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CO_2 Mitigation in the Power Sector in Cambodia: Analysis of Cleaner Supply-side Options beyond INDC

Lyheang Chhay*, [1] and Bundit Limmeechokchai*

Abstract *– The increasing fossil fuel supply to meet the rapidly growing electricity demand is resulting in rising carbon dioxide (CO_2) emissions in Cambodia. The purpose of this paper is to analyze CO_2 mitigation options from the power sector under the cleaner supply-side options beyond the Intended Nationally Determined Contribution (INDC) of Cambodia. The Long-range Energy Alternative Planning (LEAP) model is used to analyze the share of electricity generation and CO_2 emissions during 2015 to 2050 under four main scenarios, namely Business-as-Usual (BAU), Renewable Energy (RE), Carbon Capture and Storage (CCS), and Carbon Tax (CT). Results illustrate that in the BAU scenario, electricity generation and CO_2 emissions from the power sector would be increased by almost 16 and 42 times respectively in 2050 when compared to 2015. Results also show with CO_2 emission reduction potential of about 32.94% in 2050. The imposition of carbon tax amounting to USD500/tCO_2 has the highest CO_2 emission reduction potential in the power sector when compared with other scenarios. Results depict that except the RE scenarios considering lower shares of solar and biomass, all scenarios would help in attainting the 27% CO_2 emission reduction target of Cambodia's INDC by 2030.*

Keywords *– Cambodia, CO_2 emission, INDC, LEAP model, power sector.*

1. INTRODUCTION

The lack of conventional sources of supply to achieve developing energy demand is the main problem for all countries. Moreover, many countries modify their energy plans in order to improve their energy supply by choosing proper renewable energy resources that are delicate to energy price, choosing domestic resources and considering global environmental issues. The development of world energy consumption has gone up dramatically as long as the increasing number of populations and social economic development. In 2015, the Gross Domestic Product (GDP) growth rate of Cambodia was about 7.2%. Agriculture and forestry play an important role in the economy with a quarter of GDP, while manufacturing and tourism significantly contribute to economic development. In the same year, the electricity demand in Cambodia significantly increased almost three times higher than in 2010 since the increase in the average income of people during that period. [1]. Cambodia has great potential in renewable energy (RE) sources such as solar, hydro and biomass. Thus, RE must be promoted as energy resources in order to provide dependable and environmentally friendly electricity. The capacity of domestic electricity generation from coal, hydro, oil, renewable energy and others would be 36.9%, 33.2%, 1.96%, 0.64%, 1.57%, respectively. Cambodia imported electricity around 4.07% of its consumption from Thailand, 21.37% from Vietnam and 0.29% from Lao PDR [2].

Based on the above information, Cambodia still uses conventional sources for electricity generation which have impacts on future supplies in the country. The problem is that most conventional sources have limitations and the prices of those sources increase year by year. As a result of the fluctuation in the price of conventional sources, the cost of electricity generation would go up. The dependence on conventional energy sources results in the environmental impact which is a serious problem in the country. The emission from the power sector could result in social and environmental degradation and increasing greenhouse gas (GHG) emissions. Thus, several studies regarding the electricity planning in the power sector have been proposed in Cambodia.

Pagnarith and Limmeechokchai studied the utilization of renewable energy and CO_2 mitigation in the power sector in selected Greater Mekong Subregion (GMS) countries namely Cambodia, Thailand, Laos, and Vietnam. This study proposed several scenarios which include renewable energy (RE) scenario by using the Long-range Energy Alternative Planning (LEAP) model in order to estimate electricity demand and supply, CO_2 emissions from the power sector and CO_2 emission mitigation. The result illustrated that the electricity generation from renewable energy sources such as biomass, wind, solar photovoltaics and geothermal will be increased to 5.74 GW in the GMS region, and accounted for 3.5% of total electricity production in 2030. Thus, the RE scenario with carbon credits could decline CO_2 emissions at around 36 million tons at a lower system cost when compared to the BAU scenario [3].

In 2018, Lyheang and Limmeechokchai determined the role of renewable energy in CO_2 mitigation in the power sector in Cambodia. The LEAP model was used with different scenarios such as business-as-usual (BAU) and three countermeasure (CM) scenarios of CO_2 mitigation. The BAU scenario in the study was constructed following the power development targets of

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PDP2020, while the CM scenarios promoted the utilization of renewable energy and efficient carbon capture and storage (CCS) technology in the power sector. The results were presented of CO_2 emissions reductions in the range of 12.47%, to 45% in 2050 when compared to the BAU scenario [4].

The objectives of this study to assess the expansion of renewable energy sources, and to promote efficient technologies with different carbon tax profiles in order to analyze cleaner supply-side option beyond Cambodia's NDC. Moreover, the Long-range Energy Alternative Planning (LEAP) model which has flexible data structure is used in order to classify electricity demand, electricity generation and emission from the power sector with differences GHG mitigation scenarios. In addition, discussions across the scenarios in terms of CO_2 emissions from in the power sector and the INDC's target are provided. Moreover, this study proposes new scenarios that integrate the potential of renewable energy sources in Cambodia with efficient technology. Thus, the results of this study are expected to be useful for future electricity expansion planning. In addition, this study considers not only the share of electricity supply but also the priority of energy that result in less environmental impacts. Furthermore, the total cost of electricity generation is included in this study which can help determine the total investment requirement in power development.

This paper is divided into six sections. Section 1 is the introduction. Section 2 describes the target of CO_2 emissions reduction in Cambodia's INDC. The situation of power sector in Cambodia such as electricity consumption, electricity generation and potential of renewable energy sources in Cambodia is discussed in section 3. Section 4 presents the methodology and description of each scenario. The last section provides the results and conclusion of this paper.

2. CAMBODIA'S INTENDED NATIONALLY DETERMINDED CONTRIBUTION

Cambodia's Intended Nationally Determined Contribution (INDC) identifies the need for respecting the principles of the United Nations Framework Convention on Climate Change (UNFCCC), in particular, the principle of common but differentiated responsibilities and respective capabilities' along with the right to the sustainable development of developing countries. Cambodia submitted its INDC and relevant information to the UNFCCC in December 2015. Its INDC includes both adaptation and mitigation actions based on national circumstances and divided into five sections. Cambodia's INDC proposes a GHG mitigation contribution for the period 2020-2030, conditional upon the availability of support from the international community. Cambodia plans to undertake action in the energy industries, manufacturing industries, transport, and other sectors which are expected to be a maximum reduction of 3,100 Mt-CO_2eq compared to the baseline emissions of 11,600 Mt-CO_2eq by 2030. In addition, Cambodia also intends to take voluntary and conditional actions to meet the target of rising forest cover to 60% of the national land area by 2030. Thus, estimated emissions reductions from that action expected to be 4.7 tCO_2eq/ha/year [5]. The estimated per capita emissions in 2050 will be 2.59 tCO_2eq, and accounted for less than half of current world per capita emissions [6].

3. POWER SECTOR IN CAMBODIA

3.1 Electricity consumption in Cambodia

Electricity consumption has increased significantly during the last decade. In 2015, the per capita consumption of electricity reached 328 kWh/capita, a more than fivefold increase from 66.5 kWh/capita in 2005 [7]. Electricity consumption is forecasted to increase by 9.4% per year until 2020, which will require more than 50% increase in energy output to keep pace with the demand growth. Moreover, electricity consumption in Cambodia reached 5,205.34 GWh in 2015. The percentage of electricity consumption in commercial and the industrial, residential, governmental and other sectors would be 59.88%, 34.55%, 3.27%, and 2.3% respectively [2].

Due to the increasing electricity consumption in recent years, the Ministry of Mine and Energy (MME) has forecasted an average annual growth rate of electricity consumption of 12% until 2020. Total electricity consumption will increase to 8,280.59 GWh in 2020 with a peak power demand of 1,556 MW [8].

3.2 Electricity generation in Cambodia

In 2015, the electricity generation in Cambodia was around 6,015 GWh with the installed capacity of 1,827 MW. According to the report of Electricity Authority of Cambodia (EAC), in 2015 electricity generation from coal bituminous will have the highest share, followed by hydropower, imported electricity, diesel and fuel oil, and biomass, respectively (see Figure 1). Cambodia partly depends on imported electricity from neighbouring countries. In 2015 the electricity imported from Viet Nam, Thailand, and Lao PDR were accounted for 1,200.39 GWh, 307.39 GWh, 18.31 GWh, respectively [2].

To achieve the future electricity demand in Cambodia, the electricity generation planning is essential in order to provide acceptable electricity quality with reliable sources. According to the power development plan (PDP), hydropower and coal power plants are used in order to meet the electricity demand. The capacity of electricity supply will be expected to increase to 6,679 MW in 2020 and the remaining capacity will be imported from neighbor countries [9].

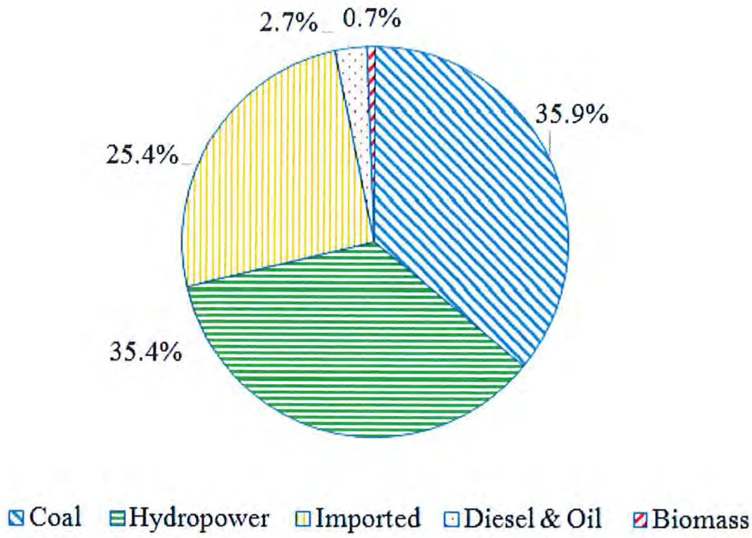

Fig. 1. The share of electricity generation in Cambodia in 2015.

Table 1. Potential of renewable energy in Cambodia.

Type of sources	Potential	Installed capacity in 2015
Hydropower	10,000 MW	927 MW
Solar	11,980 GWh/year	-
Biomass	18,852 GWh/year	16.57 MW
Wind	9,140 GWh/year	-

3.3 Indicators of Cambodia's Power Sector

In Cambodia, electricity consumption is the result of human activities. Thus, considering the links between such human activities and electricity consumption makes sense. The gross domestic production (GDP) growth rate in Cambodia in 2015 was 7% and it is predicted to remain constant until 2030 [10]. In addition, Cambodia's GDP per capita was about 1,025$/capita in 2015 [11]. It is noticed that the garment, construction, agriculture, and tourism sectors were major drivers of Cambodia's growth. Nevertheless, the household's electrification was increased from 49.37% in 2015 to 72.16% in 2018. This is because of the development of transmission and distribution lines in the rural area. Moreover, the Ministry of Mine and Energy (MME), Electricity Authority of Cambodia (EAC), and Electricite du Cambodge (EDC) under the Royal Government of Cambodia are responsible for developing the energy policy to provide reliable and affordable energy services to all users. In addition, 80% of villages will be connected to the national grid and another 20% will be supplied by other energy sources such as imported electricity or stand-alone supply system by 2020. In 2030, 95% of villages of the whole country will be connected to the national grid while another 5% of the villages will be supplied by stand-alone units with quality of supply similar to the national grid [1].

3.4 Renewable Energy in Cambodia

Cambodia has a large number of renewable sources throughout the country. Domestic renewable resources include hydropower, solar, biomass, and wind. Cambodia has an estimated possible installed capacity of hydropower at 10,000 MW with 1.5% from small and mini hydropower [12]. In addition, solar energy with the potential of solar irradiation of about 5 kWh/m^2/day and about 6-9 working hours had an estimated electricity generation of 11,980 GWh/year. The estimated electricity generation from biomass would be 18,852 GWh/year. The significant sources are rice husk, sugar cane bagasse, and cassava. The average wind speed of 7-8 m/s has been estimated to generate 9,140 GWh/year in the southern part of the TonleSap lake. Table 1 illustrates the potential of renewable energy such as hydropower, solar, biomass and wind in Cambodia [13].

3.5 CO_2 Emissions

CO_2 emissions from the power sector could be classified by relying on the basis of reference and sectoral approaches which are provided by Intergovernmental Panel on Climate Change (IPCC). It is noticed that CO_2 emissions from human activities are the most important cause of global warming. In addition, the major source of CO_2 emissions comes from fossil fuel combustion such as coal bituminous and oils. In 2010, CO_2 emission from coal bituminous and oils in Cambodia were accounted for 90 kilotons (kt), and 4,435 kt respectively. After 5 years, CO_2 emissions from coal bituminous significantly increased to 2,070 kt while CO_2 emissions from oils increased to 5,313 kt [14]. This is because of increasing coal bituminous use in the power sector during that period. In terms of CO_2 emission per capita, it was accounted for 0.51 tCO_2/capita in 2015 which is still lower than neighbouring countries [7]. Thus, CO_2 emissions in the power sector can be decreased by substitution of conventional power plans with low carbon electricity generation technologies.

Hak *et al.*, studied the formulation of a policy for a low-carbon development plan in order to achieve Cambodia's sustainable development target. The study is constructed to propose some low-carbon energy policies and to assess CO_2 emissions and reductions potential in Cambodia using the Extended Snapshot (ExSS) tool based on projected quantitative information for developing a future sustainable society in Cambodia [15].

4. METHODOLOGY

Electricity planning analyses, scenarios are generally constructed using available data and assumptions within the appropriate generation system to predict future conditions. In this study, methodology is classified into three parts such as electricity demand and supply analysis, the production of emissions from the power generation, and total cost electricity generation in each scenario. The data required in this study mostly were taken from Ministry of Mine and Energy (MME), government reports, reviewed papers, and online databases. Moreover, the estimation of future electricity demand in this study is based on gross domestic product (GDP) and GDP elasticity of electricity demand.

4.1 LEAP Model

The Long-range Energy Alternative Planning (LEAP) model is a simulation tool that can be used to analyze climate change mitigation. LEAP was developed by the Stockholm Environmental Institute [16]. The LEAP model has flexible data structure which is not only easy to use but also rich in technical and end-user details [17].

LEAP provides a suitable result of the energy demand upon policies of the government and the typical household users with dissimilar class by the level of income and financial outlook in urban and rural areas under the scheme to develop the quality of people's occupation and to cut down the wood reliance [17]. The LEAP model allows policy makers to create energy forecasted system based on existing energy demand and generation data. Moreover, users can do the comparison on the result from different scenarios. The scenarios in the LEAP model are relied on detailed accounting of energy types expended by process of production [18]. Furthermore, LEAP can be used to define medium or long-term energy and environmental planning. It can be beneficial to estimate medium and long-term energy demand and supply in countries regarding the different driving factors, and also determine the cost of electricity generation, greenhouse gas emissions, distribution and end-use activities [19].

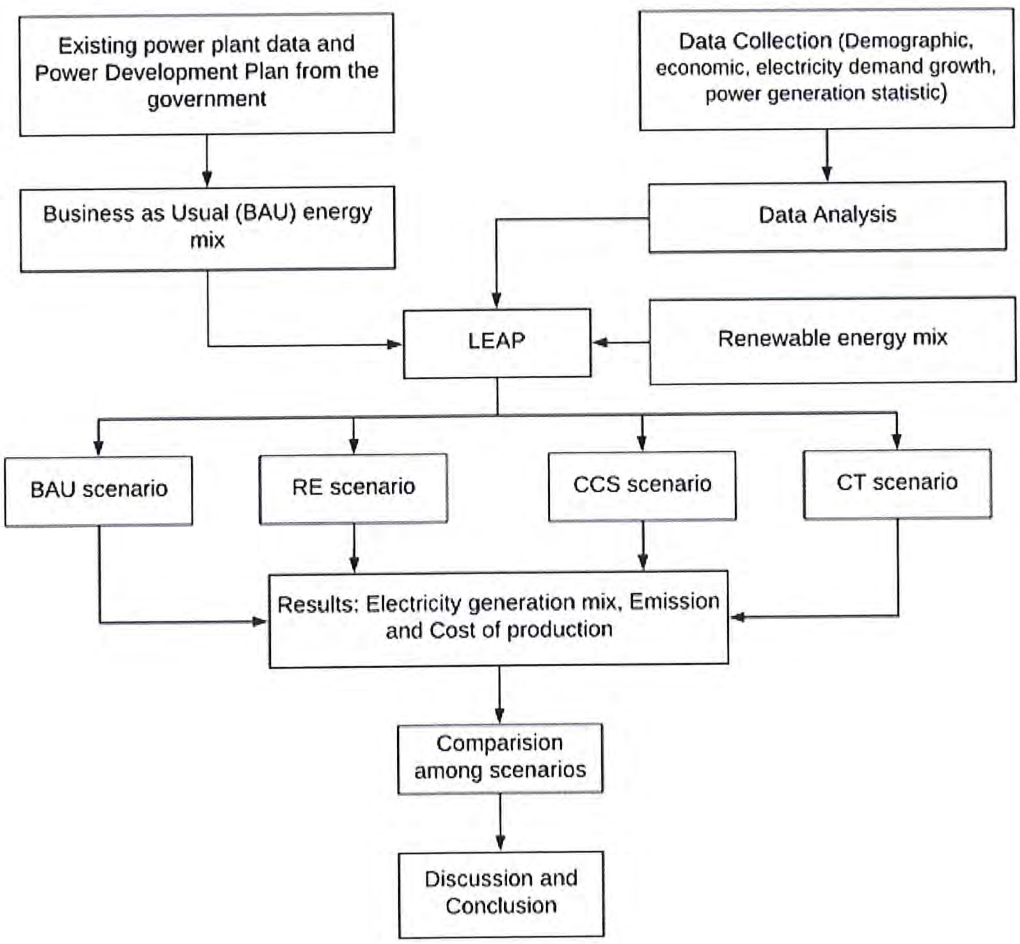

Fig. 2. Flow chart of methodology.

4.2 Description of Scenarios

This study considers four main scenarios, namely business as usual (BAU) renewable energy (RE), carbon capture storage (CCS), and carbon tax (CT) scenarios. In the BAU scenario, power development data were collected from Power Development Plans of Cambodia and the electricity demand forecast relied on population growth, GDP growth rate, history of electricity demand and electrification, transmission and distribution loss and type of power plants. In addition, three scenarios under RE namely RE1, RE2, and RE3 scenarios have been constructed by promoting renewable energy sources such as biomass and solar. Moreover, in the CCS scenario, 50% of electricity generation produced by coal and natural gas power plants will replace with carbon capture storage (CCS) technology by 2020. In the CTs scenarios, Cambodia will develop two carbon tax profile which are carbon tax of \$100/tCO_2 from 2020 to 2050 and \$20/tCO_2 from 2020, that will increase to \$500/tCO_2 by 2050.

4.2.1. Business as usual (BAU) scenario

In the BAU scenario, the future electricity demand is forecasted by relying on population growth, GDP growth, and historical data. The planning period in this study is from 2015 to 2050. The future electricity demand is forecasted by the following criteria.

- Population growth: depending on the World Development Indicators (WDI) report, the annual population growth in Cambodia would be 1.52% [11].
- GDP growth: the annual percentage growth rate of GDP at a market price based on constant local currency. In Cambodia, GDP growth from 2014 to 2015 was 7% and it is assumed that it will remain at 7% per year until 2030. The growth rate will be 6.5% per year from 2031 until 2040 followed by 3.5% from 2041 to 2050.
- Electricity demand: it is forecasted by depending on Gross Domestic Product (GDP) and GDP elasticity of electricity demand. The GDP elasticity is estimated based on the regression analysis using a linear equation.
- Population access to electricity: access to electricity is the percentage of the population accessing to electricity. The data of electrification are collected from industry, national surveys, and international sources. In Cambodia, the percentage of people accessing to electricity was 49.77% in 2015. The government aims to achieve 70% by 2030. This study assumes electrification rate of 70% during 3020-2050.
- Type of power plant: there are different types of power plants used in order to generate electricity. The capital cost, fixed O&M cost, variable O&M cost, process efficiency, capacity credit, lifetime and merit order of power plants are important. Table 2 shows characteristics of power plants such as capital cost, fix O&M cost, process efficiency, capacity credit, lifetime, and merit order which are needed to input into the LEAP model. Those data are important for providing specific results.

Table 2. Characteristics of the power plant.

Technology	Capital cost (\$/kW)	O&M cost (\$/MWh)	Process efficiency (%)	Capacity credit (%)	Lifetime	Merit order
Coal	866.5	3.71	38	100	30	1
Oil	753	3	37	100	30	2
Diesel	350	30	35.4	100	20	2
Natural gas	614	3.67	44	100	30	1
Biomass	2,180	0	35	100	30	1
Hydro	1,750	6	100	100	50	1
Solar PV	990	0	100	36	30	1

4.2.2 Renewable energy (RE) scenarios

In this paper, the main objectives of renewable energy (RE) scenarios are to integrate the use of domestic renewable energy resources in Cambodia. Two renewable energy sources with three different RE penetration scenarios, namely RE1, RE2, and RE3 scenarios have been used in this study. In the RE1 scenario, 5% of total electricity generation will be generated from solar, and in the RE2 scenario 5% of total electricity generation will be generated from biomass by 2050. In the RE3 scenario, 10% of total electricity generation will be generated from solar and biomass by 2050.

4.2.3 Carbon capture storage (CCS) scenario

The increase in coal-fired and natural gas power plants contributes significantly to total CO_2 emissions. New efficient CO_2 capture and storage (CCS) is used in order to replace coal-fired and natural gas power plants. In the CCS scenario, 50% of coal-fired power plants will be equipped with CO_2 capture storage (CCS) technology from 2020 to 2050. Thus, CO_2 emissions from coal-fired power plants is expected to be drastically reduced in the CCS scenario.

4.2.4 Carbon tax (CT) scenario

Two carbon tax rates, CT100 and CT500, are considered in this study. The CT100 scenario uses a constant rate of

\$100/tCO_2 from 2020 to 2050. In addition, a carbon tax of \$20/tCO_2 in 2020 and increasing steps to \$500/tCO_2 in 2050 has been imposed in the CT500 scenario (see Figure 3). The effects of carbon taxes are assessed in terms of total primary energy supply, sectoral energy mix, and CO_2 emissions. Figure 3 provides the variation in carbon prices during 2020-2050 under the CT500 scenario.

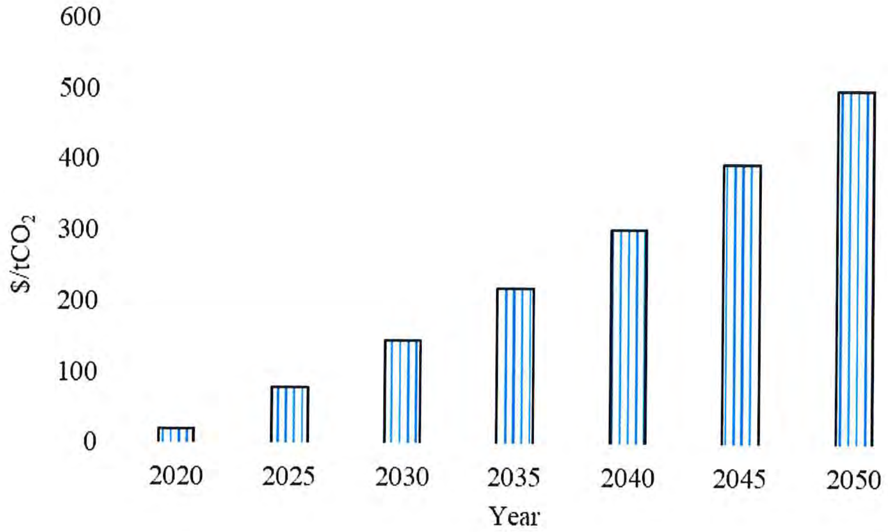

Fig. 3. Variation in carbon price from 2020 to 2050 under CT500 scenario.

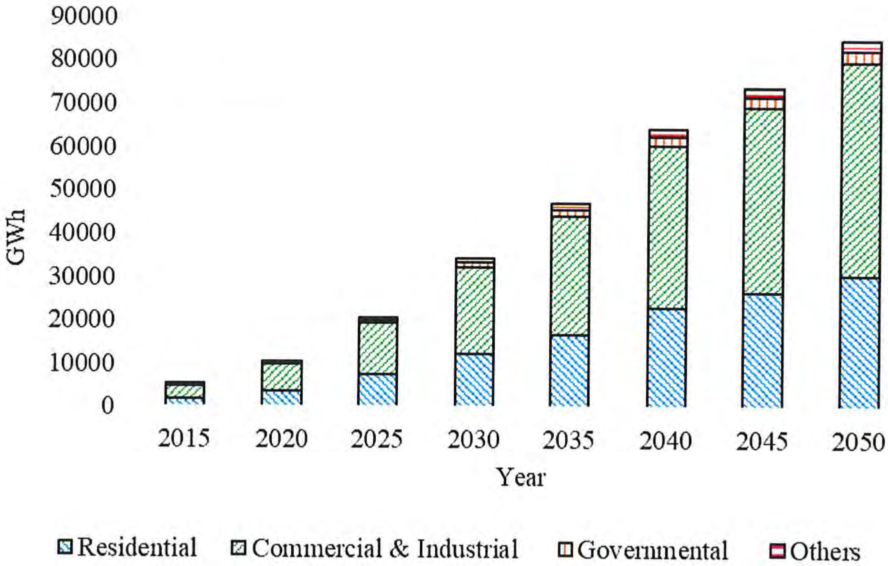

Fig. 4. Electricity demand by each sector.

5. RESULTS

Results are presented of the electricity demand and supply, the CO_2 emission from the power sector, and the cost of electricity generation in the BAU, RE, CCS and CT scenarios.

5.1 Electricity Demand

5.1.1 BAU, RE, CCS and CT scenarios

In this study, the total electricity demand in the BAU, RE, CCS and CT scenarios is assumed to be the same during the planning period. During the time span, total electricity demand in 2050 will go up 16.32 times when compared with the base year. In the base year, total electricity demand was around 5,205 GWh and it is expected to increase to 84,972 GWh by 2050. Four main sectors, namely residential, commercial and industrial, governmental and others have been classified in this study. Shares of electricity demand in the commercial and industrial, residential, governmental and other sectors will be 58%, 36%, 3% and 3% in 2050, respectively. It is noticed that commercial and industrial are the main energy consuming sectors in Cambodia. Cambodia is a lower middle-income country. Thus, the electricity consumption per capita in Cambodia was only 328 kWh/capita in 2015 and it is expected to reach 4,285 kWh/capita in 2050. Figure 4 provides the electricity demand by sectors in the BAU, RE, CCS, and CT scenarios.

5.2 *Electricity Generation*

In this section, electricity generation in the BAU, RE, CCS, CT100, and CT500 is discussed.

5.2.1 BAU scenario

There are many types of electricity generation sources such as hydropower, coal bituminous, natural gas, biomass, diesel, solar and imported have been used in Cambodia. In the base year, the total electricity generation was around 6,015 GWh and it will increase to about 94,413 GWh in 2050. Shares of natural gas and solar are promoted after 2020. Thus, the percentage of electricity generation from coal bituminous, hydropower, imported electricity, natural gas, solar and biomass will be 39%, 22%, 16%, 18%, 4% and 2%, respectively in 2050. In addition, the shares of electricity generation from hydropower, imported electricity, coal bituminous, and biomass were 47%, 31%, 21%, and 1%, respectively in 2015. Figure 5 shows the electricity generation by fuel types in Cambodia in the BAU scenario between 2015 and 2050.

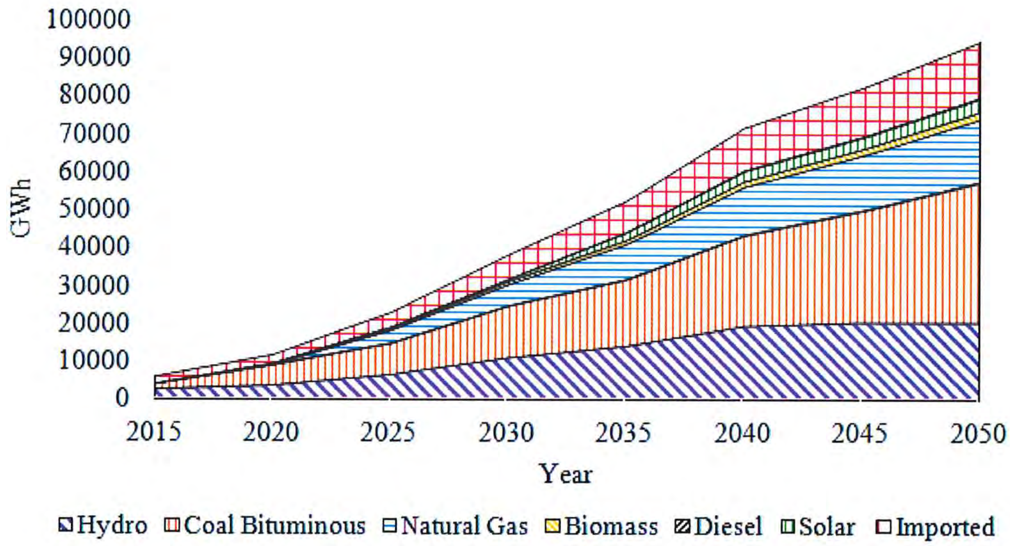

Fig. 5. Electricity generation by fuel type in the BAU scenario.

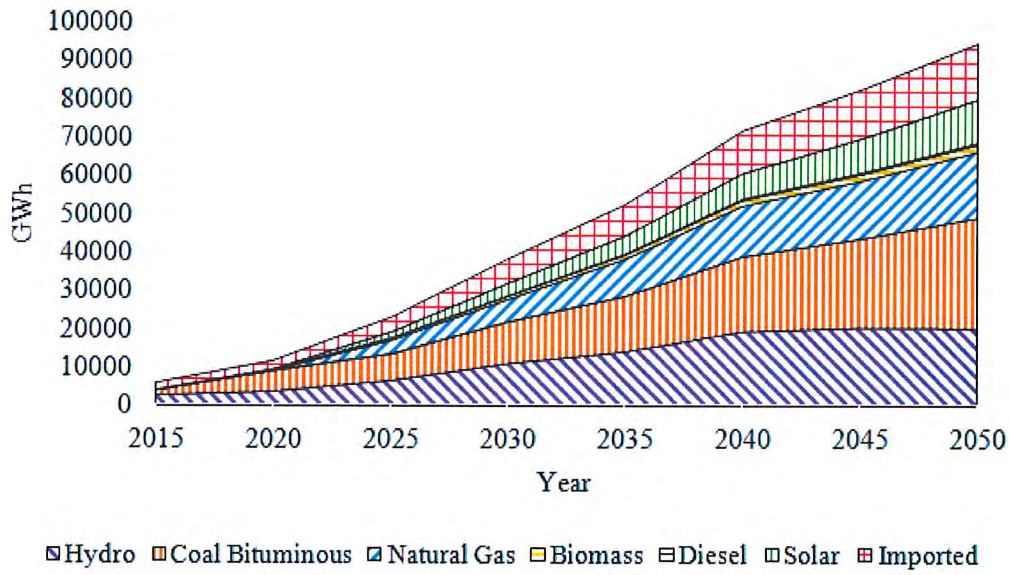

Fig. 6. Electricity generation by fuel type in the RE1 scenario.

5.2.2 RE scenario

Results in the RE scenarios are divided into three parts which are the electricity generation in the RE1, RE2, and RE3 scenarios.

With promotion of solar PV in the power sector after 2020 in the RE1 scenario, the share of electricity generation from solar PV will increase from 1% in 2020 to 12% in 2050. The percentage of electricity generation from coal bituminous, hydro, natural gas, imported electricity, solar and biomass will be 30%, 22%, 18%, 15%, 12%, and 2%, respectively in 2050. Figure 6 shows the electricity generation by fuel types between 2015 and 2050.

In the RE2 scenario with promotion of biomass utilization in power generation, share of biomass in electricity generation will increase from 3% in 2020 to 11% in 2050. In 2050, coal bituminous will have the highest amount of electricity generation at 28,742 GWh (30%) followed by hydropower at 20,349 GWh (22%), natural gas at 17,438 GWh (18%), imported electricity at 14,520 GWh (15%), biomass at 9,982 GWh (11%) and solar PV at 3,384 GWh (4%).

In the RE3 scenario, which integrates renewable energy sources such as solar and biomass in power generation, the percentage of solar and biomass will increase from 3% in 2020 to 22.1% in 2050. Due to promotion of renewable energy sources, the share of electricity generation from coal bituminous will decrease to 17.6% (16,610.8 GWh) when compared with the BAU scenario in 2050. In 2050, the electricity generation from coal bituminous, hydropower, natural gas, imported electricity, solar and biomass will be 20,4167 GWh (21.6%), 19,940 GWh (21.1%), 18,986 GWh (20.1%), 14,228 GWh (15.1%), 11,063 GWh (11.7%), and 9,781 GWh (10.4%), respectively. The electricity generation by fuel types in the RE3 scenario is presented in Figure 7.

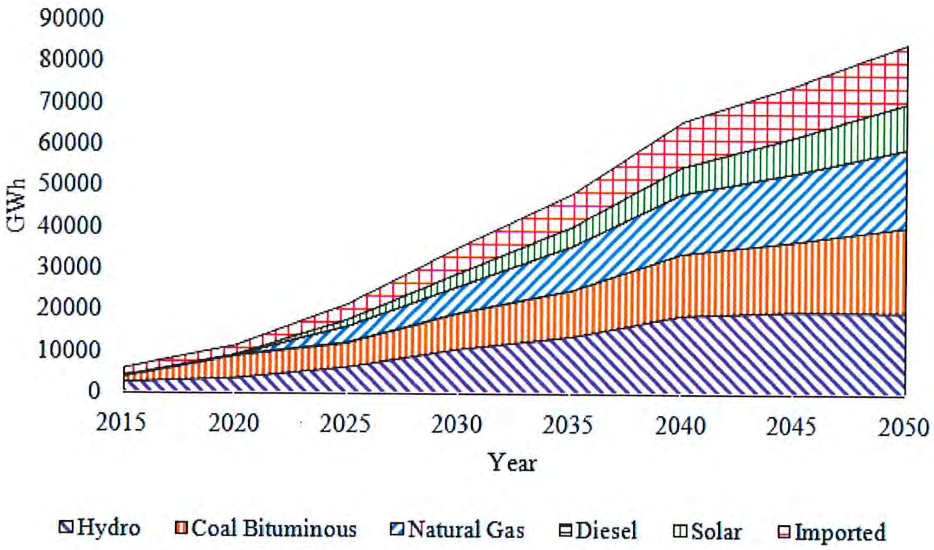

Fig. 7. Electricity generation by fuel type in the RE3 scenario.

5.2.3 CCS scenario

In the CCS scenario, the electricity generation share will be the same as in the BAU scenario. CCS technologies will affect the CO_2 emission from the power sector in this scenario. It is predicted that the electricity generation from coal bituminous will increase almost 30 times from 1,241.5 GWh in 2015 to 37,027.3 GWh in 2050.

5.2.4 CT scenario

Regarding the two carbon tax rates in this scenario, results will be divided into two parts which are the total electricity generation in the CT100 and in the CT500 scenario. The introduction of carbon tax does not have a significant effect on the total electricity generation. As a result of carbon tax, the share of imported electricity is found to increase by 11.5% and 14.2% in CT100 and CT500, respectively, when compared with the BAU scenario, while the share of coal bituminous and natural will decrease by 2050. In addition, the share of hydropower is estimated to remain the same.

In the CT100 scenario, the share of electricity generation from coal bituminous is expected to decline from 30.2% in 2020 to 25.8% by 2040, while it would increase to 31.4% until 2050. The share of natural gas will increase to 10.3% by 2030 and will reduce to 8.9% by 2050. Figure 8 shows the share of electricity generation in the CT100 scenario.

In the CT500 scenario, the share of electricity generation from imported electricity, coal bituminous, hydropower, natural gas, solar, biomass, and diesel will be 30.2%, 26.7%, 22.8%, 7.8%, 5.8%, 3.5%, and 3.2% respectively in 2050. Imported electricity will have the highest share and will remain the same during the planning horizon. Figure 9 shows the electricity generation in the CT500 scenario.

5.3 CO_2 Emissions

5.3.1 BAU scenario

The aim of this study is to propose renewable energy sources and efficient technologies in order to minimize CO_2 emissions from the power sector beyond Cambodia's NDC target. In the BAU scenario, CO_2 emissions from the power sector in 2015 are accounted for 1 million ton of CO_2 equivalent (Mt-CO_2e) and it is expected to reach 42 Mt-CO_2e by 2050. It is noticed that coal-based power plant has the highest CO_2 emission and accounted for 1 Mt-CO_2e in 2015 and expected to reach 30.9 Mt-CO_2e in 2050. Figure 10 illustrates CO_2 emissions from the power sector during 2015-2050. Figure 11 presents the CO_2 emissions from electricity generation by fuel types in the BAU scenario. It is noticed that coal bituminous contributes in the highest CO_2 emission and followed by natural gas and diesel.

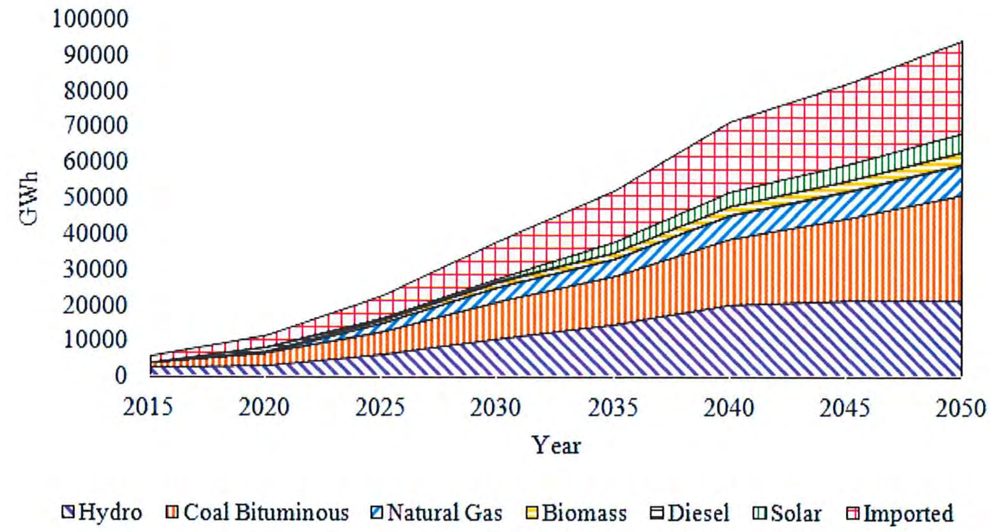

Fig. 8. Electricity generation by fuel type in the CT100 scenario.

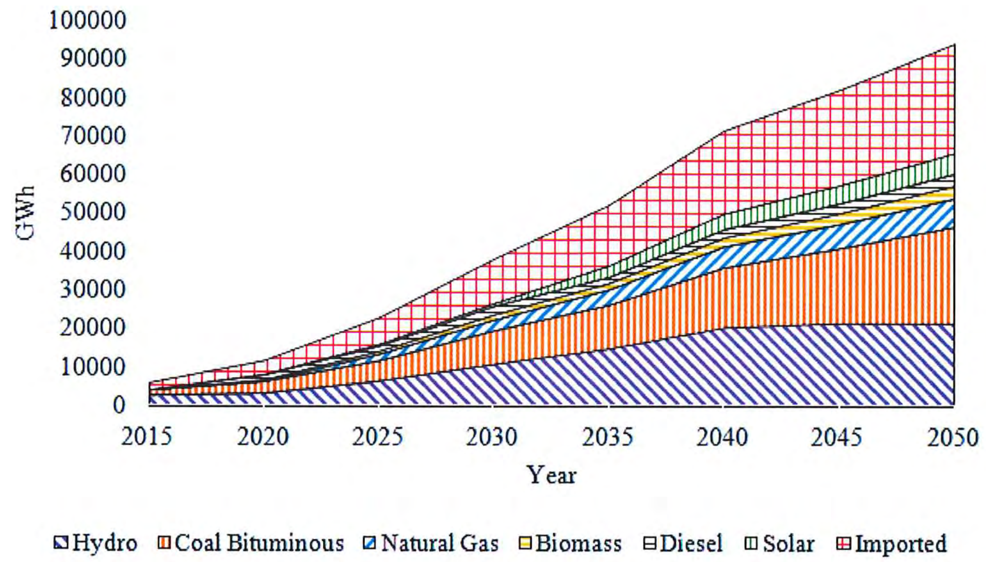

Fig. 9. Electricity generation by fuel type in the CT500 scenario.

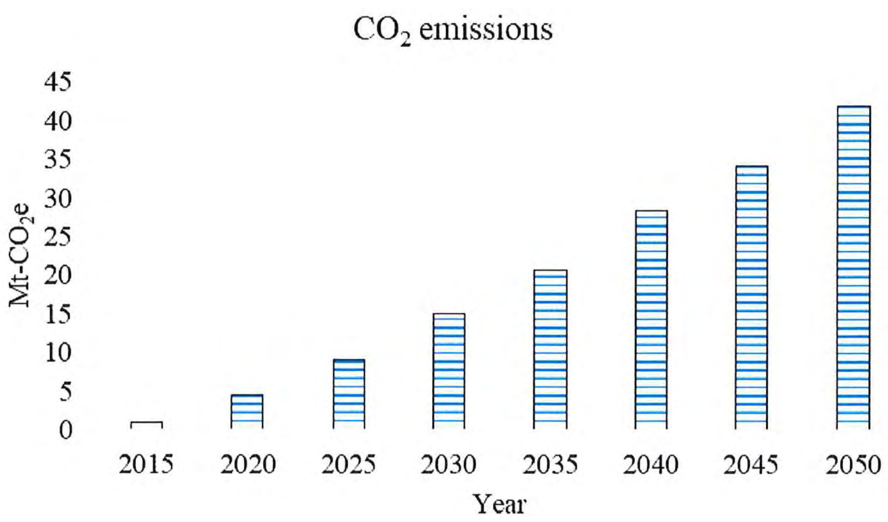

Fig. 10. CO_2 emission from the power sector in the BAU scenario.

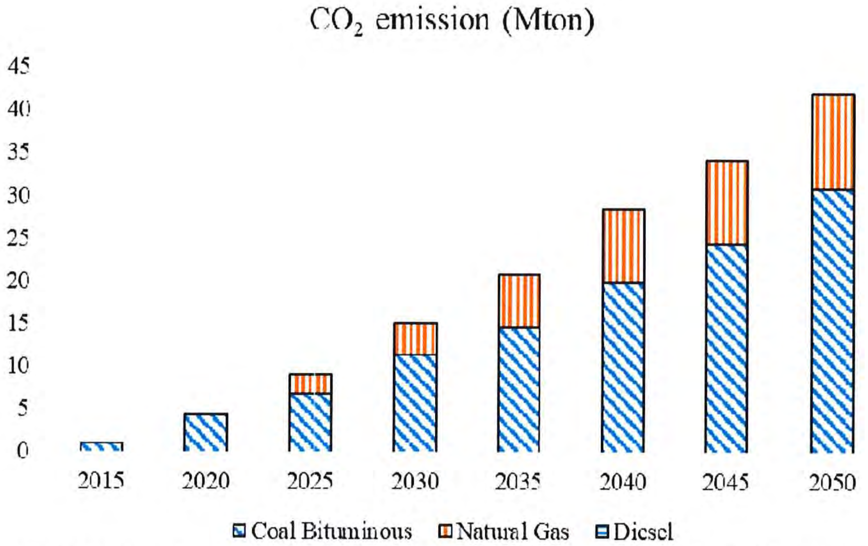

Fig. 11. CO_2 emissions from electricity generation by fuel types in the BAU scenario.

5.3.2 RE scenarios

Results in the RE scenario are divided into three parts which are the electricity generation in the RE1, RE2 and RE3 scenarios. Promotion of solar and biomass energy in power generation results in decreasing CO_2 emission in all RE scenarios after 2020. In 2050, CO_2 emissions reduction in the RE3 and RE1 scenarios will be 12.97 Mt-CO_2e and 6.37 Mt-CO_2e, respectively when compared with the BAU scenario. Figure 12 shows CO_2 emissions reduction in the RE scenarios.

5.3.3 CCS scenario

The new efficient CO_2 capture and storage (CCS) is promoted in coal-fired power plants. Thus, CO_2 emissions in the CCS scenario will be reduced by 1.97 Mt-CO_2e in 2020 and 13.7 Mt-CO_2e in 2050 when compared with the BAU. Figure 13 shows CO_2 emissions in the CCS scenario when compared with the BAU scenario.

5.3.4 CT scenarios

Among the carbon tax scenarios, the CT500 scenario will result in the highest CO_2 emission reduction (13.84 Mt-CO_2e), followed by the CT100 scenario (11.57 Mt-CO_2e) in 2050. With the introduction of carbon tax, the CO_2 emission reduction in the power sector is principally accomplished through the use of imported electricity and renewable energy sources such as solar and biomass. Figure 14 compares CO_2 emissions in the carbon tax scenarios and the BAU scenario

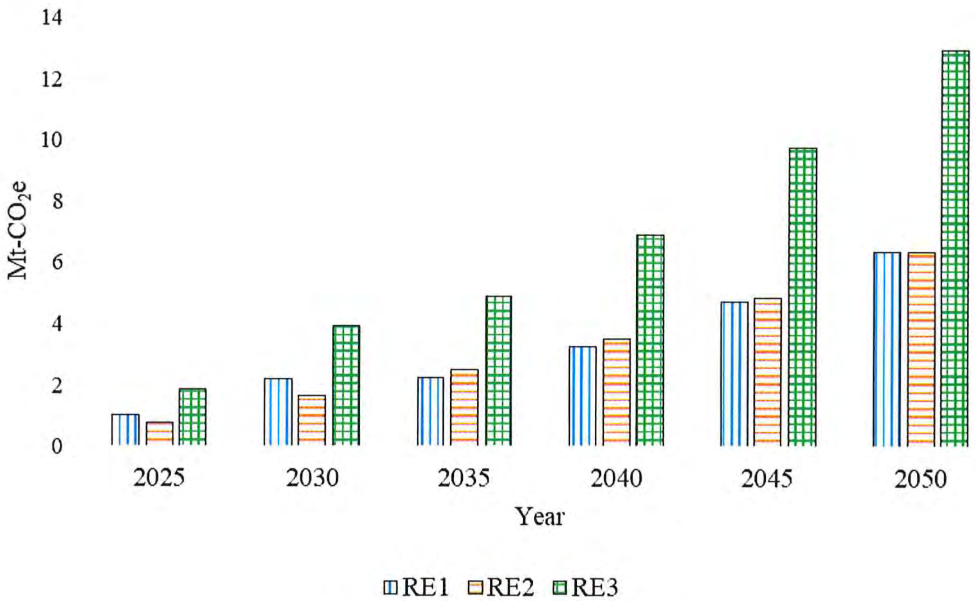

Fig. 12. CO_2 mitigation in the RE scenarios.

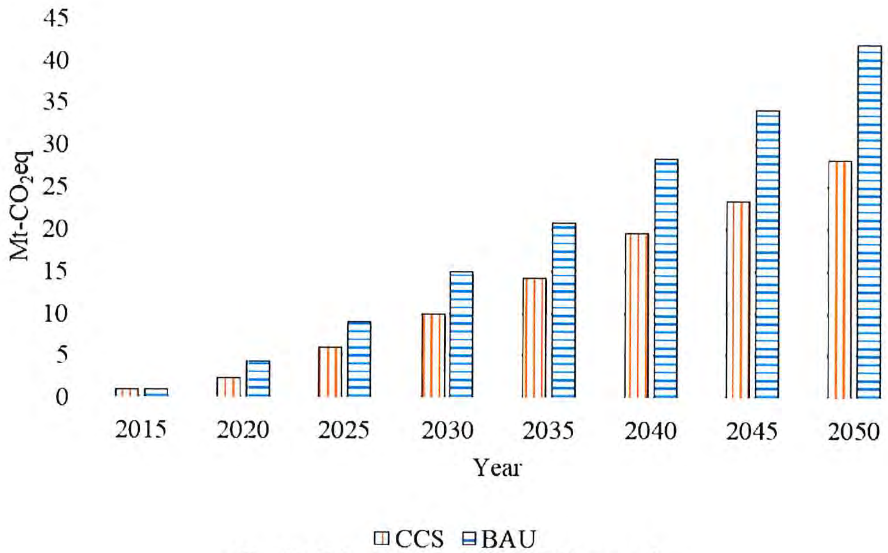

Fig. 13. CO_2 emissions in the CCS scenario.

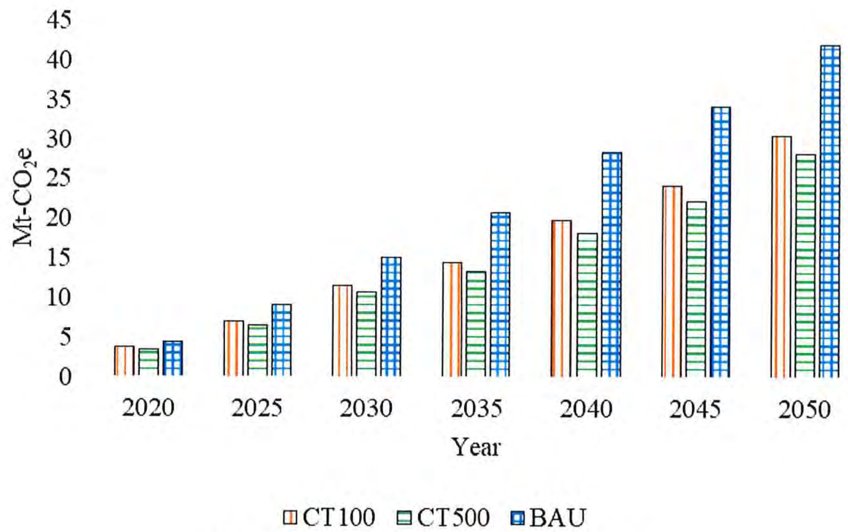

Fig. 14. CO_2 emissions in the CT scenarios.

5.4 CO_2 Emissions per Capita

CO_2 emissions per capita is estimated using the estimated population and total CO_2 emissions. CO_2 emissions per capita increase in the BAU scenario from 0.07 metric tons/capita (t/capita) in 2015 to 1.91 (t/capita) in 2050. Cambodia still has lower CO_2 emissions per capita than neighbor countries such as Thailand and Vietnam. Although the emission per capita in Cambodia is low, the Royal Government of Cambodia has set up ambitious policy to reduce more CO_2 emission. The CT500 scenario results in the lowest CO_2 emission per capita in 2050, followed by CCS (1.29 t/capita), RE3 (1.32 t/capita), CT100 (1.38 t/capita), and RE2 and RE1 (1.62 t/capita).

5.5 The Cost of Electricity Generation

Figure 16 shows the costs of electricity generation in all scenarios which are calculated by the LEAP model.

Total cost of electricity generation in the BAU scenario will increase from 29.4 million USD to 2,162.3 million USD during 2015-2050. In 2050, the CT500 scenario has the highest total cost of electricity generation among all scenarios which will increase by almost 9 times when compared with the BAU scenario. The second highest cost of electricity generation comes from the CCS scenario at 10,246.8 million USD, followed by the CT100 scenario at 8,228 million USD, RE3 scenario at 2,355.5 million USD, RE1 scenario at 2,227.8 million USD, and RE2 scenario at 2,289.1 million USD in 2050.

5.6 Comparison between CO_2 Mitigation Scenarios and INDC's Target

Figure 17 illustrates comparison of CO_2 emission reductions by all scenarios with CO_2 emission reduction in Cambodia's INDC target in 2030

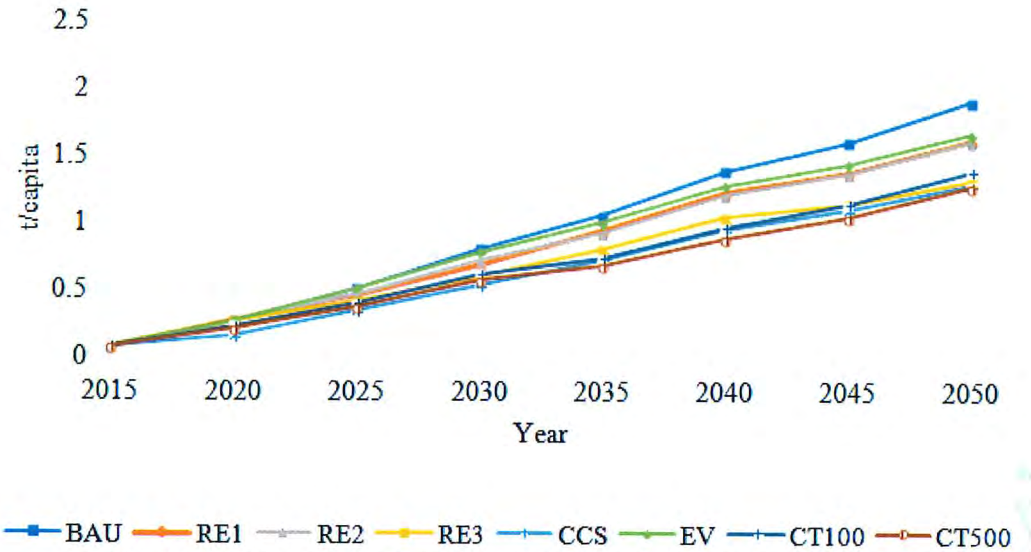

Fig. 15. CO_2 emissions per capita in all scenario in Cambodia between 2015 and 2050.

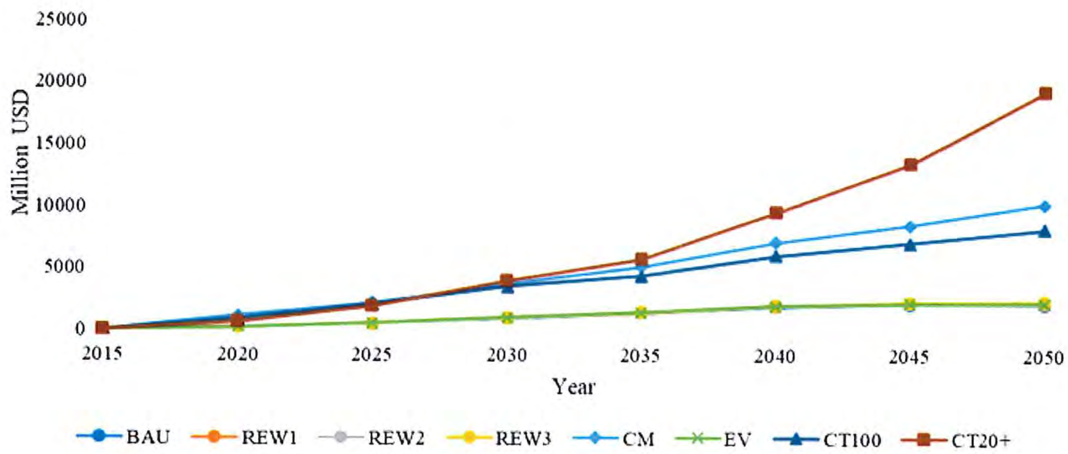

Fig. 16. Total cost of electricity generation in all scenarios in Cambodia.

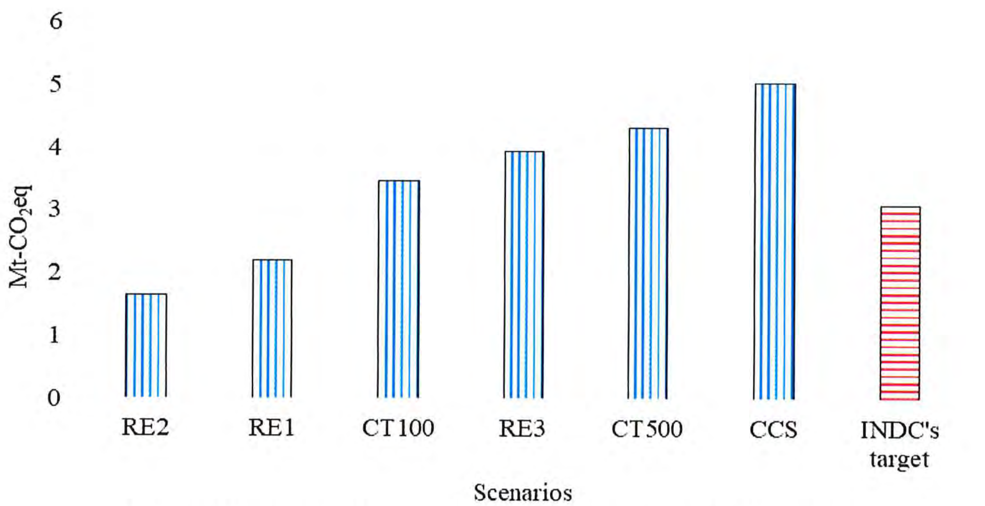

Fig. 17. CO_2 emission reduction in all scenarios and the INDC target.

In Figure 17, CO_2 emissions reduction in the RE1 and RE2 scenario will be 2.2 Mt-CO_2e and 1.65 Mt-CO_2e in 2030 respectively. Thus, promotion of only solar and biomass in the RE1 and RE2 scenarios will not achieve Cambodia's INDC target at 3.1 Mt-CO_2e in 2030. In addition, CO_2 reductions in the CCS, CT500, RE3, and CT100 scenarios are expected to be 5.04 Mt-CO_2e, 4.33 Mt-CO_2e, 3.94 Mt-CO_2e, and 3.47 Mt-CO_2e in 2030 respectively. The CCS, CT500, RE3, and CT100 scenarios will achieve CO_2 reductions of 1.94 Mt-CO_2e, 1.23 Mt-CO_2e, 0.84 Mt-CO_2e, and 0.37 Mt-CO_2e higher than the INDC target in 2030. The share of electricity generation from coal-based power plant increased significantly, therefore using carbon capture and storage technologies and the carbon tax policy will allow Cambodia to achieve its INDC target. However, total costs will be higher when compared with the BAU scenario. Cambodia could achieve the INDC target by promotion of higher renewable energy in electricity generation by 2030. The mitigation actions in the key sectors in the INDC target included four main sectors such as energy industries, manufacturing industry, transport and others. However, this study considered only CO_2 emissions in the power sector. Results show that Cambodia can achieve its INDC target by using measures in the RE3, CT100, CT500 and CCS scenarios. However, total costs of electricity generation in these scenarios in 2030 will be higher than the BAU.

6. CONCLUSION

Cambodia is a developing country facing the impacts of climate change. This study considered the possibility of options for CO2 mitigation by using renewable energy, efficient technology, and carbon tax in the power sector. Results provide clean energy supply beyond INDC target in 2030.

Results also show that in the BAU scenario total electricity generation in Cambodia is expected to increase from 6,015 GWh in 2015 to 94,413 GWh in 2050. CO2 emissions in the CCS scenario will be reduced by 1.97 Mt-CO2e in 2020 and 13.7 Mt-CO2e in 2050 when compared with the BAU. However, in the CCS scenario, share of coal-based power plants will increase and total cost of the CCS scenario will be higher than the BAU. Regarding total cost of electricity generation, the CT500 scenario with the high CO2 reduction is expected to have the highest total cost at 54.68 trillion USD during the planning period. Total costs of electricity generation in the CCS, CT100, RE3, RE2, RE1 and BAU scenarios would be 38.14 trillion USD, 32.32 trillion USD, 9.89 trillion USD, 9.67 trillion USD, 9.49 trillion USD and 9.28 trillion USD, respectively during the planning period. Results highlighted that either carbon tax or CCS scenario has a high potential for CO2 emission mitigation, but at a higher cost of electricity generation in Cambodia. It is found that all scenarios except RE1 and RE2 scenarios. which only solar and biomass are promoted into the power sector will achieve the INDC's target by 2030. Furthermore, results indicated that share of imported electricity with the imposition of carbon tax will be higher than with the promotion of renewable energy and CCS technology. In conclusion, renewable energy, efficient technologies, and carbon tax offer many advantages in terms of CO2 reduction with a considerable cost of electricity generation.

Finally, the Royal Government of Cambodia should create the policy which is included the integration of renewable energy sources in the power generation. To achieve its INDC in 2030 without CCS and carbon tax, Cambodia should promote the highest level of renewable electricity from solar PV and biomass.

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