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# A qualitative and quantitative design of low-carbon development in Cambodia: Energy policy

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ABSTRACT

The formulation of a policy for a low-carbon development plan is one of the most important steps to help Cambodia achieve sustainable development objectives, promote a greener development path, and contribute to the global effort to reducing $CO_2$ emissions. This study is designed to propose some low-carbon energy strategies and quantitatively to assess $CO_2$ emissions and reductions. The Extended Snapshot (ExSS) tool is used to quantify socioeconomic assumptions and to estimate $CO_2$ emissions and reduction potentials. The results show that $CO_2$ emissions are projected to increase to about 23,277 (by about 5.5 times) and 91,325 $ktCO_2$/year (by about 21.6 times) in 2030BaU and 2050BaU, respectively, from 4,221 $ktCO_2$/year in 2010. This study proposes five strategies for low-carbon development plan towards 2050 which are expected to reduce $CO_2$ emissions by about 12,826 (about 55%) and 52,153 $ktCO_2$/year (about 57%) in 2030CM and 2050CM, respectively. The present results should help researchers and experts gain a better understanding of $CO_2$ emissions and reduction potentials by applying a number of low-carbon measures in Cambodia. While the results should be counted as a preliminary study because of limited available country information, they are expected to provide useful insights for the government in formulating a concrete climate change mitigation policy for the country.

## 1. Introduction

$CO_2$ emissions from the energy sector had increased from about 26% in 2004 to 35% of total world anthropogenic greenhouse gas (GHG) emissions in 2010 (IPCC, 2007, 2014); however, this sector in Cambodia attributed only around 4% in 2000 (MoE, 2013). To achieve the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC), Parties should protect the climate system on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities (UNFCCC, 1992). On this, international communities agreed to hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels (Article 2 of the Paris Agreement, UNFCCC, 2015). Although Cambodia is not obliged to reduce GHG emissions (MoE, 2013, 2013a), her participation could be important in contributing to the global effort to achieve the emissions reduction target (UNFCCC, 2015). Cambodia has developed a number of policies and strategies related to low-carbon development (LCD) and climate change mitigation, including its climate change strategic plan (2014–2023) (MoE, 2013a), the first and second national communication (MoE, 2013, 2002), its energy efficiency policy and action plan (MME, 2013), technology need assessment for climate change mitigation (RGC, 2013), national strategic plan on green growth (2013–2030) (NCGG, 2013), and Intended Nationally Determined Contribution (INDC) (RGC, 2015), and so forth. Thus, it is a good time to propose scenarios for the qualitative and quantitative design of a low-carbon development plan in Cambodia focusing mainly on energy policies.

The main objectives of this study were: (1) to propose several low carbon energy strategies; (2) to quantify the socioeconomic parameters and project $CO_2$ emissions and reduction potentials towards 2050; and (3) to conduct a systematic and quantitative assessment of $CO_2$ emissions reduction by using a quantitative methodology for each low carbon development strategy and associated actions. The structure of the paper is as follows: Section 2 introduces methodologies which include data quantification and assumptions in order to estimate energy demand and $CO_2$ emissions. Section 3 illustrates the results of energy demands and $CO_2$ emissions and reduction potentials. Section 4

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discusses important findings and presents a low-carbon development plan towards 2050, while the last section offers conclusions and policy implications.

## 2. Methodologies

### 2.1. Scenario of the study

"Scenarios" in this study means a plausible description of how the future may develop based on a coherent and internally consistent set of social, economic, and industrial assumptions about key driving forces and relationships. The scenario for the LCD consists of two stages: 1) preparing and adjusting the tools for the Cambodian study to quantify projections, and 2) identifying the low-carbon measures based on projected quantitative information for developing a future sustainable society. The scenarios developed are valuable material for decision-makers to design an LCD with several images of the future, based on the different assumptions of socioeconomic indicators, from which decision-makers can select the most suitable for socioeconomic development and for lowering $CO_2$ emissions in Cambodia.

### 2.2. Methodology development

In order to estimate energy demand and $CO_2$ emissions and reduction potential, the Extended Snapshot (ExSS) tool (Gomi and Fukuda, 2010), which has been applied to several Asian countries (Gomi et al., 2009; Bundit et al., 2010; Nguyen, 2012; Tahsin et al., 2012; Ochi et al., 2013; Siong et al., 2013), is applied. It is also used to quantify information on macro-socioeconomic indicators and environmental variables. Because of the limited country information, additional calculations and assumptions are made to apply the model. A number of parameters are adjusted to reflect the real economic structure of Cambodia. The Input-Output (IO) table 2010 is converted from the IO table 2008 by using an IO table conversion tool. In addition, the Analysis of Global Energy Markets (SAGE, 2003), which is an integrated set of regional models that provides a technology-rich basis for estimating regional energy supply and demand, is used to split energy consumption by energy service sector.

### 2.3. Data quantification

In order to estimate the activity of industrial, commercial, and residential sectors related to a macro-socioeconomic framework, an input-output approach is applied, and adjustments of parameters are made to reflect the real economic structure of Cambodia. Using these sectoral activities coupled with energy device characteristics, energy consumption and $CO_2$ emissions are calculated. Based on the prescribed changes in population and numbers of households, gross domestic product (GDP), industrial structure, employment, passenger and freight transport, 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.

### 2.4. Data collection

Given the limited country information, additional calculations and assumptions were used to apply the model based on available data, historical trends, and the professional insights of the authors. The data collection was based primarily on relevant government documents and a series of discussions with key government officers, and involved institutions were conducted so as to envision the future development pathway of Cambodia. The data estimates and assumptions were done in three steps. First, relevant documents were collected and discussed with the involved government officers and experts (Table 1) to ensure the validity, reliability, and applicability of the collected information. Second, a series of workshops (Table 2) were organized to disclose a

**Table 1**
Lists of a number of collected documents and the interviewees who are mainly from the government officers.

| 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 and National Focal Point for the IEA; 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. |
| Transport | Data on vehicle fleet of Cambodia in 2009; Overview on Transport Infrastructure Sectors; Annual Transport Sector Report; National Implementation Plan on Environmental Improvement in Transport 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 second national communication; transport development strategy and action plan; and long term perspective, inland, air, and railway transport sector, etc. |
| Cross sector | Draft Second National Communication; Technology Needs Assessment and Technology Action Plans for Climate Change Mitigation; Cambodia Climate | 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 |

(continued on next page)

**Table 1** *(continued)*

| Sectors | Documents | Interviewees | Explanation |
|---|---|---|---|
| | Change Strategic Plan (2014–2023) of the Ministry of Environement (MoE) | | transport, etc. |

**Table 2**
Lists of workshops. This table illustrates a series of workshops organized to collect comments and inputs from the participants who can make a decision from different institutions to improve the assumptions and estimation.

| Titles | Objectives | Date | Venue | Participants |
|---|---|---|---|---|
| Workshop on a Systematic and Quantitative Design of Low Carbon Development Plan for Cambodia | To introduce a preliminary study on a systematic and quantitative design of low carbon development and to collect the inputs and comments from the participants. | 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 | To share the progress of climate change related policies and activities among Cambodia, Lao PDR, and Myanmar; and to convince some Asian countries to recognize the importance of using the ExSS tool to estimate GHG emissions and reductions in their respective countries. | 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 |
| Workshop on the Advancement and Enhancement on Low Carbon Development Researches and Policies among Cambodia, Lao PDR, and Myanmar | To update the climate change and low carbon development related activities among those countries and to disclose the results of GHG emissions and reduction potentials from the ExSS tool, the AFOLU model and collect their comments and inputs as well as to introduce waste model. | 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 |

preliminary estimation and to collect further comments and inputs to improve the assumptions and estimations. Third, intensive subsequent interviews were conducted with related government officers and experts as shown in Table 1.

### *2.5. Procedure of the ExSS tool*

The procedure of the ExSS tool is classified into seven steps (Fig. 1) as follows:

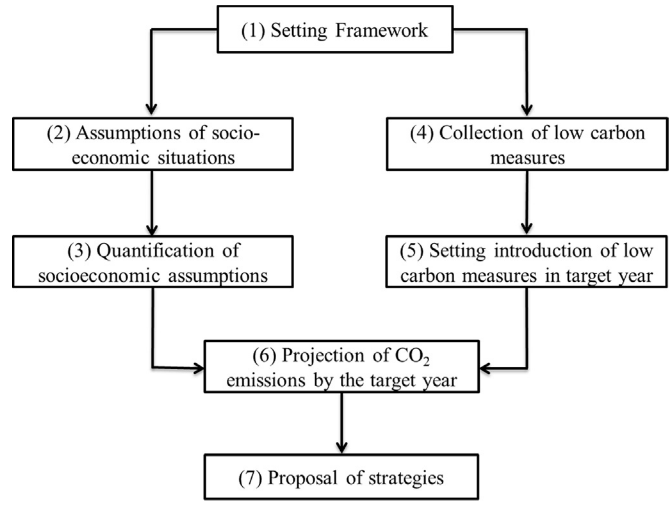


**Fig. 1.** The seven steps of the methodology for the low carbon study for Cambodia.

(1) construction of the framework: framework of an LCD scenario including target area, base year, target year, environmental target, and the number of scenarios; (2) assumptions of socioeconomic situations: population, GDP, and so forth, before conducting more detailed quantitative estimation and projection. The assumptions are based primarily on qualitative future images, including images of lifestyle, economy and industry, land use and so forth; (3) quantification of socioeconomic assumptions: to provide an estimate a future snapshot of a society based on the future image of (2), values of exogenous variables and parameters are estimated. The ExSS tool (Fig. 2) uses these inputs to calculate socioeconomic indices of the target year such as composition of GDP, outputs by industries, transport demand, and so forth; (4) collection of low-carbon measures: to be implemented by the target year; for example, high-energy-efficiency devices, public transport, the use of renewable energy, and energy saving behaviors, and so forth; (5) setting the introduction of low-carbon measures by the target year: technological parameters related to energy demand and $CO_2$ emissions, energy efficiency, and so forth are listed; (6) projection of $CO_2$ emissions by the target year: based on socioeconomic indices and assumptions of measures introduced, $CO_2$ emissions are calculated; and (7) proposal of strategies: proposed strategy sets to introduce the measures introduced. The ExSS tool can show the reduction potentials of each low-carbon measure and the decomposition of reduction factors. It can identify measures which have high emission reduction potentials and are important for economic development of the country. In order to reduce energy demand and $CO_2$ emissions, this study introduces a list of low-carbon measures (Table 3), which were selected from the existing government documents (MoE, 2013, 2013a; MPWT, 2013; NCGG, 2013; RGC, 2013; MME, 2013, 2014) and were approved by key stakeholders (as listed in Table 1). It is noted that the selection of low-carbon measures must be in line with national sustainable development objectives and provide the highest development benefit to the Cambodian people even if no concrete target of emissions reduction exists.

### *2.6. Framework of the scenarios*

The ExSS tool is used to estimate the snapshots of $CO_2$ emissions in 2010 as the base year and 2030 and 2050 as the target years for the present study. We identified 2030 and 2050 as the target years because the government aspires to reach the status of an upper-middle income country by 2030 and a high-income country by 2050 (RGC, 2013a). As well, relevant data are available for those years, including projections of the population towards 2030 and 2050 (NIS, 2011; UN, 2013), GDP growth rate towards 2030 and 2050 (RGC, 2013a, 2014), energy

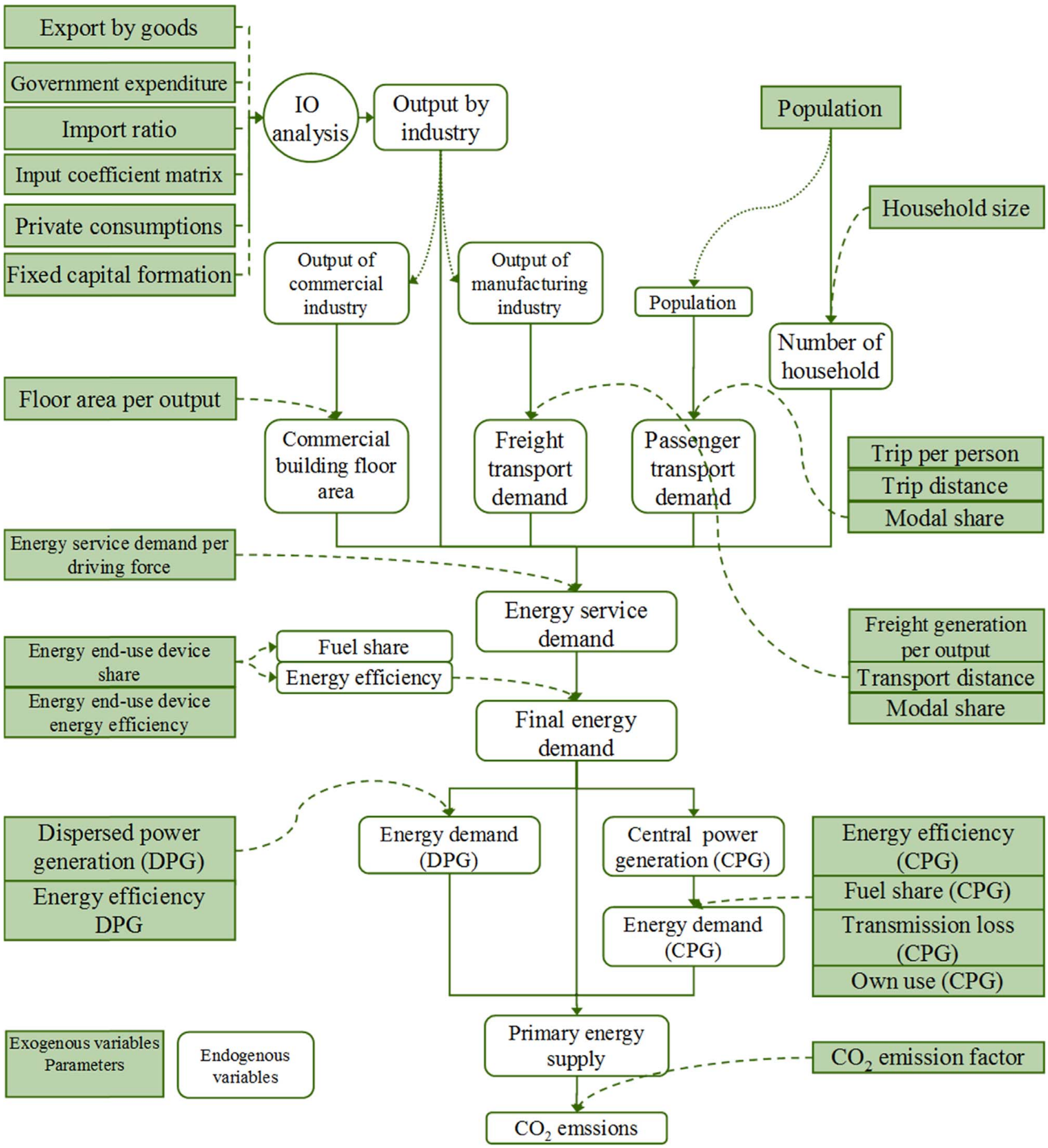


**Fig. 2.** The structure of the Extended Snapshot (ExSS) tool. The ExSS tool covers input parameters and exogenous variables. Exogenous variables parameters are the most important information to be collected and assumed for estimating energy demand and $CO_2$ emissions.

demand by demand sectors towards 2035 (Lieng, 2013), and fuel mix of the power supply towards 2030 (MME, 2014), and so forth.

The energy-induced $CO_2$ emissions are estimated with 2010 as the base year, and the projections are based on two scenarios:

1. 2030BaU and 2050BaU (business as usual): without additional low-carbon measures besides the existing government's plans in 2030 and 2050, and
2. 2030CM and 2050CM (countermeasures) with intensive low-carbon measures through adopting measures additional to the existing government's plans in 2030 and 2050 to reduce $CO_2$ emissions.

In this study, emission sectors include: residential, commercial, industrial, passenger and freight transport, and power sectors. Thus, low-carbon measures are introduced into these sectors. This study shows the potential reductions of $CO_2$ emissions in 2030CM and 2050CM compared to 2030BaU and 2050BaU, respectively, by adopting several low-carbon measures. Since there is no commitment for emissions-reduction in Cambodia, no specific reduction target is assumed. The projected potential emissions-reduction will, then, provide important information for Cambodia to specify $CO_2$ emissions-reduction targets and to formulate concrete climate change mitigation policies in the future.

**Table 3**
List of low carbon measures used to reduce energy demand and $CO_2$ emissions in the target years.
Sources: MoE (2013, 2013a), MPWT (2013), MME (2013, 2014), NCGG (2013).

| Sectors | Low carbon measures |
|---|---|
| Residential | Energy efficiency improvement of electrical and non-electrical equipment (e.g. Cook stoves, lighting, refrigerators, hot water, heating, other equipment), fuel switch, and energy saving behavior |
| Commercial | Efficiency improvement in electric devices (e.g. Lighting, refrigerators, hot water, heating, other equipment), insulation buildings (passive house), and energy saving behavior |
| Industrial | Energy efficiency improvement (e.g. Steam boilors, furnaces, motors, and other equipment), fuel switch, and energy saving technology |
| Transport | Fuel efficient vehicles, fuel switch (e.g. Gasoline to natural gas, electric and biofuel), and modal shift (e.g. 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) |

### 2.7. Data quantification of the present and future

In order to estimate $CO_2$ emissions, several quantitative socio-economic and energy demand assumptions are required as a premise. Socioeconomic indicators used for this study are shown in Table 4.

#### 2.7.1. Population growth and numbers of households

Cambodia's population was about 13.96 million in 2010 (NIS, 2012). At that time, 19.5% and 80.5% were living in the urban and rural areas, respectively. The population is projected to reach about 18.39 million by 2030 (NIS, 2011) and about 21.96 million by 2050 (UN, 2013). Households numbered approximately 3 million- – 0.6 and 2.4 million were in the urban and rural areas, respectively, in 2010 (NIS, 2011) and are predicted to increase to about 4.2 and 5 million in 2030 and 2050, respectively. The average persons per household in the urban and rural areas gradually decreased from 5.5 and 5.1, respectively, in 1998, to a similar number of 4.8 in 2010 (NIS, 2011). It was also observed that the urban areas had decreased rather faster than the rural ones, and this trend is expected to remain constant in the future because of behavioral change in family management, competition for jobs, and economic development (MoP, 2013). Therefore, this study assumes that the average persons per household will decrease to 4.2 for the urban areas and 4.5 for the rural ones, which are almost the minimum average members per family in the urban and rural areas, respectively, in Cambodia (Mr. Mam Marady as shown in Table 1) in both 2030 and 2050.

#### 2.7.2. GDP growth and projections

Cambodia had experienced an average annual GDP growth of approximately 7.0% from 1994 through to 2013, while per capita GDP had increased from roughly around 216USD in 1992 to more than 1,000 USD in 2013 and is expected to reach around 1,579 USD in 2018 (RGC, 2012, 2014). The government has aspired to reach the status of an upper-middle income level by 2030 and a high-income one by 2050 and the country will maintain a strong and constant annual GDP growth of approximately 7.0% (RGC, 2013a).

This study assumes the average annual GDP growth of around 7.0% from 2010 through to 2050, which is the same as that of the government's projection (RGC, 2013a). And we do expect that it will be plausible as the government is planning to expand and enhance industrial development, and to increase value added from agriculture, and so forth (RGC, 2013a). Besides, the government is encouraging a rapid transformation of industrial structure to move from a labor-intensive and low- productivity industry to a more broad-based, high-tech and high-skilled one (RGC, 2015a). The government has also

**Table 4**
The assumptions of socioeconomic indicators used to estimate energy demand and $CO_2$ emissions and reduction potentials.

| Indicators | 2010 | 2030 | 2050 | 2030/2010 | 2050/2010 | Sources |
|---|---|---|---|---|---|---|
| Population ('000 persons) | 13,959 | 18,391 | 21,964 | 1.32 | 1.57 | NIS (2011); UN (2013) |
| No. of households ('000) | 2,918 | 4,185 | 5,003 | 1.43 | 1.71 | NIS (2011, 2012) |
| GDP (million USD at 2000 constant price) | 7,518 | 29,093 | 112,582 | 3.87 | 14.97 | NIS (2011); RGC (2013a); Mao and Matsuoka (2015) |
| Primary industry (share %) | 29.71 | 22.68 | 19.03 | | | |
| Secondary industry (share %) | 28.60 | 34.33 | 37.83 | | | |
| Tertiary industry (share %) | 41.70 | 42.99 | 43.14 | | | |
| GDP per capita (USD at current price) | 833 | 2,448 | 7,932 | 2.94 | 9.52 | NIS (2011); RGC (2013a); Mao and Matsuoka (2015) |
| Gross outputs (million USD at 2000 constant price) | 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 | |
| Final demand sectors (million USD at 2000 constant price) | 14,728 | 56,993 | 220,544 | 3.87 | 14.97 | NIS (2011); RGC (2013a); Mao and Matsuoka (2015) |
| Passenger transport demand (million pass km/year) | 53,829 | 276,819 | 831,678 | 5.14 | 15.45 | JICA (2006a, 2006b); ADB (2011); MPWT (2009, 2011, 2015); NIS (2011); |
| Freight transport demand (million ton km/year) | 18,562 | 116,048 | 619,725 | 6.25 | 33.39 | RGC (2013a, 2014); Mao and Matsuoka (2015) |

planned to exploit oil resources in the near future (RGC, 2013a). As a result, Cambodia's per capita GDP, which was around 833 USD (at 2010 current price) in 2010 (NIS, 2011), is expected to increase to about 2,448 USD/year in 2030, which is similar to that of the Philippines in 2013 (2,496 USD/year) and to around 7,932 USD/year in 2050, which is similar to that of Malaysia in 2008 (8,088 USD/year) (IMF, 2014).

#### 2.7.3. Industrial structure

The ExSS tool applies the Input-Output (IO) analysis to determine the future industrial structure. Since there is no information on the IO

**Table 5**
The aggregated sectors of the IO table in 2008 modified for this study.

| 10-sector classification in IO table 2008 | | 22-sector classification in IO 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 |

table in 2010 in Cambodia, it is extrapolated from the IO table in 2008 (Sophal and Sothea, 2011). The IO table in 2008 consisted of 22 sectors and is aggregated into a competitive import type, which means the value of supply for domestic demand is the combined sum of domestic and imported goods, of 10 sectors to make it more precise and easy to estimate (Table 5). An IO table conversion tool designed to convert from the IO table 2008–2010 is used. A cross-entropy method, which is a methodology to minimize the distance between the two IO tables (to make IO 2010 close to IO 2008), under constraints of controlled totals (Foana et al., 2005), is used in the adjustment calculation under input value and constraints. It formalizes as a nonlinear programming problem, which minimizes the objective function. The result of the IO table in 2010 is shown in Appendix 1.

Cambodia's industrial structures are available for 2025 (RGC, 2015a) and 2030, which were assumed and adjusted based on national development policies and plans by Mao and Matsuoka (2015). While towards 2050, other countries' experiences, such as Malaysia and Thailand, where the economic structures relied mainly on secondary and tertiary industries (Bundit et al., 2010; Ochi et al., 2013), are used and adjusted. Cambodia is planning to shift to a high-income country by 2050; thus, secondary and tertiary industries are expected to grow substantially. Indeed, the government is diversifying the secondary industry base through encouraging investments in new high-value-added, more creative and competitive industries, and promoting further development of small and medium enterprises (RGC, 2013a, 2014). It is also giving priority to the agro-processing industry and promoting other industries such as energy and heavy industries, water supplies, and green-based technology (RGC, 2015a).

For this study, the share of products of the primary industry in private consumption in 2010 is collected from the national institute of statistics 2011 (NIS, 2011), while 2030 is collected from Mao and Matsuoka (2015), which was assumed to decrease based on governmental development policies. It is assumed to continue to decrease in 2050, replaced by the increase in goods and services of secondary and tertiary industries. Similarly, the share of products of the primary industry in export in 2010 is collected from NIS (2011), while 2030 is collected from Mao and Matsuoka (2015), which share was assumed to decrease based on the government's development policies and plans. That share is also assumed to continue to decrease in 2050, replaced by

**Table 6**
The percentage distribution of private consumption and expenditure and export (%). This table explains the assumptions of industrial structures in 2030 and 2050. It is very important to identify the characteristic of economic development structure in Cambodia, which influences energy demand and $CO_2$ emissions.

| 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 |

the increase of products of the secondary industry, whereas the share of products of the tertiary industry in 2050 is assumed to be the same as that of 2030 as it is already high (Mao and Matsuoka, 2015). The percentage distribution of government consumption and expenditure and gross fixed capital formation in 2010 is collected from NIS (2011), while such data for 2030 are collected from Mao and Matsuoka (2015) and is assumed to remain the same for 2050 (Table 6).

#### 2.7.4. Passenger transport demand

Passenger transport demand (Million pass.km/year) is estimated by multiplying population (persons) by trip generation per person per day (trip/(person.day)), modal share (%*100), average trip distance (km/trip), and days in a year (365.25 days). Table 7 shows the assumed passenger transport indicators and transport demand used in this study. Trip generations in 2010 and 2030 are 2 trips/(person day), which are the same as Mao and Matsuoka (2015) and are expected to increase to about 2.5 trips/(person day) in 2050, which are similar to that of Thailand in 2030 (2.6 trips/(person day)) (Bundit et al., 2010), as a result of the increased incomes of people and more convenient infrastructures and transport services (RGC, 2013a, 2014).

The share of passenger transport modes in 2010 is collected from MPWT (2011) and NIS (2011), while 2030BaU and 2030CM is assumed to be the same as Mao and Matsuoka (2015), which used the historical trend as the main assumption. It is assumed and estimated based on available country information (JICA, 2006a, 2006b; ADB, 2011; MPWT, 2011; NIS, 2011; RGC, 2014) towards 2050BaU and 2050CM. Because of limited information, this study assumes the share of motorized vehicles to be similar to the projected increase in numbers of motorized vehicles. Numbers of motorbikes have increased about 9.5 times between 2000 and 2010; the notable increase was observed from 2005 to 2009 (NIS, 2011; MPWT, 2013a); however, they started decreasing gradually from 2010 onward (MPWT, 2015). This study assumes that the numbers of motorbikes will increase more slowly (about 2 times) between 2010 and 2030BaU as a result of an increase in tourist cars and public transport services, which are the same as Mao and Matsuoka (2015) and are expected to continue to increase another 2 times between 2030BaU and 2050BaU. Numbers of tourist cars had increased around 2.9 times between 2000 and 2010 (NIS, 2011) and are expected to have a similar growth between 2010 and 2030BaU, as seen in Mao and Matsuoka (2015). However, they are expected to grow more slowly between 2030BaU and 2050BaU (about 2.5 times) because of the expected increase in public

**Table 7**
Passenger transport indicators and transport demand. This table shows passenger transport indicators used to estimate passenger transport demand, which are the main cause of energy consumption and $CO_2$ emissions.

| Mode | Average trip distance (km) | | | | | Model share (%) | | | | | Transport demand (Mil pass.km/year) | | | | | Sources |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2030BaU | 2030CM | 2050BaU | 2050CM | 2010 | 2030BaU | 2030CM | 2050BaU | 2050CM | 2010 | 2030BaU | 2030CM | 2050BaU | 2050CM | |
| Motorbike | 10 | 10 | 6 | 10 | 6 | 8.40 | 16.79 | 11.20 | 33.59 | 25.84 | 8,562 | 22,560 | 9,024 | 67,360 | 31,089 | JICA (2006a, 2006b); ADB (2011); MPWT, 2009, 2011, 2015); NIS (2011); RGC (2013a, 2014); Mao and Matsuoka (2015) |
| Tourist Car | 68 | 103 | 86 | 103 | 86 | 2.45 | 7.34 | 4.89 | 18.35 | 17.35 | 17,073 | 101,544 | 56,523 | 378,983 | 299,184 | |
| Bus | 82 | 82 | 57 | 82 | 57 | 1.79 | 4.47 | 6.71 | 11.18 | 14.54 | 14,988 | 49,283 | 51,387 | 183,935 | 166,215 | |
| Train | 0 | 96 | 66 | 96 | 66 | 0.0 | 7.00 | 10.50 | 10.0 | 15.6 | 0.0 | 90,279 | 93,100 | 192,536 | 206,495 | |
| Ship | 36 | 36 | 36 | 36 | 36 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2 | 5 | 7 | 14 | 21 | |
| Air | 237 | 474 | 474 | 711 | 711 | 0.0 | 0.0 | 0.0 | 0.01 | 0.01 | 32 | 171 | 171 | 765 | 765 | |
| Walk | 1 | 1 | 1 | 1 | 1 | 45.56 | 32.20 | 37.05 | 13.44 | 15.26 | 4,646 | 4,325 | 4,978 | 2,695 | 3,061 | |
| Bicycle | 2 | 2 | 2 | 2 | 2 | 42 | 32.20 | 29.64 | 13.44 | 11.41 | 8,526 | 8,651 | 7,965 | 5,390 | 4,576 | |

transports as set by the government (RGC, 2014). Numbers of buses have increased approximately 2.5 times between 2000 and 2010 (NIS, 2011) and are projected to experience the same growth between 2010 and 2030BaU as a result of the introduction of public bus systems in some major cities (Mao and Matsuoka, 2015). They are assumed to continue to increase another 2.5 times between 2030BaU and 2050BaU, as they are expected to further expand to include other cities in the country (RGC, 2014; MPWT, 2015).

As indicated above, this study assumes that the share of motorbikes will increase approximately 2 times between 2010 and 2030BaU and is expected to retain the same growth between 2030BaU and 2050BaU. The share of tourist cars is assumed roughly to triple between 2010 and 2030BaU and is expected to increase only 2.5 times between 2030BaU and 2050BaU. The share of buses is assumed to increase by about 2.5 times between 2010 and 2030BaU and is expected to maintain the same growth in 2050BaU from 2030BaU level. The share of trains is assumed to contribute about 7.0% in 2030BaU (Mao and Matsuoka, 2015) and 10.0% in 2050BaU, because the government is planning to restore and construct several railways as well as to introduce commuter light trains in a number of major cities (RGC, 2014). This sector used to contribute approximately 20.0% before 2005, during which time the road infrastructures were almost completely destroyed by the civil war (JICA, 2006a, 2006b). Road infrastructures, however, are currently playing a more active role as the government is renovating and constructing a country-wide (MPWT, 2015). The shares of airplanes and ships are assumed approximately to double between 2010 and 2030BaU and are expected to maintain this pace between 2030BaU and 2050BaU, as the government is planning to renovate several more domestic airports and to introduce more domestic airlines (MPWT, 2011); for instance, the operation of the Cambodia Bayon Airlines for domestic flights in 2014. Also, the government is improving inland waterway infrastructures to facilitate ship navigation, especially along the Mekong River and Tonle Sap Lake (MPWT, 2015). The increase of the shares of each travel mode as described above is due to the decrease of the shares of walks and bicycles as the people will opt for modern and more convenient means of transport.

Under low carbon measures, the shares of motorbikes and cars are assumed to decrease; conversely, the shares of buses, ships, and trains are assumed to increase in 2030CM, as seen in Mao and Matsuoka (2015) and will continue to increase in 2050CM as we expect that the government will further expand these modes to meet the increasing demand (MPWT, 2015). The share of aircraft is assumed to remain the same as those of the BaU levels. The share of walks is assumed to increase, while the share of bicycles is assumed to decrease.

The average trip distances of all modes in 2010 are collected from MPWT (2009), while 2030BaU and 2030CM are assumed to be the same as Mao and Matsuoka (2015), which used the historical experiences and available country information as the main assumptions. Furthermore, towards 2050, they are assumed to be based on available country information and discussion with national experts. The average trip distances of motorbikes, buses, ships, trains, bicycles, and walks in 2050BaU are assumed to be the same as those of the 2030BaU (Mao and Matsuoka, 2015); however, the average trip distance of tourist cars is assumed to increase by approximately 1.5 times in 2050BaU from 2030BaU level as a result of the expected increases of road construction and expansion and incomes of the people (RGC, 2013a; MPWT, 2015). This assumption is very similar to those of Vietnam and Bangladesh, where the average trip distance of this mode was assumed to increase as the result of the increases of road infrastructures and incomes of the people (Nguyen, 2012 and Tahsin, 2013). The average trip distance of airplanes is assumed to increase by about 1.5 times in 2050BaU from 2030BaU as the government is planning to expand several new domestic airports, which, in response to customers' demands, are far from the current locations (MPWT, 2015).

Under low carbon measures, the average trip distances of tourist cars, airs, ships, bicycles, and walks are assumed to be the same as

**Table 8**
Freight transport indicators and transport demand. This table shows freight transport indicators used to estimate passenger transport demand, which are the main cause of energy consumption and $CO_2$ emissions.

| Mode | Average trip distance (km) | | | | | Model share (%) | | | | | Transport demand (Mil ton.km/year) | | | | | Sources |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2030BaU | 2030CM | 2050BaU | 2050CM | 2010 | 2030BaU | 2030CM | 2050BaU | 2050CM | 2010 | 2030BaU | 2030CM | 2050BaU | 2050CM | |
| Small cargo truck | 110 | 109 | 100 | 109 | 100 | 28.86 | 25.05 | 24.05 | 24.05 | 23.20 | 4,731 | 25,655 | 22,597 | 132,517 | 117,280 | JICA (2006a, 2006b); ADB (2011); |
| Big cargo truck | 130 | 130 | 115 | 130 | 115 | 70.31 | 63.29 | 58.45 | 53.45 | 49.05 | 13,688 | 77,315 | 63,170 | 351,332 | 285,209 | MPWT (2009, 2011, 2015); |
| Train | 12 | 120 | 110 | 120 | 110 | 0.0 | 10.0 | 15.0 | 20.0 | 24.0 | 0.04 | 11,277 | 15,506 | 121,341 | 133,475 | NIS (2011); RGC (2013a, 2014); Mao and Matsuoka (2015) |
| Ship | 115 | 115 | 115 | 115 | 115 | 0.83 | 1.67 | 2.50 | 2.50 | 3.75 | 143.45 | 1,801 | 2,702 | 14,535 | 21,802 | |

those of the BaU levels; however, the average trip distances of motorbikes, tourist cars, buses, and trains are assumed to decrease as a result of the compact city development and a better land-use design prepared by the government.

#### 2.7.5. Freight transport demand

Freight transport demand (Million ton km/year) is estimated by multiplying outputs of industries (Million USD) by freight generation per industrial output (ton/USD), modal share (%*100), and average trip distance (km/trip). Table 8 shows the assumed freight transport indicators and transport demand used in this study. Freight transport generation per output of industry in 2010 and 2030 is collected from Mao and Matsuoka (2015) and is expected to increase about 2 times in 2050 from 2030 due to the expected increase in freight transport demand resulting from economic growth (RGC, 2014). It is assumed to be the same in both BaU and CM scenarios.

The shares of all freight transport modes in 2010 are collected from MPWT (2011) and NIS (2011), while 2030BaU and 2030CM are assumed to be the same as Mao and Matsuoka (2015), which based their assumptions on historical trends. The shares of small and large cargo trucks are assumed to decrease in 2050BaU from 2030BaU level; in contrast, the share of trains is expected to increase significantly because of the improvement and expansion of railway infrastructures for economic development and trade facilitation (ADB, 2011; RGC, 2013a, 2015; MPWT, 2015). In this regard, the share of trains is assumed to increase to about 15.0% in 2050BaU from 10.0% in 2030BaU (JICA, 2006a, 2006b; Mao and Matsuoka, 2015). Meanwhile, the share of ships is assumed to increase about 1.5 times in 2050BaU from the 2030BaU level, as the government is improving inland waterways to facilitate marine navigation (MPWT, 2015). Under low carbon measures, the shares of trains and ships are assumed to increase further, while the shares of other modes are assumed to decrease further in both 2030CM and 2050CM.

The average trip distances of freight transport modes in 2010 are collected from MPWT (2009), while 2030BaU and 2030CM are assumed to be the same as Mao and Matsuoka (2015), which used the historical experiences and available country information as the main assumption. They are assumed to remain the same for 2050BaU as a result of limited information. Under low carbon measures, the average trip distances of small cargo trucks and trains are assumed to decrease in both 2030CM and 2050CM, while the average trip distances of ships in 2030CM and 2050CM is assumed to be the same as those of the BaU levels.

#### 2.7.6. Energy supply

Cambodia is an energy-poor country with only 29.7% of all households connected to the national grid in 2010 (MIME, 2010). In that year, around 65% of the total national energy supply was imported from Lao PDR, Thailand, and Vietnam (EAC, 2010). The government has boosted and diversified energy supply sources to reduce reliance on fossil fuels and imports from the neighboring countries (MME, 2014). In fact, renewable energy sources have been introduced for the households where the national grid cannot be accessed (RGC, 2013a).

The government recently prepared a master plan for the power supply towards 2030, the plan included natural gas (40.0%), hydropower (35.0%), coal (15.0%), import (6.0%), oil (3.0%), and renewable energy (1.0%) (MME, 2014). These values are used for the present study in 2030 and are assumed to be the same for 2050 because of limited information (Table 9). Simultaneously, the government is improving energy efficiency, especially from coal and oil, in an effort to match that of several advanced countries in order to ensure a sufficient energy supply (MME, 2014). Hence, energy efficiency of coal and oil is assumed to increase from about 33.0% and 32.5%, respectively, in 2010 to 38.0% (MME, 2014) in 2030BaU and 2050BaU for this study. The efficiency of gas is assumed to be approximately 46.0%, similar to a number of developed countries in

**Table 9**
Share (%) of fuel mix of power generation in both BaU and CM cases.

| Fuel/year | 2010 | 2030BaU | 2030CM | 2050BaU | 2050CM | Sources |
|---|---|---|---|---|---|---|
| Coal | 1.3 | 15.0 | 12.0 | 15.0 | 12.0 | JICA (2006a); Erik (2011); Rogier (2011); MME (2014) and assumed solar power increased in CM cases |
| 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** | |

2008 (Erik, 2011) in both 2030BaU and 2050BaU. The transmission loss is assumed to decrease from about 12.2% in 2010 to 7.0% (EAC, 2012) in both 2030BaU and 2050BaU as the government is restoring existing transmission lines and is setting up several new ones for the whole country (MME, 2014).

Under low-carbon measures, solar power is assumed to increase its share to about 5.0% with the reduction of oil and coal, respectively. This study introduces solar power because several studies have revealed that Cambodia has a very high potential for this source (JICA, 2006a). Besides, it is a good alternative energy option for the people living in the areas where the national grid cannot be accessed (Rogier, 2011; RGC, 2013a). The energy efficiency of coal and oil is assumed to increase to about 41.0% and 44.0% (Erik, 2011) in 2030CM and 2050CM, respectively, while the efficiency of gas is assumed to increase to about 52.0%, which is similar to that of the UK and Ireland in 2008 (Erik, 2011) in both 2030CM and 2050CM. Moreover, the transmission loss is also assumed to decrease to about 6.5% (MME, 2014) in both 2030CM and 2050CM.

### 2.7.7. Energy demand

In the base year, the total volume of energy demand is collected from the energy balance table in 2010 (IEA, 2012) (Appendix 2). Energy demand by agriculture, fisheries, and forestry in 2010 is not recorded because of a lack of data; it is available for 2009 (Mr. Heng Kunleang as shown in Table 1). Thus, this study assumes the energy demand of agriculture, fisheries, and forestry in 2010 to be in proportion to the increased rate of the agricultural machines between 2009 and 2010, which increased about 1.06 times (Vuthy, 2013). For the purpose of this study, we combined energy demand in agriculture, fishery, and forestry into the industrial sector. Energy demand is projected to increase in the future as the result of growth in population and economic development. To meet the increasing energy needs, the government has set two long-term energy development targets: first, is to achieve the 100% level of village electrification by 2020, the second to achieve a 70.0% level of household electrification by 2030 (MME, 2013). As well, Lieng (2013) has projected that energy demand would increase annually by about 4.7% between 2010 and 2035, with the strongest growth is the industrial sector at 5.4%, followed by the transport sector at 4.6%, and residential and commercial sectors at 4.4%.

*2.7.7.1. Energy demand in the residential and commercial sectors*. Energy demand in the residential and commercial sectors in the base year is collected from the energy balance table in 2010 (IEA, 2012). It can be seen that the majority of energy consumption in the residential sector derived mostly from biofuels/waste. For this study, we assume that 5.0% of energy demand from petroleum products and biofuels/waste in this sector are used in (allocated to) the commercial sector because the table shows that only electricity is considered as the primary source of energy supply for this sector, which doesnot reflect the real situation, as this sector also covered many hotels (440), guesthouses (1,087), and restaurants in 2010 (NIS, 2011, 2012), which consumed large amounts of petroleum products and biofuels/ waste from cooking food to serve the customers. The adjusted energy balance 2010 is shown in Appendix 3.

In the future, energy demand in the residential and commercial sectors is expected to increase because of the population growth (NIS, 2011; UN, 2013), increased incomes (RGC, 2013a, 2015), the improvement of energy access, and the diffusion of electric appliances to advance living standards (MME, 2013, 2014). Energy demand in these sectors is assumed to increase annually by around 4.4% between 2010 and 2030BaU (Lieng, 2013) and will continue to grow annually by only half (2.2%) in 2050BaU from the 2030BaU level. Under low carbon measures, energy consumption is expected to decrease by about 20.0% through to 2035 as a result of implementing several simple energy saving behaviors such as turning on air-conditioners at 25 °C, turning them off 30 min prior to leaving the office, and unplugging all devices when stopping usage and so forth (Lieng, 2013; MME, 2013). Hence, this study assumes that energy consumption in the residential and commercial sectors will decrease by about 20.0% in 2030CM and 2050CM through introducing energy-saving behaviors alone, and that energy will significantly decrease even further as a result of other low-carbon measures, (as shown in Table 2).

*2.7.7.2. Energy demand in the industrial sector*. Energy demand in this sector in the base year is collected from the energy balance table in 2010 (IEA, 2012). Since we do not yet energy demand in each industry, it is assumed to be in proportion to the intermediate input of each industry of the IO table in 2010. Moreover, energy demand in this sector is expected to increase significantly in the future resulting from the ambitious economic development plan of the government (RGC, 2013a and 2015). This study assumes that energy demand in this sector will continue to grow annually by about 5.4% between 2010 and 2030BaU (Lieng, 2013) and will increase annually by only half (2.7%) between 2030BaU and 2050BaU. This assumption has been discussed and agreed to by the national experts listed in Table 1. Under low-carbon measures, energy consumption is expected to decrease by about 20.0% through to 2035 by implementing a number of simple energy saving behaviors (Lieng, 2013; MME, 2013). Hence, this study assumes that energy consumption in this sector will decrease about 20.0% in both 2030CM and 2050CM from the introduction of energy-saving behaviors alone, and will decrease even further as a result other low carbon measures, (as shown in Table 2).

*2.7.7.3. Energy demand in the transport sector*. Energy services of the transport sector are transport modes. Energy demand in the base year is obtained from the energy balance table in 2010 (IEA, 2012). Since the table expresses energy demand only for road, rail, inland waterway, and airplane, this study assumes energy demand of each energy service to be in proportion to the average vehicle distance multiplied by fuel efficiency of each mode (MPWT, 2009). Besides, energy demand in this sector is expected to increase considerably in the future (Lieng, 2013) owing to the projected increase of transport demand resulting from the economic growth and increased incomes of the people.

## 3. Results

This section explains the results of energy demand and $CO_2$ emissions and reduction potentials estimated by using the ExSS tool,

**Table 10**
Detail primary energy supply by fuel type (ktoe/year) in both BaU and CM cases.

| Sector/year (ktoe/year) | 2010 | 2030BaU | 2030CM | 2050BaU | 2050CM | 2030BaU/2010 | 2030CM/2010 | 2050BaU/2010 | 2050CM/2010 |
|---|---|---|---|---|---|---|---|---|---|
| Coal | 8 | 440 | 142 | 1,693 | 368 | – | – | – | – |
| 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** |

which is adjusted to make it suitable to apply to Cambodia, based on the assumptions in Chapter 2.

### 3.1. Primary energy supply

The results indicate that the total primary energy supply is projected to increase to about 19,327 (roughly 4.2 times) and 70,598 ktoe/year (roughly 15.4 times) in 2030BaU and 2050BaU, respectively, from 4,587 ktoe/year in 2010. With regard to low-carbon measures, they are expected to decrease to approximately 8,499 (about 56% of energy supply reductions) and 28,515 ktoe/year (about 60%) in 2030CM and 2050CM, respectively (Table 10). The results project that biofuels, waste, and petroleum products, which comprise the highest shares of primary energy supply in 2010, will remain dominant sources in 2030BaU and 2050BaU. The results also indicate that natural gas will be the highest fuel source of power generation, accounting for about 404 and 1,555 ktoe/year in 2030BaU and 2050BaU, respectively, followed by hydropower, accounting for about 354 and 1,361 ktoe/year in 2030BaU and 2050BaU, respectively.

### 3.2. Final energy demand

Our results suggest that final energy demand will increase from 4,386 ktoe/year in 2010 to 18,374 (about 4.2 times) and 66,932 ktoe/year (about 15.3 times) in 2030BaU and 2050BaU, respectively. Concerning low-carbon measures, the final energy demand is expected to drop to about 8,180 (about 55% of energy demand reductions) and 27,691 ktoe/year (about 59%) in 2030CM and 2050CM, respectively, (Table 11). The results indicate that per capita energy consumption will increase to approximately 999 and 3,047 kgoe/year in 2030BaU and 2050BaU, respectively, and is expected to decrease to about 445 and 1,261 ktoe/year in 2030CM and 2050CM, respectively. At the same time, energy consumption per GDP (at the 2000 constant price) is projected to increase from about 0.58 kgoe/USD in 2010 to about 0.63 and 0.59 kgoe/USD in 2030BaU and 2050BaU, respectively. Furthermore, energy consumption per GDP is expected to decrease to 0.28 and 0.25 kgoe/USD in 2030CM and 2050CM, respectively.

### 3.3. Total $CO_2$ emissions and reduction potentials

The ExSS tool is used to estimate $CO_2$ emissions and reduction potentials based on fuel inputs and domestic energy demand (Gomi and Fukuda, 2010). In order to reduce $CO_2$ emissions, a number of low carbon measures are introduced. Table 12 shows detail low carbon measures by different measures and quantitative emissions reduction. The results project that $CO_2$ emissions will increase from 4,221 ktCO2/year in 2010 to approximately 23,277 (about 5.5 times higher) and 91,325 $ktCO_2$/year (about 21.6 times higher) in 2030BaU and 2050BaU, respectively, and are expected to decrease to around 10,451 (about 55% of $CO_2$ reductions) and 39,172 $ktCO_2$/year (about 57%) in 2030CM and 2050CM, respectively, (Table 13). The results also suggest that per capita $CO_2$ emissions will increase from 0.3 $tCO_2$/year in 2010 to approximately 1.27 and 4.16 $tCO_2$/year in 2030BaU and 2050BaU, respectively, and are expected to decrease to around 0.57 and 1.78 $tCO_2$/year in 2030CM and 2050CM, respectively. $CO_2$ emissions per GDP were around 0.36 $kgCO_2$/USD in 2010 or 0.48$kgCO_2$/USD (at the 2005 constant price) and are similarly predicted to increase to roughly 0.52 $kgCO_2$/USD in both 2030BaU and 2050BaU. However, they are expected to decrease to about 0.23 and 0.22 $kgCO_2$/USD in 2030CM and 2050CM, respectively.

### 3.4. $CO_2$ emissions reduction by energy demand sectors

The results show that the residential sector can reduce $CO_2$ emissions by about 1,497 and 7,855 $ktCO_2$/year in 2030CM and 2050CM, respectively, by implementing a number of low-carbon measures; for example, (1) energy efficient improvements in electrical and non-electrical equipment (1,193 $ktCO_2$/year in 2030CM and 6,498 $ktCO_2$/year in 2050CM); (2) fuel switch (49 $ktCO_2$/year in 2030CM and 464 $ktCO_2$/year in 2050CM); and (3) energy-saving behaviors (255 $ktCO_2$/year in 2030CM and 893 $ktCO_2$/year in 2050CM). $CO_2$-emissions reductions in the commercial sector are expected to decrease by roughly 951 and 2,365 $ktCO_2$/year in 2030CM and 2050CM, respectively, through the implementation of several low-carbon measures; for example, (1) efficiency improvements in electric devices and insulated buildings (755 $ktCO_2$/year in 2030CM and 1,924 $ktCO_2$/year in 2050CM); (2) fuel switch (44 $ktCO_2$/year in 2030CM and 46 $ktCO_2$/year in 2050CM); and (3) energy-saving behaviors (152 $ktCO_2$/year in 2030CM and 396 $ktCO_2$/year in 2050CM). Meanwhile, $CO_2$ emissions in the industrial sector are expected to decrease by about 3,610 and 12,554 $ktCO_2$/year in 2030CM and 2050CM, respectively, through implementing a number of low carbon measures such as (1) energy-

**Table 11**
Detail final energy demand by energy demand sectors (ktoe/year) in both BaU and CM cases.

| Sector/year (ktoe/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 transport | 321 | 2,005 | 879 | 7,006 | 3,027 | 6.24 | 2.74 | 21.81 | 9.42 |
| Freight transport | 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** | **4.56** | **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 |

**Table 12**
List of detail low carbon measures and quantitative $CO_2$ emissions reduction in 2030CM and 2050CM.

| 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 transport | 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 transport | Effciency improvement | | | | | | |
| | Modal shift | | | | | | |
| | Motorized vehicle to train | Share of train=15.0% (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 | 41.0% (from base year=33.01%) | | | 41.0% ( from base year=33.01%) | | |
| | Oil | 44.0% (from base year=32.50%) | | | 44.0% ( from base year=32.50%) | | |
| | Gas | 52.0% | | | 52.0% | | |
| | 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** |

**Table 13**
Total $CO_2$ emissions and reduction potentials by energy demand sectors ($ktCO_2$/year) in both BaU and CM cases. $ktCO_2$: kiloton of carbon dioxide emissions. $tCO_2$: ton of carbon dioxide emissions. $kgCO_2$: is kilogram of carbon dioxide emissions.

| $CO_2$ emissions/year ($ktCO_2$/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 transport | 996 | 6,374 | 2,743 | 22,276 | 9,431 | 6.40 | 2.75 | 22.36 | 9.47 |
| Freight transport | 1,004 | 5,521 | 2,383 | 31,806 | 15,273 | 5.50 | 2.37 | 31.67 | 15.21 |
| **Total emissions and reductions** | **4,221** | **23,277** | **10,451** | **91,325** | **39,172** | **5.52** | **2.48** | **21.64** | **9.28** |
| Per capita emissions ($tCO_2$) | 0.30 | 1.27 | 0.57 | 4.16 | 1.78 | 4.19 | 1.88 | 13.75 | 5.90 |
| Per GDP emissions ($kgCO_2$/USD) | 0.36 | 0.52 | 0.23 | 0.52 | 0.22 | 1.43 | 0.64 | 1.45 | 0.62 |

efficiency improvements (2,451 $ktCO_2$/year in 2030CM and 8,317 $ktCO_2$/year in 2050CM); (2) fuel switch (10 $ktCO_2$/year in 2030CM and 377 $ktCO_2$/year in 2050CM); and (3) energy-saving behaviors (1,149 $ktCO_2$/year in 2030CM and 3,462 $ktCO_2$/year in 2050CM). Lastly, $CO_2$ emissions in the transport sector are expected to reduce by about 6,769 and 29,379 $ktCO_2$/year in 2030CM and 2050CM, respectively, through implementing low-carbon measures such as (1) energy efficient vehicles (4,814 $ktCO_2$/year in 2030CM and 24,945 $ktCO_2$/year in 2050CM); (2) modal shift (1,854 $ktCO_2$/year in 2030CM and 3,324 $ktCO_2$/year in 2050CM); and (3) fuel switch (101 $ktCO_2$/year in 2030CM and 1,110 $ktCO_2$/year in 2050CM). Passenger transport is expected to decrease by about 3,631 and 12,845 $ktCO_2$/year in 2030CM and 2050CM, respectively; while freight transport is expected to drop by approximately 3,138 and 16,533 $ktCO_2$/year in 2030CM and 2050CM, respectively.

## 4. Discussion

This section will discuss important findings based on quantitative assessments of energy demand and $CO_2$ emissions and reduction potentials.

### 4.1. Energy sector

Energy is the most vital instrument of socioeconomic development, while population and economic growths are major driving forces to increase energy demand (Sahir and Qureshi, 2007). As the standard of living and the population continues to grow, energy use also rises (Aqeel and Butt, 2001; Fong et al., 2007; Saidi and Hammami, 2015). Nguyen-Van (2008) suggested that energy consumption in the developing countries would rise more rapidly than expected, while Huang et al. (2008) echoed that economic growth in middle- and high-income countries would lead to a higher energy consumption. The present study finds that energy demand in Cambodia will increase about 4.6 and 15.3 times in 2030BaU and 2050BaU, respectively, as a result of the population growth and increased incomes of people. Our results postulate similar causal relationships between growths in energy demand and population and economic development as previous studies (Aqeel and Butt, 2001; Fong et al., 2007; Sahir and Qureshi, 2007; Nguyen-Van, 2008; Huang et al., 2008; Saidi and Hammami, 2015). Moreover, per capita energy consumption (kgoe/year) is expected to increase about 3.2 and 9.7 times in 2030BaU and 2050BaU, respectively. The results show that the trends of per capita energy consumption (kgoe/year) and per capita GDP of Purchasing Power Parity (PPP) in Cambodia in 2030BaU and 2050BaU are very similar to those of the Republic of Korea, Malaysia, and Thailand, which experienced the same economic growth. However, the trends of per capita energy consumption and per capita GDP in Cambodia in 2030CM and 2050CM stay far below those countries (Fig. 3). The results imply that Cambodia can maintain the same economic growth with lower energy demand if the country adopts a policy of transitioning to low-carbon development.

Indeed, Cambodia could gain massive reductions in energy demand through implementing a number of low-carbon measures. Specifically, by introducing low-carbon measures such as advanced energy technologies, energy efficiency improvement, and energy saving behaviors, approximately 55% and 59% of energy demand can be reduced in 2030CM and 2050CM, respectively, compared to those of the BaU levels. The above analysis recommends that in the future, Cambodia should consider designing a low-carbon energy plan to promote sustainable economic growth with lower energy consumption in the future.

### 4.2. $CO_2$ emissions

Several studies disclosed cohesive relationships between population and economic growth and energy demand and $CO_2$ emissions (Sahir and Qureshi, 2007; Fong et al., 2007; Lean and Smith, 2009; Menyah and Rufael, 2010; Niu et al., 2011; Arouri et al., 2012). The results of the current study propose that $CO_2$ emissions are projected to increase about 5.52 and 21.64 times in 2030BaU and 2050BaU, respectively, because of population growth (1.32 and 1.57 times), GDP (3.87 and 14.97 times), and energy demand (4.19 and 15.26 times). The present results imply relationships among population increases, economic development, energy demand, and $CO_2$ emissions similar to those of the previous studies. Because of the limited study of $CO_2$ emissions in Cambodia, we compare and discuss the results of this study with those of the second national communication (SNC) (MoE, 2013).

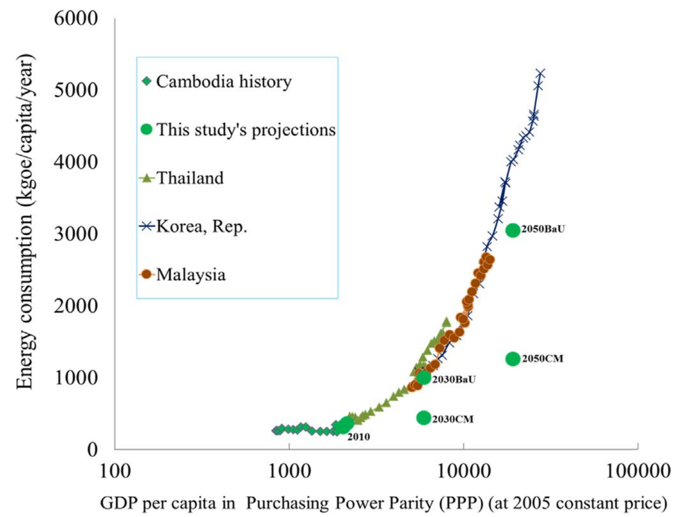


**Fig. 3.** Comparisons of per capita energy consumption (kgoe/year) and per capita GDP of Purchasing Power Parity (PPP) at 2005 constant price between Cambodia and several Asian countries. This figure indicates that trends of per capita energy consumption (kgoe/year) and per capita GDP of Purchasing Power Parity (PPP) at 2005 constant price in Cambodia in 2030BaU and 2050BaU are very similar to those of Malaysia, the Republic of Korea, and Thailand, which experienced the same economic growth. However, Cambodia can sustain the same per capita GDP with smaller energy consumption than those of countries when Cambodia implements a number of low carbon measures in 2030CM and 2050CM.

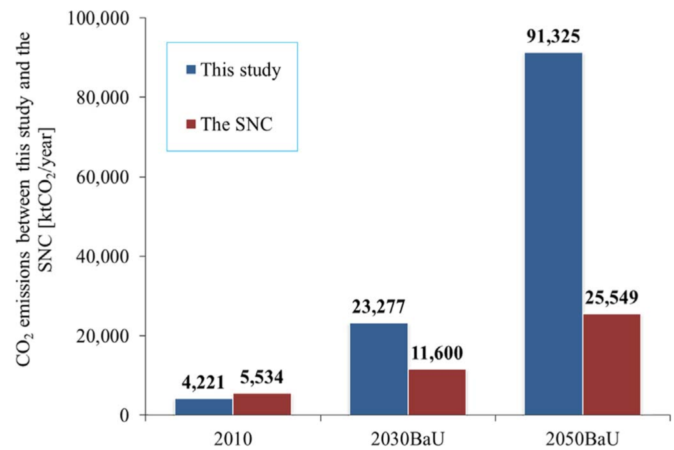


**Fig. 4.** The comparisons of $CO_2$ emissions between this study and the second national communication. This figure implies that $CO_2$ emissions in the base year between this study and the SNC are very similar; however, they are drastic differences in the target years. It is argued that the different results resulting from differences in assumptions.

The results suggest that total $CO_2$ emissions in 2010 in this study are very similar to those of the SNC in the same year, suggesting that the applied tool (ExSS) is well suited to Cambodia's situation. However, because $CO_2$ emissions in 2030BaU and 2050BaU are much larger than those of the SNC (MoE, 2013) in the same years (Fig. 4), we argue that the differences in $CO_2$ emissions are due mainly to differences in the

**Table 14**
Decomposition analysis of $CO_2$ emissions reduction by each energy demand sector in 2030CM. This table shows several low carbon measures introduced to reduce $CO_2$ emissions in Cambodia and potential emissions reduction are identified accordingly 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 transport | | | 57 | 61 | 2,100 | 1,413 | 0 |
| Freight transport | | | 4 | 40 | 2,714 | 379 | 0 |
| **Total reductions ($ktCO_2$/year)** | | **12,826** | **560** | **204** | **8,714** | **1,793** | **1,555** |

**Table 15**
Decomposition analysis of $CO_2$ emissions reduction by each energy demand sector in 2050CM. This table shows low carbon measures introduced to reduce $CO_2$ emissions in Cambodia and potential emissions reduction are identified accordingly 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 transport | | | 187 | 189 | 9,572 | 2,897 | 0 |
| Freight transport | | | 75 | 733 | 15,373 | 352 | 0 |
| **Total reductions ($ktCO_2$/year)** | | **52,153** | **1,726** | **2,207** | **40,220** | **3,248** | **4,751** |

assumptions of such factors as GDP growth, energy demand, and sources of the power supply. At the time the SNC was prepared, the Government did not formulate a long-term economic development plan, and the assumed annual GDP growth rate (only 6.5% from 2008) towards 2050 in the SNC (MoE, 2013) was lower than the current one (7.0% from 2010) (RGC, 2013a). Besides, this study assumed energy demand to be based on the government development target, which is expected to move to an upper-middle income level by 2030 and a high-income one by 2050 (Lieng, 2013; RGC, 2013a), while the SNC was not taken it into account (MoE, 2013). Furthermore, sources of the power supply in the present study are dominated by natural gas (up to 40%) and hydropower (only 35.0%) (MME, 2014); conversely, the SNC was assumed to cover by natural gas (only 8.0%) and hydropower (upto 68.0%) (MoE, 2013). As discussed, it is obvious that the projected $CO_2$ emissions in the current study should be higher than those of the SNC (MoE, 2013).

Additionally, our results show that per capita $CO_2$ emissions (0.3 $tCO_2$/year) in Cambodia in 2010 were lower than those of several Association of South East Asian Nations (ASEANs), including Indonesia (1.71 $tCO_2$/year), Malaysia (6.46 $tCO_2$/year), Thailand (3.42 $tCO_2$/year), and Vietnam (1.56 $tCO_2$/year) in the same year (IEA, 2013). Moreover, per capita $CO_2$ emissions in 2030BaU and 2050BaU in Cambodia remained far behind those of some Asian countries in 2010, including China (11.66 $tCO_2$/year), Japan (8.89 $tCO_2$/year), the Republic of Korea (11.42 $tCO_2$/year), Malaysia (6.46 $tCO_2$/year), and Singapore (12.66 $tCO_2$/year) (IEA, 2013). Meanwhile, per GDP $CO_2$ emissions (at 2005 constant price) in Cambodia in 2010 were higher than those of Singapore (0.38 kg/USD) but lower than those of some ASEANs, including Indonesia (1.09 kg/USD), Malaysia (1.03 kg/USD), Thailand (1.12 kg/USD), and Vietnam (1.74 kg/USD) in the same year (IEA, 2013). While, per GDP emissions in 2030BaU and 2050BaU in Cambodia are comparatively higher than those of Japan (0.24 kg/USD) and the Republic of Korea (0.55 kg/USD) in 2010 (IEA, 2013).

Further, in order to analyze and examine factors that influence changes in the level of energy-related $CO_2$ emissions, a decomposition method is used (Shyamal and Rabindra, 2004; Sheinbaum-Pardo et al., 2012). Thus, this study used decomposition analysis to assess and quantify $CO_2$ emissions reduction by each low-carbon measure by each energy demand sector in 2030CM (Table 14) and 2050CM (Table 15). The results show that among total emissions reduction of around 12,826 $ktCO_2$/year in 2030CM, and the passenger transport and industrial sectors achieve a similar emissions reduction of about 28.3%, while the freight transport reduces emissions by approximately 24.5%. However, freight transport contributes the highest emissions reduction of around 31.7%, followed by the passenger transport of around 24.6%, while the industrial sector contributes around 24.1% of total $CO_2$ emissions reduction of around 52,153 $ktCO_2$/year in 2050CM.

The above analysis strongly suggests that Cambodia could reduce $CO_2$ emissions significantly (55% in 2030CM and 57% in 2050CM) if the country were to shift to a low carbon paradigm through introducing such energy-efficiency improvements as the use of renewable energy, fuel switch, advanced technologies, better infrastructure design, and modal shift. Thus, adopting a policy to design a low-carbon development plan would play a critical role in achieving emissions reduction targets, simultaneously ensuring sustainable economic growth and environmental sustainability in Cambodia.

### *4.3. A design of low carbon energy plan moving towards 2050*

Cambodia has seen low-carbon development as a win-win approach to help the country avoid pervasive economic growth by increasing energy efficiency improvement and promoting renewable energy, while sustaining social and economic development (MoE, 2013a; NCGG, 2013). The findings of the present study suggest that Cambodia could gain massive $CO_2$ emissions reduction of about 55.1% and 57.1% in 2030CM and 2050CM, respectively, through implementing a number

**Table 16**
Detail quantitative emissions reduction of low carbon strategies and actions. This table explains the proposed strategies and actions with quantitative emissions reduction. It also indicates the most effective strategies, which contribute the largest emissions reduction.

| Strategies | Actions | Quantitative emissions reductions 2030CM | 2050CM |
|---|---|---|---|
| Green energy | Introduction of renewable energy through the construction of hydropower plants and installation of solar, and biogas/biomass, and so forth; | 103 | 1,284 |
| | Improvement of the quality of electricity distribution lines through reducing transmission losses and own uses; and | 560 | 1,726 |
| | Introduction of smart appliances and home automation systems including energy-saving and energy efficient appliances, and power control devices. | 3,467 | 11,430 |
| Green technologies and investment | Promotion of green industries and industrial ecology; | 572 | 1,440 |
| | Introduction of green technologies such as cleaner products, and sustainable product innovation; and | 872 | 5,604 |
| | Promotion of green business competition and green credit (indirect contribution). | | |
| Green building | Promotion of energy saving in households and institutions; | 255 | 625 |
| | Promotion and implementation of green building designs and construction through the use of energy efficient materials; and | 76 | 268 |
| | Introduction of the embedded renewable energy and energy saving appliances in building designs. | 152 | 396 |
| Green transport | Promotion of public transport system in major cities by constructing intensive urban mass transit facilities; | 1,470 | 2,897 |
| | Introduction of hybrid and biodiesel motorized vehicles; | 101 | 1,110 |
| | Introduction of low-emission and energy-efficient vehicles; and | 2,714 | 15,373 |
| | Promotion of eco-driving and vehicle technical inspection. | 1,400 | 6,381 |
| Low carbon infrastructure | Use the freight train for long-distance shipment; | 384 | 427 |
| | A design of comfortable and safe pavements to produce a walkable city; and | 700 | 3,191 |
| | A design of a standard road facility to differentiate between vehicle, motorist, cyclist, and walking lanes (indirect contribution). | | |
| **Total emission reductions ($ktCO_2$/year)** | | **12,826** | **52,153** |

of low-carbon measures. However, to achieve the emissions reduction target a concrete and tangible low-carbon development plan must be designed. Therefore, this study proposes five strategies and a list of actions, already discussed and approved by the relevant government stakeholders, toward a low-carbon energy plan in Cambodia. The quantitative emissions reductions to be achieved by those strategies and actions are shown in Table 16. It can be seen that the strategy of green transport achieves the highest emissions reduction potential of around 44.3% and 49.4%, followed by green energy of around 32.2% and 27.7% in 2030CM and 2050CM, respectively; the strategy of green technology and investment attributes about 11.3% and 13.5%, while low carbon infrastructure reduces about 8.4% and 6.9% in 2030CM and 2050CM, respectively. The strategy of green building contributes only around 3.8% and 2.5% in 2030CM and 2050CM, respectively. While the research is still somewhat limited, the results of this study are expected to provide insights for the government to take low-carbon development into account for designing climate change mitigation policy in the country. The findings are expected not only to provide useful information for Cambodia to prepare the third national communication but also to become the fundamental assessment on $CO_2$ emissions and reduction potentials in the energy sector for other researchers. Besides, the results of the current study are expected to illustrate how low income countries like Cambodia could voluntarily contribute to the global effort to reducing $CO_2$ emissions into the atmosphere.

## 5. Conclusions and policy implications

The analysis of this paper indicates significant potential for Cambodia to reduce growths in energy consumption and $CO_2$ emissions through implementing low carbon measures such as energy efficiency improvement, energy saving behaviors, the use of low emission technologies, and energy sources. This study indicates that the effective implementation of five low-carbon development strategies are expected to reduce $CO_2$ emissions by about 55.1% and 57.1% in 2030CM and 2050CM, respectively. However, because projections are not precise predictions, a range of possible future outcomes is possible. The authors used expert judgment based on the literature to identify and describe possible future trends. This paper provides a preliminary assessment of quantitative $CO_2$ emissions reduction as a result of the five low carbon development strategies. Additional research is also needed to provide a wide range of alternative options for decision-makers to design a productive low carbon development plan for Cambodia. It is suggested that the formulation of a policy for a low-carbon development plan be regarded as one of the most important steps to help Cambodia achieve sustainable development objectives, promote a greener development path, and contribute to the global effort to reducing $CO_2$ emissions. Hence, the results of this study are expected not only to provide fundamental insights for Cambodia to formulate a concrete and progressive climate-change mitigation policy but also to provide useful information for preparing the third national communication for the UNFCCC.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.enpol.2016.10.017.

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