 2030CM and 2050CM. Besides, the average trip distance of bus and train is assumed to decrease to 57km and 66km in both 2030CM and 2050CM, respectively; thanks to the compact city development and better land use design.

Freight transportation

In the target year, freight transportation demand is expected to increase significantly thanks to the projected increase of outputs of industry as the Government is promoting industrial development through increasing manufacturing industries, handicrafts, and other agro-processing industries (RGC, 2013). It is projected to increase to 116,048 million ton.km/year (about 6.25 times) and 619,725 million ton.km/year (33.39 times) in 2030BaU and 2050BaU, respectively; however, under low carbon measures, it is expected to decrease to 103,975 million ton.km/year and 557,766 million ton.km/year in 2030CM and 2050CM, respectively. Freight transportation demand indicators used in this study both in the BaU and CM are shown Table 3.34 and the detail procedure to derive these values is explained as followings.

Table 3.34: Freight transportation demand indicators in BaU and CM

Mode	Average trip distance (km)				Model share (%)				Transportation demand (Mil ton.km/year)			
	2030BaU	2030CM	2050BaU	2050CM	2030BaU	2030CM	2050BaU	2050CM	2030BaU	2030CM	2050BaU	2050CM
Small cargo truck	109	100	109	100	25.05	24.05	24.05	23.20	25,655	22,597	132,517	117,280
Big cargo truck	130	115	130	115	63.29	58.45	53.45	49.05	77,315	63,170	351,332	285,209
Train	120	110	120	110	10.00	15.00	20.00	24.00	11,277	15,506	121,341	133,475
Ship	115	115	115	115	1.67	2.50	2.50	3.75	1,801	2,702	14,535	21,802

Freight transportation generation per industrial output (ton/USD):

Freight transportation generation per industrial output is expected to increase due to the projected increase of freight demand. This study assumed the freight generation per industrial output increased by 1.5 times and 2 times in 2030BaU and 2050BaU, respectively; compared to the base year and it is assumed to remain the same in both 2030CM and 2050CM.

Modal share (FTS_{ftm}) (%*100):

This study assumed that the share of the small cargo and big cargo truck will decrease in both 2030BaU and 2050BaU, substituted by the increase of the share of train and ship. As indicated previously, the Government is renovating the existing railways and also expanding several more lines in the future and they will be used mainly for freight purpose (MPWT, 2013). A similar prediction was carried out by ADB (2011), indicating that the train mode will grow significantly due to the increasing freight demand for economic development in the future in Cambodia. Therefore, we assumed that the share of train is expected to increase to 10.0% and 15.0% in 2030BaU and 2050BaU, respectively. The value of this assumption referred to the experience between 2002 and 2007 where the share of train was around 10.0% before it was destroyed (JICA, 2006a). Besides, the Government will improve the inland waterways to facilitate the navigation for both small and big cargo and oil tanker ships. Thus, the share of ship is assumed to increase twice in 2030BaU since 2010 and expected to increase another 1.5 times in 2050BaU from 2030BaU. Under low carbon measures, the share of train and ship is assumed to further increase, while the share of other modes is assumed to further decrease in both 2030CM and 2050CM.

Average trip distance (km/trip):

This study assumed the average trip distance of small cargo, big cargo truck, and ship to be similar to those of the base year in both 2030BaU and 2050BaU. The average trip distance of train in 2030BaU and 2050BaU is assumed to be the same as in 2011 and 2012 which was around 120km/trip (MPWT, 2013a).

Under low carbon measures, the average trip distance of the small cargo truck is assumed to decrease to 100km/trip, while the big cargo truck is assumed to decrease to 115km/trip in 2030CM and 2050CM. Similarly, the average trip distance of train is assumed to decrease to 110km/trip in 2030CM and 2050CM. However, the average trip distance of ship in 2030CM and 2050CM is assumed to be the same as in the BaU.

3.5.4 Energy sector

Energy supply and demand are expected to increase substantially in the target year due to the projected increase of population, economy, outputs of industry, and reducing electricity tariffs (RGC, 2013). The industrial sector, which was identified as a key dynamic indicator for industrialization and modernization of Cambodia’s economy, is a key sector consuming more electricity. Besides, residential and commercial sectors are also projected to consume large amount of electricity. Since the detail information of energy demand was not fully acquired, some of the data were estimated by the author based on the professional judgement and the consultation with the Cambodian experts and some other relevant stakeholders. The projected energy supply and demand indicators used in this study are shown in Table 3.35. The detail procedure to derive these values is explained thereafter.

Table 3.35: Projected energy supply and demand in Cambodia [ktoe/year]

Sector/year	2010	2030BaU	2030CM	2050BaU	2050CM	2030BaU/ 2010	2030CM/ 2010	2050BaU/ 2010	2050CM/ 2010
Residential	2,549	7,396	2,409	25,997	6,690	2.90	0.95	10.20	2.63
Commercial	172	1,107	672	3,086	1,560	6.45	3.91	17.98	9.09
Industry	1,021	6,100	3,453	20,868	11,497	5.97	3.38	20.43	11.26
Passenger transportation	321	2,005	879	7,006	3,027	6.24	2.74	21.81	9.42
Freight transportation	324	1,765	768	9,975	4,917	5.45	2.37	30.80	15.18
Total final energy demand	**4,386**	**18,374**	**8,180**	**66,932**	**27,691**	**4.19**	**1.86**	**15.26**	**6.31**
Coal	8	440	142	1,693	368	54.51	17.63	209.62	45.60
Petroleum products	1,351	6,210	2,905	24,464	11,429	4.60	2.15	18.11	8.46
Natural gas	0	970	374	3,729	968	-	-	-	-
Hydropower	2	390	170	1,501	440	-	-	-	-
Solar/wind	0	11	24	43	63	-	-	-	-
Biofuels and waste	3,109	11,241	4,854	38,918	15,173	3.62	1.56	12.52	4.88
Import	117	65	28	251	74	0.56	0.24	2.15	0.63
Total primary energy supply	**4,587**	**19,327**	**8,499**	**70,598**	**28,515**	**4.21**	**1.85**	**15.39**	**6.22**

Power supply

To meet the pressing need of energy demand, the RGC adopted the best alternative options for more constant, reliable, and affordable sources of energy. The share of fuel mix of power generation is expected to change drastically from the base year, according to the recent Government's power development plan. The Government has boosted and diversified energy supply sources to reduce reliance on fossil fuels for electricity generation. In that sense, the construction of hydropower and coal-fired power plants is prioritized after natural gas and the Government has strongly confirmed the country's available capacity and facilities to build either hydropower dams or coal power plants, while natural gas is still under study by the experts (Kunleang, 2012). Furthermore, the expansion of the transmission line and distribution networks as well as a reduction in electricity losses to accommodate the electricity demand as a result of economic growth and a rise in the number of households, businesses, and industries are also focused. The Government has also encouraged introducing and investing in other sources of energy originated from renewable sources such as biomass/biogas, wind and solar power to respond to the need of the people where the national grid cannot be accessed (RGC, 2013).

According to the power development master plan of Cambodia towards 2030 supported by the Chugoku electric power company in Japan indicated that the share of fuel mix of power generation in 2030 comprised Natural gas (40.0%), Hydropower (35.0%), Coal (15.0%), Import (6.0%), Oil (3.0%), and Renewable energy (1.0%) (MME, 2014) and these values will be used for this study. In addition, since there is no information on the projected fuel mix of power generation towards 2050, this study assumed it will be the same as in 2030. Besides, to ensure the sufficient energy supply, the Government will also improve energy efficiency, especially from coal and oil in the future to be similar to some advanced countries such as Japan and France, etc. This study assumed energy efficiency of coal and oil will increase from 33.01% and 32.5% in 2010 to 38.0% in 2030BaU and 2050BaU, respectively, (Erik, 2011 and MME, 2014). Similarly, the efficiency of gas is assumed to be 46.0% in both 2030BaU and 2050BaU, which is similar to the average value of some developed countries such as Australia, France, Japan, Korea Republic, and the United States in 2008 (Erik, 2011). The transmission loss and own use are also assumed to decrease where the transmission loss is assumed to decrease from 12.23% in 2010 to 7.0% in both 2030BaU and 2050BaU. This assumption was referred to the historical experience where the transmission loss had decreased from more than 14.0% in 2004 to 7.42% in 2012 and we expected it will continue to decrease in the future (EAC, 2012).

Under low-carbon measures, renewable energy (including, solar power, biogas/ biomass, and wind power) is assumed to increase its share to 5.0% with the reduction of oil and coal accordingly, while hydropower is assumed to remain the same as in BaU. This study introduced the solar power as the main source of renewable energy because several studies yielded that Cambodia has very high potential for this source in every part of the country. For instance, JICA (2006a) figured out that Cambodia could generate the average annual solar irradiation of more than 5.10kWh/m^2/day. Besides, Rogier (2011) indicated solar power is a good alternative energy option for Cambodia's people living in the rural areas where the national grid cannot be accessed. He added that Cambodia developed a solar roadmap towards 2020 aiming at identifying areas and activities required to professionalize the solar market to be affordable, attractive and accessible and to enable as many as possible of 1.6 million households that are at present relying on car batteries and kerosene lamps. Moreover, the energy efficiency of coal and oil is assumed to increase to 41.0% and 44.0% in 2030CM and 2050CM, respectively; which is similar to some advanced countries (Erik, 2011). The efficiency of natural gas is assumed to increase to 52.0% in both 2030CM and 2050CM, which is similar to UK and Ireland in 2008 (Erik, 2011). The transmission loss is also assumed to further decrease to 6.5% in both 2030CM and 2050CM. Table 3.36 shows the share of the fuel mix of power generation and Table 3.37 shows power supply by fuel type (ktoe).

Table 3.36: Projected fuel mix of power generation in Cambodia [%]

Fuel/year	2010	2030BaU	2030CM	2050BaU	2050CM
Coal	1.3	15.0	12.0	15.0	12.0
Petroleum products	38.2	3.0	2.0	3.0	2.0
Hydropower	1.1	35.0	35.0	35.0	35.0
Natural gas	0.0	40.0	40.0	40.0	40.0
Biofuels and waste	0.8	0.0	0.0	0.0	0.0
Solar/wind	0.1	1.0	5.0	1.0	5.0
Import	58.4	6.0	6.0	6.0	6.0
Total	**100**	**100**	**100**	**100**	**100**

Table 3.37: Projected power supply by fuel type [ktoe/year]

Fuel/year	2010	2030BaU	2030CM	2050BaU	2050CM
Coal	3	152	53	583	138
Petroleum products	79	30	9	117	23
Hydropower	2	354	155	1,361	401
Natural gas	0	404	177	1,555	459
Biofuels and waste	2	-	-	-	-
Solar/wind	0	10	22	39	57
Import	117	61	27	233	69
Total	**202**	**1,011**	**443**	**3,888**	**1,147**

Energy demand

The higher the population growth, the higher the growth rate of electricity consumption. The higher the urbanization rate, increase of incomes and improvement of living standard, the more heavily consuming electrical appliances such as refrigerators, air conditioners, rice cookers, TV sets, radios and washing machines, and the energy efficiency of these appliances as well as their efficient uses become important issues.

In response to the increasing energy needs, the RGC set two long-term energy development targets, first is to achieve the 100% level of village electrification by 2020 and second is to achieve 70.0% level of household electrification with grid quality electricity by 2030 (MME, 2013). Theoretically, energy consumption by the end users indicated by the energy service demand per driving force (Esvg) and they are assumed to increase due to the projected increase of incomes of the people, industrial activities, and increase of areas and population who can access to electricity.

According to Lieng (2013), energy demand was projected to increase annually by 4.7% between 2010 and 2035. He stressed that the strongest growth is the industrial sector at 5.4%; followed by the transportation sector at 4.6%, while the residential and commercial sector is at 4.4%. With limited information, this study assumed that energy demand by sectors between 2010 and 2030BaU to be similar to Lieng's one. However, we assumed that energy demand will grow annually only by half between 2030BaU and 2050BaU. This assumption is similar to the projected energy demand in the draft SNC in which energy demand sectors are projected to grow slower between 2025 and 2050 compared to a projection between 2008 and 2024. Furthermore, it was noted that energy demand is already projected to peak between 2010 and 2030 to respond to the pressing needs of the people and economic development.

Energy demand by energy demand sectors:

Final energy demand is projected to increase to around 18,374ktoe/year (4.56 times) and 66,932ktoe/year (15.26 times) in 2030BaU and 2050BaU, respectively; however, by adopting low-carbon measures, the Government can limit final energy demand to about 8,180ktoe/year (2.34 times) and 27,691ktoe/year (6.31 times) in 2030CM and 2050CM, respectively. Energy consumption per capita is projected to increase to around 999koe/year and 3,047koe/year in 2030BaU and 2050BaU, respectively, from around 314koe/year in 2010. It is expected to decrease to about 445koe/year and 1,261koe/year in 2030CM and 2050CM, respectively. GDP per unit of energy is projected to be around 5.93koe/USD and 6.30koe/USD in 2030BaU and 2050BaU, respectively, compared to around 6.42koe/USD in 2010 (GDP in PPP at 2005 constant price). Table 3.38 presents final energy demand by fuel type and Table 3.39 shows final energy consumption by energy demand sectors.

Table 3.38: Projected final energy demand by fuel types [ktoe/year]

2030BaU	Coal	Petroleum products	Biofuels and waste	Electricity	**Total**
Residential	0	373	6,727	296	**7,396**
Commercial	0	20	765	323	**1,107**
Industrial	0	2,137	3,749	214	**6,100**
Passenger transportation	0	1,870	0	135	**2,005**
Freight transportation	0	1,722	0	42	**1,765**
Total	**0**	**6,122**	**11,241**	**1,011**	**18,374**
2030CM					
Residential	0	138	2,127	144	**2,409**
Commercial	0	14	529	128	**672**
Industrial	0	1,141	2,198	114	**3,453**
Passenger transportation	0	826	0	53	**879**
Freight transportation	0	763	0	4	**768**
Total	**0**	**2,883**	**4,854**	**443**	**8,180**
2050BaU					
Residential	0	1,533	23,255	1,209	**25,997**
Commercial	0	49	2,210	826	**3,086**
Industrial	0	6,804	13,453	610	**20,868**
Passenger transportation	0	6,524	0	481	**7,006**
Freight transportation	0	9,214	0	762	**9,975**
Total	**0**	**24,125**	**38,918**	**3,888**	**66,932**
2050CM					
Residential	0	306	6,066	318	**6,690**
Commercial	0	30	1,176	353	**1,560**
Industrial	0	3,316	7,931	250	**11,497**
Passenger transportation	0	2,884	0	143	**3,027**
Freight transportation	0	4,835	0	82	**4,917**
Total	**0**	**11,371**	**15,173**	**1,147**	**27,691**

Table 3.39: Projected final energy demand by energy demand sectors [ktoe/year]

Sector/year	2010	2030BaU	2030CM	2050BaU	2050CM	2030BaU /2010	2030CM /2010	2050BaU /2010	2050CM /2010
Residential	2,549	7,396	2,409	25,997	6,690	2.90	0.95	10.20	2.63
Commercial	172	1,107	672	3,086	1,560	6.45	3.91	17.98	9.09
Industry	1,021	6,100	3,453	20,868	11,497	7.55	5.43	20.43	11.26
Passenger transportation	321	2,005	879	7,006	3,027	6.24	2.74	21.81	9.42
Freight transportation	324	1,765	768	9,975	4,917	5.45	2.37	30.80	15.18
Total	**4,386**	**18,374**	**8,180**	**66,932**	**27,691**	**4.56**	**2.34**	**15.26**	**6.31**
Per capita (koe/person)	**314**	**999**	**445**	**3,047**	**1,261**	**3.18**	**1.42**	**9.70**	**4.02**

Residential sector:

Energy demand in the residential sector depends primarily on living standard and life style and increase of areas and population who can access to electricity. This study assumed energy demand per household increased due to the growth of per capita income and the improvement of energy access through urbanization and rural electrification as well as the diffusion of electric appliances to advance the living standards between 2010 and 2050. It was indicated when the income per household increased; more households are expected to equip with air conditioners and more electric appliances such as TV, refrigerator, washing machine, personal computer, etc. that will contribute to increasing energy demand accordingly.

This study assumed energy demand in this sector will grow annually by 4.4% between 2010 and 2030BaU and it is expected to grow annually by only half from 2030BaU to 2050BaU; that is 2.2%. However, under low carbon measures, energy savings and conservation are chosen. MME (2013) indicated in national policy, strategy, and action plan on energy efficiency that Cambodia is expected to reduce energy consumption by 20.0% between 2009 and 2035 by effective implementation of energy consumption savings and conservation. Hence, this study assumed that energy consumption in the residential sector is expected to reduce by 20.0% in 2030CM and 2050CM accordingly. This means that energy consumption in this sector decreases to 3.5% and 1.8% in 2030CM and 2050CM, respectively, from the BaU.

Therefore, energy demand in the residential sector was around 2,549ktoe/year in 2010 and it is expected to increase to around 7,396ktoe/year and 25,997ktoe/year in 2030BaU and 2050BaU, respectively; however, it is projected to decrease to about 2,409ktoe/year and 6,690ktoe/year in 2030CM and 2050CM, respectively. Table 3.40 shows the final energy demand in the residential sector by energy service sector by fuel type (ktoe/year).

Table 3.40: Energy demand in the residential sector by energy service sectors by fuel type [ktoe/year]

Energy service/fuel type	Coal	Petroleum products	Biofuels and waste	Electricity	**Total**
2030BaU					
Cooling	0	0	0	47	**47**
Heating	0	17	161	8	**186**
Hot water	0	21	241	11	**273**
Kitchen	0	243	6,325	20	**6,588**
Lighting	0	92	0	112	**204**
Refrigerator	0	0	0	31	**31**
Other electric equipment	0	0	0	66	**66**
2030CM					
Cooling	0	0	0	21	**21**
Heating	0	14	94	4	**112**
Hot water	0	15	212	7	**234**
Kitchen	0	74	1,821	13	**1,909**
Lighting	0	35	0	46	**81**
Refrigerator	0	0	0	18	**18**
Other electric equipment	0	0	0	35	**35**
2050BaU					
Cooling	0	0	0	139	**139**
Heating	0	60	675	35	**770**
Hot water	0	68	770	37	**874**
Kitchen	0	1,025	21,809	56	**22,890**
Lighting	0	381	0	503	**884**
Refrigerator	0	0	0	140	**140**
Other electric equipment	0	0	0	299	**299**
2050CM					
Cooling	0	0	0	32	**32**
Heating	0	23	216	8	**247**
Hot water	0	22	651	9	**682**
Kitchen	0	199	5,199	20	**5,419**
Lighting	0	63	0	117	**180**
Refrigerator	0	0	0	36	**36**
Other electric equipment	0	0	0	95	**95**

Commercial sector:

Energy demand in the commercial sector is expected to grow at a high rate, in parallel with economic growth. JICA (2012) reported that electricity consumption in this sector dropped down to 31.7% in 2010 from 33.0% in 2009. It is, however, projected to increase in the future due to economic growth and increase of areas which can access to electricity.

This study assumed energy demand in this sector will grow annually by 4.4% between 2010 and 2030BaU and it is expected to grow annually by only half from 2030BaU to 2050BaU; that is 2.2%. However, under low carbon measures, energy savings and conservation are chosen. MME (2013) indicated in national policy, strategy, and action plan on energy efficiency that Cambodia is expected to reduce energy consumption by 20.0% between 2009 and 2035 by effective implementation of energy savings and conservation. Hence, this study assumed that energy consumption in the commercial sector is expected to reduce by 20.0% in 2030CM and 2050CM accordingly. This means that energy consumption in this sector decreases to 3.5% and 1.8% in 2030CM and 2050CM, respectively, from the BaU.

Therefore, energy demand in this sector is projected to increase to about 1,107ktoe/year and 3,086ktoe/year in 2030BaU and 2050BaU, respectively, from about 172ktoe/year in 2010 and it is projected to decrease to around 672ktoe/year and 1,560ktoe/year in 2030CM and 2050CM. Table 3.41 shows the final energy demand in the commercial sector by energy service sectors by fuel type (ktoe/year).

Table 3.41: Energy demand in the commercial sector by energy service sectors by fuel type [ktoe/year]

Energy service/fuel type	Coal	Petroleum products	Biofuels and waste	Electricity	**Total**
2030BaU					
Cooling	0	0	0	27	**27**
Heating	0	13	306	16	**335**
Hot water	0	6	255	16	**277**
Kitchen	0	1	204	2	**206**
Lighting	0	0	0	137	**137**
Refrigerator	0	0	0	78	**78**
Other electric equipment	0	0	0	48	**48**
2030CM					
Cooling	0	0	0	19	**19**
Heating	0	11	258	7	**277**
Hot water	0	3	108	4	**114**
Kitchen	0	0	163	1	**165**
Lighting	0	0	0	36	**36**
Refrigerator	0	0	0	29	**29**
Other electric equipment	0	0	0	32	**32**
2050BaU					
Cooling	0	0	0	104	**104**
Heating	0	25	597	31	**654**
Hot water	0	22	896	63	**981**
Kitchen	0	2	717	11	**730**
Lighting	0	0	0	281	**281**
Refrigerator	0	0	0	160	**160**
Other electric equipment	0	0	0	176	**176**
2050CM					
Cooling	0	0	0	69	**69**
Heating	0	21	504	21	**546**
Hot water	0	8	320	20	**349**
Kitchen	0	1	352	4	**356**
Lighting	0	0	0	73	**73**
Refrigerator	0	0	0	79	**79**
Other electric equipment	0	0	0	87	**87**

Industrial sector:

The industrial sector showed a strong growth within the last several years. Among the energy consuming industries, the garment sector was considered as the main driving force, followed by the fabrication of clay bricks for construction, the rice mills for processing paddy into polished rice, the rubber production and the food sector (MME, 2013). In addition, the Government just set an ambitious target to shift from a low income level to the middle income one by 2030 and to a developed level by 2050; thus energy demand in this sector is expected to increase significantly and its share in total final energy demand is projected to be higher than other sectors.

This study assumed energy demand in this sector will grow annually by 5.4% between 2010 and 2030BaU and it is expected to grow annually by only half from 2030BaU to 2050BaU; that is 2.7%. However, under low carbon measures, energy savings and conservation are chosen. MME (2013) indicated in national policy, strategy, and action plan on energy efficiency that Cambodia is expected to reduce energy consumption by 20.0% between 2009 and 2035 by effective implementation of energy savings and conservation. Hence, this study assumed that energy consumption in the industrial sector is expected to reduce by 20.0% in 2030CM and 2050CM accordingly. This means that energy consumption in this sector decreases to 4.3% and 2.2% in 2030CM and 2050CM, respectively from the BaU.

Therefore, energy demand in the industrial sector is projected to spike to about 6,100ktoe/year and 20,868ktoe/year in 2030BaU and 2050BaU, respectively; and it is expected to decrease to around 3,453ktoe/year and 11,497ktoe/year in 2030CM and 2050CM, respectively. Table 3.42 shows the final energy demand in each industry (ktoe/year) and Table 3.43 shows the final energy demand by industries, by energy service, and by fuel type (ktoe/year).

Table 3.42: Energy demand in each industry by fuel type [ktoe/year]

Industry/fuel type	Coal	Petroleum products	Biofuels and waste	Electricity	**Total**
2030BAU					
Agriculture, forestry, and fishery	0	829	0	0	**829**
Mining	0	11	0	0	**11**
Manufacturing	0	1,122	3,417	189	**4,728**
Electricity & Water	0	82	332	11	**425**
Construction	0	93	0	15	**107**
Total	**0**	**2,137**	**3,749**	**214**	**6,100**
2030CM					
Agriculture, forestry, and fishery	0	392	0	0	**392**
Mining	0	7	0	0	**7**
Manufacturing	0	654	2,002	101	**2,757**
Electricity & Water	0	45	196	6	**247**
Construction	0	44	0	7	**50**
Total	**0**	**1,141**	**2,198**	**114**	**3,453**
2050BAU					
Agriculture, forestry, and fishery	0	2,269	0	0	**2,269**
Mining	0	41	0	0	**41**
Manufacturing	0	3,894	12,392	529	**16,815**
Electricity & Water	0	279	1,061	36	**1,376**
Construction	0	321	0	45	**366**
Total	**0**	**6,804**	**13,453**	**610**	**20,868**
2050CM					
Agriculture, forestry, and fishery	0	1,011	0	0	**1,011**
Mining	0	22	0	0	**22**
Manufacturing	0	2,015	7,281	212	**9,508**
Electricity & Water	0	134	650	18	**803**
Construction	0	134	0	20	**154**
Total	**0**	**3,316**	**7,931**	**250**	**11,497**

Table 3.43: Projected final energy demand in industry by energy service sectors by fuel type [ktoe/year]

Energy service/fuel type	Coal	Petroleum products	Biofuels and waste	Electricity	**Total**
2030BAU					
Direct heat (furnace)	0	272	0	20	**292**
Steam boiler	0	925	3,749	0	**4,674**
Motor	0	0	0	171	**171**
Other industrial energy service	0	940	0	24	**964**
2030CM					
Direct heat (furnace)	0	116	0	7	**123**
Steam boiler	0	528	2,198	0	**2,726**
Motor	0	0	0	95	**95**
Other industrial energy service	0	497	0	11	**509**
2050BAU					
Direct heat (furnace)	0	826	0	51	**877**
Steam boiler	0	3,235	13,453	0	**16,688**
Motor	0	0	0	486	**486**
Other industrial energy service	0	2,744	0	73	**2,817**
2050CM					
Direct heat (furnace)	0	341	0	20	**361**
Steam boiler	0	1,534	7,931	0	**9,465**
Motor	0	0	0	192	**192**
Other industrial energy service	0	1,442	0	38	**1,479**

Transportation sector:

Since this study assumed transportation demand will increase substantially in the future, energy demand in this sector is expected to increase accordingly. Energy demand in the passenger transportation sector is projected to increase to approximately 2,005ktoe and 7,006ktoe in 2030BaU and 2050BaU, respectively; however, it is projected to decrease to roughly 879ktoe and 3,027ktoe in 2030CM and 2050CM, respectively. Similarly, energy demand in the freight transportation sector is projected to increase to around 1,765ktoe and 9,975ktoe in 2030BaU and 2050BaU, respectively; however, it is expected to decrease to about 768ktoe and 4,917ktoe in 2030CM and 2050CM, respectively. Table 3.44 shows the final energy demand in the transportation sector by transportation modes by fuel types.

Table 3.44: Energy demand in transportation sector by modes by fuel types [ktoe/year]

	Transportation mode/fuel type	Coal	Petroleum products	Biofuels and waste	Electricity
	2030BAU				
Passenger transportation	Motorbike	0	169	0	0
	Tourist car	0	1,098	0	0
	Bus	0	379	0	0
	Train	0	144	0	135
	Ship	0	48	0	0
	Air	0	32	0	0
	Total	**0**	**1,870**	**0**	**135**
	2030BAU				
Freight transportation	Small cargo truck	0	445	0	0
	Big cargo truck	0	809	0	0
	Train	0	402	0	42
	Ship	0	66	0	0
	Total	**0**	**1,722**	**0**	**42**
	2030CM				
Passenger transportation	Motorbike	0	64	0	0
	Tourist car	0	387	0	0
	Bus	0	189	0	0
	Train	0	148	0	53
	Ship	0	21	0	0
	Air	0	18	0	0
	Total	**0**	**826**	**0**	**53**
Freight transportation	Small cargo truck	0	178	0	0
	Big cargo truck	0	199	0	0
	Train	0	366	0	4
	Ship	0	20	0	0
	Total	**0**	**763**	**0**	**4**
	2050BAU				
Passenger transportation	Motorbike	0	792	0	0
	Tourist car	0	4,189	0	0
	Bus	0	973	0	0
	Train	0	219	0	481
	Ship	0	258	0	0
	Air	0	93	0	0
	Total	**0**	**6,524**	**0**	**481**
Freight transportation	Small cargo truck	0	2,209	0	0
	Big cargo truck	0	3,566	0	0
	Train	0	3,087	0	762
	Ship	0	352	0	0
	Total	**0**	**9,214**	**0**	**762**
	2050CM				
Passenger transportation	Motorbike	0	212	0	0
	Tourist car	0	1,676	0	0
	Bus	0	558	0	0
	Train	0	235	0	143
	Ship	0	139	0	0
	Air	0	64	0	0
	Total	**0**	**2,884**	**0**	**143**
Freight transportation	Small cargo truck	0	696	0	0
	Big cargo truck	0	634	0	0
	Train	0	3,395	0	82
	Ship	0	109	0	0
	Total	**0**	**4,835**	**0**	**82**

3.6 Results

3.6.1 CO_2 emissions and reduction potentials

The ExSS tool is used to estimate CO_2 emissions based on fuel inputs and domestic energy consumption; however, if the Government plans to export the electricity, CO_2 emissions will be calculated exogenously. CO_2 emissions in Cambodia are projected to increase to about 23,277ktCO_2/year (about 5.52 times) and 91,325ktCO_2/year (21.64 times) in 2030BaU and 2050BaU, respectively; however, under low carbon measures, they are expected to decrease to approximately 10,451ktCO_2/year (about 2.48 times) and 39,172ktCO_2/year (9.28 times) in 2030CM and 2050CM, respectively. The result suggested that, under low carbon measures, CO_2 emissions are projected to reduce by 55.10% and 57.11% in 2030CM and 2050CM, respectively. Per capita CO_2 emissions were about 0.30tCO_2/year in 2010 and are expected to increase to around 1.27tCO_2/year and 4.16tCO_2/year in 2030BaU and 2050BaU, respectively; however, under low carbon measures; they are expected to decrease to about 0.57tCO_2/year and 1.78tCO_2/year in 2030CM and 2050CM, respectively. CO_2 emissions per GDP were around 0.36kgCO_2/USD/year in 2010 (or 0.48kgCO_2/USD/year in 2005 constant price) and are expected to increase to around 0.52kgCO_2/USD/year in both 2030BaU and 2050BaU. Under low carbon measures; they are projected to decrease to about 0.23kgCO_2/USD/year and 0.22kgCO_2/USD/year in 2030CM and 2050CM, respectively. A summary of the projected CO_2 emissions and mitigation potentials is shown in Table 3.45.

Table 3.45: CO_2 emissions and mitigation potentials [ktCO_2/year]

CO_2 emissions/year	2010	2030BaU	2030CM	2050BaU	2050CM	2030BaU /2010	2030CM /2010	2050BaU /2010	2050CM /2010
Residential	830	2,414	918	9,889	2,034	2.91	1.11	11.91	2.45
Commercial	217	1,433	482	3,663	1,298	6.61	2.22	16.90	5.99
Industrial	1,173	7,536	3,926	23,691	11,136	6.42	3.35	20.19	9.49
Passenger transportation	996	6,374	2,743	22,276	9,431	6.40	2.75	22.36	9.47
Freight transportation	1,004	5,521	2,383	31,806	15,273	5.50	2.37	31.67	15.21
Total emissions and reduction	4,221	23,277	10,451	91,325	39,172	5.52	2.48	21.64	9.28
Per capita emission (tCO_2/person)	0.30	1.27	0.57	4.16	1.78	4.19	1.88	13.75	5.90
Per GDP emission (kgCO_2/USD)	0.36	0.52	0.23	0.52	0.22	1.43	0.64	1.45	0.62

3.6.2 CO_2 emissions and reduction potentials by sectors

The results yield that the industrial sector accounts for the largest share of total CO_2 emissions, emitting about 7,536ktCO_2/year (about 32.37%), followed by the passenger transportation which emitted about 6,374ktCO_2/year (about 27.38%) in 2030BaU. The freight transportation is projected to emit about 5,521ktCO_2/year (about 23.72%), while residential and commercial sectors are projected to emit about 2,414ktCO_2/year and 918ktCO_2/year (about 10.37% and 6.15%), respectively, in 2030BaU. However, it is projected that freight transportation accounts for the largest share of total CO_2 emissions, emitting about 31,806ktCO_2/year (about 34.83%), followed by the industrial sector, which emitted about 23,691ktCO_2/year (about 25.94%) in 2050BaU. Passenger transportation is projected to emit about 22,276ktCO_2/year (about 24.39%), while residential and commercial sectors are projected to emit about 9,889ktCO_2/year and 3,663ktCO_2/year (about 10.83% and 4.01%), respectively, in 2050BaU.

Under low carbon measures, the results yield that around 8,714ktCO_2/year of total emissions reduction can be achieved by improving energy efficiency in 2030CM and 40,220ktCO_2/year in 2050CM, while about 1,793ktCO_2/year and 3,248ktCO_2/year in 2030CM and 2050CM, respectively, can be achieved by adopting a modal shift. Energy efficiency improvement in the power sector (reducing transmission loss and fuel switch to renewable energy) is projected to reduce CO_2 emissions by about 560ktCO_2/year and 1,726ktCO_2/year in 2030CM and 2050CM, respectively. The implementation of fuel switch is expected to reduce CO_2 emissions of around 204ktCO_2 and 2,207ktCO_2/year in 2030CM and 2050CM, while energy saving behavior and conservation are expected to reduce CO_2 emissions by approximately 1,555ktCO_2/year and 4,751ktCO_2/year in 2030CM and 2050CM, respectively. CO_2 emission reductions by sectors and by each category of measures in 2030CM and 2050CM are shown in Figure 3.5.

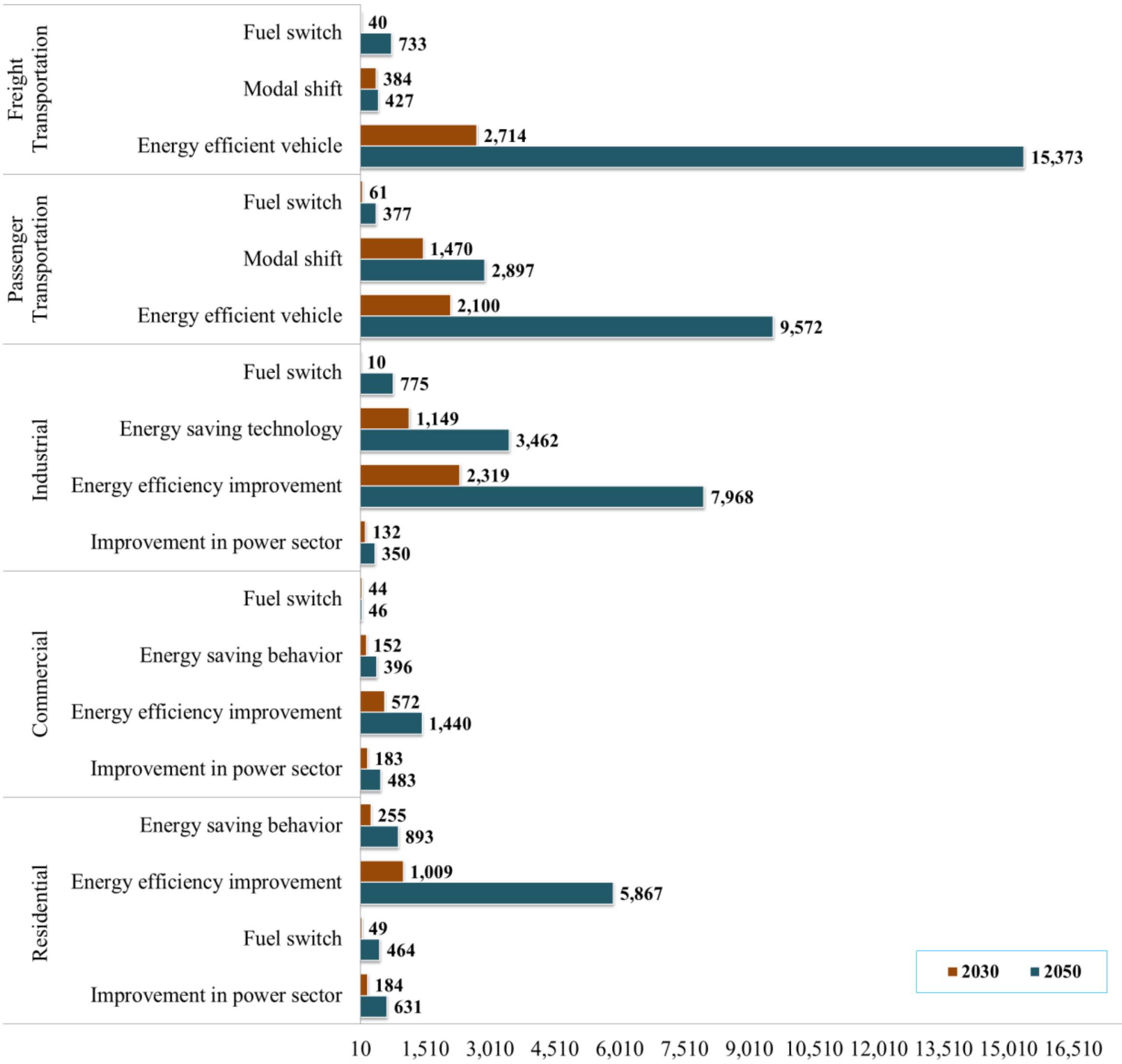

Figure 3.5: CO_2 emissions reduction by sectors, and by each category of measures [ktCO_2/year] in 2030CM and 2050CM

Residential sector's emissions and reduction potentials

Increasing energy demand in the residential sector depends on the population growth, increasing incomes of the people, and increase of areas and population who can access to electricity. Cambodia's population is projected to increase to about 18.46 million by 2030 and about 19.96 million by 2050, while the GDP growth rate is expected to be 7.0% from 2010 to 2050. Energy demand in this sector is projected to increase about 2.9 times and 10.2 times in 2030BaU and 2050BaU, respectively, larger than in 2010. The result yields that CO_2 emissions in this sector are projected to increase to about

2,414ktCO_2/year and 9,889ktCO_2/year, which are about 2.91 times and 11.91 times in 2030BaU and 2050BaU, respectively, bigger than in 2010. However, CO_2 emissions reduction of around 1,313ktCO_2/year and 7,224ktCO_2/year in 2030CM and 2050CM, respectively, can be achieved by adopting low carbon measures, *e.g.* energy efficiency improvement of electrical and non-electrical equipment, fuel switch, and energy saving behavior and conservation. Among them, efficient cooking system, energy efficient lighting, refrigerator, and cooling options are the most potential of emissions reduction in this sector. Figure 3.6 shows CO_2 emissions reduction by energy service sector (ktCO_2) in the residential sector.

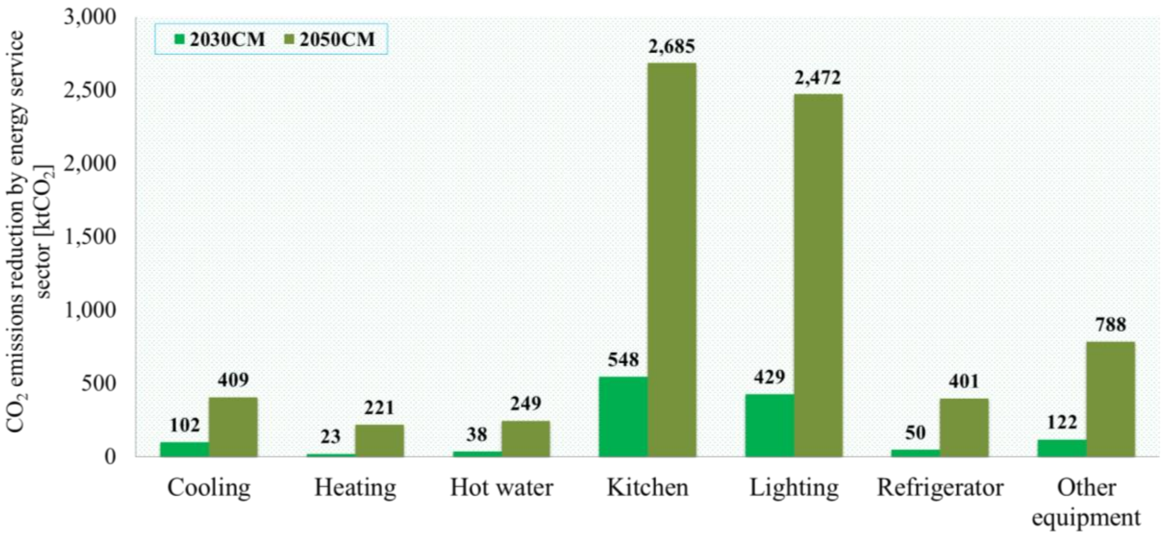

Figure 3.6: CO_2 emissions reduction by energy service sectors in the residential sector [ktCO_2/year]

Commercial sector's emissions and reduction potentials

Energy demand in the commercial sector is driven by the growth of the outputs of tertiary industry, which is projected to increase about 4.01 times and 15.56 times in 2030 and 2050, respectively, larger than in 2010. Energy demand in this sector is projected to increase about 6.45 times and 17.98 times in 2030BaU and 2050BaU, respectively. The result yields that CO_2 emissions in this sector are expected to emit about 1,443ktCO_2/year and 3,663ktCO_2/year, which are about 6.61 times and 16.90 times in 2030BaU and 2050BaU, respectively, from 2010. However, under low carbon measures, improvement in energy efficiency (electric devices, insulation buildings), efficient improvement in the power sector, and energy saving behavior and conservation are the potential options for CO_2 emissions reduction, and expected to reduce CO_2 emissions by about 768ktCO_2/year and 1,882ktCO_2/year of total emissions reduction in 2030CM and 2050CM, respectively. Figure 3.7 shows CO_2 emissions reduction by energy service sector in the commercial sector.

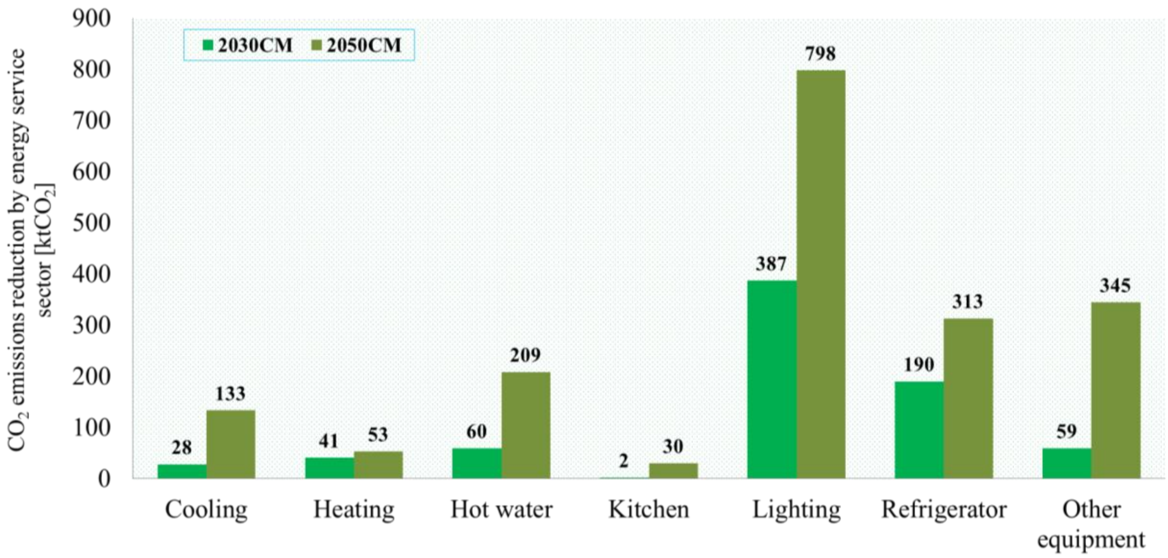

Figure 3.7: CO_2 emissions reduction by energy service sectors in the commercial sector [ktCO_2/year]

Industrial sector's emissions and reduction potentials

This study assumed the average annual GDP growth rate of 7.0% from 2010 to 2050. Energy demand in this sector is projected to increase about 7.55 times and 20.43 times in 2030BaU and 2050BaU, respectively, larger than in 2010. Disregard of low-carbon measures; CO_2 emissions are expected to increase about 7,536ktCO_2/year and 11,136ktCO_2/year, which are about 6.42 times and 20.19 times in 2030BaU and 2050BaU, respectively, larger than in 2010.

However, by adopting low-carbon measures such as energy efficiency improvement, fuel switch, and energy saving technology and conservation, CO_2 emissions are expected to reduce by around 3,477ktCO_2/year and 12,205ktCO_2/year in 2030CM and 2050CM, respectively. Figure 3.8 shows CO_2 emissions reduction by energy service sector in the industrial sector.

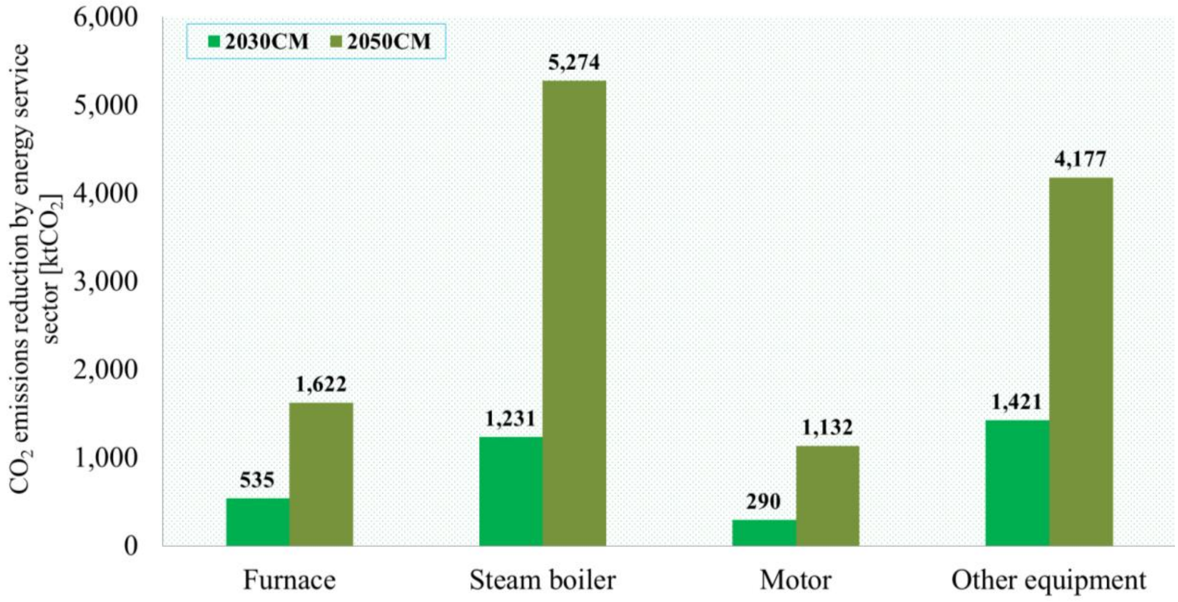

Figure 3.8: CO_2 emissions reduction by energy service sectors in the industrial sector [$ktCO_2$/year]

Transportation sector's emissions and reduction potentials

With the projected increase of transportation demand, energy demand in this sector is projected to increase about 11.69 times and 52.61 times in 2030BaU and 2050BaU, respectively, bigger than in 2010. The result yields that CO_2 emissions from the transportation sector are projected to increase from about 2000$ktCO_2$/year in 2010 to 11,895$ktCO_2$/year and 54,082$ktCO_2$/year, which are about 11.90 times and 54.03 times in 2030BaU and 2050BaU, respectively, larger than in 2010. Among them, CO_2 emissions from the passenger transportation are projected to increase to about 6,374$ktCO_2$/year and 22,276$ktCO_2$/year, which are about 6.40 times and 22.36 times in 2030BaU and 2050BaU, respectively, compared to 2010, while CO_2 emissions from the freight transportation are projected to increase from around 1,004$ktCO_2$/year in 2010 to around 5,521$ktCO_2$/year and 15,273$ktCO_2$/year in 2030BaU and 2050BaU, respectively. Under low-carbon measures, *e.g.* improvement of energy efficiency, fuel switch, and modal shift; CO_2 emissions in this sector are expected to reduce by approximately 6,708$ktCO_2$/year and 29,116$ktCO_2$/year, which accounted for about 52.3% and 55.83% of total CO_2 emissions reduction in 2030CM and 2050CM, respectively. Among them, the passenger transportation is expected to reduce by about 3,574$ktCO_2$/year and 12,658$ktCO_2$/year in 2030CM and 2050CM, respectively, while the freight transportation is expected to reduce by about 3,134ktCO_2/year and 16,458ktCO_2/year in 2030CM and 2050CM, respectively.

Power supply's emissions and reduction potentials

In this study, the projected composition of fuel mix of power generation referred to the power development master plan of Cambodia in 2014, which projected fuel mix of power generation by 2030 and it is assumed to be the same share by 2050 and CO_2 emissions are estimated accordingly. By adopting low-carbon measures such as reduction of transmission loss, energy efficiency improvement, and fuel switch from non-renewable to renewable energy (solar/wind), CO_2 emissions in this sector are expected to reduce by about 560ktCO_2/year and 1,726ktCO_2/year of total CO_2 emissions reduction in 2030CM and 2050CM, respectively.

3.7 Discussion

This section will discuss about some of the above-mentioned results. Since the detailed information in Cambodia was not fully acquired at the time of the study, some assumptions were made based on the professional judgment of the author and personal communication with the country's experts. Therefore, the trends of projections are not precise predictions; a range of possible future outcomes is possible.

3.7.1 Macro economy

This study projected that the GDP in Cambodia will increase significantly in the future and GDP per capita is also projected to increase accordingly. The result indicated that the projected GDP per capita in 2030 in Cambodia is similar to that of the Philippines in 2013; it means that the projected economic development in Cambodia stays 17 years behind that of the Philippines. The projected GDP per capita in 2050 in Cambodia is similar to that of Malaysia in 2008; it means that the projected economic development in Cambodia stays 42 years behind that of Malaysia. Cambodia must, therefore, ensure and increase more GDP growth rate from today in order to reach a high income level where GDP per capita is the more than 12,476USD (UN, 2013) as stated by the Government. The projected GDP per capita of Cambodia stayed even far behind some of the advanced countries such as the Republic of Korea (20,756USD), Japan (42,783USD), and Sweden (49,183USD) in 2010 (IMF, 2014). In general, in terms of the annual growth, there is no doubt that the primary industry would decrease, while the secondary industry would increase when a country shifts from a low-income level to a middle level or a high-income one. The RGC set a long term economic development target by shifting from a low income country to an upper middle income and high income level by 2030 and 2050, respectively. It is, therefore, secondary industry is projected to grow substantially in the future; however, Cambodia still counts the primary industry as a key contributor to her GDP growth. The result of the assumption of this study suggested that the secondary industry in Cambodia contributes lower to GDP than some other ASEANs, which experienced a similar GDP growth, while the tertiary industry illustrates a similar trend as other countries like Malaysia and Thailand. Figures 3.9, 3.10, and 3.11 show the correlation between per capita of GDP growth in Purchasing Power Parity (PPP) at 2005 constant price (GDP per capita in PPP at 2005 constant price was used to compare with other countries' GDP) and value added (%) of the respective industries, contributing to GDP growth between Cambodia and some other countries.

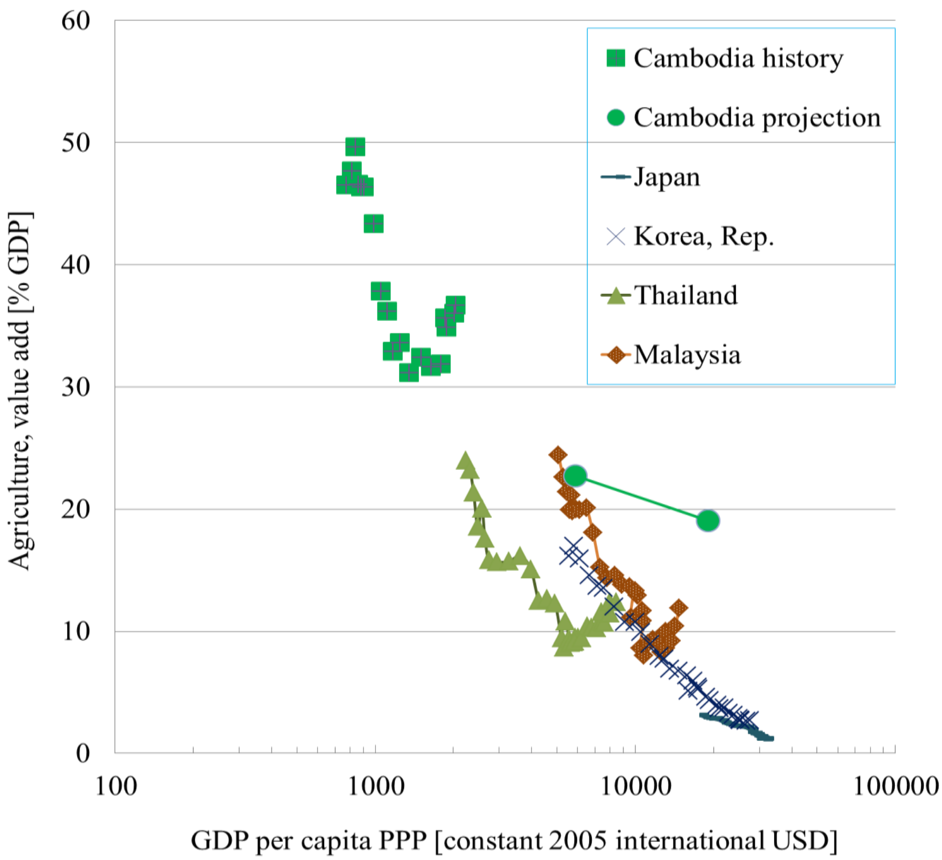

Figure 3.9: The correlation between primary industry contributions to the GDP and per capita [PPP at 2005 constant price] among Cambodia and other countries

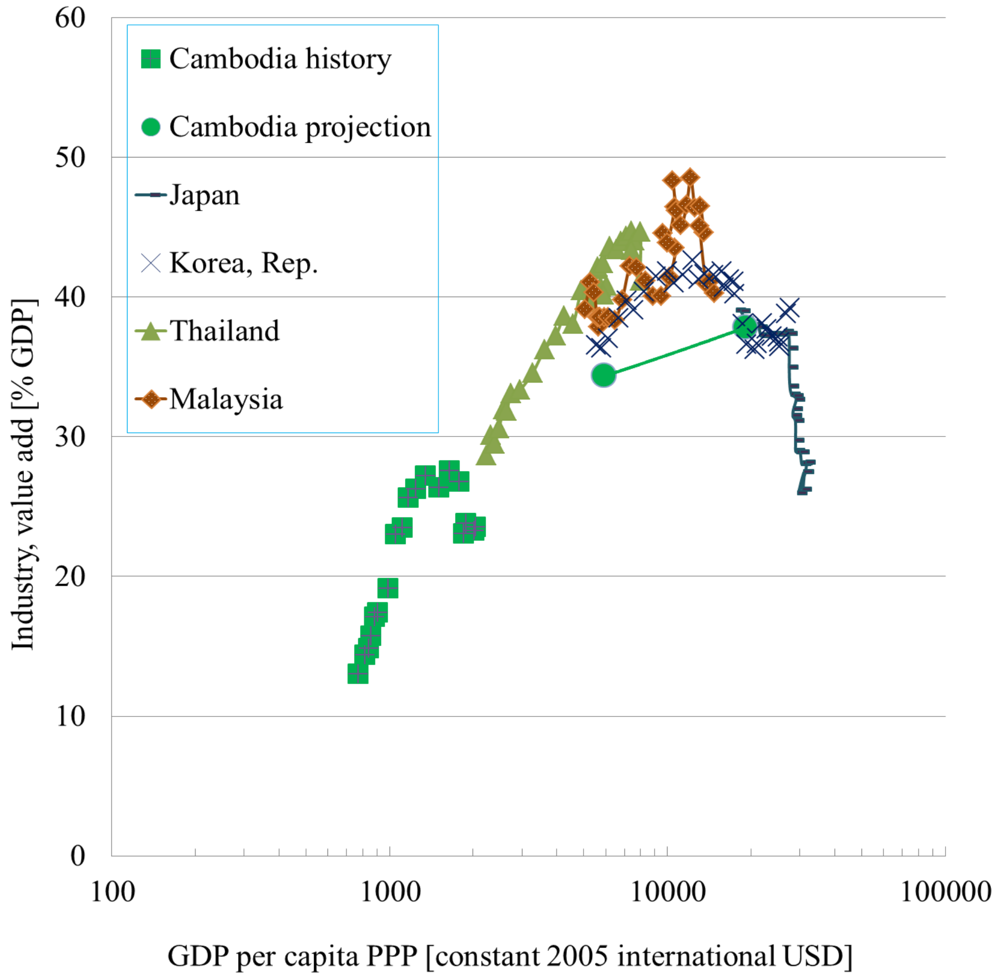

Figure 3.10: The correlation between secondary industry contributions to the GDP and per capita [PPP at 2005 constant price] among Cambodia and other countries

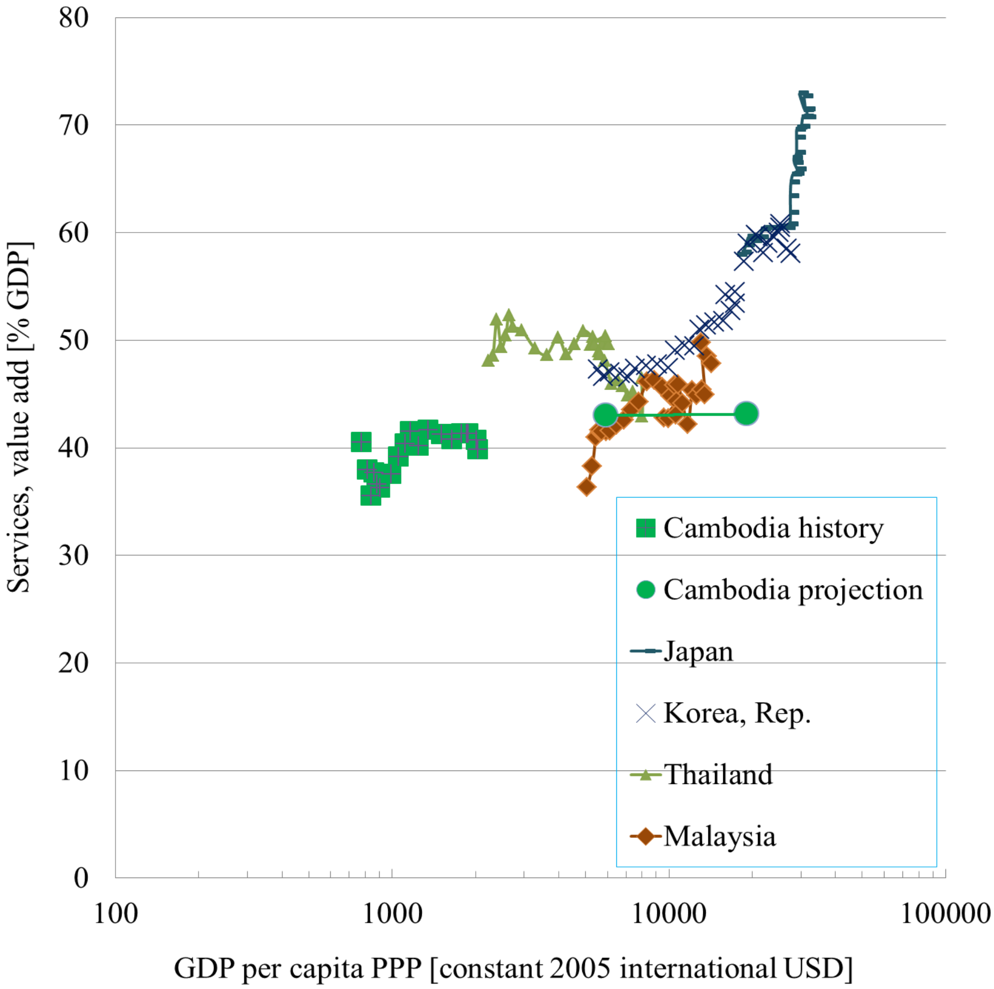

Figure 3.11: The correlation between tertiary industry contributions to the GDP and per capita [PPP at 2005 constant price] among Cambodia and other countries

3.7.2 Transportation demand

The result of the assumption yields that passenger transportation demand in Cambodia is dominated by road where the number of motorbikes is majorities; however, transportation demand (Million pass.km/year) from this mode is smaller than other modes due to its short average trip distance. Total passenger transportation demand is projected to increase significantly in the target year; this is due to the projected increase of incomes, which make the people to use more motorized vehicles, especially private cars for travelling and going to work. It can be observed that the projected transportation demand is high as most of the passengers, using motorized vehicles mainly switched from walks and bicycles. Cambodia can reduce transportation demand through introducing more public buses and trains, especially in the major cities. Further reduction can be achieved when the passengers switch from private cars. The projected passenger per capita (about 15,052km/person) in Cambodia in 2030 is higher than Vietnam's one (about 5,226km/person) in the same year (Nguyen, 2012) and it is even higher in 2050. This is because this study assumed the share of walk and bicycle of 64.39% and 26.88% in 2030 and 2050, respectively, while it was assumed to be higher (93.0% in 2030) in Vietnam.

Similarly, the result yields that freight transportation demand is projected to increase significantly in the future; however, it remains lower than a projection of some ASEANs such as Malaysia, Thailand, and Vietnam in the same year of 2030 (Nguyen, 2012; Limmeechokchai *et al.*, 2010; and Siong *et al.*, 2013); however, it is projected to increase further in Cambodia by 2050 (Table 3.46). Cambodia must put more effort to stimulate and expand her economic development, especially promoting industrial development policies and by doing so, the Government is expected to reach the economic development aspiration to be a high-income country by 2050.

Since Cambodia has very limited studies on transportation demand and the future trends of energy demand and CO_2 emissions, more studies are needed to better understand the possible future transportation scenarios so that the Government can develop an appropriate and effective infrastructure and traffic management plan to avoid traffic congestion and air pollution as well as to mitigate CO_2 emissions accordingly.

Table 3.46: Comparative studies of projected freight transportation demand between Cambodia and some Asian countries [Million (ton.km)/year]

Countries	Freight transportation demand [Million ton.km/year]		Sources
	2030	2050	
Cambodia	116,048	619,725	This study
Malaysia	214,000	N/A	Siong et al. (2013)
Thailand	589,859	N/A	Limmeechokchai et al. (2010)
Vietnam	235,212	N/A	Nguyen (2012)

3.7.3 Energy sector

It was observed that biomass was the main source of energy supply in 2010, which accounted for about 72.8%, followed by oil (about 23.1%) and electricity (about 4.1%) (IEA, 2012) where the residential sector was the highest biomass consumer (about 78.8%), followed by the industrial sector (about 21.2%); however, Cambodia stood the second after Myanmar (about 81.4%) in terms of biomass consumption in ASEANs in that year (IEA, 2013). Table 3.47 shows the comparison of total final energy consumption between Cambodia and some of ASEANs. It was indicated that most of Cambodian households relied mainly on firewood; thus, it puts more pressures on forest resources (RGC, 2012). In order to address this concern, the Government has encouraged researchers and investors to invest and to find appropriate alternative energy technologies whereby some improved energy technologies were recommended and two of them are introduced. First is the introduction of energy efficient cook stoves, *Neang Kongrey stove* and *New Lao stove*, which are more energy efficient than *"traditional three-stone one"* (WB and MIME, 2009). These cook stoves use approximately 21.0% less fuel wood than a traditional Lao's one and 64.0% less than a three-stone one. Currently, about 40.0% of the urban population is using energy efficient cook stoves, while most of households in the rural areas are still using the traditional ones. It is expected that all households will be able to afford and change from traditional cook stoves to the efficient ones by 2030. Second is the introduction of "*Bio-digester"*, which has been implemented in Cambodia since 2006, to produce methane gas for both cooking and lighting (MAFF, 2011). It helps to reduce deforestation, eliminate harmful indoor smoke from wood fires, reduce GHG emissions, and improve sanitation and so far, 20,338 of Bio-disgesters have been installed (MAFF, 2013).

The results of the assumption yield that energy demand in Cambodia increased considerably in the future. In response, the RGC adopted the best alternative options for more constant, reliable, and affordable sources of energy by shifting from the biomass-based energy supply to more advanced one. Furthermore, the result suggested that the further improvement of energy efficiency and transmission loss in the supply side could provide more electricity generation with the same fuel input. Similarly, the improvement of energy efficiency, introduction of advanced technology devices, and smart energy consumption by the end users, the people can use more devices with the same or even lower energy consumption compared to the conventional devices.

The results of the projected energy demand also illustrate that the trend of energy consumption per capita in Cambodia is very similar to some other Asian countries, which experienced the same economic growth. Figure 3.12 shows the correlation between energy use per capita (koe) and GDP per capita of PPP at 2005 constant price. The trend of the projected GDP per unit of energy use (GDP per capita of PPP at 2005 constant price) in Cambodia is also very similar to some other Asian countries, which experienced the same economic growth (Figure 3.13). The country has gradually shifted away from oil-based power supply to more renewable one. It can be noted that hydropower is one of the highest shares of future fuel mix of power generation after natural gas. The Government strongly confirmed the country's available capacity and facilities to build hydropower dams as stated in the power development master plan.

In general, hydropower helps Cambodia to access to electricity and to promote economic growth, job creation, and to reduce CO_2 emissions (MoE, 2013). In addition, Cambodia can earn additional benefits from selling carbon credit to some developed countries through implementing the CDM projects under the framework of carbon market mechanisms of the Kyoto Protocol (UN, 1998). Cambodia has currently been registered four CDM projects from the hydropower with the total emissions reduction of around 1,812ktCO_2/year (IGES, 2015). Hydropower dam construction, however, caused various concerns such as changing water flow regime, impacts on biodiversity, forestry, fisheries, agricultural land, the people living within and around the dam construction areas, and the indigenous culture (GIZ, 2014). Cambodia faced some challenges when she started building hydropower dams. One of the most controversial projects was the Lower Se San II with the installed capacity of about 400MW, constructed in 2013. This project impacted 797 families, houses, pagodas, schools, health centers, other private assets, and some parts of the land granted to five concession companies (RGC, 2013c). To solve the problem, the national assembly of

Cambodia approved a law on the Government guarantee of payments to the Hydropower Lower Se San II in February 2013. The law stipulated that the compensation provided for the loss of both public and private properties such as rice fields, residential lands and other public infrastructures. This law was only used to solve the problem on case by case basis; it was not widely used in the country.

Table 3.47: Comparison of total final energy consumption in ASEANs in 2010

Total final	Share [%] of		
consumption	Biomass	Oil	Electricity
Cambodia	72.8	23.1	4.1
Indonesia	34.0	38.1	8.1
Myanmar	81.4	8.0	4.2
Malaysia	4.0	56.8	22.0
Philippines	23.3	48.1	20.0
Thailand	17.0	44.9	15.2
Vietnam	28.5	33.8	15.4

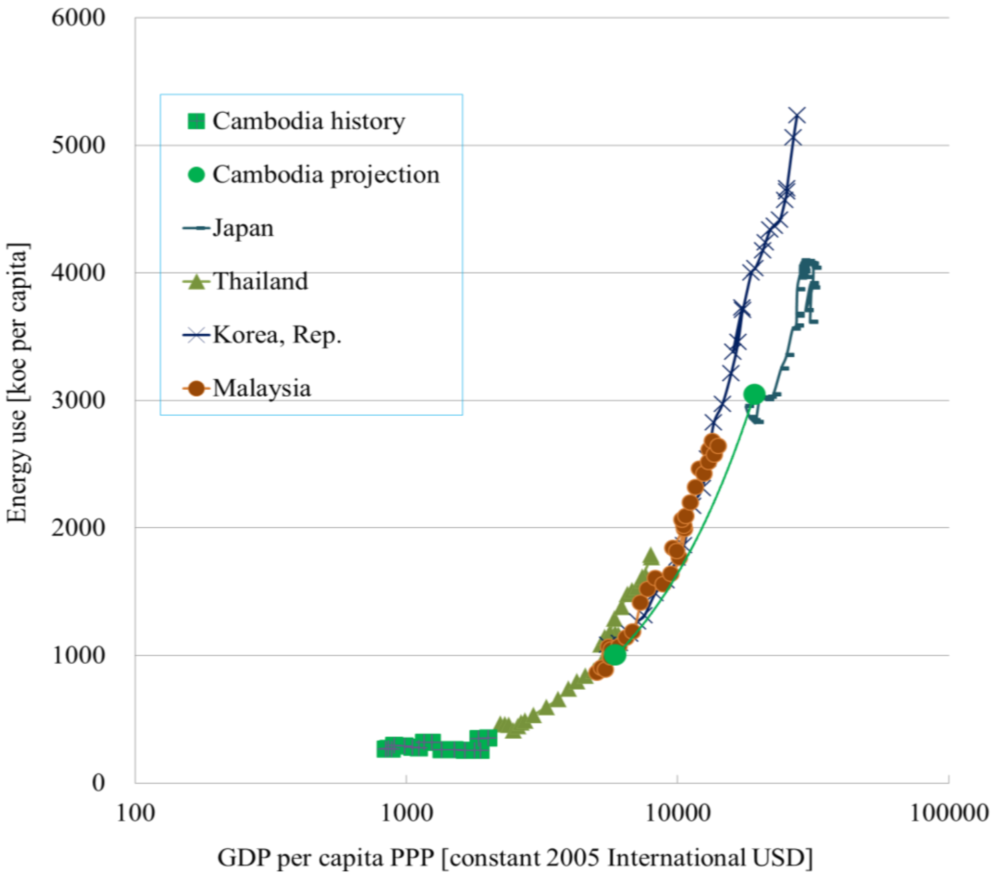

Figure 3.12: The correlation between energy use [koe] per capita and GDP per capita [PPP at 2005 constant price] among Cambodia and some Asian countries

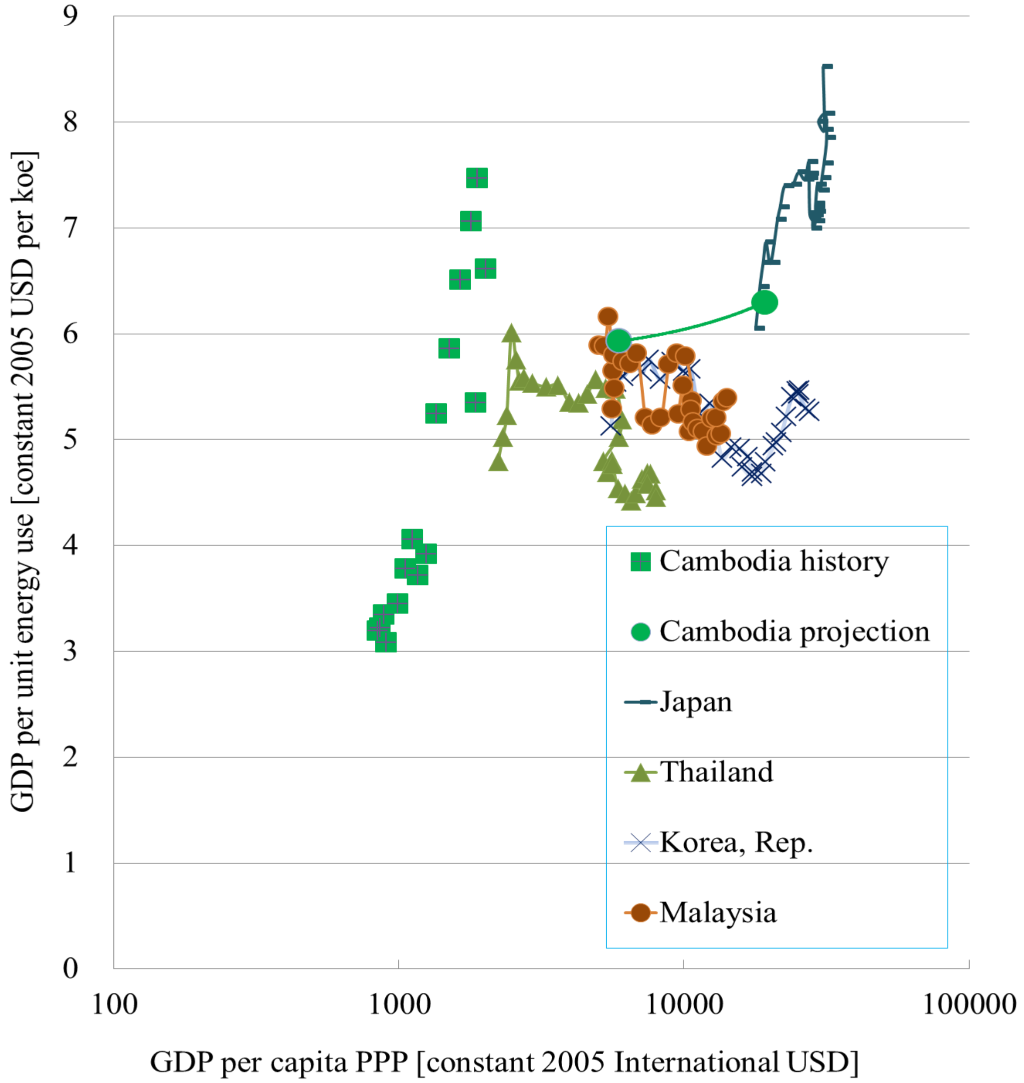

Figure 3.13: The correlation between GDP per unit of energy use and GDP per capita [PPP at 2005 constant price] among Cambodia and some Asian countries

3.7.4 CO_2 emissions

The results of this study yield that CO_2 emissions are projected to increase dramatically in the future and so are per capita CO_2 emissions. The analysis of key drivers led to such a drastic change of CO_2 emissions between the base year (2010) and the target years (2030BaU and 2050BaU) is shown in Table 3.48. It can be observed from the table that the projected population in this study slowly increased between 1.32 times and 1.57 times in 2030BaU and 2050BaU, respectively, compared to 2010. This analysis suggested that the population growth should not be the main driver of significant increase of CO_2 emissions. However, it can be investigated that the GDP grew tremendously between 3.87 times and 14.97 times in 2030BaU and 2050BaU because of the Government's ambiguous target to move to an upper-middle income country and a high-income one in 2030 and 2050, respectively, (RGC, 2013). It can also be observed that the sources of the power supply are unlikely the main sources of CO_2 emissions as they originated almost entirely from hydropower, which is considered as zero emissions (IPCC, 2006) and natural gas, which is considered as lower quantities of GHG emissions than coal or oil (EPA, 2015). According to the analysis in the table, it is explicitly implied that the considerable increases of CO_2 emissions stimulated intensively by the incremental growth of the GDP.

In the meantime, Cambodia could reduce CO_2 emissions significantly by adopting some low carbon measures such as energy efficiency improvement, fuel switch, diffusion of advanced energy technologies, and modal shift, etc. By doing so, CO_2 emissions are projected to increase lower than the GDP growth in 2030CM (2.48 times) and 2050CM (9.28 times). It is suggested that Cambodia can develop her economy in a healthy and environmentally friendly manner if the Government takes low carbon development into account.

Furthermore, the result suggests that total CO_2 emissions in 2010 in this study were very similar to those of the Second National Communication (SNC) in the same year (MoE, 2013); however, the projected CO_2 emissions in 2030BaU and 2050BaU in this study are much larger than those of the SNC in the same years (Figure 3.14). It can be observed that the differences in the CO_2 emissions are due mainly to the differences in assumptions of GDP growth, energy demand and fuel mix of power generation. At the time of the SNC prepared, the Government did not formulate a concrete long-term economic development plan and the assumed GDP growth rate in the SNC was lower than the current Government's one (MoE, 2013a). Besides, the fuel mix of power generation in this study included natural gas (40.0%), hydropower (35.0%), and coal (15.0%) (MME, 2014); in contrast, the SNC were dominated entirely by hydropower (68.0%), while natural gas was very small (8.0%) (MoE, 2013). The result also suggested that per capita CO_2 emissions in Cambodia were lower than those of some other countries in the Association of South East Asian Nations (ASEANs) in 2010 (IEA, 2013a) (Figure 3.15). Moreover, the projected per capita CO_2 emissions in 2030BaU and 2050BaU are still lower than those of some Asians in 2010 such as China (11.66tCO_2/year), Japan (8.89tCO_2/year), Republic of Korea (11.42tCO_2/year), Malaysia (6.46tCO_2/year), and Singapore (12.66tCO_2/year) (IEA, 2013).

The higher level of CO_2 emissions per GDP indicated a larger share of more energy intensive-economic activities, the use of less energy efficient technologies, and a larger share of coal in the energy mix (Oliver *et al*., 2013). He also stressed that China owned one of the largest shareholding of coal for power generation where her CO_2 emissions per capita were comparable to those in the EU and almost half of the USA; but her CO_2 emissions per GDP were almost double those of the EU and the USA, while Japan emitted less CO_2 emissions per GDP than other countries in the world (Oliver *et al*., 2013). The estimated CO_2 emissions per GDP in Cambodia in 2010 were higher than those of Singapore; they were, however, lower than those of some other countries in ASEANs (IEA, 2013a) (Figure 3.16). Moreover, the projected CO_2 emissions per GDP in Cambodia in 2030BaU and 2050BaU are larger than those of Japan (0.24kg/USD at 2005 constant price) and Republic of Korea (0.55kg/USD at 2005 constant price) in 2010 (IEA, 2013). Moreover, the results argued that Cambodia could significantly reduce CO_2 emissions through adopting some appropriate low carbon measures such as energy efficiency improvement, fuel switch, modal shift, etc. The detail decomposition analysis for CO_2 emission reductions is shown in Table 3.49 and Table 3.50 in 2030CM and 2050CM, respectively. These tables implied that energy efficiency equipment and vehicles contribute to the largest share of CO_2 emission reductions in both 2030CM (around 68%) and 2050CM (around 77%). Conversely, fuel switch attributes to the smallest share of CO_2 emission reductions in 2030CM, while in 2050CM is renewable energy in power generation as the Government introduced very small amount of renewable energy source.

The projected results suggested that Cambodia should consider renewable and clean energy as the main sources of the power supply for the economic development in order to avoid the perverse economic expense and environmental distress in the future. In doing so, the country must have sufficient financial and human resources. It can be observed that the results of this study are found to go in line with the Government policies and strategies to promote energy efficiency improvement (MME, 2013) and low carbon technology planning for sustainable development (MoE, 2013a). Besides, this study can estimate quantitative reductions of energy demand and CO_2 emissions, which are considered as very useful outcomes for the Government to formulate a comprehensive and concrete low carbon development policy in the future.

Table 3.48: Key drivers for changes of CO_2 emissions in the energy sector in Cambodia

Key drivers	2010	2030BaU	2030CM	2050BaU	2050CM	Explanation
Population [1,000 persons]	13,959	18,391		21,964		The population growth is relatively slow, only 1.3 and 1.6 times in 2030 and 2050, respectively, (NIS, 2011 and UN, 2012). It would not be the main cause of the increase of CO_2 emissions.
GDP [Mil USD, at 2000 constant price]	7,518	29,093		112,582		The GDP growth is at a very high incremental rate, around 3.9 and 14.97 times in 2030 and 2050, respectively, (RGC, 2013). The GDP growth goes in line with energy demand and CO_2 emissions. Hence, the GDP growth is considered as the main contributor to accelerating CO_2 emissions in this study.
Power supply [fuel share %]						
Coal	1.30	15.0	12.0	15.0	12.0	The fuel mix of power generation has changed drastically between 2010 and 2030 and 2050 (MME, 2014). The low CO_2 emissions in 2010 resulted mainly from the high rate of electricity import (around 60%) (EAC, 2010) as it is considered as zero emissions in the model. Besides, the future sources of the power supply dominated by renewable energy (hydropower, 35%) and low emissions sources (natural gas, 40%) (MME, 2014). Therefore, the change of sources of the power supply should not be the potential contributor for increasing CO_2 emissions.
Petroleum products	38.21	3.0	2.0	3.0	2.0	
Hydropower	1.09	35.0	35.0	35.0	35.0	
Natural gas	0	40.0	40.0	40.0	40.0	
Biofuels and waste	0.84	0.0	0.0	0.0	0.0	
Solar/wind	0.15	1.0	5.0	1.0	5.0	
Import	58.43	6.0	6.0	6.0	6.0	
Energy saving behaviour (%)	-	-	20.0	-	20.0	Energy saving behaviour can reduce energy consumption by 20% in 2030CM and 2050CM, which was referred to MME (2013).
Diffusion of energy effeciency equipment (%)		-	50	-	80	The advanced energy efficiency equipment is expected to be diffused in Cambodia at around 50% in 2030CM and 80% in 2050CM due to the Government plan to improve technologies for low carbon planning and green growth development (MME, 2013; MoE, 2013a; and RGC, 2013b).
Transmission loss (%)	12.23	7.0	6.50	7.00	6.50	Transmission loss had decreased from 14.0% in 2004 to 7.42% (EAC, 2012) and the Government continue to improve the transmission loss in the future (MME, 2014 and RGC, 2013). Hence, this study assumed to decrease to 7% in both 2030BaU and 2050BU and further decrease to be similiar (6.5%) in 2030CM and 2050CM.
Energy demand (ktoe/year)	4,386	18,374	8,180	66,932	27,691	The energy demand increased around 4.19 and 15.26 times in 2030BaU and 2050BaU, which is proportionated to the GDP growth.
CO_2 emissions ($ktCO_2$/year)	4,221	23,277	10,451	91,325	39,172	The main drivers for the subtantial increases of CO_2 emissions in 2030 (5.5 times) and 2050 (21.6 times) are virtually certain to instigate mainly by the GDP growth and energy demand, followed by fuel mix of power generation.
Per capita emissions (tCO_2/person)	0.30	1.27	0.57	4.16	1.78	

Table 3.49: Decomposition analysis for CO_2 emission reductions in 2030CM

Year	2030BaU	2030CM	Distribution of CO_2 emission reductions in 2030CM				
Total CO_2 emissions ($ktCO_2$/year)	23,277	10,451					
			Renewable energy in power generation	Fuel switch	Energy efficiency equipment and vehicles	Modal shift	Improvement in energy intensity
Residential			184	49	1,009	0	255
Commercial			183	44	572	0	152
Industrial			132	10	2,319	0	1,149
Passenger transportation			57	61	2,100	1,413	0
Freight transportation			4	40	2,714	379	0
Total reductions ($ktCO_2$/year)		**12,826**	**560**	**204**	**8,714**	**1,793**	**1,555**
Share of emission reductions			4.4%	1.6%	67.9%	14.0%	12.1%

Table 3.50: Decomposition analysis for CO_2 emission reductions in 2050CM

Year	2050BaU	2050CM	Distribution of CO_2 emission reductions in 2050CM				
Total CO_2 emissions ($ktCO_2$/year)	91,325	39,172					
			Renewable energy in power generation	Fuel switch	Energy efficiency equipment and vehicles	Modal shift	Improvement in energy intensity
Residential			631	464	5,867	0	893
Commercial			483	46	1,440	0	396
Industrial			350	775	7,968	0	3,462
Passenger transportation			187	189	9,572	2,897	0
Freight transportation			75	733	15,373	352	0
Total reductions ($ktCO_2$/year)		**52,153**	**1,726**	**2,207**	**40,220**	**3,248**	**4,751**
Share of emission reductions			3%	4%	77%	6%	9%

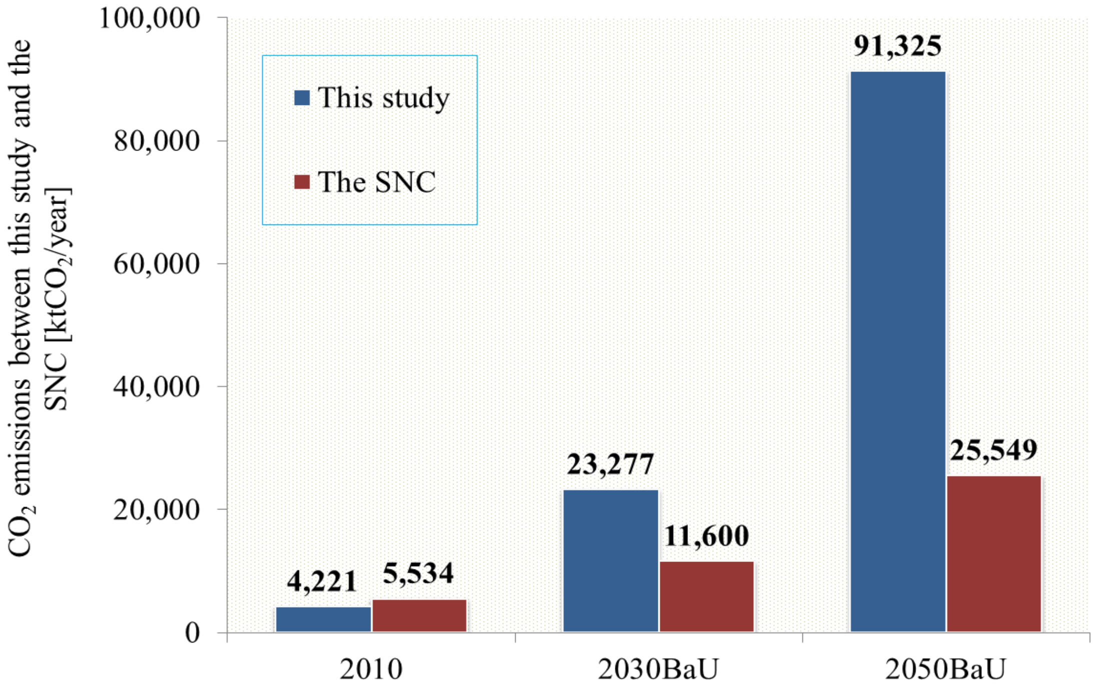

Figure 3.14: Comparison of projected CO_2 emissions ($ktCO_2$/year) between this study and the Second National Communication (SNC)

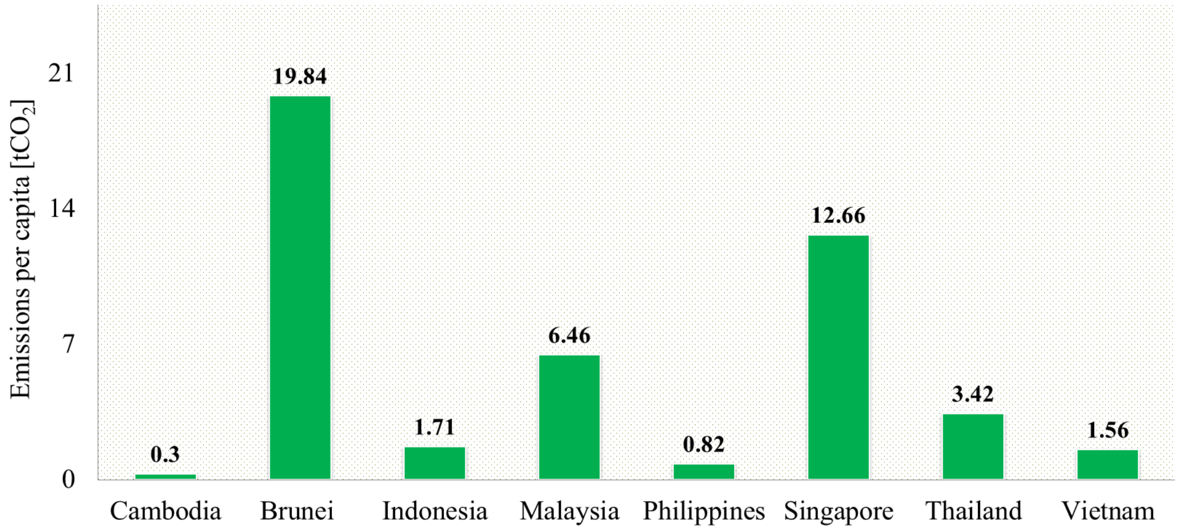

Figure 3.15: CO_2 emissions per capita [tCO_2/person] between Cambodia and ASEANs

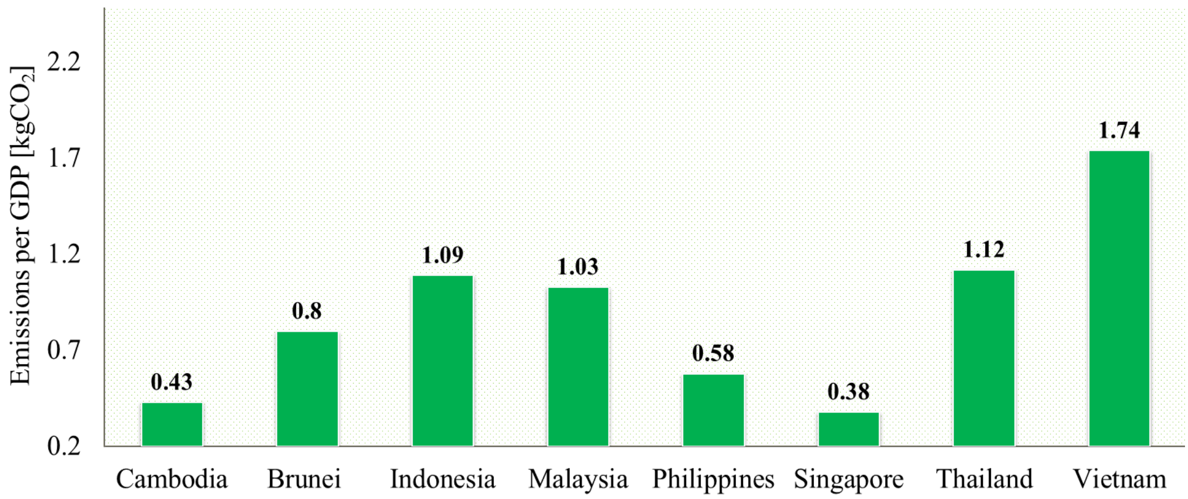

Figure 3.16: CO_2 emissions per GDP [$kgCO_2$/USD at 2005 constant price] between Cambodia and ASEANs

CHAPTER 4 THE AFOLU SECTOR

4.1 Overview of Agriculture, Forestry and Other Land-Use Bottom-up (AFOLU-B) Model

The AFOLU-B model is a bottom-up type model to estimate GHG emissions and mitigation potentials in the AFOLU sector at a country or regional level, dealing with quantified mitigation measures (Hasegawa and Matsuoka, 2013) and has been applied to some Asian countries so far (Tahsin *et al*., 2014 and Nguyen *et al*., 2014). GHG emissions and mitigation potentials are calculated using a function of abatement costs, which are representative parameters representing willingness of GHG reductions under several constraints for mitigation costs and measures. Moreover, the calculation is also based on future assumptions of crop harvested areas, numbers of livestock and areas of land use change, etc.

The model illustrates selections of production countermeasures of the agricultural commodities and mitigation measures by producers (i.e. farmers) based on economic rationality. The model illustrates a selection of GHG mitigation options (low carbon measures) based on minimizing net benefits. Since the selection depends not only on evaluation methodologies of cost and mitigation, but also among countermeasures, the dependency is considered in the model. For example, for reducing fertilizer, which is one of low carbon measures for croplands, the balance among decrease in output of the crop due to fertilizer reduction, decrease in GHG emissions cost and an increase in revenue due to saving fertilizer is considered in the model. Another example, the improvement of livestock productivity, the balance among the increase in mitigation costs, increase in output of livestock products and decrease in GHG emissions cost is also taken into account in the model. The AFOLU-B model consists of two modules: AGriculture Bottom-up (AG/Bottom-up) and Land Use, Land Use Change and Forestry Bottom-up (LULUCF/Bottom-up) (Figure 4.3 shows the AFOLU-B model).

4.1.1 AG/Bottom-up module

The AG/Bottom-up module calculates GHG emissions and mitigation potentials in agricultural production; and energy consumption of agricultural machines; and combination of production and mitigation measures under several abatement costs. (See more detail in Hasegawa and Matsuoka, 2013). This module is based on the assumption that producers produce commodities to supply the amount of productions given exogenously. The term of applying countermeasure application term is divided into several periods and the producers select ways of producing commodities and combinations of mitigation measures in order to maximize their net profits. The profit is defined by "benefit – cost + benefit by bioenergy sales". Production is calculated as a "multiplication of productivity (i.e. crop production per unit area or carcass weight) and quantity of activity (area of cropland or numbers of livestock)". Yields are defined as the production of commodities per unit activity; for example, crop production per unit area harvested and carcass weight of livestock. It can be observed that yields may change due to application of countermeasures. For example, yields may decrease by fertilizer reduction and carcass weight of livestock may increase by improving feed systems. The model considers impacts of climate conditions on crop yields. Figure 4.1 shows the structure of the AG/Bottom-up module. The AFOLU-B model takes into account emissions from fossil fuel directly consumed in the agricultural sector (*e.g.* energy for agricultural machinery, pumps, seeders, milking machines, tractors, combine harvesters, manure spreaders, fertilizer distributions, and so on). However, basically, GHG emissions from energy consumption are categorized into different IPCC guideline from the AFOLU sector.

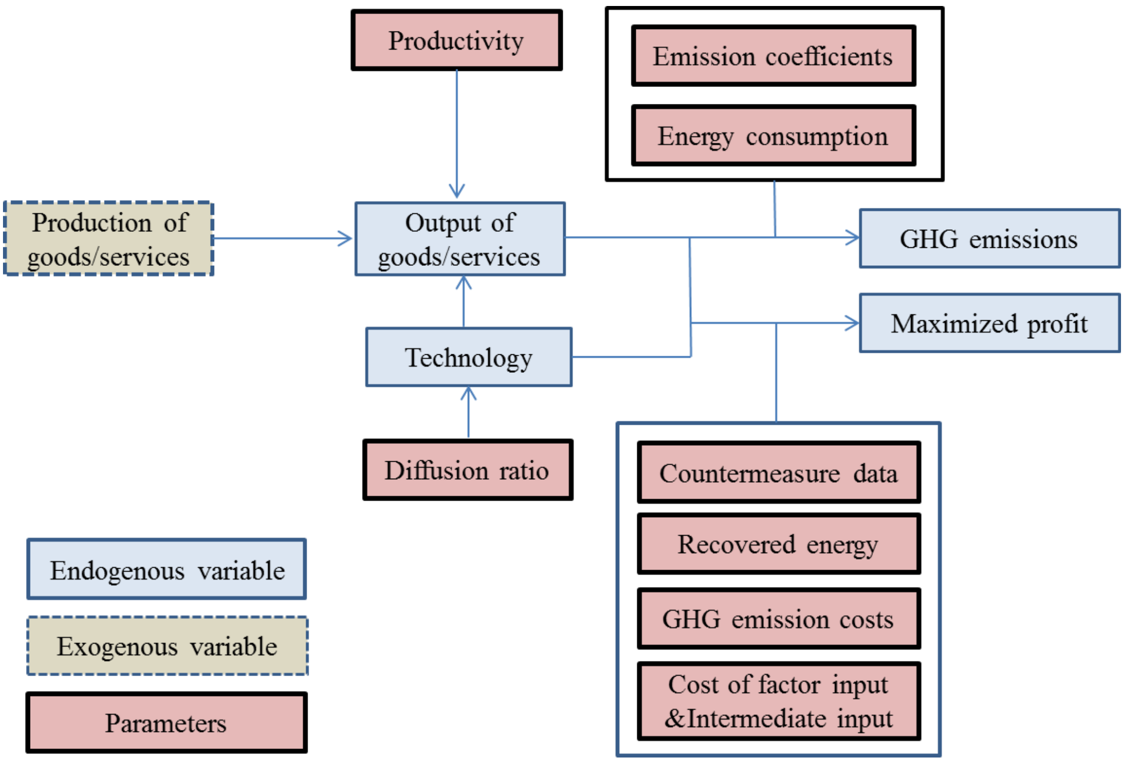

Figure 4.1: The structure of AG/Bottom-up module

4.1.2 LULUCF/Bottom-up module

The LULUCF/Bottom-up module calculates GHG emissions from carbon stock changes in biomass and soils on the land and those from fire, natural disturbance and peat lands and mitigation by specific countermeasures. Since Cambodia does not have peat land, we exclude it for this study. The module does not capture emissions from wood harvesting as it is assumed that wood harvesting is not too a large factor to make great impacts on change in land use and change in emissions and sink coefficients. Assumption of the future land use change is given exogenously. Also, the module calculates GHG emissions and sink caused by historical land use change. GHG emissions reduction is calculated based on schemes assumed for mitigation measures selection. The schemes can be set as conditions of allowable minimum reduction or total maximum cost in a certain application period. The module does not cover benefit from activity (i.e. improved land use and wood production). The module calculates total mitigation impacts in an assumed period since mitigation impacts of some countermeasures last for the long term after the application.

Figure 4.2 shows the structure of the LULUCF/Bottom-up module.

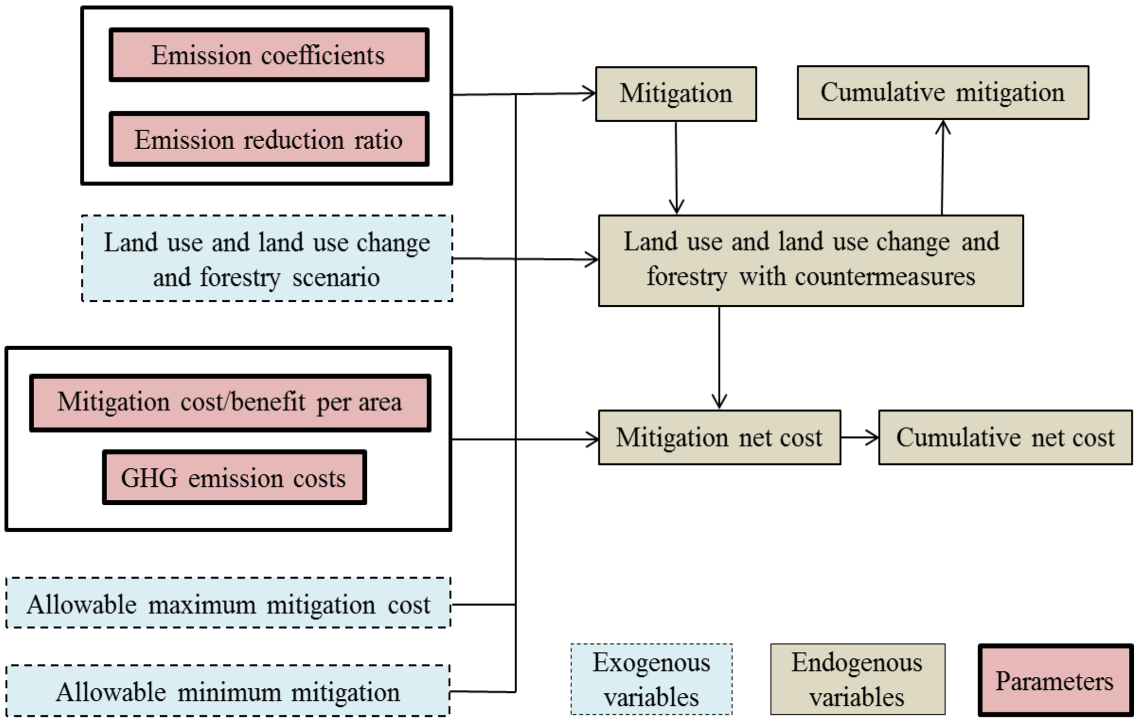

Figure 4.2: The structure of the LULUCF/Bottom-up module

4.2 Input and output of the AFOLU-B model

The data input to the AFOLU-B model includes: i) list of countermeasures; ii) characteristics of countermeasures such as cost, reduction effect, life time, diffusion ratio, energy consumption and recovery; iii) scenarios of crop production, numbers of livestock and areas of land use, land use change and forestry; iv) scenarios of fertilizer input, price of commodity and energy, and production technologies; and vi) future assumption on policy such as allowable abatement costs for GHG reduction, energy cost, subsidy and so on. Based on the information, countermeasures to be applied to reduce GHG emissions are evaluated.

The module considers only additional cost, which is caused by the installation of mitigation measures. The additional cost is defined to be a difference from a cost in the BaU case. The cost includes i) wage for additional mitigation measures, ii) cost for additional intermediate inputs, iii) surcharges of GHG emissions, etc. They are described in annual costs. The detail framework of the Input and Output of the AFOLU-B model is shown in Figure 4.3.

Sources of GHG emissions in the AFOLU-B model are defined in the IPCC guideline (IPCC, 2006). Emission/sink sources taken into account in the study are enteric fermentation (3A1, this code represents categories of emission and sinks in IPCC (2006)), manure management (3A2) of livestock, LULUCF (3B), managed soils (3C4-3C6) and rice cultivation (3C7). The target GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The LULUCF sector is considered as a source of both emissions and sink of carbon. The detail information on the emission sources and target GHG emissions is shown in Table 4.1.

The management of livestock manure causes both CH_4 and N_2O emissions. CH_4 is produced by the anaerobic decomposition of livestock manure, while N_2O is produced through the nitrification and denitrification of the inorganic nitrogen derived from livestock manure and urine. Normal digestive process in animals can produce CH_4. The microbial fermentation process in animal's digestive system ferment food consumed by the animal is referred to as enteric fermentation and produces CH_4 as a by-product. Decomposition of organic material process in anaerobic condition in paddy fields can produce both CH_4 and N_2O. Anaerobic decomposition of soil organic matter by methanogenic bacteria generates CH_4.

GHG emission coefficients were listed in the IPCC guideline (IPCC, 2006). The IPCC guideline defined that GHG emissions are calculated by "multiplying quantity of activity and at least one coefficient". For the LULUCF sector, GHG emissions are calculated by "multiplying land area and carbon stock change per unit area (emissions coefficients)". To consider emissions and mitigation caused by land use change in the past, the coefficients for the land with the conversion are assumed to change over time due to time-varying emission and sink through biomass growth. For example, quantity of emissions and mitigation potentials due to forest growth is different depending on the time from plantation. In contrast, the coefficients stay constant for the remaining land.

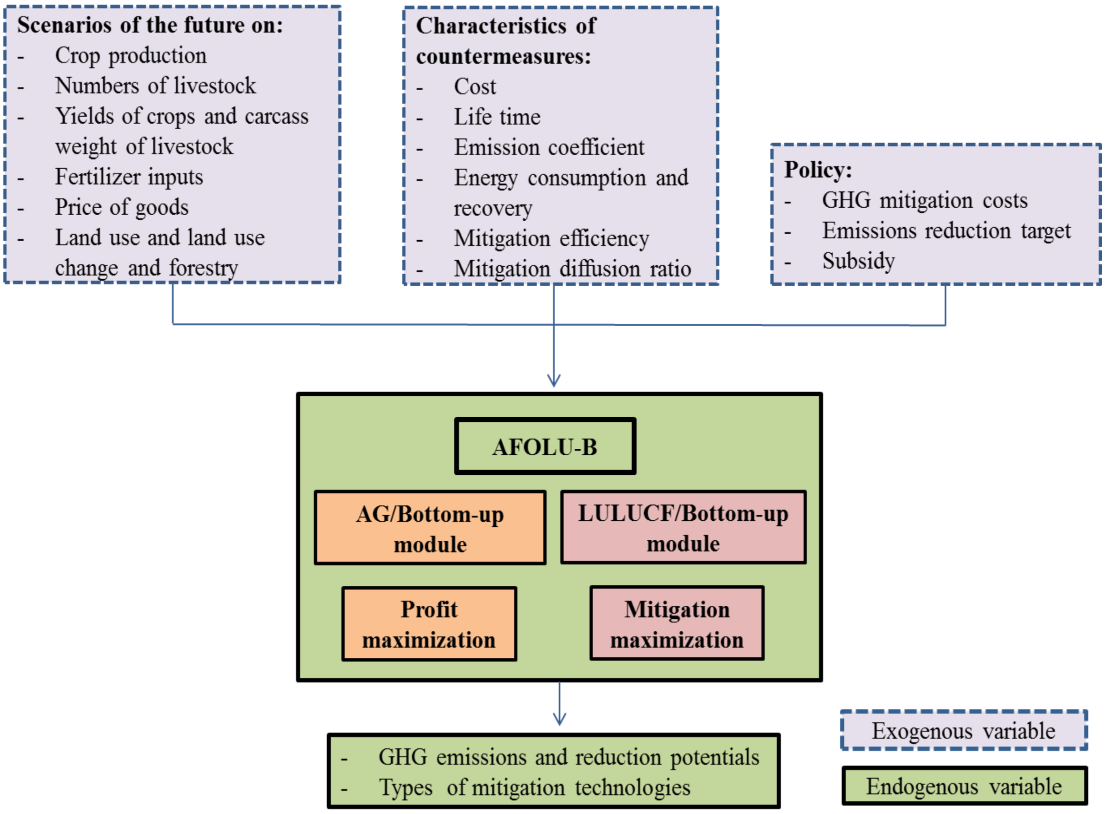

Figure 4.3: Input and Output of the AFOLU-B model

Table 4.1: Emission sources and target GHG emissions in the AFOLU sector

Emission sources	Classification	Gases	IPCC categories[1]
Enteric fermentaion	Dairy cattle, Other cattle, Buffalo, Sheep, Goats, Horses, Mules, Asses, Swine	CH_4	3A1
Manure management	Dairy cattle, Other cattle, Buffalo, Sheep, Goats, Horses, Mules, Asses, Swine, Chickens, Ducks	CH_4, NO_2	3A2
Aggregate sources and Non-CO_2 emission sources on land	Emissions from Biomass Burning[2]	CO_2, CH_4, NO_2	3C1
	Liming[2]	CO_2	3C2
	Urea Application[2]	CO_2	3C3
	Direct N_2O emission from managed soil	NO_2	3C4
	Indirect N_2O emission from managed soil	N_2O	3C5
	Indirect N_2O emission from manure management	N_2O	3C6
Rice cultivations	Wetland and upland rice	CH_4	3C7
Land use, land use change and forestry (LULUCF)	Cropland, forestland, settlement, grassland, wetland and other land	CO_2	3B

Note: [1] Emission categories of IPCC (2006); [2] Grey color is not estimated in this study

4.3 Framework of the scenarios

Two scenarios are assumed:

- Business As Usual (BaU) scenario without applying mitigation measures and
- Countermeasure (CM) scenario with the application of mitigation measures to reduce GHG emissions.

The GHG mitigation is defined to be a difference of emissions between the two scenarios. In the CM case, we assumed several alternative mitigation costs: less than 0, 10, 20, 50, and 100USD/tCO_2eq. to estimate financial feasibility of the measures and no cost consideration case. Countermeasures are assumed to be applied after 2015.

4.4 Mitigation measures

The information on mitigation measures is collected from various international and domestic literatures, including the SNC (MoE, 2013a). Table 4.2 shows the types of countermeasures, reduction amount, cost, lifetime, maximum expanding area per year and target area in the LULUCF sector used in this study. Then, the emissions reduction potentials are calculated within the model based on the assumption that the annual effect will last for a certain times after introducing the measures (i.e. planting the intact forests and reforestation). To reflect a characteristic of land-based mitigation measures in terms of mitigation cost and effects lasting over years, information of reduction effects, costs, and area used for the mitigation measures implemented in the year are considered in the next year. Table 4.3 presents types of countermeasures and cost for the agricultural sector used in this study. Technology is defined as a combination of agricultural production technology (main technology) and GHG mitigation technologies (additional technology).

Characteristics of the measures including cost, mitigation effects, agricultural productivity and emission coefficient are calculated based on the combinations of the two technologies. Parameters representing the characteristics of a technology are provided by multiplying the parameters of the characteristics of the main technologies and adjustment factors of additional technologies. For example, an emission coefficient of main technology (*e.g.* 50tCO_2eq./ha) is adjusted by using a parameter of additional technology (*e.g.* 0.8 for 20% reduction technology). Therefore, countermeasures selection depends not only on cost and mitigation potentials, but also on combinations of the technologies. Mitigation amount of each technology is calculated from mitigation amount per unit area or animal where countermeasure is applied. The costs reported in the literatures are exchanged into costs in Cambodia using wage from (NIS, 2012) based on the idea that the labor cost dominates the agricultural mitigation measures. See (Hasegawa and Matsuoka, 2013) for more details.

Table 4.2: Lists of countermeasures for the LULUCF sector

Countermeasures	CODE	Cost [USD (ha・yr)]*	Mitigation effect of CO_2 reduction [tCO_2(ha・yr)]	Maximum expanding area per year [1000 ha/year]	Target area [1000 ha]	Period of cost required [year]	Effective period of measure [year]
Plantation-short rotation	PSR	47.25	13.57	0.22	2.19	10.0	10.0
Plantation-long rotation	PLR	58.47	18.90	0.06	2.19	35.0	35.0
Reforestation-fast growing species	RFS	39.75	30.86	0.18	2.19	12.0	12.0
Reforestation-slow growing species	RSS	52.50	30.80	0.06	2.19	35.0	35.0
Reduced Impact Logging	RIL	31.14	5.13	862.40	10,348.80	12.0	12.0
Enhanced natural regeneration	ENR	10.75	7.33	0.15	2.19	15.0	15.0
Agro-forestry	AGF	7.97	43.45	0.22	2.19	10.0	10.0

*The cost represents that of in base year.

Table 4.3: Lists of countermeasures for the agriculture sector

Emission sources	Countermeasures	CODE	Cost [USD/(ha・yr)] or [USD/(head・yr)]	Mitigation [tCO_2eq/(ha・yr)] or [tCO_2eq/(head・yr)]	Change in productivity from baseline level [%]	Maximum application ratio [%]	Explanation	Reference
Enteric fermentation (3A1)	Improvement of genetic merit of dairy cows	HGM	0.35	0.32	10.00	100	It escalated with the import of Holstein genetic material for use on native dairy breeds.	Bates (1998)
	Replacement of roughage with concentrated feed	RRC	-0.05	0.45	10.00	100	Replace roughage that contains high portions of structural carbohydrates with concentrates to improve propionate generation in rumen.	Graus et al. (2004), Shibata et al. (2010)
Manure management (3A2)	Anaerobic Digestion by centralised plant	ADC	0.04	0.33	0.00	100	Capture and use of manure CH_4 through anaerobic digesters.	Bates (2001)
	Daily spread of manure	DSM	0.00	0.33	0.00	100	Manure is routinely removed from a confinement facility and is applied to cropland within 24 hours of excretion.	Bates (1998), IPCC (2006)
	Dome digester for cooking fuel and light	CFL	-0.14	0.62	0.00	100	A small-scale unheated digesters generate biogas used by households for cooking and lighting	USEPA(2006)
	Covered anaerobic digesters	CAD	0.52	0.65	0.00	100	CH_4 is captured by covering lagoon where manure is stored and piping the gas out to a flare or used on-farm.	USEPA (1999, 2003), Bates (1998, 2001), IPCC(2007)
	Aerobic decomposition	AD	0.30	0.59	0.00	100	The biological oxidation of manure collected as a liquid with either forced or natural aeration can reduce CH_4 emissions from current levels.	Bates (1998), IPCC (2006)
Rice cultivation (3C7)	Replace urea with ammonium sulphate	RAS	0.23	0.31	0.00	100	Ammonium sulfate additions to soil can elevate reduction potential, which suppresses CH_4 production.	USEPA (2006), Graus et al. (2004)
	Midseason drainage	MD	0.00	1.15	0.00	32	Rice fields are dried three times within a growing period. Not applied on rain-fed areas.	USEPA (2006)
	Off-season incorporation of rice straw	OIR	0.23	0.87	0.00	100	Shifting straw amendment from in-season to off-season can reduce availability of dissolved organic carbon and methanogens.	USEPA (2006)
Managed soils (3C4-3C6)	High efficiency fertilizer application	HEF	0.03	0.00	-10.00	100	Apply nitrogen fertilizer is divided into three smaller increments during crop uptake period to reduce nitrogen availability for leaching, nitrification, denitrification and volatilization.	USEPA (2006), Hendriks et al. (1998), Amann et al. (2005)
	Tillage and residue management	TRM	0.35	0.00	0.00	100	Conversion fertilizational tillage to no till where soils are disturbed and less and more crop residue is retained. Avoiding the burning of residues also avoids emissions.	USEPA (2006), IPCC (2007), Smith et al. (2007)
	Slow-release fertilizer	SRF	8.21	0.03	0.00	100	Coated or tablet fertilizer releases nitrogen slowly over a 30-day period and increase fertilizer-use efficiency.	USEPA (2006), Akiyama et al. (2010)

4.5 Data collection

In order to apply the model, country specific information of Cambodia is needed such as land use classifications, livestock population, crop yields, fertilizer consumption, etc. Given the limited country information, additional calculations and assumptions were made based on available data, historical trend, and professional insights as well as discussions with national experts. The data estimations and assumptions were primarily based the relevant Government documents and a series of discussions with key Government officers and involved institutions to make the assumptions more precise, reliable and acceptable. The procedures to acquire the information were made in three steps.

First, relevant documents such as forest cover and management, agriculture production and management, livestock requirement and projection, and fertilizer consumption, etc. were collected from relevant institutions and subsequent discussions were made with key persons from respective institutions (Table 4.4) to ensure the validity and applicability of the collected information.

Second, a workshop on the "Advancement and Enhancement on Low Carbon Development Researches and Policies among Cambodia, Lao PDR, and Myanmar" was organized on 26 February 2015 in Cambodia aiming to disclose the preliminary estimation of the AFOLU sector and to collect further comments and inputs from the participants in order to improve the estimations. The workshop was attended by around 70 participants who were the representatives of Japan, Myanmar and Cambodia.

Third, intensive interviews with relevant Government officials and experts were conducted in order to clarify assumptions and estimations as indicated in Table 4.4.

Table 4.4: Lists of collected documents and interviewees for the AFOLU sector

Sectors	Documents	Interviewees	Explanation
Settlement	Land reform in Cambodia	Dr. Meng Bundarith, Director of Dept. of Land Management of the Ministry of Land Management, Urban Planning and Construction in 2014	Cambodia has not developed the detail plan on land use classification and the information provided by Forestry Administration, MAFF.
Forest cover and Grassland	Strategy for Natural Rubber Development in Cambodia (2011-2020); National Forest Pogramme (NFP) (2010-2029)	H.E Chea Sam Ang, Deputy Director General of Forestry Administration (FA) of the Ministry of Agriculture, Forestry and Fisheries (MAFF) in 2013	Discussed about the forest cover target as set by the Government to maintain 60% by 2015 and the future plan to manage forests. The NFP is a very important document for the government to follow. The NFP doesn't only mean to ensure the sustainable forest management but also to enhance carbon sequestration and stock capacity.
	Forest Cover 2010 in Cambodia	Mr. Leng Chivin, Deputy Director of Forestry and Community Forestry and Country Focal Point of National REL/MRV Development Systems of FA, MAFF in 2013 and 2015	Discussed about the land use classifications since Cambodia has not develop detail land classifications as recommended by IPCC. The country will prepare such an information in the near future.
Crop production	Annual Report of the Agricultural Sector (2010-2013); Strategy for Agriculture and Water (2010-2013)	Mr. Am Phirum, Deputy Director of Dept. of Agronomy, MAFF in 2013	Discussed about the validity and reliability of the information on cropland and production and the long term crop management and improvement.
Livestock population	The Strategic Planning Framework for Livestock (2015-2024)	Ms. Ok Savin, Deputy Director of Dept. of Animal Health and Animal Production, MAFF in 2015	Discussed about the methodology for livestock demand estimation and projection and the future prospective to manage livestock.
Wetland	-	Mr. Kong Kimsreng, Programme Officer of the International Union for Conservation of Nature in 2014	Discussed about the wetland situation in Cambodia and how the country defined the wetland area.
Fertilizer	Annual Report on Fertilizer Import and Export	Mr. Chhup Thavith, Officer of Dept. of Planning and Statistics, MAFF	Discussed the informaton on import and export of fertilizer and the reliability of the data.

4.6 Present quantification

4.6.1 Land use and its change

The land use classification in this study followed the IPCC guideline 2006 in which six categories were classified including cropland (potential cultivated land), grassland, forestland, settlement, wetland, and other land (IPCC, 2006). This study chose 2010 as the base year and the target year is 2050 to project land use change and to estimate GHG emissions and reduction potentials. The information on land use in Cambodia was not reported every year; it was available in 1965, 1996/97, 2002, and 2010; however, the year 2002 was sorted out as the reference year for estimating land use change as the information from that year was considered as more reliable and acceptable after the country pertained full peace in 1999. Due to limited country information, some estimations and assumptions were made based on the available data and discussions with national experts. Table 4.5 shows land use change in Cambodia in

2002 and 2010, while the detail description to acquire this information explains thereafter.

Table 4.5: Land use change in Cambodia [1,000 ha]

Land use categories/year	2002	2010
Cropland	2,245.28	3,227.20
Grassland	1,150.00	1,500.00
Forest land	11,104.29	10,363.79
Settlement	996.02	1,000.00
Wetland	552.63	552.63
Other land	2,055.27	1,459.88
Total	**18,103.50**	**18,103.50**

Cropland:

The cropland areas in 2002 and 2010 were 2,245.28 and 3,227.20 thousand ha, respectively, (NIS, 2011).

Grassland:

The grassland areas in 2002 and 2010 were 1,150.0 and 1,500.0 thousand ha, respectively, (FAO, 2002 and 2010)

Forest land:

The forest land in 2002 and 2010 was 11,104.29 and 10,363.79 thousand ha, respectively, (RGC, 2011).

Settlement:

The settlement areas in 2010 were 1,000 thousand ha (Sovan, 2010); however, the information in 2002 was not acquired and it was back-casted from 2010. As a result, there was around 996.02 thousand ha in 2002.

Wetland:

The information on wetland areas in 2002 and 2010 was not fully acquired. In order to assume this data, some interviews were made. According to Kim Sreng, Country Officer for International Union for Conservation of Nature and Natural Resources (IUCN), the estimated volume of wetland areas in Cambodia is quite large and includes flooded forests, rice field, and settlement (floating houses) (Kim Sreng, 2014).

However, Bun Heng (2002) and FAO (2010a) reported that the net wetland areas in Cambodia were around 83.46 thousand ha in 1996-1997 and remain constant up to now. This study merged the inland water into the wetland areas.

Other land:

In this study, other land areas include bare soil, rock, and all unmanaged land areas that do not fall into any of the above-mentioned categories. It allows the total of identified land areas to match the national areas, where data are available. The information on the other land areas was subtracted from the total country land areas and the above-mentioned land use categories.

Harvested cropland areas

This study classified the harvested cropland areas into six main categories to make it more precise and easy to estimate. The detailed crop land classification and aggregation used for this study is shown in Table 4.6. The information of the cropland in 2010 was collected from NIS (2011), FAO (2010), and MAFF (2011) (Table 4.7).

Table 4.6: The cropland classification and aggregation

Crop types	Composition
Paddy rice production	Rice
Other coarse grain production	Maize
Vegetable, fruits, and nut production	Cassava, Sweet potatos, Vegetables, Mung bean, Roots and tubers, Bananas, Mangoes, Mangosteens, Guavas, Oranges, Lemons and Limes, Pineapples, Fruit, etc.
Oil crop production	Peanuts, Soybeans, Sesame, Coconuts, Oilseeds, etc.
Sugar production	Sugar cane
Other's production	Rubber, Tobacco, Jute, Coffee, Green pepper, and Chillies and Peppers, etc.

Table 4.7: The harvested cropland areas in Cambodia [1,000 ha]

Cropland types/year	2010	Sources
Paddy rice production	2,777.30	MAFF (2011) and NIS (2011)
Other coarse grain production	189.50	MAFF (2011) and NIS (2011)
Vegetable, fruits, and nut production	400.75	FAO (2010) and MAFF (2011)
Oil crop production	139.33	FAO (2010) and MAFF (2011)
Sugar production	17.10	MAFF (2011)
Other's production	207.63	FAO (2010), MAFF (2011) and NIS (2011)
Total	**3,731.61**	

Crop yields

Although the total population is comparatively small, agricultural production for domestic consumption will have to increase in line with population growth to maintain self-sufficiency and food security. It was indicated that agricultural productivity remains low compared to the neighboring countries, such as Vietnam and Thailand. Several factors account for the poor productivity such as poor agricultural technology, limited access agricultural extension, poor soil quality, and poor infrastructure (Vuthy *et al*., 2014). The classifications and assumptions of the respective crop yields in 2010 used in this study are shown in Table 4.8. The detail description of the procedure to acquire these assumptions explains as follows.

Table 4.8: The crop and others' yield in Cambodia [ton/ha]

Crop yields/year	2010
Paddy rice production	3.00
Other coarse grain production	3.58
Vegetable, fruits, and nut production	22.65
Oil crop production	1.53
Sugar production	19.72
Other's production	1.04

Paddy rice production: The rice yield in 2010 was 3 tons/ha NIS (2011) and MAFF (2011), which was lower than Lao PDR (3.5 tons/ha) and Vietnam (4.9 tons/ha) (TWG-AG, 2010) due to the lack of irrigation system and low fertilizer usage, etc. The yield was projected to increase to 3.3 tons/ha by 2018 (RGC, 2014). The country must improve the rice productivity and intensity in order to achieve the Government's target to export at least one million tons of milled rice by 2015 (RGC, 2010).

Other coarse grain production: It is referred to maize in this study and the biggest production area for this crop is Battambang province, followed by Banteay Meanchey, Kandal, Pailin and Kampong Cham. The output of maize has increased mainly due to yield improvements from the introduction of quality seeds and some additional plantations. The increased maize production was stimulated by an increase in demand of the animal feed industry. The maize yield in 2010 was 3.6 tons/ha (TWG-AG, 2010) and increased to 4.4 tons/ha in 2012 (ACI, 2014) and it is used to project the future yield.

Vegetable, fruits and nut production: The main driver in this category is cassava, which is the second largest crop cultivated in Cambodia by volume and main production areas are Kampong Cham, Battambang, Banteay Meanchey and Pailin provinces. Cassava is mainly harvested in the dry season as drying is dependent upon the sun. This causes an oversupply in the dry season and under supply in the rainy season. This product is mainly produced for exporting to Thailand and Vietnam. The cassava yield in 2010 was 22.7 tons/ha (TWG-AG, 2010), the highest yield in the region and it is assumed to remain constant in the future.

Oil crop production: The main driver in this category is soybean, which is the important source of food. Main production areas are Battambang and Kampong Cham provinces. The soybean yield in 2010 was 1.5 tons/ha (TWG-AG, 2010) and increased to 1.7 tons/ha in 2012 (ACI, 2014) and it is used to project the future yield.

Sugar production: It refers to sugar cane and the yield in 2010 was 19.7 tons/ha (MAFF, 2011) and increased to 33.2 tons/ha in 2012 (ACI, 2014), which seemed very high yield in Cambodia and it is expected to remain the same in the future.

Other's production: The dominant sector in this category is rubber tree, a kind of economic production, which does not only provide multiple benefits for farmers, the national economy, but also for the society as a whole; particularly, it can generate income to improve livelihoods and creates jobs of the people in the rural areas, and it also contributes to mitigating GHG emissions, which is considered as the main cause of global warming and climate change (GDR, 2011). There are three kinds of rubber plantations in Cambodia, including industrial plantations, which is applied to the land area of over 200ha and is managed by the State company or the authorities and employs State labor forces; agro-industrial plantations, which is managed by companies, associations or communities with the land area over 200ha; and small and medium sized family plantations, which is managed by households or private planters with the land areas ranging from 5 to 200 ha (GDR, 2011). The rubber plantation area is mainly located in Kampong Cham province and most of the rubber production is exported to China. The rubber yield in 2010 was 1.1 tons/ha (ACI, 2014) and was projected to increase to 1.7 tons/ha in 2018 (RGC, 2014) and it is used to project the future yield.

4.6.2 Livestock data

Protein, minerals and vitamins are essential for a healthy balanced diet and can be provided from milk, meat and fish. In response to the country development and the increasing food demand, the Government has set a goal to ensure food security, increase incomes, create employment and improve nutrition status for all people (RGC, 2014). In addition, the Government developed a national strategic planning framework for livestock (2015-2025) (RGC, 2015) with the objective to improve the livelihoods of small producers, household incomes and food security and provide a safe and sufficient supply of livestock products to the people and for export. Besides, this strategy also indicated the Government's direction to improve animal health and increase of both quantity and quality of feeding sources in order to respond to the required amount of livestock (RGC, 2015).

It was observed that livestock have a vital role in nutrition security as well as household incomes and livelihoods; also, fish is regarded as another primary source of food, nutrition and income of millions of Cambodians. Livestock production in Cambodia is mainly a small scale. The population of cattle has increased about 20.0%, while buffalo was declining over the last ten years (RGC, 2015). It was observed that the population of pigs increased up to 2006 but has declined since then and Cambodia currently does not produce enough pig meat for domestic consumption. Cambodia has, so far, exported very small amount of beef; however, the country has a high potential for beef export to the neighboring countries in the future such as Vietnam, etc. (RGC, 2015). Table 4.9 shows the livestock population in 2010 and the detail procedure to acquire these assumptions explains as follow.

Table 4.9: Livestock population in Cambodia [1,000 heads]

Types of livestock/year	2010
Dairy cattle	7.11
Meat cattle	3,546.67
Buffalo	640.01
Sheep	5.0
Goats	35.0
Horses	24.0
Pigs	3,047.32
Chickens	21,260.55
Ducks	4,049.63

Dairy cattle population: The detail information on the number of dairy cattle in 2010 in Cambodia was not fully acquired at the time of the study; however, a national strategic planning framework for livestock (2015-2025) (RGC, 2015) indicated that milk consumption in Cambodia is expected to increase from around 108 thousand tons in 2010 to around 191 thousand tons in 2020 and 75% of which would be imported. This report also illustrated that around 50 thousand dairy cattle would be needed in order to produce around 191 thousand tons of milk production (RGC, 2015). It is explicitly suggested that one dairy cattle could be able to produce around 3.8 tons of milk production per year. As a result, the number of dairy cattle of around 7 thousand heads was obtained in 2010.

Meat cattle and buffalo population: The information on the number of cattle and buffalo in 2010 was collected from NIS (2011 and 2012) and MAFF (2011).

Sheep, goat and horse population: The information on the number of horses, goats, and sheep in 2010 was collected from NIS (2011 and 2012) and MAFF (2011).

Pig population: The information on the number of pigs in 2010 was collected from NIS (2011 and 2012) and MAFF (2011).

Poultry population: The information on the number of chickens and ducks in 2010 was collected from NIS (2011 and 2012) and MAFF (2011).

4.6.3 Fertilizer consumption

Cambodia has an abundance of fertile (the land, which is capable of producing crops and other vegetables) agricultural land, accounting for about 4 million ha in 2012, of which around 3 million ha is under rice crop production (MAFF, 2013). The country has a low fertilizer usage rate; the amount of ammonia applied in paddy cultivation is one third that of Lao PDR and Thailand, and 15% that of Vietnam (TWG-AG, 2010). It was emphasized that fertilizer is very important for achieving an increase in crop productivity in Cambodia. Since the majority of the poor depend largely on farming for their livelihoods, increasing crop productivity is a key to improve the incomes of farmers (Yu and Fan, 2009).

Nitrogen fertilizer per unit harvested area by crop is estimated by using the cross-entropy methodology (Golan *et al*., 1996) using total fertilizer consumption (214 thousand tons in 2010, Department of Planning and Statistics of the MAFF) and fertilizer input per harvested area by crop in 2010 (Vuthy *et al.*, 2014). It was observed that fertilizer supply in Cambodia has increased rapidly over the last few years, especially since the launch of the rice export policy in mid-2010. Hence, this study assumed that fertilizer consumption will increase in proportion to the projected increase of crop yields in the future.

4.7 Future quantification

4.7.1 Land use and its change

The information on land use projection towards 2050 was not fully acquired. For the purpose of this study, the projection was made based on the historical trend and some other relevant documents. This study projected the future land use in Cambodia in a 10-year interval between 2010 and 2050 (see Table 4.10) and the procedure to derive these assumptions is explained as follows.

Table 4.10: The historical information and the projected land use [1,000 ha]

Land use categories/year	2002	2005	2010	2020	2030	2040	2050
Cropland	2,245.28	2,915.59	3,227.20	3,768.25	4,400.0	4,400.0	4,400.0
Grassland	1,150.00	1,281.25	1,500.0	700.0	700.0	700.0	700.0
Forest land	11,104.29	10,730.0	10,363.79	10,862.10	10,862.10	10,862.10	10,862.10
Settlement	904.01	919.34	1,000.0	1,161.33	1,322.66	1,448.06	1,573.47
Wetland	552.63	552.63	552.63	552.63	552.63	552.63	552.63
Other land	2,147.29	1,704.69	1,459.88	1,059.19	266.11	140.70	15.30
Total	**18103.5**	**18103.5**	**18,103.50**	**18,103.50**	**18,103.50**	**18,103.50**	**18,103.50**

Cropland: The information on the projection of the cropland areas towards 2050 were collected from MoE (2013a). This study assumed that the potential cropland areas would be able to extend up to the maximum level of 4,400 thousand ha by 2030 (MoE, 2013a) and is assumed to remain constant until 2050 from 2030 level. It can be noted that the expansion of cropland areas results from the increasing food demand due to the increase of the population, the availability of irrigation systems and agricultural technologies in the country. The Government obviously stressed that the country has to renovate and construct new the irrigation systems in the country wide in order to ensure the sufficient water supply for the farmers to cultivate agricultural crops and the country also needs to introduce new and high agricultural technologies in the near future (RGC, 2013).

Grassland: There is no information on the projection of the grassland areas towards 2050. The assumption was referred to the historical experience. It was reported that the grassland areas had decreased by around 80 thousand ha annually between 1992 and 1996 (MoE, 2013a) and the trend is expected to remain constant as the country needs to expand more agriculture land in order to increase crop production (Phirum, 2013); however, the country needs some grassland areas for animal habitat and feeding sources. Therefore, this study assumed that the grassland areas will continue to decrease until 2020 and is assumed to remain constant between 2020 and 2050.

Forest land: The information on the forest cover in 2050 is assumed to be similar to the Government's target to maintain the forest cover by 60.0% (RGC, 2011). The country has not set any plan to change the status of forest cover (Sam Ang, 2013). Besides, the RGC has formulated the National Forest Programme (2010-2029), which serves as an appropriate mechanism and provides a transparent and participatory process for planning, implementation, monitoring, evaluation and coordination of all forestry activities in order to maintain the forest cover by 60.0% and also to ensure the sustainability of forest management in the long term.

Settlement: The information on the projection of the settlement areas in 2050 was not available at the time of study; therefore, this study assumed that the settlement areas in 2050 would increase to be proportioned to the population growth rate, which was around 1.14% per year from 2010 (UN, 2011 and 2013). As a result, the total settlement areas of around 1,573 thousand ha were obtained in 2050.

Wetland: The information on the projection of the wetland areas in 2050 was not acquired; therefore, this study assumed that the wetland in 2050 would be the same as in 2010.

Other land: The other land in 2050 is the remaining land from the above-mentioned five land use categories.

Harvested crop land areas

Since the detail information on the harvested cropland areas projection towards 2050 was not fully acquired, some assumptions based on other countries' experience, relevant documents and discussions with key experts in Cambodia were made for this study. The future harvested cropland areas in a10-year interval are shown in Table 4.11, while the detailed procedure to acquire these assumptions explains thereafter.

Table 4.11: Projected harvested cropland areas in Cambodia [1,000 ha]

Cropland types/year	2010	2020	2030	2040	2050
Paddy rice production	2,777.30	3,457.08	4,303.25	5,356.52	5,356.52
Other coarse grain production	189.50	233.72	288.27	288.27	288.27
Vegetable, fruits, and nut production	400.75	763.29	763.29	763.29	763.29
Oil crop production	139.33	230.34	230.34	230.34	230.34
Sugar production	17.10	28.50	28.50	28.50	28.50
Other's production	207.63	429.93	429.93	429.93	429.93
Total	**3,731.61**	**5,015.61**	**5,916.32**	**6,969.60**	**6,969.60**

Paddy rice production: The harvested paddy rice land areas towards 2050 were extrapolated from the historical trend because there is no information available at the time of the study. It was observed that the harvested rice land areas had increased notably between 1980 and 2013 due to the increase of food demand and export orientation in order to nurture the economic development and this trend is expected to remain constant in the future due to the increasing population growth, available agriculture technologies and irrigation systems (with only around 32% in 2010 (RGC, 2012a)) as well as encouraging agriculture extension activities to the farmers (NIS, 2011); MAFF, 2011; and RGC, 2013). The Government will also increase cultivation times for some provinces where the irrigation systems are yearly available so as to achieve the Government’s target for rice export (RGC, 2010). The harvested rice land areas are, therefore, assumed to increase until 2040 and to remain constant until 2050.

Other coarse grain production: It refers to the harvested maize land areas, which were observed to increase about 2 times between 1980 and 2010 with the average annual growth rate of 2.12%; however, it was observed to decrease between 1990 and 2005 and started to increase from 2005 onward (NIS, 2011 and MAFF, 2011). This study assumed that the maize harvested area will continue to grow until 2030 and is assumed to remain constant until 2050.

Vegetable, fruits and nut production: The land use under this category had significantly increased between 1980 and 2013 (NIS, 2011 and MAFF, 2013), especially the land for cassava and mango as they were the main industrial crops for export (TWG-AG, 2010). This study assumed that the land for these crops will continue to increase until 2020 and is assumed to remain constant until 2050 since the increase of these areas may come at the cost of forest area.

Oil crop production: The harvested oil crop land areas had increased from 1980 to 2005 and decreased afterward (NIS, 2011). Therefore, this study assumed the land areas in 2050 to be similar to 2005's one, which was around 230.34 thousand ha.

Sugar production: The harvested sugar cane plantation areas had increased from around 2 thousand ha in 1980 to around 17 and 29 thousand ha in 2010 and 2013 (MAFF, 2013), respectively. However, the expansion of the sugar cane plantation areas came at the expense of forest land areas which are contrary to the Government's target to manage forest resources in a sustainable manner. Therefore, this study assumed the harvested sugar land areas in 2050 to be the same as in 2013's one.

Other's production: Rubber plantations are regarded as the main driver to the harvested other's land areas. It was indicated that the Government planned to increase rubber plantation areas to around 400 thousand ha by 2020 (DGR, 2011). And the recent report disclosed that the rubber plantation areas have recently approached the planned target (MAFF, 2013). In the meantime, it was also observed that the expansion of the rubber plantation may come at the cost of forest land areas. Thus, this study assumed that the total harvested land areas of this production will increase to 430 thousand ha (400 thousand ha for rubber plantations, while another 30 thousand ha for other production plantations) in 2020 and is assumed to remain constant until 2050.

Crop yields

The information on the future projection of crop yields was not fully acquired at the time of the study. This study, hence, projected them in a 10-year interval until 2050 based on the historical experience and the world agriculture projection towards 2030 and 2050 (Alexandratos and Bruinsma, 2012) as well as other related documents. The projected crop yields used in this study are shown in Table 4.12 and the procedure to derive these assumptions explains as follows.

Table 4.12: Projected agricultural crop yields in Cambodia [ton/ha]

Crop yields/year	2010	2020	2030	2040	2050
Paddy rice production	3.00	3.46	3.99	4.61	5.32
Other coarse grain production	3.58	4.09	4.67	5.33	6.09
Vegetable, fruits, and nut production	22.65	22.65	22.65	22.65	22.65
Oil crop production	1.53	1.99	2.45	2.92	3.38
Sugar production	19.72	33.23	33.23	33.23	33.23
Other's production	1.04	1.34	1.73	2.24	2.90

Paddy rice production: Cambodia has not projected the paddy rice yield towards 2050; however, the SNC assumed that the rice yield in 2050 would increase to be similar to Vietnam's one in 2003, which was 4.9 tons/ha (MoE, 2013a). It was investigated that after the Government's target for rice export, the yield had notably increased from 2.5 to 3.1 tons/ha in 2005 and 2012, respectively, (NIS, 2011 and ACI, 2014) and was projected to increase to 3.3 tons/ha by 2018 (RGC, 2014). It is indicated that the country has a potential opportunity to increase rice production per unit activity. Furthermore, the Government declared to reduce poverty and promote economic growth through rehabilitating the existing and constructing more irrigation networks for crop intensification. The country will also increase the fertilizer consumption to improve crop productivity and will shift from extensive to intensive cultivation in the future. Therefore, we expected that the rice yield in 2050 would reach the world's average, which is 5.3 tons/ha (with the average annual growth rate of around 1.44% since 2010) (Alexandratos and Bruinsma, 2012). Therefore, this study assumed the average rice yield in 2050 to be similar to the world's average one.

Other coarse grain production: The information on the projection of the maize yield towards 2050 was not acquired. Since the Government set the target to become a developed country by 2050 (RGC, 2013), the yield is expected to increase significantly due to available technologies and increasing food demand for both people and animals. This study assumed that the yield is expected to increase to be similar to the world's average in 2050, which is 6.1 tons/ha (with the average annual growth rate of around 1.34% from 2010) (Alexandratos and Bruinsma, 2012).

Vegetable, fruits and nut production: As explained in the previous section, the cassava production is the main driver in this category and the yield in 2010 was the highest one among the countries in the region. Therefore, this study assumed the cassava yield in 2050 to be similar to the 2010's one.

Oil crop production: As indicated in the previous section, soybean is one of the important cash crops in Cambodia. The soybean yield had increased from 1.2 to 1.5 tons/ha in 2002 and 2010, respectively, (ACI, 2014). Due to the limited country information, this study assumed that the yield in 2050 will increase to be in proportion to the historical growth between 2002 and 2010, which was 0.05 ton/year (NIS, 2011). Based on this assumption, the yield is projected to increase to around 3.4 tons/ha by 2050, which is similar to the world's average (3.2 tons/ha) (Alexandratos and Bruinsma, 2012).

Sugar production: The sugar cane yield had increased significantly from 18.1 to 33.2 tons/ha in 2002 and 2012, respectively. Due to the limited country information, this study assumed that the yield in 2050 will be the same as in 2012.

Other's production: Although the rubber tree is the main economic production for national economy and incomes of the rural people, the Government has not set a clear target to increase the rubber yield in the future. It was observed that the yield had slightly increased from 0.9 to 1.1 tons/ha between 2002 and 2012, respectively, (with the average annual growth rate of around 2.6%) (ACI, 2014). This study projected the yield towards 2050 by extrapolating from the historical experiences.

4.7.2 Livestock population

Since the detail information on the projected number of livestock requirement and population in 2050 was not acquired, this study projected it by using some available information, historical trends, and discussions with national experts. Table 4.13 shows the projected number of livestock in a 10-year interval from 2010 to 2050 used in this study and the detail procedure to acquire these assumptions explains as follows.

Table 4.13: Livestock population and projection in Cambodia [1,000 heads]

Types of livestock/year	2010	2020	2030	2040	2050
Dairy cattle	7.11	12.50	27.0	27.0	27.0
Meat cattle	3,546.67	3,642.67	4,895.44	6,579.07	8,841.72
Buffalo	640.01	657.33	883.40	883.40	883.40
Sheep	5.0	5.0	5.0	5.0	5.0
Goats	35.0	35.0	35.0	35.0	35.0
Horses	24.0	24.0	24.0	24.0	24.0
Pigs	3,047.32	4,000.0	5,489.94	7,378.02	9,915.45
Chickens	21,260.55	30,240.0	35,094.75	40,728.90	47,267.55
Ducks	4,049.63	5,760.0	6,684.72	7,757.88	9,003.34

Dairy cattle population: Cambodia is expected to be able to accommodate around 27 thousand dairy cattle, which can produce approximately 102.6 thousand tons of milk production in 2020 (RGC, 2015); however, the number of dairy cattle as of 2014 was not significant and only Phnom Penh City and Kandal Province are raising dairy cattle with the cooperation and support from Japan (MAFF, 2015). It is suggested there is a very low possibility to increase the number dairy cattle to the planned amount by 2020. Therefore, this study assumed that the number of dairy cattle will reach around 27 thousand heads by 2030 and is assumed to remain constant until 2050 due to limited feeding sources, breeding technologies, and management measures as well as animal health control technologies.

Cattle and buffalo population: RGC (2015) projected the number of cattle and buffalo by 2020. Since there is no detail information on the projection towards 2050, we assumed the annual growth rate of the number of cattle towards 2050 to be similar to a projection conducted by RGC (2014), which grows annually by 3.0% from 2010. However, the number of buffalo is assumed to increase until 2030 and to remain constant until 2050 as buffalo meat is not preferred by Cambodians.

Horse, goat, and sheep population: The number of horses, goats, and sheep towards 2050 is assumed to be similar to 2010 as most of Cambodians do not eat the meat from those animals.

Pig population: RGC (2015) projected the number of pig requirement by 2020. Since there is no information on the projection towards 2050, this study assumed the annual growth rate of the number of pigs towards 2050 to be similar to a projection conducted by RGC (2014), which grows annually by 3.0% from 2010.

Poultry population: RGC (2015) projected the poultry requirement by 2020. It was indicated that the poultry requirement will grow slower than those of cattle and pigs in the future. Hence, this study assumed that the poultry requirement will grow annually 1.5% towards 2050 from 2010. The share of the duck requirement in 2050 is assumed to be similar to the 2010's data, which was around 16% of the total poultry (NIS, 2011).

4.8 Results

The emission sources used in this study followed the IPCC guideline (IPCC, 2006). Table 4.14 indicates GHG emissions in the BaU case from agriculture and LULUCF sectors in a 10-year interval from 2010 to 2050, while Table 4.15 presents GHG emissions reduction in a 10-year interval, applied from 2020 to 2050.

Table 4.14: GHG emissions in agricultural and LULUCF sectors in the BaU case

Emission sources [ktCO_2eq./year]	CODE*	2010	2020	2030	2040	2050
The agricultural sector						
Enteric fermentation	3A1	4,326	4,470	6,015	8,068	10,826
Manure management	3A2	606	794	993	1,244	1,568
Rice cultivation	3C7	17,090	21,273	26,479	32,961	32,961
Managed soil	3C4-3C6	4,120	6,899	10,574	16,515	21,454
Sub-total		26,142	33,436	44,062	58,788	66,808
The LULUCF sector**						
Changes in forest and other woody biomass stocks	5A	-46,015	-45,691	-45,691	-45,691	-45,691
Forest and grassland conversion	5B	18,933	-7,135	-7,135	-7,135	-7,135
Sub-total		-27,082	-52,826	-52,826	-52,826	-52,826
Total		-940	-19,390	-8,764	5,962	13,982

*The code of the IPCC guideline 2006, while ** (-) means carbon sink capacity

Table 4.15: Mitigation potentials in agricultural [with cost the less than 10USD/tCO_2eq.] and LULUCF [with the cost less than 50USD/tCO_2eq.] sectors

Mitigation measures [ktCO_2eq./year]	CODE*	2020	2030	2040	2050
The agricultural sector					
Daily spread of manure	DSM	157	213	285	381
Dome digester and biogas is used as energy	CFL	45	60	79	106
High genetic merit	HGM	387	521	699	938
Replacement of roughage with concentrates	RRC	568	766	1,028	1,379
Replace urea with ammonium sulphate	RAS	1,191	1,483	1,846	1,846
Midseason drainage in rice paddy	MD	6,905	8,595	10,699	10,699
Off-season incorporation of rice straw	OIR	2,155	2,683	3,339	3,339
Convert fertilizational tillage to no-tillage	CFT	22	24	26	17
High efficiency fertilizer application	HEF	956	1,227	1,594	1,814
Tillage and residue management	TRM	0	0	2	31
Slow-release fertilizer	SRF	0	0	0	0
Sub-total		12,386	15,572	19,597	20,550
The LULUCF sector					
Plantation-short rotation	PSR	3	3	3	0
Plantation-long rotation	PLR	1	1	1	1
Reforestation-fast growing species	RFS	6	6	6	6
Reforestation-slow growing species	RSS	2	2	2	2
Enhanced natural regeneration	ENR	1	1	1	1
Agro-forestry	AGF	9	9	9	9
Reduced impact logging	RIL	8,866	8,866	8,866	8,866
Sub-total		8,889	8,889	8,889	8,886
Total		**21,275**	**24,461**	**28,485**	**29,435**

* The code used in the AFOLU-B model

4.8.1 GHG emissions from the AFOLU sector

The results yield that the AFOLU sector in Cambodia was a net sink with total carbon sink of around 940ktCO_2eq./year in 2010 and is expected to become a net emitter with total GHG emissions of about 13,982ktCO_2eq./year in 2050. GHG emissions per capita are projected to increase from a negative value of around -0.07tCO_2eq./year in 2010 to around 0.64tCO_2eq./year in 2050. GHG emissions from the agricultural sector are projected to increase about 3 times in 2050 compared to 2010. Among them, rice cultivation (3C7) was the largest contributor, contributing about 65% of total GHG emissions in 2010 and is projected to increase about 2 times in 2050BaU; followed by enteric fermentation (3A1), which contributed about 17% in 2010 and is expected to increase around 3 times in 2050. Meanwhile, managed soil (3C4-3C6) contributed about 16% in 2010 and is projected to increase around 5 times, which is the highest incremental rate among other sources. The smallest contributor was manure management (3A2), contributing about 2% in 2010 and will increase around 2 times in 2050.

The results yield that the LULUCF sector was a net sink with total carbon sink of around 27,082ktCO_2eq./year in 2010. Among them, change in forest and other woody biomass stocks (5A) contributed about 72%, while the rest contributed by forest and grassland conversion (5B). Carbon sinks from 2020 to 2050 in 5B shows carbon uptake along with the growth of planted forest in 2015 to meet the Government’s target in 2015. The result yields that the sink capacity increases significantly from 2010 to 2020 and remains constant until 2050.

4.8.2 Mitigation potentials in the agricultural sector in different costs

Table 4.16 indicates that the higher the costs the larger the economic reduction potentials in 2050. The result illustrates that the cost of less than 0USD/tCO_2eq. generates a mitigation potential of around 5,959ktCO_2eq./year. The rice cultivation (3C7) is the largest contributor, followed by enteric fermentation (3A1), while managed soil (3C4-3C6) cannot be applied under the cost of less than 0USD/tCO_2eq. Meanwhile, the cost of less than 10USD/tCO_2eq. generates emissions reduction potential of about 20,532ktCO_2eq./year. The rice cultivation (3C7) still contributes the biggest emissions reduction potential of around 77%, followed by enteric fermentation (3A1) (around 11%), while managed soil (3C4-3C6) contributes around 1.9%. The manure management (3A2) contributes the smallest share of 2%. The cost ranging over 10USD/tCO_2 does not cause a great increase in emissions reduction potential. This indicates that agricultural countermeasures are relatively low cost and most of the effects are applied with the cost of less than 10USD/tCO_2eq. The maximum mitigation potentials without considering economic constraints (technical potential) are expected to reduce emissions by about 22,651ktCO_2eq./year in 2050, about 1.5 times higher than the cost of less than 10USD/tCO_2eq.

Table 4.16: GHG mitigation potentials of the agricultural sector in different costs [USD/tCO_2eq.] in 2050CM

Mitigation potential [ktCO_2eq./year]	CODE	0	10	20	50	100	Max.*
Enteric fermentation	3A1	302	1,043	943	980	980	974
Manure management	3A2	0	381	581	547	547	556
Rice cultivation	3C7	5,657	17,263	17,263	17,248	17,248	17,248
Managed soil	3C4-3C6	0	1,845	2,647	3,877	3,877	3,872
Total		5,959	20,532	21,434	22,651	22,651	22,651

*Max. represents technological potential without considering economic constraints.

4.8.3 Mitigation potentials in the LULUCF Sector in different costs

Table 4.17 shows GHG emissions mitigation potentials in the different costs in the LULUCF sector in Cambodia. This table indicates that the reduced impact logging dominated the other mitigation measures because the land for forest plantation is limited due to cropland and settlement expansion. The result yields that the cost of less than 0USD/tCO_2eq. generates a mitigation potential of 0ktCO_2eq./year. It implies that mitigation measures cannot be applied under the cost of less than 0USD/tCO_2eq. Meanwhile, the cost of less than 10USD/tCO_2eq. generates mitigation potential of around 9ktCO_2eq./year and can be applied only with agro-forestry (AGF). The cost of less than 20USD/tCO_2eq. generates GHG emissions mitigation potential of about 15ktCO_2eq./year, while the cost ranging from less than 50USD/tCO_2eq. and above contributes to the same mitigation potentials of around 8,886ktCO_2eq./year. The result suggests that the cost of less than 50USD/tCO_2eq. is the most cost effective mitigation potential in Cambodia whereby reduced impact logging (RIL) generates the largest mitigation potentials, followed by agro-forestry (AGF) and reforestation-fast growing species (RFS). The maximum mitigation potentials at the cost without considering economic constraints (technical potential) is expected to mitigate GHG emissions by about 8,889ktCO_2eq./year in 2050.

Table 4.17: GHG mitigation potentials [$ktCO_2$eq./year] in the LULUCF sector in different costs in 2050CM

Mitigation measures [USD/tCO_2eq.]	Code	0	10	20	50	100	Max.*
Plantation-short rotation	PSR	0.00	0.00	0.00	0.00	2.97	2.97
Plantation-long rotation	PLR	0.00	0.00	0.00	1.18	1.18	1.18
Reforestation-fast growing species	RFS	0.00	0.00	5.62	5.62	5.62	5.62
Reforestation-slow growing species	RSS	0.00	0.00	0.00	1.92	1.92	1.92
Enhanced natural regeneration	ENR	0.00	0.00	0.00	1.07	1.07	1.07
Agro-forestry	AGF	0.00	9.50	9.50	9.50	9.50	9.50
Reduced impact logging	RIL	0.00	0.00	0.00	8,866.47	8,866.47	8,866.47
Total		0.00	9.50	15.12	8,885.76	8,888.73	8,888.73

*Represents technological potential without considering economic constraints.

4.9 Discussion

According to the results, the agricultural sector is a net emitter and the cumulative GHG emissions were projected to increase considerably between 2010, 2030 and 2050. In contrast, the LULUCF sector was projected to be a net carbon sink in 2010, 2030 and 2050. The analysis of main drivers led to the increase of GHG emissions and carbon sequestration is shown in Table 4.18. It can be observed from the table that the increase of agriculture crop production, land expansion, and livestock demand (MoE, 2013 and RGC, 2013 and 2015) derived largely from the population growth (NIS, 2011 and UN, 2012) as well as the Government's plan to export some agricultural products (RGC, 2013) and meat (cattle) (RGC, 2015). These drives are extremely certain to stimulate the considerable increase of GHG emissions from the agricultural sector. However, it can be noted that the Government has the target to increase forest cover by 60% in 2015 (RGC, 2011), which was assumed to be the same in 2030 and 2050 for estimating GHG emissions in the LULUCF sector in this study. The increase of forest cover is very important strategy to mitigate global warming and to balance forest ecosystem (RGC, 2010a). As explained, the LULUCF sector was projected to remain a net carbon sink and sink capacity still increased in both 2030 and 2050.

Moreover, the estimated results of GHG emissions in the agricultural sector in 2010 of this study were very similar to the SNC's ones (MoE, 2013); however, they were larger than a projection and an estimation by the Initial National Communication (INC) (MoE, 2002) and the United States Environmental Protection Agency (U.S.EPA) (EPA, 2012), respectively. A comparison of GHG emissions by sources in the agriculture sector in Cambodia from different studies is shown in Figure 4.4. Meanwhile, GHG emissions in the LULUCF sector, both GHG emissions and sink capacity in this study were slightly lower than the SNC's ones in 2010 (Figure 4.5). This resulted from the differences in assumptions and limited access to information in the SNC (MoE, 2013). In addition, both GHG emissions and sink capacity in this study were almost half of the INC because under the INC the forest exploitation was assumed at a high rate (MoE, 2002) since the Government granted very large forest concessions to the international forest logging companies during that time (RGC, 2010a and Turton, 2004) and there was no concrete plan for forest management (MoE, 2002). All the logged forests would regrow afterward that led to increase of the biomass growth rate, which was the source of both carbon stock and sequestration.

The projected GHG emissions in the agricultural sector in 2020 and 2030 between this study and the SNC were very similar; however, they were larger than in the U.S.EPA (EPA, 2012) in the same years (Table 4.19). This is due mainly to the limited access to the country information under the U.S.EPA and most of the information was collected from the FAOSTAT database (EPA, 2012) where it was observed to be different from the national reports in 2010 (MAFF, 2011 and NIS, 2011). Projected GHG emissions in the agricultural sector in 2050 in this study are almost double those of the SNC; this is thanks to the limited access to information in the SNC (MoE, 2013).

The result also yields that the most effective mitigation measures in the agricultural sector can be applied with the cost of less than 10USD/tCO_2eq.; however, it cannot be applied under the LULUCF sector where the most plausible mitigation measures are applied with the cost of less than 50USD/tCO_2eq. Besides, the mitigation potential in the AFOLU sector would be much higher than that of the energy sector. BaU emissions are projected to be about 20,800ktCO_2/year in the energy sector in 2045 under the SNC (MoE, 2013) and around 13,982ktCO_2eq./year in the AFOLU sector in 2050 for this study. From the BaU emissions, around 5,400ktCO_2eq./year (about 26%) of energy-induced CO_2 emissions under the SNC (MoE, 2013) and around 29,438ktCO_2eq./year (about 200% due to increase of carbon sequestration in the LULUCF sector) of the AFOLU sector can be mitigated at maximum. It is clear that the application of mitigation measures in the AFOLU sector has a greater potential to reduce GHG emissions at this cost level in Cambodia. Furthermore, this study suggests that the land limitation to apply mitigation measures in the LULUCF sector is one of the main challenges to increase mitigation potentials since increase of land areas for forest plantations would decrease other land areas (*e.g.* cropland and settlement), while the SNC did not take the land limitation into account.

In order to improve the future analysis, additional studies are needed, especially by combining the AFOLU-B model with the AFOLU Activity model (AFOLU-A) (Gomi and Misumi, 2013) in order to assess mitigation potentials under different assumptions; for instance, improving crop intensity and productivity can reduce the demand for cropland areas, building more compact cities can reduce the demand for settlement areas, and improving feeding sources and alternative healthy diet can reduce meat demand from livestock, etc. Thus, Cambodia has more lands to increase forest plantations which help reduce deforestation and increase reforestation and afforestation. The AFOLU-A model is a top-down model formulated to estimate amounts of human activities in the AFOLU sector based on population and socioeconomic indicators (Gomi and Misumi, 2013).

Table 4.18: Key drivers for changes of GHG emissions and carbon sequestration in the AFOLU sector in Cambodia

Key drivers	2010	2030	2050	Explanation
Population [1,000 persons]	13,959	18,391	21,964	The population was projected to increase about 1.3 and 1.6 times in 2030 and 2050, respectively, (NIS, 2011and UN, 2012). The population growth led to the increase of food demand and land expansion, which are the main drivers for GHG emissions.
Crop land [1,000 ha]	3,227	4,400	4,400	Crop land areas are expected to increase about 1.4 times in both 2030 and 2050 (MoE, 2013) because the Government needs to increase rice production for domestic comsumption and export target of at least one million ton of milled rice by 2015 (RGC, 2010).
Livestock requirement [1,000 heads]				
Meat cattle	3,547	4,895	8,842	The meat cattle is projected to increase about 1.4 and 2.5 times in 2030 and 2050, respectively, compared to 2010 and the increase of meat demand thanks to the population growth and export oriented (RGC, 2014 and 2015).
Pigs	3,047	5,490	9,915	The pig requirement is projected to increase about 1.8 and 3.3 times in 2030 and 2050, respectively, compared to 2010 and the increase of number of pigs thanks to the population growth (RGC, 2014 and 2015).
Chickens	21,261	35,095	47,268	The chicken requirement is projected to increase about 1.7 and 2.2 times in 2030 and 2050, respectively, compared to 2010 and the increase of number of chickens thanks to the population growth (RGC, 2014 and 2015).
Forest land [1,000 ha]	10,364	10,862	10,862	Forest cover increased from around 57% in 2010 to around 60% in 2030 and 2050 due to the Government's commitment to increasing forest cover to respond to the CMDGs (RGC, 2011)
Harvested land areas [1,000 ha]	3,732	5,916	6,970	Harvested land areas are projected to increase about 1.6 and 1.9 times in 2030 and 2050, respectively, (MoE, 2013) due to the available irrigation systems and advanced agriculture technologies and the Government also needs to increase crop production for domestic comsumption and for export (RGC, 2013). The expansion of harvested land areas would increase fertilizer demand
GHG emissions [ktCO_2eq./year]				
The agricultural sector	26,142	44,062	66,808	GHG emissions from the agriculture sector are projected to increase about 1.7 and 2.6 times in 2030 and 2050, respectively; this would result from the population growth, which caused the increase of the demand for meat and crop production as well as land expansion.
The LULUCF sector	-27,082	-52,826	-52,826	The LULUCF sector is a net carbon sink and sink capacity is expected to increase about 2 times in both 2030 and 2050 due to the increase of forest cover set by the Government.

Table 4.19: Comparisons of GHG emissions projections in the agricultural sector in Cambodia between this study, the SNC and the U.S.EPA ($ktCO_2eq./year$)

Emission sources [$ktCO_2eq./year$]	CODE	This study				The SNC				The U.S.EPA		
		2010	2020	2030	2050	2010	2020	2030	2050	2010	2020	2030
Enteric fermentation	3A1	4,326	4,470	6,015	10,826	5,836	6,882	7,927	10,018	4,407	5,267	6,248
Manure management	3A2	606	794	993	1,568	-	-	-	-	2,122	2,533	3,005
Rice cultivation	3C7	17,090	21,273	26,479	32,961	17,940	19,620	21,178	22,625	3,753	3,629	3,243
Managed soil	3C4-3C6	4,120	6,899	10,574	21,454	3,552	4,206	4,888	6,305	1,836	2,320	3,069
Others*										7,312	7,312	7,312
Total		**26,142**	**33,436**	**44,062**	**66,808**	**27,328**	**30,708**	**33,993**	**38,948**	**19,430**	**21,061**	**22,878**

* GHG emissions from the agriculture sector additional to the above four categories and are used by the U.S.EPA (2012)

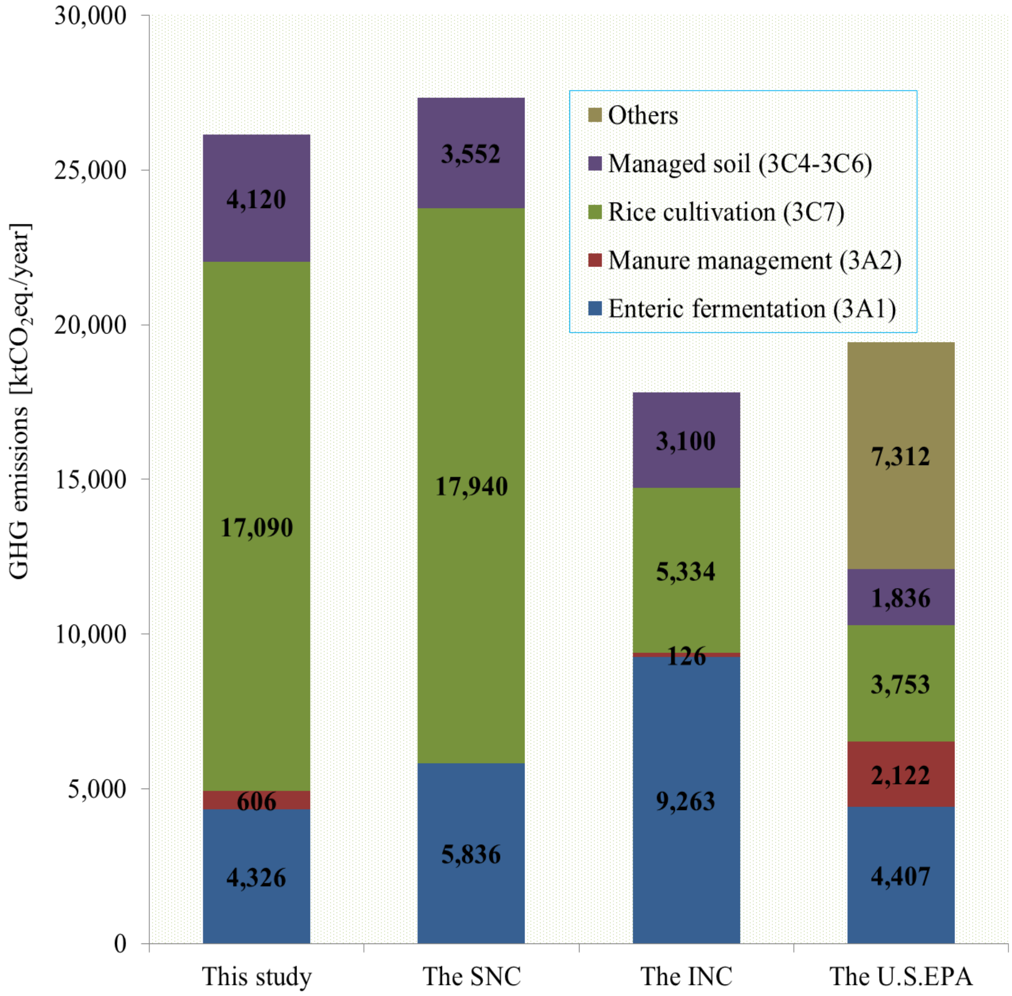

Figure 4.4: Comparison of GHG emissions in the agricultural sector between this study, the SNC and the U.S. EPA in 2010

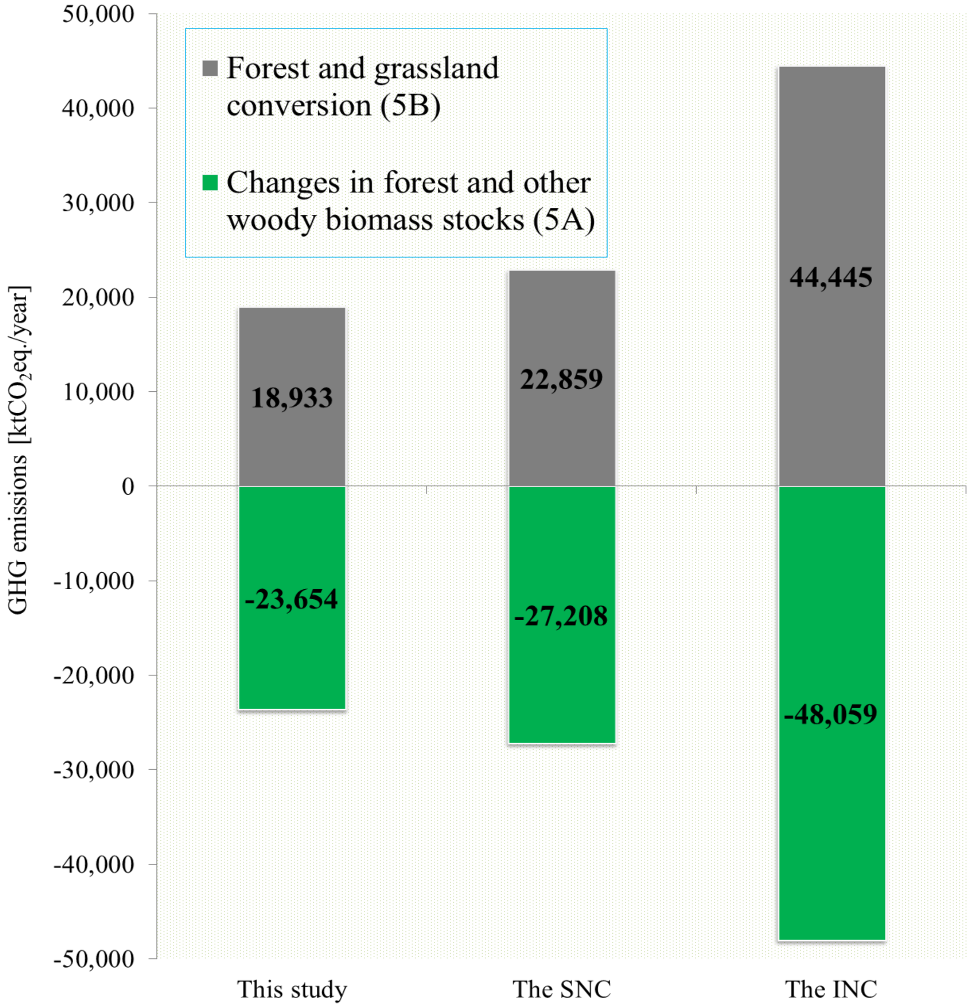

Figure 4.5: Comparison of GHG emissions in the LULUCF sector between this study, the INC and the SNC in 2010

CHAPTER 5 SUMMARY OF GHG EMISSIONS AND REDUCTION POTENTIALS AND A PROPOSAL FOR LOW CARBON DEVELOPMENT ACTION TOWARDS 2050 IN CAMBODIA

5.1 Summary of GHG emissions and reduction potentials

It is witnessed that climate change risks and threats to Cambodia's economic growth, livelihoods and ecosystem functions called for the need for integrated approaches to design a climate change policy aligning to the sustainable economic development agenda (MoE, 2013a). Although the country gives the priority to the climate change adaptation, some mitigation activities have been implemented. The country is also designed to balance between adaptation and mitigation. For instance, Cambodia is promoting the society toward a green, low carbon and climate resilient economy (MoE, 2013a and RGC, 2013b).

In order to estimate GHG emissions and reduction potentials in Cambodia, this study applied two quantitative models including the ExSS tool and the AFOLU-B model. Table 5.1 shows the results of GHG emissions and reductions by sectors in energy and AFOLU sectors. The results yield that total GHG emissions in Cambodia are projected to increase about 4 times and 32 times in 2030BaU and 2050BaU, respectively, compared to 2010. The agriculture sector contributed to the biggest share of GHG emissions, followed by the energy sector in 2030BaU; however, the energy sector becomes the largest emitter in 2050BaU. The LULUCF sector is the net carbon sink and the sink capacity is expected to increase from around 27,082ktCO_2eq./year in 2010 to about 52,826ktCO_2eq./year (about 2 times) in both 2030BaU and 2050BaU. GHG emissions per capita are projected to increase from about 0.24tCO_2eq./year in 2010 to about 0.79tCO_2eq./year and 4.79tCO_2eq./year in 2030BaU and 2050BaU, respectively. However, they are projected to decrease to a negative value of around -1.24tCO_2eq./year in 2030CM and to 1.08tCO_2eq./year in 2050CM.

The results illustrate total GHG emissions of around 37,287ktCO_2eq./year and 81,588ktCO_2eq./year are expected to reduce in 2030CM and 2050CM, respectively, by implementing some appropriate low carbon measures. Table.5.2 shows the detail of GHG reductions by sectors and measures in 2030CM and 2050CM. The results also yield that the AFOLU sector is projected to contribute to the largest GHG reduction potentials of approximately 24,461ktCO_2eq./year (66%), while the energy sector is expected to reduce by about 12,826ktCO_2eq./year in 2030CM (34%); however, the energy sector is predicted to attribute to the highest reduction potentials of about 52,153ktCO_2eq./year (64%), while the AFOLU sector is expected to reduce by around 29,435ktCO_2eq./year (36%) in 2050CM.

The results suggest that Cambodia becomes a net carbon sink, offsetting around 22,774ktCO_2eq./year in 2030CM; this is because the LULUCF sector was already a net carbon sink in the 2030BaU and the sink capacity increased even further under low carbon measures in 2030CM. The results suggest that although low carbon measures applied, Cambodia remains a net carbon emitter, emitting about 23,713ktCO_2eq./year in 2050CM due to the tremendous increase of CO_2 emissions from the energy sector in 2050BaU. The results indicate that around 77% of GHG emissions are expected to reduce in 2050CM.

The detail decomposition analysis is shown in Table 5.3 and Table 5.4 in 2030CM and 2050CM, respectively. According to Table 5.3, non-energy related GHG reductions contributes to the highest share (around 66%) of GHG emission reductions, followed by energy efficiency equipment and vehicles (around 23%) in 2030CM, while fuel switch contributes to the smallest share (about 0.5%). Conversely, energy efficiency equipment and vehicles attribute to the highest share of GHG emission reductions (about 49%), followed by non-energy related GHG reductions (around 36%) in 2050CM, while renewable energy in power generation shares the smallest GHG emission reductions (around 2%). The results of this study obviously argue that Cambodia has extensive opportunity to reduce GHG emissions through implementing some appropriate low carbon development strategies, which will be explained in the following section.

Table 5.1: GHG emissions and reductions by sectors in energy and AFOLU sectors [ktCO_2eq./year]

GHG emissions and reductions	2010	2030BaU	2030CM	2050BaU	2050CM
The energy sector					
Residential	830	2,414	918	9,889	2,034
Commercial	217	1,433	482	3,663	1,298
Industrial	1,173	7,536	3,926	23,691	11,136
Passenger transportation	996	6,374	2,743	22,276	9,431
Freight transportation	1,004	5,521	2,383	31,806	15,273
Sub-total	**4,221**	**23,277**	**10,451**	**91,325**	**39,172**
The agricultural sector					
Enteric fermentation	4,326	6,015	4,728	10,826	8,509
Manure management	606	993	721	1,568	1,081
Rice cultivation	17,090	26,479	13,695	32,961	17,059
Managed soil	4,120	10,574	9,348	21,454	19,609
Sub-total	**26,142**	**44,062**	**28,490**	**66,808**	**46,259**
The LULUCF sector*					
Changes in forest and other woody biomass stocks	-46,015	-45,691	-54,559	-45,691	-54,559
Forest and grassland conversion	18,933	-7,135	-7,156	-7,135	-7,156
Sub-total	**-27,082**	**-52,826**	**-61,715**	**-52,826**	**-61,715**
Total	**3,281**	**14,514**	**-22,774**	**105,307**	**23,716**
Per capita GHG emissions (tCO_2eq./person)	0.24	0.79	-1.24	4.79	1.08

* minus means carbon sink

Table.5.2: Detail quantitative GHG reductions by sectors and measures in energy and AFOLU sectors [ktCO_2eq./year]

GHG emissions reduction/year	2030CM	2050CM
The energy sector		
Residential	1,497	7,855
Commercial	951	2,365
Industrial	3,610	12,554
Passenger transportation	3,631	12,845
Freight transportation	3,138	16,533
Sub-total	12,826	52,153
The agricultural sector		
Daily spread of manure	213	381
Dome digester and biogas is used as energy	60	106
High genetic merit	521	938
Replacement of roughage with concentrates	766	1,379
Replace urea with ammonium sulphate	1,483	1,846
Midseason drainage in rice paddy	8,595	10,699
Off-season incorporation of rice straw	2,683	3,339
Convert fertilizational tillage to no-tillage	24	17
High efficiency fertilizer application	1,227	1,814
Tillage and residue management	0	31
Slow-release fertilizer	0	0
Sub-total	15,572	20,550
The LULUCF sector		
Plantation-short rotation	3	0
Plantation-long rotation	1	1
Reforestation-fast growing species	6	6
Reforestation-slow growing species	2	2
Enhanced natural regeneration	1	1
Agro-forestry	9	9
Reduced impact logging	8,866	8,866
Sub-total	8,889	8,886
Total	**37,287**	**81,588**

Table 5.3: Decomposition analysis for GHG emission reductions in 2030CM

Year	2030BaU	2030CM						
Total GHG emissions ($ktCO_2eq$./year)	14,514	-22,774	Distribution of GHG emission reductions in 2030CM					
			Renewable energy in power generation	Fuel switch	Energy efficiency equipment and vehicles	Modal shift	Improvement in energy intensity	Non-energy related GHG reductions
AFOLU								24,461
Residential			184	49	1,009	0	255	
Commercial			183	44	572	0	152	
Industrial			132	10	2,319	0	1,149	
Passenger transportation			57	61	2,100	1,413	0	
Freight transportation			4	40	2,714	379	0	
Total reduction ($ktCO_2eq$./year)	**37,287**		**560**	**204**	**8,714**	**1,793**	**1,555**	**24,461**
Share			1.5%	0.5%	23.4%	4.8%	4.2%	66%

Table 5.4: Decomposition analysis for GHG emission reductions in 2050CM

Year	2050BaU	2050CM						
Total GHG emissions ($ktCO_2eq$./year)	105,307	23,719	Distribution of GHG emission reductions in 2050CM					
			Renewable energy in power generation	Fuel switch	Energy efficiency equipment and vehicles	Modal shift	Improvement in energy intensity	Non-energy related GHG reductions
AFOLU								29,435
Residential			631	464	5,867	0	893	
Commercial			483	46	1,440	0	396	
Industrial			350	775	7,968	0	3,462	
Passenger transportation			187	189	9,572	2,897	0	
Freight transportation			75	733	15,373	352	0	
Total reductions ($ktCO_2eq$./year)	**81,588**		**1,726**	**2,207**	**40,220**	**3,248**	**4,751**	**29,435**
Share			2%	3%	49%	4%	6%	36%

5.2 Eight low carbon development strategies in energy and AFOLU sectors

The concept of the LCD doesn't only mean to reduce GHG emissions, but also to focus on a better energy efficiency improvement, which then may improve economic growth, energy security, and environmentally sound development. Renewable energy is considered as one of the best energy options to reduce CO_2 emissions. Japan counted renewable energy as an alternative energy source after the nuclear disaster in 2011, and hydroelectricity was counted as the main source of energy supply (Oliver *et al*., 2013). Likewise Japan, Cambodia adopted hydropower as one of the major sources of energy supply in the future in order to meet the increasing demand and reduce GHG emissions (MME, 2014). Besides, the country developed national policy, strategy and action plan on energy efficiency in 2013 aiming to introduce energy efficiency and energy saving technologies so as to reduce energy demand and CO_2 emissions and to provide reliable and affordable energy services to all of the end users in the most efficient and sustainable manner (MME, 2013). On top of that, the Government is promoting and implementing national forest programme (2010-2029) (RGC, 2010a) in order to increase forest cover by 60% in 2015, which contribute to reducing sources of GHG emissions and enhancing carbon stock and sequestration, accordingly. The country also formulated sustainable agriculture and livestock management strategies aiming to increase and improve agriculture and livestock production as well as to reduce GHG emissions (MAFF, 2013 and RGC, 2015).

The RGC realized that the LCD is very important approach to address not only the environmental challenges of climate change, but also the social, economic, cultural, and political challenges (MoE, 2013a). We need to develop the country on the basis of a close, reasonable, harmonious coordination of inclusive economic and social development, environmental sustainability, and cultural conservation as well as to make Cambodia a more liveable country to all her residents (RGC, 2009 and 2013b). A design of low carbon development plan is regarded as one of most important approaches to direct and encourage Cambodia to formulate a concrete and feasible LCD policy in the future.

The results of this study indicated that Cambodia has a big window of opportunity to reduce GHG emissions through applying some appropriate low carbon measures. Therefore, this study proposed eight low carbon development strategies coupled with a list of actions in order to reach the expected amount of GHG reductions. The detail low carbon development strategies and actions with quantitative reduction are shown in Table 5.5. These strategies were selected in consultation with key relevant stakeholders and also supported by the leader of the Ministry of Environment of Cambodia. The effective implementation of the proposed strategies and actions, Cambodia is expected to become a net carbon sink, offsetting about 22,774ktCO_2eq./year in 2030CM and around 77% of total GHG emissions is expected to reduce in 2050CM.

Table 5.5: Quantitative GHG emissions reduction by each LCD strategy and action [$ktCO_2$eq./year]

Eight LCD Strategies	Actions	Quantitative GHG reductions			
		2030CM	Share (%)	2050CM	Share (%)
Green energy		**4,281**	**11.48**	**16,559**	**20.30**
	Use of renewable energy	253		1,284	
	Reduce transmission losses and own uses	560		1,726	
	Smart appliances and home automation (energy efficiency improvement and energy saving technology)	3,467		13,548	
Green technologies and investment		**1,443**	**3.87**	**4,927**	**6.04**
	Green industries and industrial ecology	572		1,440	
	Green technologies transfer (cleaner production)	872		3,486	
	Green business competition and green credit (indirect contribution)				
Green building		**333**	**0.89**	**1,289**	**1.58**
	Energy saving in households and institutions	155		625	
	Green building designs and construction	76		268	
	Energy saving appliances in building designs	102		396	
Green transportation		**5,685**	**15.25**	**25,761**	**31.57**
	Use of public transport system	1,470		2,897	
	Introduce hybrid and biodiesel motorized vehicles	101		1,110	
	Low-emission and energy-efficient vehicles	2,714		15,373	
	Eco-driving and vehicle technical inspection	1,400		6,381	
Low carbon infrastructure		**1,084**	**2.91**	**3,618**	**4.43**
	Use the freight train for long-distance shipment	384		427	
	Design comfortable and safe pavements	700		3,191	
	Design a standard road facility for different transport mode				
Sustainable forest management		**8,889**	**23.84**	**8,886**	**10.89**
	Reductions of impact logging	8,866		8,866	
	Agro-forestry plantation	9		9	
	Reforestation of fast and slow growing species	8		8	
	Plant short and long rotation forest	4		1	
	Natural forest regeneration enhancement	1		1	
Green agriculture management		**14,012**	**37.58**	**17,746**	**21.75**
	Midseason drainage	8,595		10,699	
	Off-season incorporation of rice straw	2,683		3,339	
	Replace urea with ammonium Sulfate	1,483		1,846	
	High efficiency fertilizer application	1,227		1,814	
	No-tillage	24		48	
Sustainable livestock management		**1,560**	**4.18**	**2,803**	**3.44**
	Replace roughage with concentrates	766		1,379	
	High genetic species	521		938	
	Daily spread of manure	213		381	
	Construct dome digester	60		106	
Total GHG reduction		**37,287**	**100**	**81,588**	**100**

Comprehensive and subsequent descriptions of both qualitative and quantitative GHG emissions reductions by each strategy and action are as follows.

5.2.1 Strategy on green energy

The strategy on green energy focuses on energy efficiency improvement in residential, commercial, and industrial sector; fuel switch; and reduction of transmission losses and own uses in the power sector. GHG emissions of about 4,281ktCO_2eq./year and 16,559ktCO_2eq./year or about 11.48% and 20.30% of total GHG emissions reduction in 2030CM and 2050CM, respectively, are projected to reduce under this strategy. The detail actions, coupled with quantitative emissions reduction are shown in Table 5.6.

Table 5.6: Strategy on green energy and quantitative emissions reduction by each action [ktCO_2eq./year]

No.	Actions	Quantitative GHG reductions	
		2030CM	2050CM
1	The encouragement of the use of renewable energy through the construction of hydropower plants and installation of solar, wind, mini-hydro, tidal, and biogas/biomass, and so forth	253	1,284
2	The improvement of the quality of electricity distribution lines through reducing transmission losses and own uses	560	1,726
3	The promotion of the use of smart appliances and home automation systems including energy-saving and energy efficient appliances, power control devices, and electricity appliance maintenance	3,467	13,548
Total GHG emissions reduction		**4,281**	**16,559**

5.2.2 Strategy on green technology and investment

The Government is promoting green technology and investment through encouraging investors to invest capital in green agriculture, industry, transportation, energy, and construction, etc. (RGC, 2013b). This strategy is expected to reduce GHG emissions by around 1,443ktCO_2eq./year and 4,927ktCO_2eq./year or around 3.87% and 6.04% of total GHG emissions reduction in 2030CM and 2050CM, respectively. A package of low carbon actions, coupled with quantitative emissions reduction is shown in Table 5.7.

Table 5.7: Strategy on green technology and investment and quantitative emissions reduction by each action [ktCO_2eq./year]

No.	Actions	Quantitative GHG reductions	
		2030CM	2050CM
1	The promotion of green industries and industrial ecology	572	1,440
2	The implementation of transfer of green technologies such as cleaner production, sustainable product innovation, renewable energy utilization	872	3,486
3	The promotion of green business competition and green credit (indirect contribution)		
Total GHG emissions reduction		**1,443**	**4,927**

5.2.3 Strategy on green building

Green building is a new concept in Cambodia (RGC, 2013b). It is referred to the implementation of renewable energy, energy saving behaviour and energy efficiency improvement, water saving, and environmental beauty (RGC, 2013b). The implementation of this strategy is expected to reduce GHG emissions of around 333ktCO_2eq./year and 1,289ktCO_2eq./year or about 0.89% and 1.58% in 2030CM and 2050CM, respectively. The detail actions, coupled with quantitative emissions reduction are shown in Table 5.8.

Table 5.8: Strategy on green building and quantitative emissions reduction by each action [ktCO_2eq./year]

No.	Actions	Quantitative GHG reductions	
		2030CM	2050CM
1	The encouragement of all households and institutions to save energy	155	625
2	The promotion and implementation of green building designs and construction through the use of energy efficient materials	76	268
3	The introduction of embedding renewable energy and energy saving appliances in building designs	102	396
Total GHG emissions reduction		**333**	**1,289**

5.2.4 Strategy on green transportation

Cambodia is facing many challenges in the transportation sector, such as traffic jam, lack of public transportation, and traffic violation, etc. (MPWT, 2013). The Government is managing to solve such a difficult situation through enforcing road safety related regulations, constructing sky bridges, and introducing public buses and trains, etc. This study expected that the implementation of the green transportation does not only help address this concern, but also mitigate GHG emissions. We expected that the implementation of this strategy can reduce GHG emissions by around 5,685ktCO_2eq./year and 25,761ktCO_2eq./year or about 15.25% and 31.57% of total GHG emissions reduction in 2030CM and 2050CM, respectively. A package of low carbon actions, coupled with quantitative emissions reduction is shown in Table 5.9.

Table 5.9: Strategy on green transportation and quantitative emissions reduction by each action [ktCO_2eq./year]

No.	Actions	Quantitative GHG reductions	
		2030CM	2050CM
1	The promotion of public transportation system (energy efficient urban mass transportation) in major cities by intensive urban mass transit facilities	1,470	2,897
2	The introduction of hybrid and biodiesel motorized vehicles	101	1,110
3	The introduction of low-emission and energy-efficient vehicles	2,714	15,373
4	The promotion of Eco-driving to save energy and motorized vehicle technical inspection	1,400	6,381
Total GHG emissions reduction		**5,685**	**25,761**

5.2.5 Strategy on low carbon infrastructure

This strategy focuses on modal shift and compact city design and planning for major cities. The implementation of this strategy, GHG emissions are expected to reduce by about 1,084ktCO_2eq./year and 3,618ktCO_2eq./year or about 2.91% and 4.43% of total GHG emissions reduction in 2030CM and 2050CM, respectively. The detail actions, coupled with quantitative emissions reduction are shown Table 5.10.

Table 5.10: Strategy on low carbon infrastructure and quantitative emissions reduction by each action [ktCO_2eq./year]

No.	Actions	Quantitative GHG reductions	
		2030CM	2050CM
1	The use of freight train for long-distance shipment	384	427
2	A design of comfortable and safe pavements to produce a walkable city	700	3,191
3	A design of a standard road facility to differentiate between vehicle, motorist, cyclist, and walking lanes to avoid accidents and traffic congestion (indirect contribution)		
Total GHG emissions reduction		**1,084**	**3,618**

5.2.6 Strategy on sustainable forest management

Forests provide significant resources, functions and services such as wood and forest by-products, recreational opportunities, wildlife habitat, water and soil conservation, a filter for pollutants, producing oxygen, and absorbing CO_2 emissions (RGC, 2010a). The Government has made significant efforts to maintain forest cover of 60% by 2015 (RGC, 2011) and the NFP (2010-2029) was developed whereby the REDD-plus scheme has been implemented (RGC, 2010a). This study is expected that the strategy on sustainable forest management can help not only increase forest cover, but also reduce GHG emissions and balance forest ecosystem. The effective implementation of this strategy, similar GHG emissions of about 8,889ktCO_2eq./year or about 23.84% and 10.89% are expected to reduce in 2030CM and 2050CM, respectively, and the mitigation measures can be applied with the cost of less than 50USD/tCO_2eq. Detail actions, coupled with quantitative emissions reduction are shown in Table 5.11.

Table 5.11: Strategy on sustainable forest management and quantitative emissions reduction by each action [ktCO_2eq./year]

No.	Actions	Quantitative GHG reductions	
		2030CM	2050CM
1	The effective implementation of forest logging management and improvement	8,866	8,866
2	The encouragement of the application of agro-forestry, which can also provide agriculture products for household consumption	9	9
3	The promotion of reforestation of fast and slow growing species, including commercial plantation	8	8
4	The promotion of forest plantation of short and long rotation	4	1
5	Effective law enforcement to avoid illegal forest land encroachment in order to enhance natural regeneration	1	1
Total GHG emissions reduction		**8,889**	**8,886**

5.2.7 Strategy on green agriculture management

The agricultural sector plays a vital role in Cambodia, where around 80% of Cambodians are relying on (MAFF, 2011). The stable and steady growth of Cambodia's economy is largely attributed to the continued good performance of the agricultural sector (RGC, 2013) and the Government is promoting to export of at least one million ton of milled rice by 2015 (RGC, 2010). The implementation of the strategy on green agriculture management can not only help increase the agriculture products, but also reduce GHG emissions and improve soil quality as well. The effective implementation of this strategy, GHG emissions of around 14,012ktCO_2eq./year and 17,746ktCO_2eq./year or approximately 37.58% and 21.75% are expected to reduce in 2030CM and 2050CM, respectively, and the mitigation measures can be applied with the cost of less than 10USD/tCO_2eq. The detail actions, coupled with quantitative emissions reduction are shown in Table 5.12.

Table 5.12: Strategy on green agriculture management and quantitative emissions reduction by each action [ktCO_2eq./year]

No.	Actions	Quantitative GHG reductions	
		2030CM	2050CM
1	The implementation of midseason drainage in rice paddy, which involves the removal of surface floodwater from the rice crop for about seven days toward the end of tilling. It aerates the soil and shifts drainage time from vegetative period to reproductive one and helps reduce CH_4 production and emission (ClimateTech Wiki, n.d.)	8,595	10,699
2	The introduction of off-season incorporation of rice straw, which is the application of rice straw in the fallow period, would significantly reduce CH_4 emissions. On this, rice straw is best applied to dry soil in the off-season and emits even less CH_4 if composted (Richards and Sander, 2014)	2,683	3,339
3	The encouragement of the replacement of urea with ammonium Sulfate to suppress CH_4 production	1,483	1,846
4	The promotion of the high efficiency fertilizer application, which is required to apply nitrogen fertilizer in three smaller increments during crop uptake period to better match nitrogen application with crop demand and to reduce nitrogen availability for leaching, nitrification,	1,227	1,814
5	The introduction of the conversion from tillage to no-tillage, which is applied where soils are disturbed and less and more crop residue is retained. Soil disturbance tends to stimulate soil carbon losses through enhanced decomposition and erosion	24	48
Total GHG emissions reduction		**14,012**	**17,746**

5.2.8 Strategy on sustainable livestock management

In order to provide sufficient and safe food supply, ensure food security and improve incomes of the people, Cambodia developed national strategic planning framework for livestock (2015-2025) (RGC, 2015). The strategy on sustainable livestock management is expected not only to increase meat productivity and improve the livelihood condition of the rural communities, but also to reduce GHG emissions. The effective implementation of this strategy, GHG emissions of around 1,560ktCO_2eq./year and 2,803ktCO_2eq./year or about 4.18% and 3.44% are expected to reduce in 2030CM and 2050CM, respectively, and mitigation measures can be applied with the cost of less than 10USD/tCO_2eq. The detail actions, coupled with quantitative emissions reduction are shown Table 5.13.

Table 5.13: Strategy on sustainable livestock management and quantitative emissions reduction by each action [ktCO_2eq./year]

No.	Actions	Quantitative GHG reductions	
		2030CM	2050CM
1	The introduction of the replacement of roughage with concentrates, which is the most promising and cost-effective way to reduce CH_4 emissions from cattle, is to enhance productivity by improving feed quality. CH_4 production with high-concentrate feed is lower than that with high-roughage feed. Feeding starchy crop waste is also an effective way to reduce CH_4 emissions from ruminants (Shibata and Terada, 2009)	766	1,379
2	The introduction of high genetic species, which involves with the improvement of the genetic merit of dairy cows through the import of Holstein genetic material for use on native dairy breeds. It increases average yield in a dairy herd	521	938
3	The encouragement of the daily spread of manure where the manure is routinely removed from a confinement facility and is applied to crop land or pasture within 24 hours of excretion	213	381
4	The introduction and encouragement of the construction of dome digester (bio-digester) and biogas to use as energy sources, which generate biogas for cooking and lighting, while the effluence can be used as organic fertilizer for vegetable and other agriculture crops	60	106
Total GHG emissions reduction		**1,560**	**2,803**

5.3 Low carbon research network (LoCAR-Net) in Cambodia

Having experienced for this study, the establishment of a LoCAR-Net is found very useful in Cambodia. It can facilitate not only data collection, but also distribute LCD related information through trainings, workshops, and other climate change events. In addition, the network can provide the opportunity to get together different relevant stakeholders, including national agencies, local Governments and concerned Government/non-Government organizations, research institutes and academia and also help bridge the gap between decision-makers and researchers in the country. For instance, to facilitate this study, three workshops were organized subsequently in order to disclose the findings and to collect comments and inputs. There were around 70 participants who came from different Government agencies, research institutes, NGOs, and academia for each workshop. As a result of this study, we propose a LoCAR-NET for the Government to maintain, enhance and expand the collaboration and cooperation among different key stakeholders as well as to encourage the implementation of the proposed eight low carbon development strategies in the future (Appendix 15).

CHAPTER 6 CONCLUSIONS AND RECOMMENDATION

6.1 Conclusions

The Royal Government of Cambodia set out a comprehensive socioeconomic development plan to ensure all people live in peace, stability, security, social order, prosperity, and harmonization (RGC, 2009). Besides, the Government has set a goal to ensure food security, increase incomes, create employment and improve nutrition status for all Cambodians (RGC, 2015). Cambodia experienced an average annual economic growth rate of around 7.7% from 1994 to 2011, while the GDP per capita increased from around 216USD in 1992 to more than 1,000USD in 2013 and is expected to reach around 1,579USD in 2018 (RGC, 2012 and 2014). Due to the robust and steady economic growth, Cambodia was ranked as one of the most rapid economic development among developing countries (RGC, 2014). In addition, the Government has set a target to shift to the status of an upper-middle income country by 2030 and a high-income level by 2050 (RGC, 2013).

Cambodia still realizes that the stable and steady economic growth is largely attributed to the continued good performance of the agricultural sector whereby the country is increasing the value added of milled rice production for export and other high value agriculture products (RGC, 2013). The Government also declared that the land reform is a crucial tool to increase agricultural production by providing tittles and security of land tenure to the poor, especially rural farmers who are legally occupying the land. There is an implication that due to the ambiguous economic development plan, energy demand is expected to increase proportionally and so are CO_2 emissions. To meet the pressing need of energy demand, the RGC adopted the best alternative options for more constant, reliable, and affordable sources of energy whereby most of sources of the power supply originated from the renewable energy (hydropower).

At the time of enjoying the economic growth, Cambodia has faced a lot of challenges of climate change where there is a need to take actions. The Government stressed that addressing economic and social development by taking climate change into account will assist the country in reducing vulnerability to potential climate risks, improving air quality and mitigating GHG emissions (MoE, 2013a). Cambodia has seen the LCD as one of the priority policy approaches not only to address the adverse impacts of climate change, but also to significantly contribute to the achievement of CMDGs, the NSDP, and other Government development policies and strategies. The

LCD doesn't not only mean to reduce GHG emissions, but also to focus on a better energy efficiency improvement, which then may improve economic productivity, energy security, and environmentally sound development. The results of this study yield that total GHG emissions in Cambodia were projected to increase from around 3,281ktCO_2eq./year in 2010 to about 14,514ktCO_2eq./year (about 4 times) and 105,307ktCO_2eq./year (about 32 times) in 2030BaU and 2050BaU, respectively. However, GHG emissions of around 37,287ktCO_2eq./year and 81,588ktCO_2eq./year are expected to reduce in 2030CM and 2050CM, respectively, through implementing some appropriate low carbon measures.

This study proposed eight strategies for the low carbon development plan in Cambodia towards 2050, focused on energy and AFOLU policies. They are green energy, green technologies and investment, green building, green transportation, low carbon infrastructure, sustainable forest management, green agriculture management, and sustainable livestock management. The effective implementation of the proposed eight strategies, Cambodia is expected to become a net carbon sink, offsetting around 22,774ktCO_2eq./year in 2030CM and about 77% of total GHG emissions are expected to reduce in 2050CM. Among them, green agriculture management and sustainable forest management were projected to attribute to the largest share (about 38% and 24%) of GHG emissions reduction in 2030CM, respectively, followed by green transportation (about 13%). However, green transportation and green agriculture management contribute to the biggest share of GHG emissions reduction of around 31% and 22% in 2050CM, respectively, followed by green energy (about 21%). In order to effectively implement these strategies, the country has to ensure sufficient financial resources, especially from development partners and donor countries and enough qualified human capacity. Besides, the participation and cooperation from Government's institutions and different stakeholders are a must. We also expected that the implementation of the low carbon development plan will help Cambodia bridge the gap between researchers and decision-makers through workshops, trainings, dialogues, and debates, etc. In short, Cambodia must to move to a low-carbon paradigm to facilitate the effective medium- and long-term strategies for socioeconomic development and also to set GHG emissions reduction target in the long-run. Therefore, the results of this study are expected to be used to formulate a concrete and feasible LCD policy in Cambodia in the future.

6.2 Recommendation

Although the acceptable and satisfied results were produced to respond to the objectives of this study, some uncertainties were observed for both present quantification and future projection. For instance, the country has very limited information on transportation demand, economic structure (the IO table), energy demand by sectors, land use categories, and harvested areas, etc. Therefore, the trends of projections are not precise predictions; a range of possible outcomes is possible. The author used expert judgment based on the literature and a series of discussions with the national experts. In order to make the projection high quality enough, the country must improve data recording, management, and accessibility. Furthermore, there is a need to encourage more studies related to climate change mitigation in Cambodia.

Besides, this study was limited to energy and AFOLU sectors, while other sources of GHG emissions such as the waste sector and industrial processes were not covered. Hence, the scope of the study should be extended to wider areas. In terms of the applied models, for the ExSS tool, it should be considered the issue of transportation model, especially international transportation problems. While the AFOLU-B model estimated GHG reduction potentials based only on mitigation measures and costs, limited to mitigation activities. Therefore, there is a need to combine the AFOLU-B model with the AFOLU Activity model (AFOLU-A) (Gomi and Misumi, 2013) in order to assess mitigation potentials under different assumptions; for instance, improving crop intensity and productivity can reduce the demand for cropland area, building more compact cities can reduce the demand for settlement area, and improving feeding sources and alternative healthy diet can reduce meat demand from livestock, etc. The AFOLU-A model (see more detail in Gomi and Misumi, 2013) is a top-down model formulated to estimate amounts of human activities in the AFOLU sector based on population and socioeconomic indicators.

REFERENCES

1. ACI, 2014. Diagnostic Study Cambodia Agriculture in Transition. Draft Final Report. Agrifood Consulting International, Kensington, Maryland, USA.
2. Alexandratos, N., and Bruinsma, J., 2012. World Agriculture towards 2030/2050: The 2012 Revision. ESA Working paper No. 12-03. Rome, FAO.
3. Asian Development Bank (ADB), 2013. Asian Development Outlook 2013 Update: Governance and Public Service Delivery. Mandaluyong City. The Philippines.
4. Asian Development Bank (ADB), 2011. Transportation Sector Assessment, Strategy, and Road Map of Cambodia. Mandaluyong City. The Philippines.
5. Amann, M., Hoglund Isaksson, L., Winiwarter, W., Tohka, A., Wagner, F., Schopp, W., Bertok, I., Heyes, C., 2008. Emission Scenarios for Non-CO_2 GHGs in the EU-27. Mitigation Potentials and Costs in 2020. Final Report. http://ec.europa.eu/ climate/policies/package/docs/ir_07_ nonco$_2$_en.pdf.
6. Akiyama, H., Yan, X., Yagi, K., 2010. Evaluation of Effectiveness of Enhanced -Efficiency Fertilizers as Mitigation Technologies for N_2O and NO emission from Agricultural Soils: Meta-analysis. Global Change Biology 16(6), 1837–1846.
7. Bates, J., 1998. Technologies to Reduce CH_4 emission (Final Report). AEAT Environment 3773(3). Environmental Economics. http://ec.europa.eu/ environment/enveco/climate_change/ index.htm.
8. Bun Heng, S., 2002. Desk Study on National Wood Fuels and Wood Energy Information Analysis. Phnom Penh, Cambodia.
9. ClimateTechWiki. (n.d.). Rice: Mid-season Drainage. Retrieved 30 June, 2014 from http://www.climatetechwiki.org/technology/rice-mid-season-drainage
10. Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ). 2014. Case Study: Expected Impact and Management of Lower Se San II Hydropower Project. Vientiane, Lao PDR.
11. Erik, L., 2011. International Comparison Fossil Power Efficiency and CO_2 intensity-Update 2011.
12. Electricity Authority of Cambodia (EAC), 2012. Annual Report on Power Sector of Cambodia in 2012. Phnom Penh, Cambodia.
13. Electricity Authority of Cambodia (EAC), 2010. Report on Power Sector of Cambodia in 2010. Phnom Penh, Cambodia.

14. EPA, 2015. United States Environmental Protection Agency. Available at http://www.epa.gov/cleanenergy/energy-and-you/affect/natural-gas.html
15. FAO, 2002. FAOSTAT Statistical Data. Food and Agriculture Organization of the United Nations. Available online at: http://faostat.fao.org/default.aspx.
16. FAO, 2010. FAOSTAT Statistical Data. Food and Agriculture Organization of the United Nations. Available online at: http://faostat.fao.org/default.aspx.
17. Food and Agriculture Organization (FAO), 2010a. Global Forest Resources Assessment 2010. Country Report. Rome, Italy.
18. General Directorate of Rubber (DGR), 2011. Strategy for Natural Rubber Development in Cambodia (2011-2020). General Directorate of Rubber of the Ministry of Agriculture, Forestry and Fisheries. Phnom Penh, Cambodia.
19. Gomi, K., and Fukuda, T., 2010. User's Manual of Extended Snapshot Tool. Kyoto University, Japan.
20. Gomi, K., and Misumi, T., 2013. User's Manual of Agriculture, Forestry and Other Land-use Activity Model (AFOLU-A). Kyoto University, Japan.
21. Golan, A., Judge, G., and Miller, D., 1996. Series in Financial Economics and Quantitative Analysis, Maximum Entropy Econometrics, Robust Estimation with Limited Data. Wiley. New York, USA.
22. Graus, W., Harmelink, M., and Hendriks, C., 2004. Marginal GHG-abatement Curves for Agriculture. Ecofys, Utrecht, Netherlands.
23. Hendriks, CA., De Jager, D., and Blok, K., 1998. Emission Reduction Potential and Costs for CH_4 and N_2O in the EU-15. Interim Report by Order of DGXI, EC, M714. ECOFYS, Utrecht, Netherlands.
24. Hasegawa, T., and Matsuoka, Y., 2013 Climate Change Mitigation Strategies in Agriculture and Land Use in Indonesia. Mitigation and Adaptation Strategies for Global Change, 20 (3): 400-424.
25. IPCC, 2014. Summary for Policymakers. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to 5th Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlomer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge.

26. IPCC, 2013. Summary for Policymakers. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to 5th Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge.
27. IPCC, 2007. 4th Assessment Report. The Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
28. IPCC, 2006. IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4. Agriculture, Forestry and Other Land-Use.
29. ITTO, 2005. Cambodia – Status of Tropical Forest Management 2005. Available at: http://219.127.136.74/live/Live_Server/1237/Cambodia.e.pdf.
30. International Energy Agency (IEA), 2013. World Energy Outlook. OECD/IEA, Paris.
31. International Energy Agency (IEA), 2013a. CO_2 Emissions from Fuel Combustion. 2013ed. OECD/IEA, Paris.
32. International Energy Agency (IEA), 2012. Energy Balances of Non-OECD Countries. OECD/IEA, Paris.
33. International Monetary Fund (IMF), 2014. World Economic Outlook. Available at http://www.imf.org/external/pubs/ft/weo/2014/01/weodata/download.aspx. Accessed June 26th, 2014.
34. Institute for Global Environmental Strategies (IGES), 2015. IGES CDM Project Database: IGES CDM Programmes of Activities Database. Available at http://www.iges.or.jp/en/climate-energy/mm/publication.html#03. Accessed on May 21st 2015.
35. Japan International Cooperation Agency (JICA), 2012. Data Collection Survey on Electric Power Sector in Cambodia. The Chugoku Electric Power Co., Inc., Japan.
36. Japan International Cooperation Agency (JICA), 2006. The Master Plan Study on Rural Electrification by Renewable Energy in the Kingdom of Cambodia. Nippon Koei Co., Ltd. and Kri International Corp., Tokyo, Japan.
37. Japan International Cooperation Agency (JICA), 2006a. The Study on the Road Network Development in the Kingdom of Cambodia. Nippon KOEI Co., Ltd. KATAHIRA & Engineers International.
38. Jeremy, B., and Rebeca, I., 2010. Assessment of Land Use, Forest Policy and Governance in Cambodia. Working Paper. FAO, Regional Office for Asia and the Pacific, Country representation. Phnom Penh, Cambodia.

39. Kim Sreng, K., 2014. Wetland information in Cambodia. International Union for Conservation of Nature and Natural Resources (IUCN). Direct interview. Phnom Penh, Cambodia.
40. Kunleang, H., 2012. Cambodia Power Development Plan presented in ASEAN Energy Business Forum 2012. Energy Development Department of the Ministry of Industry, Mines and Energy of Cambodia. Phnom Penh, Cambodia.
41. Limmeechokchai, B., Chungpaibulpatana, S., Nitisoravut, P., Winyuchakrit, P., Pattanapongchai, A., Kainuma, M., Masui, T., Fujino, J., Shichi, A., Matsuoka,Y., Gomi, K., Hibino, G., Ehara, E., Shrestha, R.M., 2010. Thailand's Low Carbon Society Vision 2030. Bangkok, Thailand.
42. Lieng, V., 2013. Cambodia Country Report in Kimura, S. (ed.). Analysis on Energy Saving Potential in East Asia. ERIA Research Project Report 2012-19, pp.99-113. ERIA. Available at: http:/www.eria.org/RPR_FY2012_No.19_ Chapter_4.pdf.
43. Mareth, M., (2014). Economic Land Concessions in Cambodia. An interview to Radio Free Asia on 21st April 2014. Phnom Penh, Cambodia.
44. Ministry of Environment (MoE), 2013. Draft Second National Communication. Phnom Penh, Cambodia.
45. Ministry of Environment (MoE), 2013a. Cambodia Climate Change Strategic Plan (2014-2023). Cambodia.
46. Ministry of Environment (MoE), 2002. Initial National Communication. Phnom Penh, Cambodia.
47. Ministry of Agriculture, Forestry and Fisheries (MAFF), 2015. Annual Report 2014 and its target 2015. Phnom Penh, Cambodia.
48. Ministry of Agriculture, Forestry and Fisheries (MAFF), 2013. Annual Report 2013 and its target 2014. Phnom Penh, Cambodia.
49. Ministry of Agriculture, Forestry and Fisheries (MAFF), 2011. Annual Report 2011 and its target 2012. Phnom Penh, Cambodia.
50. Ministry of Planning (MoP), 2013. Integration of Demographic Perspectives in Development, Cambodia. Phnom Penh, Cambodia.
51. Ministry of Mines and Energy (MME), 2014. Power Development Master Plan in the Kingdom of Cambodia. Mitsubishi Research Institute, Japan.
52. Ministry of Mines and Energy (MME), 2013. National Policy, Strategy and Action Plan on Energy Efficiency in Cambodia. Phnom Penh, Cambodia.

53. Ministry of Industry, Mines, and Energy (MIME), 2010. Electricity Development Status in Cambodia in 2010 and its target 2011. Phnom Penh, Cambodia.
54. Ministry of Tourism (MoT), 2012. Cambodia's Tourism Development Strategic Plan (2012-2020). Phnom Penh, Cambodia.
55. Ministry of Public Works and Transport (MPWT), 2013. National Implementation Plan on Environmental Improvement in Transport Sector of Cambodia. Phnom Penh, Cambodia.
56. Ministry of Public Works and Transport (MPWT), 2013a. Annual Report in 2012 and its action plan 2013. Phnom Penh, Cambodia.
57. Ministry of Public Works and Transport (MPWT), 2010 and 2012. Overview on Transportation Infrastructure Sectors in Cambodia of Infrastructure and Regional Integration Technical Working Group. Phnom Penh, Cambodia.
58. Ministry of Public Works and Transport (MPWT), 2012. RAMP Baseline Traffic and Road Users Survey Report on National and Provincial Road. Version 2.0. Phnom Penh, Cambodia.
59. National Institute of Statistics (NIS), 2012. Cambodia Socio-economic Survey 2010. NIS of the Ministry of Planning. Phnom Penh, Cambodia.
60. National Institute of Statistics (NIS), 2011. Statistical Year Book of Cambodia 2011. NIS of the Ministry of Planning. Phnom Penh, Cambodia.
61. Nguyen, T. H., Hasegawa, T., and Matsuoka, Y., 2014. Climate Change Mitigation Strategies in Agriculture, Forestry and Other Land-Use in Vietnam. Mitigation and Adaptation Strategy of Global Change 19:15-32.
62. Nguyen, T. H., 2012. Development of Middle-term Low Carbon Society Scenario of Vietnam. Kyoto, Japan.
63. Oliver, JGJ., Janssens-Maenhout, G., Muntean, M., and Peters, JAHW., 2013. Trends in Global CO_2 Emissions, 2013 Report. The Hague: PBL Netherlands Environmental Assessment Agency.
64. Phirum, A., 2013. The status of crop Production in Cambodia. Department of Agronomy. Direct interview. Phnom Penh. Cambodia.
65. Richards, M., and Sander, B. O., (2014). Alternate Wetting and Drying in Irrigated Rice: Implementation Guidance for Policymakers and Investors. Retrieved 30 June, 2014fromhttp://cgspace.cgiar.org/bitstream/handle/10568/35402/info-note_CCAF S _AWD_final_A4.pdf?sequence=1.
66. Rogier, V. M., 2011. The Solar Roadmap for Cambodia. Phnom Penh, Cambodia.

67. Royal Government of Cambodia (RGC), 2015. The Strategic Planning Framework for Livestock (2015-2024) of the Ministry of Agriculture, Forestry and Fisheries. Phnom Penh, Cambodia.
68. Royal Government of Cambodia (RGC), 2014. National Strategic Development Plan (2014-2018). Phnom Penh, Cambodia.
69. Royal Government of Cambodia (RGC), 2013. Rectangular Strategy Phase III (2013-2018) of the Council Ministers. Phnom Penh, Cambodia.
70. Royal Government of Cambodia (RGC), 2013a. Technology Needs Assessment and Technology Action Plans for Climate Change Mitigation. Phnom Penh, Cambodia.
71. Royal Government of Cambodia (RGC), 2013b. National Strategic Plan on Green Growth (2013-2030). Phnom Penh, Cambodia.
72. Royal Government of Cambodia (RGC), 2013c. Law on Cambodian Government Guarantee of Payments to Hydropower Lower Se San II. Phnom Penh, Cambodia.
73. Royal Government of Cambodia (RGC), 2012. Cambodian Government's Achievements and Future Direction in Sustainable Development: National Report for Rio+20 United Nations Conference on Sustainable Development. Phnom Penh, Cambodia.
74. Royal Government of Cambodia (RGC), 2012a. Mid-term Review 2011 on National Strategic Development Plan Update (2009-2013). Phnom Penh, Cambodia.
75. Royal Government of Cambodia (RGC), 2011. Cambodia Forest Cover 2010. Forestry Administration of the Ministry of Agriculture, Forestry and Fisheries. Phnom Penh, Cambodia.
76. Royal Government of Cambodia (RGC), 2010. Policy Paper on the Promotion of Paddy Production and Rice Export of the Council Ministers. Phnom Penh, Cambodia.
77. Royal Government of Cambodia (RGC), 2010a. National Forest Programme (2010-2029). Forestry Administration of the Ministry of Agriculture, Forestry and Fisheries. Phnom Penh, Cambodia.
78. Royal Government of Cambodia (RGC), 2009. National Sustainable Development Strategy updated (2009-2013) for Cambodia. Phnom Penh, Cambodia.
79. Royal Government of Cambodia (RGC), 2005. National Sustainable Development Strategy (2006-2010) for Cambodia. Phnom Penh, Cambodia.

80. Royal Government of Cambodia (RGC), 2005a. Sub-degree on Economic Land Concessions. Phnom Penh, Cambodia.
81. Royal Government of Cambodia (RGC), 2002. National Assessment of Implementation of Agenda 21: Progress, Challenges and Directions of the Council Ministers. Phnom Penh, Cambodia.
82. Royal Government of Cambodia (RGC), 2001. Land Law in Cambodia. Phnom Penh, Cambodia.
83. Sam Ang, C., 2013. The implementation of national forest programme in Cambodia. Forestry Administration. Direct interview. Phnom Penh, Cambodia.
84. Shibata, M., and Terada, F., 2009. Factors Affecting CH_4 production and Mitigation in Ruminants, National Institute of Livestock and Grassland Science, Japan.
85. Sovan, S., 2010. Land Reform in Cambodia. Presented at FIG Congress 2010: Facing Challenges-building Capacity on 11-16 April 2010. Sydney, Australia.
86. Siong, H.C., Wai, C. L., Matsuoka, Y., Gomi, K., Simon, J., Osawa, R., Kainuma, M., Fujino, J., and Hasegawa, T., 2013. Malaysia's Low Carbon Society Scenarios 2010. Kualalumpur, Malaysia.
87. Skea, J., and Nishioka, S., 2008. Policies and Practices for a Low-Carbon Society. Climate Policy.
88. Sophal, C., and Sothea, O., 2011. Impact of Garment and Textile Trade Preferences on Livelihoods in Cambodia. Oxfam America Research Backgrounder series: Oxfamamerica.org/publications/impact-garment-textile-trade-preferences-Cambodia.
89. System for the Analysis of Global Energy Markets (SAGE), 2003. Model Documentation Report. Office of Integrated Analysis and Forecasting Energy Information Administration U.S. Department of Energy Washington DC.
90. Smith P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E. A., Haberl, H., Harper, R., House, J., Jafari, M., Masera, O., Mbow, C., Ravindranath, N. H., Rice, C. W., Robledo Abad, C., Romanovskaya, A., Sperling, F., and Tubiello, F., 2014. AFOLU. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to 5th Assessment Report of the IPCC. Cambridge University Press, Cambridge, United Kingdom and New York.

91. Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, HH., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, RJ., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M., Smith, JU., 2007. GHGs Mitigation in Agriculture. Phil Trans Roy Soc B 363:789–813. doi:10.1098/rstb.2007.2184.
92. Shibata, M., and Fuminori, T., 2010. Factors Affecting CH_4 Production and Mitigation in Ruminants. Animal Science Journal 81(1), 2-10.
93. Tahsin, J., Hasegawa, T., and Matsuoka, Y., 2014. Climate Change Mitigation in Agriculture and Land Use Change in Bangladesh. Mitigation and Adaptation Strategy of Global Change.
94. Tahsin, J., 2013. A Study on Low Carbon Society Development in Bangladesh. Kyoto, Japan.
95. Turton, C., 2004. Livelihoods and Forest Resources in IFSR, Part II.
96. TWG-AG, 2010. Programme Design Document Annexes for Strategy for Agriculture and Water 2010-2013. Technical Working Group on Agriculture and Water of the Ministry of Agriculture, Forestry and Fisheries and the Ministry of Water Resources and Meteorology. Phnom Penh, Cambodia.
97. Ty, S., Sasaki, N., Ahmad, A. H., and Zainal, A. Z., 2011. REDD Development in Cambodia-Potential Carbon Emission Reductions. Vol. 10, pp. 1-23.
98. United Nations (UN), 2013. 2013 World Economic Situation and Prospects. New York City, USA.
99. United Nations (UN), 2011 and 2013. World Population Prospects: The 2010 and 2012 Revision. Vol. I: Comprehensive Tables. Department of Economic and Social Affairs, New York City, USA.
100. United Nations Department of Economic and Social Affairs (UNDESA), 2011. World Population Prospects: The 2010 Revision. Available at http://www.un.org/esa/population. Accessed May, 25th 2013.
101. United Nations (UN), 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change. New York City, USA.
102. United Nations (UN), 1992. United Nations Framework Convention on Climate Change. New York City, USA.
103. USAID, 2011. Cambodia-Property Rights and Resources Governance. USAID Country Profile. Phnom Penh: USAID.http://usaidlandtenure.net/usaidltprproducts/country-profiles/Cambodia- country-profile.ddf.

104. USEPA, 2006. Global Mitigation of Non-CO_2 GHG emission. United States Environmental Protection Agency, 430-R-06-005. Washington, DC, USA.

105. Vuthy, T., Pirom, K., and Dary, P., 2014. Development of the Fertilizer Industry in Cambodia: Structure of the Market, Challenges in the Demand and Supply Sides and the Way Forward, CDRI Working Paper Series No. 91 (Phnom Penh: CDRI).

106. Vuthy. S., 2013. Developing Agriculture Supply Chains in Cambodia. Presented at Agricultural Productivity and Natural Resources Management, "Developing Agricultural Supply Chains in CLMV Training Programme, 18-22 February 2013, Khon Kean, Thailand. Available at http://www.adbi.org/files/2013. 02.18.cpp.day1. ses3.3.vuthy.dev.agri.supply.chains.cambodia.pdf. Accessed January, 16th 2015.

107. World Bank (WB) and the Ministry of Industry, Mines, and Energy (MIME), 2009. Improved Energy Technologies for Rural Cambodia. Washington, USA.

108. Yu, B., and Fan, S., 2009. Rice Production Response in Cambodia. IFPRI Discussion Paper. (Washington, DC: IFPRI).

109. Yu B. and Diao X., 2011. Cambodia's Agricultural Strategy: Future Development Options for the Rice Sector. (Phnom Penh: CDRI).

ACKNOWLEDGEMENTS

I could not have the learning opportunity and achieve such a great satisfaction without the support and encouragement from the leaders of the Ministry of Environment, **H.E. Dr. Mok Mareth**, Former Senior Minister and Minister of the Environment and **H.E. Say Samal**, Current Minister of the Environment. Therefore, I would like to extend my deepest gratitude to them. I would also like to take this opportunity to express my profound thanks to **H.E. Dr. Tin Ponlok**, Secretary General for Sustainable Development Council of Cambodia, and **Mr. Sum Thy**, Director of Climate Change Department for their insights, guidance, support, and facilitation for my study.

More importantly, I would like to express my deep appreciation and gratitude to my supervisor, **Prof. Yuzuru Matsuoka**, for the patient guidance and mentorship providing to me, all the way from when I was first considering applying to the PhD programme on the Low Carbon Development Action, through to completion of this degree. I am truly fortunate to have had the opportunity to work with him. I would, once again, like to offer my greatest thanks for directing my research and allowing me to grow as a research scientist and his advice on both research and my career has been priceless. I would also like to expand my sincere appreciation to Associate **Prof. Gakuji Kuruta** and Assist. **Prof. Reina Kawase**, for sharing their pearls of wisdom and providing their insights and expertise that greatly assisted my research. I would also like to thank my committee member, **Prof. Shigeo Fujii**, Graduate School of Global Environmental Studies, Kyoto University for letting my defense be an enjoyable moment, and for their brilliant comments and suggestions.

In the meantime, I am extremely thankful and indebted to **Dr. Kei Gomi**, research fellow and **Dr. Tomoko Hasegawa**, research fellow for sharing expertise, valuable guidance and instruction for the ExSS tool and the AFOLU-B model, respectively. My special thanks go to **Ms Emiko Hatanaka**, Secretary of the Atmospheric and Thermal Environmental Engineering Laboratory for providing invaluable administrative help and support during my study. I would also like to take this opportunity to express my gratitude to the programme of Human Security Engineering (HSE) for providing financial supports for the internship for data collection. I would also like to express my gratitude to my colleagues, **Tu-san, Hoa-san, Jilani-san, Ochi-san,** and **Osawa-san** for sharing their respective experiences and knowledge on operating GAMS and the ExSS tool. Additionally, my completion of this study could not have been accomplished without the kind cooperation and encouragement from my lab mates. I am thankful to all of them.

I would like to offer my greatest gratitude to **Dr. Shuzo Nishioka**, Secretary General, Institute for Global Environmental Strategies (IGES) and his colleagues and **Dr. Junichi Fujino**, Senior Researcher, National Institute for Environmental Studies (NIES) and his colleagues for providing supports to organize workshops in Cambodia in order to distribute my research findings and collect additional inputs and comments to improve the results. I would also like to place on record, my sense of gratitude to all officers from relevant Ministries and institutions for kind assistance and cooperation. In the meantime, I am very thankful to **Dr. Pat Currie**, Associate Professor of Linguistics and Language Studies (Retired), Carleton University, Ottawa, Ontario, Canada for spending her precious time to edit English language for the energy paper.

Moreover, I would like to express my hearted thanks to my respected parents, **Mr. Hak Chea** and **Mrs. Tech Ly Heang**, and my sisters (Mrs. Chea Vouch and her family, Mrs. Hak Sok and her family, and Ms. Hak Heng), my brother (Mr. Hak Nget and his family), my lovely nephews (Mr. Chea Peng and Mr. Keo Sansokheng) and my lovely nieces (Miss. Chea Sreylak, Miss. Keo Sankimhong, and Miss. Chea Panhamalysa) for the unceasing encouragement, support, attention, and sacrifice for my study.

Last but not least, I wish to offer my high gratitude to the Government of Japan **(MEXT-Monbukagakusho)** for providing the full scholarship for my study. And, I would like to take this occasion to wish **TO WHOM IT MAY CONCERN** the Four Gems of Buddhist Blessing: **Longevity, Nobility, Healthiness, and Strength**.

Sincerely yours,

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APPENDICES

Appendix 1: Lists of countermeasures and quantitative emissions reduction

Sector	Energy saving measures	2030CM			2050CM		
		Identified implementing intensity		Emissions reduction ($ktCO_2$)	Identified implementing intensity		Emissions reduction ($ktCO_2$)
Residential	Energy Efficiency Equipment						
	Air conditioner	Diffusion ratio	50%	80	Diffusion ratio	80%	356
	Heating	Diffusion ratio	50%	25	Diffusion ratio	80%	183
	Hot water	Diffusion ratio	100%	14	Diffusion ratio	100%	58
	Cook stove	Diffusion ratio	50%	419	Diffusion ratio	80%	2,095
	Lighting	Diffusion ratio	50%	347	Diffusion ratio	80%	2,167
	Refrigerator	Diffusion ratio	50%	35	Diffusion ratio	80%	345
	Other equipment	Diffusion ratio	50%	89	Diffusion ratio	80%	663
	Energy saving measures	Reduction ratio of energy service demand (20%)		255	Reduction ratio of energy service demand (20%)		893
	Fuel switch	Diffusion ratio	50%	49	Diffusion ratio	80%	464
	Sub-Total			**1,313**			**7,224**
Commercial	Energy Efficiency Equipment						
	Air conditioner	Diffusion ratio	50%	13	Diffusion ratio	80%	78
	Heating	Diffusion ratio	50%	2	Diffusion ratio	80%	2
	Hot water	Diffusion ratio	50%	33	Diffusion ratio	80%	161
	Cook stoves	Diffusion ratio	50%	0	Diffusion ratio	80%	16
	Lighting	Diffusion ratio	50%	333	Diffusion ratio	80%	686
	Refrigerator	Diffusion ratio	50%	156	Diffusion ratio	80%	237
	Other equipment	Diffusion ratio	50%	34	Diffusion ratio	80%	261
	Energy saving measures	Reduction ratio of energy service demand (20%)		152	Reduction ratio of energy service demand (20%)		396
	Fuel switch			44			46
	Sub-Total			**768**			**1,882**
Industrial	Energy Efficiency Equipment						
	Furnace	Diffusion rate	50%	402	Diffusion rate	80%	1,234
	Steam boiler	Diffusion rate	50%	774	Diffusion rate	80%	3,037
	Motor	Diffusion rate	50%	187	Diffusion rate	80%	871
	Other equipment	Diffusion rate	50%	956	Diffusion rate	80%	2,825
	Energy saving measures			1,149			3,462
	Fuel switch			10			775
	Sub-Total			**3,477**			**12,205**
Passenger transportation	Efficiency improvement						
	Modal shift						
	Bus	Share of bus = 6.71% (from base year = 1.79%)			Share of bus = 14.54% (from base year = 1.79%)		
	Train	Share of train = 10.50% (from base year = 0%)			Share of train = 15.60% (from base year = 0%)		
	Sub-Total			**3,574**			**12,658**
Freight transportation	Effeciency improvement						
	Modal shift						
	Motorized vehicle to train	Share of train = 15.00% (from base year = 0.02%)			Share of train = 24.00% (from base year = 0.02%)		
	Sub-Total			**3,134**			**16,458**
Power	Efficiency improvement						
	Coal	41.00% (from base year = 33.01%			41.00% (from base year = 33.01%		
	Oil	44.00% (from base year = 32.50%)			44.00% (from base year = 32.50%)		
	Gas	52.00%			52.00%		
	Fuel switch	Solar power = 5% (from the base year = 0.2%)			Solar power = 5% (from the base year = 0.2%)		
	Transmission loss	6.50% (from base year = 12.23%)			6.50% (from base year = 12.23%)		
	Sub-Total			**560**			**1,726**
	Grand Total			**12,826**			**52,153**

Appendix 2: Lists of socioeconomic indicators

Code in ExSS	Name	Value		Unit	Source
POP	**Population by age and sex**	13,959		('000 person)	NIS (2012). Cambodia socioeconomic survey 2010.
Sex	Age classification	**Urban**	**Rural**		NIS (2011). Statistical year book of Cambodia 2011.
Male	Age group 00-14	322	1,866		
	Age group 15-64	969	3,369		
	Age group 65+	51	262		
Female					
	Age group 00-14	336	1,943		
	Age group 15-64	1,009	3,506		
	Age group 65+	54	272		
HHD	Number of household	574	2,344	('000 household)	NIS (2012). Cambodia socioeconomic survey 2010.
PD	**Output by industry**	17,699		million USD (2000 constant price)	Estimated from IO table in 2010, converted from IO table in 2008 by using the economic data in 2010 including value added, gross domestic fixed capital formation, export, import, and private and government consumption and expenditure from the national accounts statistics of Cambodia.
	Agriculture, forestry, & fishery	3,136			
	Mining	125			
	Manufacturing	7,374			
	Electricity & Water	592			
	Construction	819			
	Trade	920			
	Transport & Communication	648			
	Finance	372			
	Government Services	203			
	Other Services	3,510			
Ptg	**Transportation generation per person per day**	2		trip/(person.day)	This study assumed 2 trips/(person.day).
Pts	**Model share**			(%)	Calculated by total passenger transportation demand (Mil pass/year) devided by passenger transportation demand of each mode.
	Motorbike	8.40			
	Tourist Car	2.45			
	Bus	1.79			
	Train	0.00			
	Ship	0.00			
	Air	0.00			
	Walk	45.56			
	Bicycle	41.81			
Ptad	**Average trip distance**			km/trip	The average trip distance of each passenger mode collected from MIME (2009), which calculated the average fleet distance of each mode for SNC. However, the average trip distance of air and ship was assumed with the consultation with the national experts while the train mode was collected from MPWT (2012). The average trip distance of walk and bicycle was assumed.
	Motorbike	10.00			
	Tourist Car	68.45			
	Bus	82.14			
	Train	0.00			
	Ship	36.00			
	Air	237.00			
	Walk	1.00			
	Bicycle	2.00			
PTD	**Passenger transportation volume**	53,829		mil pass.km/year	Calculated by total population multiplied by number of days/year (365.25 days), number of trip (2trips/day), model share (%) and average trip distance (km).
	Motorbike	8,562			
	Tourist Car	17,073			
	Bus	14,988			
	Train	0			
	Ship	2			
	Air	32			
	Walk	4,646			
	Bicycle	8,526			

Appendix 2.1 [Continued]

Ftg	**Freight transportation per output**	0.008	ton/USD	Calculated by total freight demand (Mil ton/year) devided by total output of industry.
Fts	**Modal share**		(%)	Calculated by total freight demand (Mil ton/year) devided by freight demand of each freight mode.
	Small cargo truck	28.86		
	Big cargo truck	70.31		
	Train	0.00		
	Ship	0.83		
	Air	0.00		
Ftad	**Average trip distance**		km/trip	The average trip distance of each freight mode was collected from MIME (2009), which calculated the average fleet distance of each mode for the SNC. The average trip distance of ship was assumed with the consultation with the national experts while the train mode was collected from MPWT (2012).
	Small cargo truck	109.51		
	Big cargo truck	130.05		
	Train	12.00		
	Ship	115.00		
	Air	0.00		
FTD	**Freight transportation volume**	18,562	mil ton.km/year	Calculated by industrial output (Mil USD), freight generation (ton/USD), model share (%), and average trip distance (km).
	Small cargo truck	4,731		
	Big cargo truck	13,688		
	Train	0		
	Ship	143		
	Air	0		

Appendix 3: The IO Table 2008 [Million USD at 2000 constant price]

Description	Paddy	Other Crops	Livestock	Forestry	Fishery	Mining	Food, beverage & tabacco	Textile & garment	Wood, paper & publishin	Chemical, rubber & plastic	Non metallic mineral	Basic metals	Other manufacturing	Electricity & water	Construction	Trade	Hotel & restaurants	Transport & communication	Finance	Real estate & business	Public administration	Other services	Total intermediate consumption
Paddy	59.59	2.62	2.86	0.00	0.00	0.00	813.80	0.00	0.39	0.00	0.00	0.00	0.76	0.00	0.00	0.00	0.00	0.00	0.00	3.89	0.55	0.81	885.28
Other Crops	0.00	2.16	0.00	0.00	0.00	0.00	25.72	9.36	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.22	37.72
Livestock	0.00	0.00	0.00	0.00	0.00	0.00	80.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	80.73
Forestry	0.89	2.18	1.97	0.38	0.70	1.55	11.98	1.08	101.93	15.36	29.74	0.67	3.08	0.00	32.26	0.23	0.09	0.13	0.01	16.51	0.90	4.07	225.71
Fishery	0.00	0.00	0.00	0.00	0.00	0.00	47.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	47.28
Mining	0.48	0.02	0.00	0.00	0.01	1.02	0.16	0.04	0.12	2.76	8.61	4.92	0.39	0.60	31.93	0.03	0.12	0.01	0.00	0.79	0.16	0.01	52.17
Food, beverage & tabacco	2.69	0.48	53.14	0.00	3.59	0.00	413.67	0.01	0.00	0.46	2.72	0.00	0.11	0.01	0.01	42.49	8.56	23.74	1.83	53.35	22.83	105.91	735.60
Textile & garment	7.41	6.53	0.02	0.01	0.24	0.28	4.22	2,199.95	3.13	41.93	0.60	0.76	17.69	22.70	3.94	26.97	17.58	15.07	12.13	40.64	6.57	32.55	2,460.91
Wood, paper & publishing	0.18	0.01	0.00	0.00	0.00	0.05	2.72	3.86	3.16	1.19	0.65	0.18	0.41	3.12	0.22	0.81	2.21	0.45	3.70	11.08	6.90	4.37	45.28
Chemical, rubber & plastic	144.01	19.32	0.26	0.02	10.30	1.34	12.22	19.06	2.32	35.59	2.26	5.18	2.17	67.70	3.89	2.02	152.33	1.13	1.23	15.91	7.30	8.97	514.51
Non metallic mineral	6.88	0.49	0.03	0.01	0.09	0.09	5.45	0.38	0.20	1.92	4.04	0.98	1.39	2.33	158.22	0.64	1.18	0.36	0.22	8.45	1.37	8.67	203.40
Basic metals	11.69	2.44	0.06	0.01	0.07	1.81	10.50	2.47	0.92	1.59	2.80	73.30	32.01	17.22	70.20	0.67	3.27	0.37	0.14	8.87	1.25	16.71	258.38
Other manufacturing	50.54	7.16	0.27	0.04	4.37	19.69	26.61	53.80	9.23	11.55	6.44	5.41	208.35	163.48	88.19	19.58	369.40	10.94	36.00	97.13	185.19	51.42	1,424.77
Electricity & water	4.49	0.12	0.02	0.00	0.03	0.29	7.93	23.09	1.02	6.01	1.41	4.42	32.88	36.54	0.55	22.49	4.78	12.57	4.99	7.63	11.22	13.22	195.70
Construction	9.99	0.74	0.09	0.00	0.01	0.49	1.79	1.84	0.66	0.92	0.56	0.29	0.27	18.83	5.07	2.07	2.73	1.16	4.67	7.60	10.66	66.07	136.51
Trade	245.33	12.24	1.13	0.02	2.54	1.35	58.53	81.17	7.55	30.90	3.56	7.35	12.59	8.60	17.66	3.45	13.21	1.93	5.77	38.03	11.82	85.21	649.94
Hotel & restaurants	27.16	9.90	0.07	0.06	1.05	6.26	23.41	37.36	4.66	7.73	7.76	4.77	2.47	11.43	11.05	15.16	53.83	8.47	13.28	18.90	18.76	9.68	293.23
Transport & Communication	0.11	0.13	0.01	0.00	0.03	0.01	0.64	0.89	0.08	0.34	0.04	0.08	0.14	0.09	0.19	0.04	0.14	0.02	0.06	0.41	0.13	0.93	4.52
Finance	15.09	3.60	0.05	0.00	0.38	0.27	4.58	6.84	1.00	3.26	0.56	1.08	1.15	13.58	2.96	14.72	10.20	8.23	6.76	10.81	1.66	50.54	157.31
Real estate & business	56.18	11.90	0.01	0.00	0.46	1.42	4.19	5.54	0.36	1.74	0.37	0.42	0.61	6.32	4.29	9.24	18.06	5.16	10.16	9.95	11.16	5.44	163.00
Public administration	0.17	0.01	0.00	0.00	0.00	0.02	0.03	0.14	0.01	0.06	0.01	0.01	0.01	0.74	0.14	0.09	0.14	0.05	0.16	0.65	2.51	0.10	5.04
Other services	16.26	4.30	0.01	0.00	0.15	0.18	2.42	9.34	0.33	1.83	0.35	0.48	0.77	6.54	2.95	6.23	8.97	3.48	15.10	16.09	101.39	36.65	233.82
Domestic goods	440.02	48.55	58.05	0.46	9.00	14.35	1,467.58	381.27	116.70	75.48	56.78	53.77	90.90	133.62	212.35	120.45	133.26	67.31	62.29	189.00	204.93	382.85	
Imported goods	204.46	35.04	1.78	0.08	13.55	20.11	80.80	2,045.93	15.69	84.61	13.68	53.76	209.21	225.19	210.02	42.87	489.96	23.96	49.31	163.25	177.21	103.83	
Total goods	659.14	86.34	60.01	0.56	24.04	36.13	1,558.58	2,456.22	137.13	165.16	72.48	110.28	317.26	379.83	433.71	166.93	666.80	93.28	116.21	366.88	402.31	501.55	
Labour	308.57	345.46	198.94	14.81	218.35	7.22	61.37	301.11	7.57	11.11	4.58	3.27	22.85	6.50	140.01	204.52	51.36	114.29	9.95	52.83	155.43	128.45	
Capital	23.27	13.01	11.42	180.83	176.82	12.94	102.29	619.81	57.38	27.86	17.50	8.31	70.76	28.57	276.94	397.94	443.53	222.37	65.39	78.83	212.19	580.28	
Land	169.54	94.80	83.19	27.78	172.44	3.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Tax on domestic Products	3.13	0.35	0.21	8.78	1.91	0.49	18.45	30.10	3.25	7.86	0.81	0.22	3.49	1.25	10.94	12.02	6.82	6.72	3.55	4.15	0.00	23.20	
Total cost	1,163.64	539.97	353.78	232.75	593.57	60.00	1,740.69	3,407.25	205.33	211.98	95.37	122.08	414.36	416.15	861.59	781.39	1,168.50	436.65	195.10	502.69	769.93	1,233.48	

Appendix 3.1 [Continued]

Description	Households	Investment	Government	Exports	Total demand	Imports CIF	Tax on imported products	Domestic demand
Paddy	23.12	31.58	33.05	193.99	1,167.03	3.01	0.37	1,163.64
Other Crops	553.67	0.00	0.00	7.06	598.45	57.64	0.84	539.97
Livestock	260.71	0.00	0.00	12.52	353.95	0.18	0.00	353.78
Forestry	7.03	0.01	0.00	0.00	232.75	0.00	0.00	232.75
Fishery	438.39	0.00	0.00	107.95	593.61	0.05	0.00	593.57
Mining	0.00	7.83	0.00	0.00	60.00	0.00	0.00	60.00
Food, Beverage & Tabacco	1,133.04	0.00	43.88	67.21	1,979.73	222.06	16.98	1,740.69
Textile & Garment	182.43	228.66	14.18	2,890.63	5,776.81	2,320.69	48.87	3,407.25
Wood, Paper & Publishing	130.36	0.00	0.00	62.11	237.74	31.97	0.44	205.33
Chemical, Rubber & Plastic	313.91	0.43	0.00	179.60	1,008.44	686.59	109.07	212.78
Non Metallic Mineral	4.13	4.10	0.00	0.00	211.64	114.70	1.57	95.37
Basic Metals	0.00	23.71	0.02	0.00	282.11	147.56	12.47	122.08
Other Manufacturing	270.07	580.70	0.01	166.61	2,442.17	1,811.01	216.77	414.38
Electricity & Water	241.86	0.00	0.00	0.00	437.56	21.12	0.29	416.15
Construction	0.00	745.35	0.00	0.00	881.86	19.99	0.27	861.60
Trade	105.65	27.38	0.00	0.00	782.98	2.05	0.05	780.88
Hotel & Restaurants	565.11	5.21	0.01	470.11	1,333.67	160.05	5.12	1,168.50
Transport & Communication	88.59	13.74	0.00	364.51	471.37	34.55	0.45	436.36
Finance	41.20	0.02	0.70	0.00	199.24	4.08	0.06	195.10
Real Estate & Business	214.04	8.00	164.89	16.11	566.05	62.50	0.86	502.69
Public Administration	483.71	0.00	280.12	12.05	780.92	10.84	0.15	769.93
Other Services	837.50	0.01	75.70	92.46	1,239.49	5.91	0.08	1,233.49

SOURCE: Sophal and Sothea (2011)

Appendix 4: The aggregated IO Table 2008 [Million USD at 2000 constant price]

Description	Agriculture, fishery & forestry	Mining	Manufacturing	Electricity & water	Construction	Trade	Transport & Communication	Finance	Government services	Other services	Total intermediate Consumption
Agriculture, fishery & forestry	73.35	1.55	1,141.94	0	32.26	0.23	0.13	0.01	1.45	25.77	1,276.69
Mining	0.51	1.02	17.00	0.60	31.93	0.03	0.01	0	0.16	0.92	52.18
Manufacturing	332.36	23.26	3,235.56	276.56	324.67	93.18	52.06	55.25	231.41	1,018.56	5,642.87
Electricity & water	4.66	0.29	76.76	36.54	0.55	22.49	12.57	4.99	11.22	25.63	195.70
Construction	10.83	0.49	6.33	18.83	5.07	2.07	1.16	4.67	10.66	76.40	136.51
Trade	261.26	1.35	201.65	8.60	17.66	3.45	1.93	5.77	11.82	136.45	649.94
Transport & communication	0.28	0.01	2.21	0.09	0.19	0.04	0.02	0.06	0.13	1.48	4.51
Finance	19.12	0.27	18.47	13.58	2.96	14.72	8.23	6.76	1.66	71.55	157.32
Government services	0.18	0.02	0.27	0.74	0.14	0.09	0.05	0.16	2.51	0.89	5.05
Other Services	127.51	7.86	116.91	24.29	18.29	30.63	17.11	38.54	131.31	177.57	690.02
Total intermediate inputs	830.06	36.12	4,817.10	379.83	433.72	166.93	93.27	116.21	402.33	1,535.22	8,810.79
Labor	1,086.13	7.22	411.86	6.50	140.01	204.52	114.29	9.95	155.43	232.65	2,368.56
Capital	953.10	16.16	903.91	28.57	276.94	397.94	222.37	65.39	212.19	1,102.64	4,179.21
Tax on domestic products	14.38	0.49	64.18	1.25	10.94	12.02	6.72	3.55	0	34.17	147.70
Value added	2,053.61	23.87	1,379.95	36.32	427.89	614.48	343.38	78.89	367.62	1,369.46	6,695.47
Total input	2,883.67	59.99	6,197.05	416.15	861.61	781.41	436.65	195.10	769.95	2,904.68	15,506.26

Appendix 4.1 [Continued]

Description	Private consumption	Government consumption	Investment	Export	Import	Total final demand	Total output
Agriculture, fishery & forestry	1,282.92	33.05	31.59	321.52	62.09	1,731.17	2,883.68
Mining	0	0	7.83	0	0	7.83	60.01
Manufacturing	2,033.94	58.09	837.60	3,366.16	5,740.75	12,036.54	6,197.91
Electricity & water	241.86	0	0	0	21.41	263.27	416.15
Construction	0	0	745.35	0	20.26	765.61	861.60
Trade	105.65	0	27.38	0	2.10	135.13	780.87
Transport & communication	88.59	0	13.74	364.51	35.00	501.84	436.35
Finance	41.20	0.70	0.02	0	4.14	46.06	195.10
Government services	483.71	280.12	0	12.05	10.99	786.87	769.94
Other services	1,616.65	240.60	13.22	578.68	234.52	2,683.67	2,904.65
Total intermediate inputs	5,894.52	612.56	1,676.73	4,642.92	6,131.26	18,957.99	15,506.26

Appendix 5: Sector definition of IO Table

Sector	Code	Description
Paddy	pdr	Rice, husk, and unhusked
Other crops	c_b	Cane & Beet: sugar cane and sugar beet
	gro	Other Grains: maize (corn), other cereals
	v_f	Veg & Fruit: vegetables, fruit vegetables, fruit and nuts, potatoes, cassava,
	osd	Oil Seeds: oil seeds and oleaginous fruit; soy beans, copra
	pfb	Plant Fibers: cotton, flax, hemp, and other raw vegetable materials used in textiles
	ocr	Live plants, cut flowers and flower buds, flower seeds and fruit seeds, vegetable seeds, beverage and spice crops
Livestock	ctl	Cattle, goats, horses
	oap	Other Animal Products: swine, poultry and other live animals; eggs, in shell (fresh or cooked), natural honey, snails (fresh or preserved) except sea snails; frogs' legs, edible products of animal origin n.e.c., skins and fur-skins, raw , insect waxes
	wol	Wool: wool, silk, and other raw animal materials used in textile
Forestry	frs	Forestry, logging, and related service activities
Fishery	fsh	Hunting, trapping, fishing, fish farm
Mining	coa	Coal: mining and agglomeration of hard coal, lignite and peat
	oil	Oil: extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part)
	gas	Gas: extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part)
	omn	Mining of metal ores, gems. Other mining and quarrying
Food, beverage & tobacco	cmt	Cattle Meat: fresh or chilled meat and edible offal of cattle, goats, horses.
	pcr	Processed Rice: rice, semi- or wholly milled
	omt	Other Meat: pig meat and offal. preserves and preparations of meat, meat offal or blood, flours, meals and pellets of meat or inedible meat offal; greaves
	vol	Vegetable Oils: crude and refined oils of soya-bean, maize (corn), sesame, ground-nut, cotton-seed, coconut palm,
	mil	Milk: dairy products
	sgr	Sugar
	ofd	Other Food: prepared and preserved fish or vegetables, fruit juices and vegetable juices, prepared and preserved fruit and nuts, all cereal flours, meal and pellets of wheat, meal and pellets n.e.c., other cereal grain products (including corn flakes), other vegetable flours and meals, mixes and doughs for the preparation of bakers' wares, starches and starch products; sugars and sugar syrups n.e.c., preparations used in animal feeding, bakery products, chocolate and sugar confectionery, macaroni, noodles, couscous and similar farinaceous products, food products n.e.c.
	B_t	Beverages and Tobacco products
Textile & garment	tex	Textiles and man-made fibers
	wap	Wearing Apparel: Clothing, dressing and dyeing of fur
	lea	Leather: tanning and dressing of leather; luggage, handbags, saddlery, harness and footwear

Appendix 5.1 [Continued]

Wood, paper & publishing	lum	Wood and products of wood and cork, except furniture; articles of straw and plaiting materials ;
	ppp	Paper & Paper Products: includes publishing, printing and reproduction of recorded media
Chemical, rubber & plastic	crp	Basic chemicals, other chemical products, rubber and plastics products
	p_c	Petroleum & Coke: coke oven products, refined petroleum products, processing of nuclear fuel
Non-metallic mineral	nmm	Cement, plaster, lime, gravel, concrete
Basic metals	nfm	Production and casting of copper, aluminum, zinc, lead, gold, and silver
Other manufacturing	i_s	Iron & Steel: basic production and casting
	nfm	Non-Ferrous Metals: production and casting of copper, aluminum, zinc, lead, gold, and silver
	fmp	Fabricated Metal Products: Sheet metal products, but not machinery and equipment
	mvh	Motor vehicles and parts: cars, lorries, trailers and semi-trailers
	otn	Other Transport Equipment: Manufacture of other transport equipment
	ele	Electronic Equipment: office, accounting and computing machinery, radio, television and communication equipment and apparatus
	ome	Other Machinery & Equipment: electrical machinery and apparatus n.e.c., medical, precision and optical instruments, watches and clocks
	omf	Other Manufacturing: includes recycling
Electricity and water	ely	Office, accounting and computing machinery, radio, television and communication equipment and apparatus;
	gdt	Gas Distribution: distribution of gaseous fuels through mains; steam and hot water supply
	wtr	Water: collection, purification and distribution
Construction	cns	Building houses, factories, offices, and roads
Trade services	trd	All retail sale; whole sale trade and commission trade; repairs of motor vehicles and personal and household goods, retail sale of automotive fuel
Transport and Communication	otp	Road, rail ; pipelines, auxiliary transport activities; travel agencies;
	wtp	Water transport
	atp	Air transport
	cmn	Communications: post and telecommunication
Finance	ofi	Includes auxiliary activities but not insurance and pension funding
	insr	Insurance: includes pension funding, except compulsory social security
Public administration	osg	Other Services (Government): public administration and defense; compulsory social security, education, health and social work, sewage and refuse disposal, sanitation and similar activities, activities of membership organizations n.e.c., extra-territorial organizations and bodies
Hotels, restaurants	trd	Hotels and restaurants
Real Estate and Business	obs	Real estate, renting and business activities
	dwe	Dwellings: ownership of dwellings (imputed rents of houses occupied by owners)
Other services	ros	Recreational, cultural and sporting activities, other service activities; private households with employed persons (servants)

Source: Sophal and Sothea (2011)

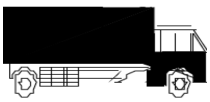
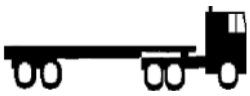
Appendix 6: The aggregated IO Table 2010 [Million USD at 2000 constant price]

Description	Agriculture, fishery & forestry	Mining	Manufacturing	Electricity & water	Construction	Trade	Transport & communication	Finance	Government services	Other services	Total intermediate consumption
Agriculture, fishery & forestry	71.65	3.21	1,168.25	0	29.83	0.26	0.19	0.02	0.38	27.76	1,301.54
Mining	0.93	2.16	75.71	0.94	34.76	0.04	0.02	0	0.04	2.00	116.60
Manufacturing	343.08	48.22	3,769.01	390.97	304.57	106.19	75.52	104.39	61.08	1,167.25	6,370.30
Electricity & water	6.32	0.61	169.69	54.38	0.55	27.76	19.29	9.74	3.01	39.84	331.20
Construction	8.09	1.00	3.45	25.04	4.37	2.15	1.57	8.49	2.76	60.97	117.89
Trade	286.07	2.81	269.82	12.29	16.82	4.00	2.83	10.98	3.13	167.04	775.79
Transport & communication	0.51	0.02	9.84	0.14	0.21	0.05	0.03	0.12	0.04	3.21	14.17
Finance	33.17	0.57	72.93	21.18	3.18	19.53	13.29	13.58	0.45	146.61	324.50
Government services	0	0.03	0	0.15	0.01	0.01	0.01	0.09	0.34	0.01	0.65
Other services	152.88	16.39	193.63	35.32	17.84	36.47	25.60	74.12	35.00	240.61	827.87
Total intermediate inputs	902.70	75.02	5,732.33	540.43	412.15	196.46	138.36	221.53	106.24	1,855.30	10,180.50
Labor	1,181.17	15.00	490.11	9.25	133.05	240.70	169.54	18.97	41.04	281.15	2,579.93
Capital	1,036.50	33.56	1,075.65	40.65	263.17	468.34	329.86	124.65	56.03	1,332.53	4,760.94
Tax on domestic products	15.64	1.02	76.37	1.78	10.40	14.15	9.97	6.77	0	41.29	177.38
Value added	2,233.31	49.58	1,642.13	51.68	406.61	723.18	509.36	150.38	97.08	1,654.98	7,518.30
Total input	3,136.01	124.60	7,374.46	592.10	818.76	919.64	647.72	371.91	203.32	3,510.27	17,698.80

Appendix 6.1 [Continued]

Description	Private consumption	Government consumption	Investment	Export	Import	Total final demand	Total output
Agriculture, fishery & forestry	1,413.36	38.59	31.21	424.13	72.83	1,834.47	3,136.01
Mining	0	0	8.00	0	0	8.00	124.60
Manufacturing	2,265.21	67.91	830.02	4,489.58	6,648.57	1,004.17	7,374.46
Electricity & water	284.19	0	0	0	23.29	260.90	592.10
Construction	0	0	726.15	0	25.27	700.87	818.76
Trade	119.04	0	27.22	0	2.40	143.85	919.64
Transport & communication	110.37	0	14.03	544.71	35.56	633.55	647.72
Finance	50.82	0.83	0.02	0	4.26	47.41	371.91
Government services	71.38	264.33	0	2.07	135.11	202.67	203.32
Other services	1,854.27	282.15	13.20	795.20	262.42	2,682.41	3,510.27
Total intermediate inputs	6,168.64	653.81	1,649.85	6,255.69	7,209.69	7,518.30	17,698.80

Appendix 7: Characteristic of motorized vehicles in Cambodia

Motorized vehicle types	**Typical features**
Motorcycle	
Motorcycle trailer	
3-wheel motorized cycle	
Car (maximum 7 seats)	
Jeep (maximum 7 seats)	
Pick-up	
Minibus (8-16 seats)	
Bigbus (> 16 seats)	
Small truck (2-4 tonnes)	
Medium truck (>4 tonnes)	
3 Axle truck	
4 Axle truck	
5 Axle truck	
Multi trailer truck	

Appendix 8: Energy balance table in 2010 [ktoe/year]

SUPPLY AND CONSUMPTION	Coal & peat	Crude oil	Oil products	Natural Gas	Nuclear	Hydro	Geotherm. solar etc.	Biofuels & waste	Electricity	Heat	Total
Production	-	-	-	-	-	2	0	3619	-	-	3621
Imports	16	-	1304	-	-	-	-	-	117	-	1437
Exports	-	-	-	-	-	-	-	-	-	-	-
Intl. marine bunkers	-	-	-	-	-	-	-	-	-	-	-
Intl. aviation bunkers	-	-	-26	-	-	-	-	-	-	-	-26
Stock changes	-8	-	-	-	-	-	-	-	-	-	-8
TPES	**8**	**-**	**1278**	**-**	**-**	**2**	**0**	**3619**	**117**	**-**	**5024**
Electricity and CHP plants	-8	-	-242	-	-	-2	-0	-7	85	-	-174
Oil refineries	-	-	-	-	-	-	-	-	-	-	-
Other transformation*	-0	-	-51	-	-	-	-	-509	-27	-	-588
TFC	**-**	**-**	**985**	**-**	**-**	**-**	**-**	**3102**	**175**	**-**	**4262**
INDUSTRY	**-**	**-**	**205**	**-**	**-**	**-**	**-**	**657**	**33**	**-**	**894**
Iron and steel	-	-	-	-	-	-	-	-	-	-	-
Chemical and petrochemical	-	-	-	-	-	-	-	-	-	-	-
Non-metallic minerals	-	-	-	-	-	-	-	-	-	-	-
Other/non-specified	-	-	205	-	-	-	-	657	33	-	894
TRANSPORT	**-**	**-**	**630**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**630**
Domestic aviation	-	-	6	-	-	-	-	-	-	-	6
Road	-	-	513	-	-	-	-	-	-	-	513
Other/non-specified	-	-	111	-	-	-	-	-	-	-	111
OTHER	**-**	**-**	**131**	**-**	**-**	**-**	**-**	**2445**	**143**	**-**	**2719**
Residential	-	-	131	-	-	-	-	2445	89	-	2665
Comm. and public services	-	-	-	-	-	-	-	-	47	-	47
Agriculture/forestry	-	-	-	-	-	-	-	-	-	-	-
Other/non-specified	-	-	-	-	-	-	-	-	7	-	7
NON-ENERGY USE	**-**	**-**	**19**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**19**
Electricity and Heat Output											
Electricity generated - GWh	31	-	914	-	-	26	3	20	-	-	994
Heat generated - TJ	-	-	-	-	-	-	-	-	-	-	-

* Includes transfers, statistical differences, energy industry own use, and losses.

Source: IEA (2012)

Appendix 9: The adjusted energy balance table in 2010 [ktoe/year]

Supply and consumption	**Coal & peat**	**Crude Oil**	**Oil products**	**Natural gas**	**Nuclear**	**Hydro**	**Geotherm, Solar, etc.**	**Biofuels & waste**	**Electricity**	**Heat**	**Total**
Production	**0**	**0**	**0**	**0**	**0**	**2.24**	**0**	**3,618.61**	**0**	**0**	**3,621.10**
Imports	**16.15**	**0**	**1,427.70**	**0**	**0**	**0**	**0**	**0**	**116.70**	**0**	**1,560.55**
Exports	0	0	0	0	0	0	0	0	0	0	0
International marine bunkers	0	0	0	0	0	0	0	0	0	0	0
International aviation bunkers	0	0	-25.69	0	0	0	0	0	0	0	-25.69
Stock changes	-7.67	0	0	0	0	0	0	0	0	0	-7.67
Total primary energy supply	**8.48**	**0**	**1,402.02**	**0**	**0**	**2.24**	**0**	**3,618.61**	**116.70**	**0**	**5,148.04**
Statistical differences	-0.40	0	-51.33	0	0	0	0	-2.08	0.17	0	-53.63
Main activity producer electricity plants	**-8.08**	**0**	**-241.85**	**0**	**0**	**-2.24**	**-0.26**	**-6.88**	**85.48**	**0**	**-173.81**
Oil refineries	0	0	0	0	0	0	0	0	0	0	0
Non-specified transformation processes	0	0	0	0	0	0	0	-507.35	0	0	-507.35
Energy industry own use	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-2.49**	**0**	**-2.49**
Losses	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**-24.60**	**0**	**-24.60**
Total final consumption	**0**	**0**	**1,108.84**	**0**	**0**	**0**	**0**	**3,102.30**	**175.27**	**0**	**4,386.42**
Industry	0	0	204.52	0	0	0	0	657.18	32.59	0	894.30
Iron and steel	0	0	0	0	0	0	0	0	0	0	0
Chemical and petrochemical	0	0	0	0	0	0	0	0	0	0	0
Non-metallic minerals	0	0	0	0	0	0	0	0	0	0	0
Non-specified (industry)	**0**	**0**	**204.52**	**0**	**0**	**0**	**0**	**657.18**	**32.59**	**0**	**894.30**
Transport	**0**	**0**	**630.37**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**630.37**
Road	0	0	512.88	0	0	0	0	0	0	0	512.88
World aviation bunkers	-	-	-	-	-	-	-	-	-	-	-
Domestic aviation	0	0	6.16	0	0	0	0	0	0	0	6.16
Rail	0	0	82.47	0	0	0	0	0	0	0	82.47
Pipeline transport	0	0	0	0	0	0	0	0	0	0	0
World marine bunkers	-	-	-	-	-	-	-	-	-	-	-
Domestic Navigation	0	0	28.86	0	0	0	0	0	0	0	28.86
Non-specified (transport)	0	0	0	0	0	0	0	0	0	0	0
Other	**0**	**0**	**255.32**	**0**	**0**	**0**	**0**	**2,445.13**	**142.67**	**0**	**2,843.12**
Residential	**0**	**0**	**131.36**	**0**	**0**	**0**	**0**	**2,445.13**	**88.75**	**0**	**2,665.24**
Commerce and public services	0	0	0	0	0	0	0	0	**46.78**	0	**46.78**
Agriculture/forestry	0	0	**123.95**	0	0	0	0	0	0	0	**123.95**
Fishing	0	0	0	0	0	0	0	0	0	0	0
Non-specified (other)	0	0	0	0	0	0	0	0	**7.14**	0	**7.14**
Non-energy use	0	0	**18.64**	0	0	0	0	0	0	0	**18.64**
Non-energy use industry /transformation/energy	0	0	2.94	0	0	0	0	0	0	0	2.94
Non-energy use in transport	0	0	14.71	0	0	0	0	0	0	0	14.71
Non-energy use in other	0	0	0.98	0	0	0	0	0	0	0	0.98
Electricity output in GWh	**31.00**	**0**	**914.00**	**0**	**0**	**26.00**	**3.00**	**20.00**	**0**	**0**	**994.00**
Electric output-main activity producer electric plants	31.00	0	914.00	0	0	26.00	3	20.00	0	0	994.00
Heat output in TJ	0	0	0	0	0	0	0	0	0	0	0

Appendix 10: Table used to split energy demand by energy service type in the residential sector [%]

Residential		Space heating	Space cooling	Hot water heating	Refrigerators and freezers	Cloth dryer	Cooking	Cloth washers	Dish washers	Other energy uses	Miscellaneous electric energy	Lighting	**Total**
		RH1	RC1	RHW	RRF	RCD	RK1	RCW	RDW	ROT	REA	RL1	
Natural gas	RESNGA	10		35			40			15			100
Diesel	RESDST	20		50			0			30			100
Heavy fuel oil	RESHFO	100		0			0						100
Kerosene	RESKER	15		30			40					15	100
Coal	RESCOA	50		40			10					0	100
LPG	RESLPG	25		40			35					0	100
Biofuels	RESBIO	20		30			50					0	100
Electiricity	RESELC	2	8	8	10	1	5	3	1		20	42	100
Heat	RESHET	100											100
Geothermal	RESGEO	100											100
Solar	RESSOL			100									100

Appendix 11: Table used to split energy demand by energy service type in the commercial sector [%]

Commercial		Space heating	Space cooling	Hot water heating	Lighting	Cooking	Refrigerators and freezers	Electric Equipment	Other Energy Use	**Total**
		CH1	CC1	CHW	CLA	CCK	CRF	COE	COT	
Natural gas	COMNGA	15		40		40			5	100
Diesel	COMDST	50		50		0				100
Heavy fuel oil	COMHFO	70		30		0				100
Kerosene	COMKER	50		40		10				100
Coal	COMCOA	60		30		10				100
LPG	COMLPG	60		35		5				100
Biofuels	COMBIO	30		30		40				100
Electiricity	COMELC	3	13	6	35	1	20	22		100
Heat	COMHET	100								100
Geothermal	COMGEO	100								100
Solar	COMSOL			100						100

Appendix 12: Table used to split energy demand by energy service type in the industrial sector

Appendix 12.1: Iron and Steel Industry [%]

Industry	**Iron and Steel**							**Total**
		Boilers	Boilers	Process Heat	Machine Drive	chemical	Others	
		ISIS	ISIS	IPIS	IMIS	IEIS	IOIS	
Electricity	INDELC			29			2	100
Natural Gas	INDNGA	7		82	69		11	100
LPG	INDLPG	3		95			2	100
NGL	INDNGL			0				100
Coal	INDCOA			100				100
Ovencoke	INDCOK			0				100
Coke Oven Gas	INDCOG	18		82				100
Blast Furnace Gas	INDBFG	6		92			2	100
Oxygen Steel Furnace Gas	INDOXY			100				100
Heavy Fuel Oil	INDHFO	18		82				100
Refined Petroleum Products	INDOIL	6		84			2	100
Ethane	INDETH				8			100
Naphta	INDNAP							100
Petroleum Coke	INDPTC							100
Biofuels	INDBIO	100						100
Geothermal	INDGEO	100						100
Heat	INDHET			100				100

Appendix 12.2: Non-Ferrous Metal Industry [%]

Industry	**Non Ferrous metals**							**Total**
		Boilers	Boilers	Process Heat	Machine Drive	chemical	Others	
		ISNF	ISNF	IPNF	IMNF	IENF	IONF	
Electricity	INDELC			47		15	3	100
Natural Gas	INDNGA	11		86	35		3	100
LPG	INDLPG			100				100
NGL	INDNGL						100	100
Coal	INDCOA	38		62				100
Ovencoke	INDCOK			100				100
Coke Oven Gas	INDCOG			100				100
Blast Furnace Gas	INDBFG			100				100
Oxygen Steel Furnace Gas	INDOXY			100				100
Heavy Fuel Oil	INDHFO	25		74				100
Refined Petroleum Products	INDOIL	25		59	1		11	100
Ethane	INDETH				5			100
Naphta	INDNAP							100
Petroleum Coke	INDPTC						100	100
Biofuels	INDBIO	100						100
Geothermal	INDGEO	100						100
Heat	INDHET			55			45	100

Appendix 12.3: Chemical Industry [%]

Industry	**Chemicals**								**Total**
		Boilers	Boilers	Process Heat	Machine Drive	Electro-chemical	Feed-stocks	Others	
		ISCH	ISCH	IPCH	IMCH	IECH	IFCH	IOCH	
Electricity	INDELC	0		5	81	10		4	100
Natural Gas	INDNGA	8		13	0		78	0	100
LPG	INDLPG	0		0	0		100	0	100
NGL	INDNGL	0		0	0		100	0	100
Coal	INDCOA	100		0	0		0	0	100
Ovencoke	INDCOK	0		0	0		0	100	100
Coke Oven Gas	INDCOG	0		100	0		0	0	100
Blast Furnace Gas	INDBFG	0		100	0		0	0	100
Oxygen Steel Furnace Gas	INDOXY	0		100	0		0	0	100
Heavy Fuel Oil	INDHFO	69		5	0		26	0	100
Refined Petroleum Products	INDOIL	50		30	3		17	0	100
Ethane	INDETH	0		0	0		100	0	100
Naphta	INDNAP	0		0	0		100	0	100
Petroleum Coke	INDPTC	0		0	0			100	100
Biofuels	INDBIO	100		0	0			0	100
Geothermal	INDGEO	100		0	0			0	100
Heat	INDHET	0		73	9			18	100

Appendix 12.4: Pulp and Paper Industry [%]

Industry	**Pulp and paper**							**Total**
		Boilers	Boilers	Process Heat	Machine Drive	Electro-chemical	Others	
		ISLP	ISLP	IPLP	IMLP	IELP	IOLP	
Electricity	INDELC	0		0	95	0	5	100
Natural Gas	INDNGA	80		19			1	100
LPG	INDLPG	23		69			7	100
NGL	INDNGL	0		0			0	100
Coal	INDCOA	89		1			10	100
Ovencoke	INDCOK	0		0			0	100
Coke Oven Gas	INDCOG	0		0			0	0
Blast Furnace Gas	INDBFG	100		0			0	100
Oxygen Steel Furnace Gas	INDOXY	100		0			0	100
Heavy Fuel Oil	INDHFO	90		10	0		0	100
Refined Petroleum Products	INDOIL	29		15			56	100
Ethane	INDETH	0		0			0	100
Naphta	INDNAP	0		0			0	100
Petroleum Coke	INDPTC	0		0			100	100
Biofuels	INDBIO	40		60			0	100
Geothermal	INDGEO	100		0			0	100
Heat	INDHET			100			0	100

Appendix 12.5: Non-Metal Mineral Industry [%]

Industry	**Non metal minerals**							**Total**
		Boilers	Boilers	Process Heat	Machine Drive	Electro-chemical	Others	
		ISNM	ISNM	IPNM	IMNM	IENM	IONM	
Electricity	INDELC	0		6	88	0	6	100
Natural Gas	INDNGA	13		82	0		5	100
LPG	INDLPG	4		88	0		8	100
NGL	INDNGL	0		0	0		100	100
Coal	INDCOA	0		100	0		0	100
Ovencoke	INDCOK	0		0	0		0	100
Coke Oven Gas	INDCOG	0		100	0		0	100
Blast Furnace Gas	INDBFG	0		100	0		0	100
Oxygen Steel Furnace Gas	INDOXY	0		100	0		0	100
Heavy Fuel Oil	INDHFO	13		84	2		0	100
Refined Petroleum Products	INDOIL	35		47	7		11	100
Ethane	INDETH	0					0	100
Naphta	INDNAP	0					0	100
Petroleum Coke	INDPTC	0					100	100
Biofuels	INDBIO	100						100
Geothermal	INDGEO	100						100
Heat	INDHET	100						100

Appendix 12.6: Other Industries [%]

Industry	**Other industries**							**Total**
		Boilers	Boilers	Process Heat	Machine Drive	Electro-chemical	Others	
		ISOI	ISOI	IPOI	IMOI	IEOI	IOOI	
Electricity	INDELC	0		9	78	3	10	100
Natural Gas	INDNGA	49		38	0		13	100
LPG	INDLPG	6		65	0		29	100
NGL	INDNGL	0		0			0	100
Coal	INDCOA	41		49			10	100
Ovencoke	INDCOK	0		0			100	100
Coke Oven Gas	INDCOG	0		0			0	0
Blast Furnace Gas	INDBFG	100		0			0	100
Oxygen Steel Furnace Gas	INDOXY	100		0			0	100
Heavy Fuel Oil	INDHFO	70		29	0		1	100
Refined Petroleum Products	INDOIL	47		13	0		40	100
Ethane	INDETH	0		0			0	100
Naphta	INDNAP	0		0			0	100
Petroleum Coke	INDPTC	100		0			0	100
Biofuels	INDBIO	100		0			0	100
Geothermal	INDGEO	100		0			0	100
Heat	INDHET			63	0		36	100

Appendix 13: The aggregated IO Table 2030 [Million USD at 2000 constant price]

Description	Agriculture, fishery & forestry	Mining	Manufacturing	Electricity & water	Construction	Trade	Transport & communication	Finance	Government services	Other services	Total intermediate consumption
Agriculture, fishery & forestry	211.68	14.36	5,648.74	0	116.46	1.01	0.72	0.08	1.48	112.47	6,106.99
Mining	2.75	9.69	366.05	4.38	135.71	0.16	0.06	0	0.17	8.09	527.06
Manufacturing	1,013.62	215.96	18,224.01	1,811.23	1,189.05	415.92	293.09	428.22	236.41	4,728.59	28,556.10
Electricity & water	18.66	2.72	820.49	251.94	2.16	108.74	74.86	39.95	11.67	161.41	1,492.60
Construction	23.90	4.49	16.67	116.02	17.06	8.40	6.11	34.83	10.66	246.98	485.14
Trade	845.16	12.56	1,304.65	56.95	65.68	15.67	11.00	45.03	12.12	676.67	3,045.50
Transport & communication	1.51	0.09	47.56	0.66	0.81	0.21	0.13	0.50	0.14	13.00	64.60
Finance	98.00	2.56	352.65	98.10	12.41	76.51	51.58	55.72	1.75	593.92	1,343.20
Government services	0.01	0.12	0.02	0.70	0.04	0.02	0.03	0.37	1.32	0.04	2.66
Other services	451.66	73.41	936.27	163.64	69.65	142.86	99.35	304.06	135.45	974.71	3,351.06
Total intermediate inputs	2,666.96	335.97	27,717.10	2,503.60	1,609.03	769.49	536.94	908.76	411.17	7,515.88	44,974.90
Labor	3,489.70	67.16	2,369.80	42.84	519.41	942.77	657.95	77.81	158.84	1,138.97	9,465.26
Capital	3,062.28	150.31	5,201.00	188.32	1,027.40	1,834.38	1,280.15	511.35	216.85	5,398.12	18,870.17
Tax on domestic products	46.20	4.56	369.29	8.24	40.59	55.41	38.69	27.76	0	167.28	758.01
Value added	6,598.19	222.03	7,940.09	239.40	1,587.40	2,832.56	1,976.79	616.92	375.70	6,704.38	29,093.44
Total input	9,265.15	558.00	35,657.19	2,743.00	3,196.43	3,602.05	2,513.73	1,525.68	786.86	14,220.26	74,068.35

Appendix 13.1 [Continued]

Description	Private consumption	Government consumption	Investment	Export	Import	Total final demand	Total output
Agriculture, fishery & forestry	2,734.64	149.34	120.79	820.62	667.23	3,158.16	9,265.15
Mining	0	0	30.94	0	0	30.94	558.00
Manufacturing	10,784.18	262.79	3,211.92	18,193.90	25,351.70	7,101.09	35,657.19
Electricity & water	1,338.44	0	0	0	88.04	1,250.40	2,743.00
Construction	0	0	2,809.97	0	98.67	2,711.30	3,196.43
Trade	460.63	0	105.32	0	9.40	556.55	3,602.05
Transport & communication	427.10	0	54.29	2,107.84	140.10	2,449.13	2,513.73
Finance	196.65	3.20	0.08	0	17.46	182.47	1,525.68
Government services	276.22	1,022.86	0	8.01	522.88	784.21	786.86
Other services	7,652.86	1,091.84	51.10	3,077.17	1,003.77	10,869.20	14,220.26
Total intermediate inputs	23,870.71	2,530.03	6,384.41	24,207.54	27,899.24	29,093.44	74,068.35

Appendix 14: The aggregated IO Table 2050 [Million USD at 2000 constant price]

Description	Agriculture, fishery & forestry	Mining	Manufacturing	Electricity & water	Construction	Trade	Transport & communication	Finance	Government services	Other services	Total intermediate consumption
Agriculture, fishery & forestry	687.28	60.17	24,582.66	0	451.10	3.94	2.80	0.30	5.71	435.46	26,229.44
Mining	8.93	40.59	1,593.02	17.48	525.69	0.62	0.25	0	0.66	31.31	2,218.54
Manufacturing	3,290.96	904.96	79,308.80	7,233.42	4,605.88	1,623.29	1,136.10	1,693.43	914.85	18,308.78	119,020.48
Electricity & water	60.59	11.41	3,570.68	1,006.15	8.38	424.39	290.19	157.97	45.15	624.98	6,199.88
Construction	77.61	18.82	72.54	463.33	66.10	32.80	23.68	137.75	41.27	956.29	1,890.19
Trade	2,744.02	52.65	5,677.69	227.45	254.42	61.15	42.63	178.09	46.91	2,620.01	11,905.02
Transport & communication	4.90	0.40	206.96	2.62	3.13	0.82	0.49	1.97	0.53	50.35	272.18
Finance	318.17	10.72	1,534.71	391.76	48.09	298.61	199.93	220.35	6.79	2,299.61	5,328.74
Government services	0.02	0.52	0.07	2.78	0.14	0.08	0.13	1.45	5.10	0.17	10.44
Other services	1,466.42	307.63	4,074.53	653.51	269.81	557.55	385.11	1,202.42	524.18	3,774.00	13,215.17
Total intermediate inputs	8,658.92	1,407.87	120,621.65	9,998.51	6,232.73	3,003.25	2,081.32	3,593.74	1,591.14	29,100.95	186,290.09
Labor	11,330.16	281.42	10,313.10	171.10	2,012.00	3,679.53	2,550.38	307.70	614.70	4,410.01	35,670.10
Capital	9,942.44	629.88	22,634.18	752.07	3,979.74	7,159.36	4,962.19	2,022.16	839.17	20,901.16	73,822.33
Tax on domestic products	150.01	19.10	1,607.09	32.90	157.21	216.25	149.96	109.78	0	647.71	3,090.01
Value added	21,422.61	930.40	34,554.37	956.07	6,148.95	11,055.14	7,662.53	2,439.64	1,453.87	25,958.88	112,582.45
Total input	30,081.53	2,338.27	155,176.02	10,954.59	12,381.67	14,058.38	9,743.85	6,033.38	3,045.01	55,059.83	298,872.53

Appendix 14.1 [Continued]

Description	Private consumption	Government consumption	Investment	Export	Import	Total final demand	Total output
Agriculture, fishery & forestry	6,046.96	577.90	467.40	1,465.63	4,705.81	3,852.09	30,081.53
Mining	0	0	119.73	0	0	119.73	2,338.27
Manufacturing	46,266.60	1,016.91	12,429.14	72,114.54	95,671.65	36,155.54	155,176.02
Electricity & water	5,179.32	0	0	0	424.62	4,754.70	10,954.59
Construction	0	0	10,873.69	0	382.21	10,491.48	12,381.67
Trade	1,782.49	0	407.55	0	36.68	2,153.37	14,058.38
Transport & communication	1,652.73	0	210.09	8,156.68	547.83	9,471.67	9,743.85
Finance	760.97	12.39	0.30	0	69.03	704.63	6,033.38
Government services	1,068.88	3,958.15	0.000	30.99	2,023.45	3,034.57	3,045.01
Other services	29,614.15	4,225.07	197.72	11,907.69	4,099.97	41,844.67	55,059.83
Total intermediate inputs	92,372.11	9,790.42	24,705.63	93,675.53	107,961.25	112,582.45	298,872.53

Appendix 15: Low carbon research network (LoCAR-Net) in Cambodia

A PROPOSAL FOR LOW-CARBON RESEARCH NETWORK (LOCAR-NET) IN CAMBODIA

1. What does Low-Carbon Development (LCD) mean?

LCD is a concept that refers to the development of an economy which has a minimal output of GHG emissions into the atmosphere. It is a sustainable developed or developing society on the basis of close, reasonable and harmonious coordination of economic and social development and environmental protection. To achieve a low carbon society, Skea and Nishioka (2008) suggested that a country should:

1) take actions that are compatible with the principles of sustainable development, ensuring that the development needs of all groups within a society are met;
2) make an equitable contribution toward the global effort to stabilize the atmospheric concentration of CO_2 and other GHGs at a level that will avoid dangerous climate change, through deep cuts in global emissions;
3) demonstrate a high level of energy efficiency and use low-carbon energy sources and production technologies; and
4) adopt patterns of consumption and behaviour that are consistent with low levels of GHG emissions.

2. Why does Cambodia need LCD?

The concept of an LCD is considered as the important economic development tool for Cambodia as it is compatible with the principles of sustainable development. Cambodia should address the development needs of all groups within the society, make a voluntary contribution toward the global effort to stabilize the atmospheric concentration of CO_2 and other GHG emissions at a level that would avoid dangerous climate change impacts, demonstrate a high level of energy efficiency and use low-carbon energy sources and production, and adopt patterns of consumption and behavior that are consistent with low levels of GHG emissions.

3. Why does Cambodia need LoCAR-Net?

The LoCAR-Net is a suitable and effective strategy to bridge the dialogues between researchers and policy makers and other stakeholders. It helps facilitate to access to the latest information on LCD in the world. As such, the establishment of the LoCAR-Net in Cambodia found very important to ensure the effective implementation of the LCD and it is used to facilitate a research network with the necessary knowledge to tackle internal and external challenges and to improve the capacity on using research-based evidence to influence policy making processes in response to the adverse impacts of climate change.

4. Opportunity for LoCAR-Net in Cambodia

Cambodia has set up various Government ministries/institutions, national committees and inter-ministerial working groups to ensure overall coordination and cooperation among the different policies and measures at all levels and to ensure the effective implementation among them. The NCCC was established in 2006 with the mandate to prepare, coordinate and monitor the implementation of policies, strategies, legal instruments, plans and programmes of the Government to address climate change related issues and it is assisted by the CCTT. It is realized that climate change becomes important and attracts the interest of the relevant key stakeholders. Based on this, the establishment of the LoCAR-Net in Cambodia should be possible in the future.

5. A proposal for LoCAR-Net in Cambodia

In order to establish the LoCAR-Net, we need to engage among national agencies, local Governments and concerned Government/non-Government organizations, research institutes and academia as well as other key stakeholders. We should build confidence, strengthen capacity, and engender a stronger sense of ownership among them. Figure 5.1 illustrates some key stakeholders involving with the LoCAR-Net in Cambodia. The MoE is considered as a key coordinator; however, we need to get the active participation and cooperation from other line ministries that are the member of the NCCC, relatively.

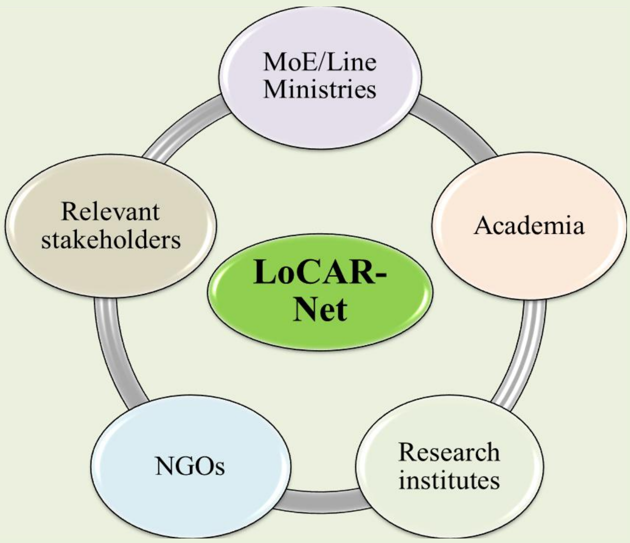


Figure 5.1: LoCAR-Net framework in Cambodia

The following proposed activities are needed to ensure the effective implementation of the LoCAR-Net in Cambodia.

Government's ministries

- Develop concrete national strategy on the LCD;
- Cooperate with the international communities for the LCD research work;
- Build human capacity through nominating for the LCD trainings and workshops;
- Establish research institute under the relevant ministries;
- Encourage researchers for the LCD research activities;
- Mobilize resources for the LCD research activities;
- Encourage the participation from academia, NGOs, research institutes and stakeholders for the LCD research; and
- Mainstream the LCD concept into respective policies, strategies and action plans.

Academia

- Encourage public universities and private universities; for example, Royal University of Agriculture, Royal University of Phnom Penh, Institute of Technology of Cambodia and other private universities, etc. to engage with the LoCAR-Net;
- Participate with international universities for the LCD training and research activities;
- Encourage researchers to conduct the LCD research activities;
- Share the research findings on the LCD related matters with other researchers and decision makers;
- Mainstream LCD concept into study calendar;
- Convince the decision makers to believe on the research findings with clear explanation and references so that they can use for economic development;
- Demonstrate the research findings via implementing a pilot project; and
- Be willing to work with international communities on the LCD.

Other stakeholders

- Share information and data from their respective offices and institutions for the purpose of the LCD research;
- Cooperate with the Government agencies to ensure effective LCD implementation; and
- Be willing to work with other stakeholders and international communities.

Research institutes

- Mainstream the LCD subject into research plan;
- Participate with international universities and institutions for the LCD trainings (*e.g.* NIES in Japan) and workshops;
- Encourage researchers to conduct the LCD research;
- Mobilize and allocate budget for the LCD research activities;
- Share the research findings with decision makers and other stakeholders;
- Convince the decision makers to believe on the research findings with clear explanation and references so that they can use for economic development;
- Demonstrate the research findings via implementing a pilot project; and
- Be willing to work with other international communities on the LCD.

Non-Governmental Organizations (NGOs)

- Mainstream the LCD concept into their respective strategies;
- Encourage researchers for the LCD research;
- Allocate budget for the LCD research activities;
- Share the research findings with decision makers and other stakeholders;
- Demonstrate the research findings via implementing a pilot project; and
- Be willing to work with international communities on the LCD.