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The Role of Renewable Energy in CO_2 Mitigation from Power Sector in Cambodia

Chhay Lyheang*,[1] and Bundit Limmeechokchai*

Abstract – *The power generation in Cambodia is dominated by hydropower and coal. In 2015, the shares of electricity generation generated from coal, hydro, oil and biomass were 48.1%, 47.40%, 3.65% and 0.85%, respectively. The government of Cambodia has set up the Power Development Plan (PDP) 2020 which mainly emphasizes the development of renewable energy and coal-based power. The drastically increasing share of coal-based electricity generation in the recent years is providing an alarming signal in terms of the increasing greenhouse gas (GHG) emissions from the power sector. Recently, renewable energy and efficient technologies have played an important role in GHG emission's reduction. The aim of this paper is to quantify the potentials of renewable energy and carbon dioxide (CO_2) mitigation options in the power sector of Cambodia. In this study, the Long-range Energy Planning (LEAP) model is used to analyze the electricity generation mix and CO_2 mitigation during 2015 to 2050. The BAU scenario is constructed in this study following the power development targets of PDP2020, and the share of renewable energy-based power generation is assumed to reach 44% by 2050. Three countermeasure (CM) scenarios of CO_2 mitigation (namely, CM1, CM2, and CM3) are modeled along with the Business as Usual (BAU) scenario. Two countermeasure scenarios, namely CM1 and CM2 considering an additional 5% of power generation based on solar PV and biomass-based technologies have been constructed in this study respectively. In the CM3 scenario, the CO_2 mitigation effects of replacing 50% of conventional coal-fired power plants with the efficient carbon capture storage (CCS) technology in coal power plants have been analyzed. The results demonstrate that in the BAU scenario, electricity supply and CO_2 emissions from the power sector will increase to 65.9TWh and 14,683.5kt-CO_{2eq}, respectively, in 2050. In countermeasures scenarios, CO_2 emissions in 2050 would be reduced by 45% in the CM3, 15% in CM1 and 12.47% in the CM2 scenario when compared to the BAU scenario.*

Keywords – Cambodia, CO_2 mitigation, LEAP model, power sector, renewable energy.

1. INTRODUCTION

The high dependence on conventional energy sources to fulfil energy demand is one of the main issues for most countries in the world. Moreover, there are many nations modifying their plans in order to improve their energy supply by choosing proper energy resources, which are delicate to energy cost, choosing domestic resources while concerning global environmental issues. The United Nation Framework Convention on Climate Change (UNFCCC) has an objective to stabilize GHG concentrations in the atmosphere to be at a safe level. In 2015, the Paris Agreement which is intended to limit the global temperature increase in this century to less than 2 degrees Celsius above pre-industrial levels was ratified [1]. The carbon emissions from fossil fuels results in an increase of greenhouse gas (GHG) emissions that cause climate change. Climate change is a worldwide issue and needs to be solved by joint efforts from all countries in promoting renewable energy and latest technologies. Cambodia, officially known as the Kingdom of Cambodia, is situated at the heart of the Greater Mekong Sub-region (GMS). It is bordered by Thailand and the Gulf of Thailand in the West and South respectively and by Vietnam in the East, and Lao PDR in the North. The electricity demand in Cambodia has increased rapidly and the peak demand has gone up approximately three times higher than in 2010. This is because of increases in the average income of people during that period. Cambodia has great potential in renewable energy (RE) sources such as solar, hydro and biomass. RE must be promoted as energy resources in order to provide dependable and environmentally friendly electricity.

The objectives of this study are to consider the expansion of renewable energy and Carbon Capture Storage technologies in Cambodia's power sector. The future electricity demand power generation mix will also be considered in this study. In addition, the Long-range Energy Alternative Planning (LEAP) model which was established by the Stockholm Environment Institute is used in order to predict electricity demand and CO_2 emissions from the power sector in four different scenarios.

2. ENERGY AND EMISSION IN POWER SECTOR IN CAMBODIA

In this section, the study on the potential of renewable energy, the historical data from the power sector, and the CO_2 emission from the power sector in Cambodia are discussed.

2.1 The Potential of Renewable Energy in Cambodia

Electricity generated from fossil fuel is used for many power plants in countries around the world. In 2015, the Intergovernmental Panel on Climate Change (IPCC) reports that increased shares of renewable energy are expected within an overall portfolio of low GHG

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emission technologies. Renewable energy has many merits such as being an environmentally friendly source of energy, improving energy access, especially in the countryside, increasing job opportunities and also ensuring energy security [2]. Renewable energy is essentially generated from sources such as hydropower, solar energy, wind, biomass, biogas, biofuel, geothermal and solid waste [3]. Cambodia has a large number of renewable energy sources throughout the country but some of those sources have not been utilized yet. According to the Asian Development Bank (ADB), the potential renewable energy sources in Cambodia are hydropower, solar, biomass, and wind in some parts of Cambodia such as the southern and coastal regions.

- *Hydropower:* Cambodia, a member of the Greater Mekong Sub-region (GMS) has a large water resource that is suitable for the installation of hydropower plants to supply electricity to the grid. According to the ADB, Cambodia has the potential of 10,000 MW for installation of hydropower that could generate 28,908 GWh/year of electricity. Most of the potential resources mentioned above are located in the Mekong River Basin while 40% of these are situated in the branches of the Mekong River and 10% are in the southwestern coastal areas [4].
- *Solar energy:* Cambodia has a high-level of solar radiation and has an extremely large amount of solar resource potential. According to an ADB report, Global Horizontal Irradiation (GHI) ranges between 1450 and 1,950 kWh/m^2/yr and 65% of the country has GHI levels of 1,800 kWh/m^2/yr or more. Cambodia has approximately 134,500 square kilometers (km^2) of land which is suitable for PV installation. To assess its potential, the evaluated levelized cost of electricity (LCOE) of solar power in Cambodia was compared with the present cost of alternative sources of energy. The estimation on LCOE of the solar power generation in Cambodia ranged between $0.166/kWh and $0.175/kWh. Cambodia has the highest energy cost compared with other countries in Southeast Asia, between $0.18/kWh and $1/kWh in the rural areas [5]. In addition, Cambodia could generate 1,000 GWh of electricity by installing 700MW of utility-scale solar on 1,400 hectares of land. The maximum estimation on solar energy in Cambodia would be under 12,000GWh/year [4].
- *Biomass:* Traditional biomass is composed of wood and charcoal and accounts for around 80% of the total energy consumption in the country. It is primarily used for animal feed, cooking, etc. Though the dependence on firewood has declined from 90.4% in 1998 to 79.5% in 2010, it remains far behind the national target of 52% by 2015. The estimated electricity generation potential of biomass is 18,852 GWh per year [6]. Data from the report of Ministry of Agriculture, Forestry, and Fisheries (MAFF) in 2010 was used to measure the effectiveness of biomass energy from the process of burning rice straw, cassava stalk, rice husks, sugarcane bagasse and corn cobs. The estimated generation capacity of biomass energy in agricultural residues is around 15,000 GWh [4].

Table 1. Potential of renewable energy and situation in 2015.

Sources	Technical potential (GWh/year)	Situation in 2015 (GWh/year)
Hydropower	28,908	2,127.82
Biomass	15,000	38.15
Solar	12,000	0
Total	55,908	2,165.97

2.2 The Power Sector in Cambodia

2.2.1. Electricity generation in Cambodia

In 2015, the total electricity generation in Cambodia reached 4,489 GWh with an installed capacity of 1,657 MW, and the imported electricity was 1,526 GWh in the same year. In 2015, electricity generation sources for hydropower, coal, diesel/heavy fuel oil and biomass were 5%, 3.2%, 91.7% and 0.1%, respectively while the corresponding shares in 2015 were 47%, 48%, 4% and 1%, respectively [7]. The high reliance on imported fossil fuels for electricity generation is a serious problem for the electricity supply in the future.

However, renewable energy is the key to reduce the level of fossil fuels responsible for an increase in CO_2 emissions. Thus, the Royal Government of Cambodia (RGC) has made an effort to increase the future electricity supply through the use of renewable energy electricity generation. The Ministry of Mine and Energy (MME) created the Power Development Plan (PDP) for the period of 2015 to 2020. Depending on the government plants, the installed capacity of hydropower and coal after 2020 would be 5,374 MW [8].

2.2.2. Electricity demand in Cambodia

In 2015, the total electricity demand in Cambodia reached 5,341 GWh. The electricity demand proportionally changed with the economic development of the country. The percentage of electricity sold to customers in distributors, commercial, residential, industrial, governmental and other was 28%, 26%, 24%, 19% and 3%, respectively [7].

2.2.3. Indicators of Cambodia's power sector

Energy utilization is the reaction of human action. Therefore, considering the connection between such human action and energy consumption makes sense. Energy intensity is a measure of the amount of energy it takes to produce a dollar's worth of economic output that can be generated by one standardized unit of energy. The Gross Domestic Product (GDP) is a popular index following a country's economy. In 2015, GDP (constant 2010) in Cambodia was about 15.903 billion dollars and GDP per capita was 1,025$. The actual GDP of Cambodia went up annually at an average of 7.5% between 2010 and 2015. The garment industry, the expansion of agriculture, and tourism have driven Cambodia's growth.

However, electricity consumption per capita measures the production of power plants and combined heat and power plants less transmission, distribution and transformation losses and own use by heat and power plants [9]. In 2015, the electricity consumption per capita was 328 kWh [10]. Cambodia's electricity per capita is still lower than some neighboring countries. Nevertheless, the percentage of household connections increased from 49.37% in 2015 to 68.64% in 2017. This is because of the expansion of transmission and distribution lines closer to the users. In addition, the Ministry of Mine and Energy, under the Royal Government of Cambodia, has responded to this issue by developing the energy policy in order to provide reliable, affordable energy services to all users. Thus, 80% of villages will be connected to the national grid and the remainder will be supplied by other energy sources such as imported electricity or single supply systems by 2020. In 2030, 95% of villages will be connected to the national grid while another 5% will have access to single systems with a quality of supply similar to the national grid [5].

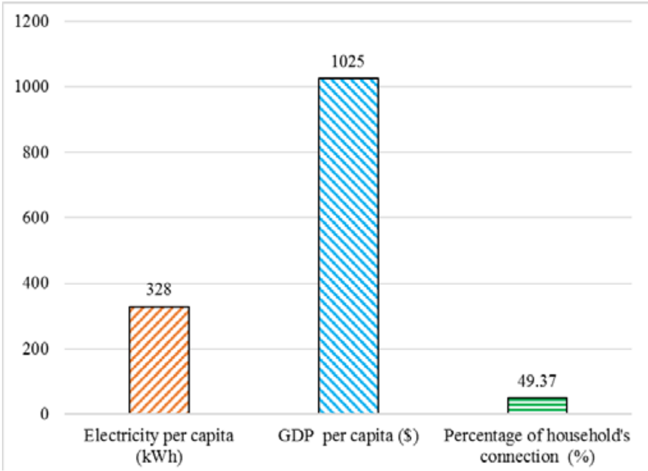

Fig. 1. Electricity and economic indicators in 2015.

2.2 CO_2 Emissions

CO_2 emission from fuel combustion could be calculated by relying on the reference and the sectoral approaches which is suggested by Intergovernmental Panel on Climate Change (IPCC) for National Greenhouse Gas Inventories in 2006. It was used to predict the CO_2 emission in Cambodia regarding Cambodia's Energy Balance 2010-2015. The result provided that CO_2 emissions developed from 2010 to 2015 at an average rate of 10.2% per year. The major source of CO_2 emissions was from fuel combustion such as coal and oil; the CO_2 emissions from coal were 90 kilotons (kt) while emissions from oil were 4,435 kt in 2010. Five years later, in 2015, CO_2 emissions from coal and oil increased to 2,070 kt and 5,313 kt, respectively [9]. In 2015, CO_2 emissions per capita was 0.51 tCO_2/capita which is still lower than in Indonesia, Vietnam, Thailand and Malaysia which were 1.72 tCO_2/capita, 1.83 tCO_2/capita, 3.64 tCO_2/capita and 7.27 tCO_2/capita, respectively [10]. CO_2 emissions from the power sector can be reduced by replacing conventional power plants with renewable-based electricity generation using efficient technologies. Some studies have shown that there are several co-benefits from the use of renewable energy such as benefits to the environment and climate; better energy access, especially in the countryside; increased job opportunities and improvement in macroeconomic achievement; and improvement in energy security, providing more economic stability [11]. Depending on the potential of renewable energy mentioned above, Cambodia highly promotes renewable energy in the power sector in order to meet future energy demand and CO_2 emission targets.

3. METHODOLOGY

The input data in this study are taken from government reports, a review paper, online databases and an official government development plan. Moreover, the estimation of future electricity demand in this study is based on gross domestic product (GDP) and GDP elasticity of electricity demand. Future electricity demand is calculated by the following equation.

$$E_t = \left(\frac{GDP_t}{GDP_{2015}} \right)^{\delta} \times E_{2015} \qquad (1)$$

Where: E_t is the electricity consumption in year t (GWh), E_{2015} is the electricity consumption in 2015 (GWh), GDP_t is the GDP (at constant 2010 price) in year t (billion \$), GDP_{2015} is the GDP (at constant 2010 price) in 2015 (billion \$), δ is GDP elasticity of electricity demand.

GDP elasticities are estimated based on the regression analysis using a linear equation with the GDP as an independent variable and electricity demand as a dependent variable. The data for the period 1995 to 2014 were used to estimate GDP elasticity. The coefficient of a linear equation is the GDP elasticity is calculated to be 2.1. In this study, it is assumed that the GDP elasticity will decrease periodically. The value is taken to be 2.1 during the period 2015 to 2020, 1.5 during 2021 to 2035, 0.8 during 2036 to 2045 and 0.5 during 2046 to 2050. The future GDP is calculated based on annual growth rate from 2015 to 2050. GDP growth rates in this study are based on some references from the government [12]. It is assumed that the growth rate from 2015 to 2020, 2021 to 2035, 2036 to 2045 and 2046 to 2050 would be 7%, 6.5%, 5% and 3.5%, respectively.

In this study, Long-range Energy Alternative Planning (LEAP) is used in order to model energy policy analysis and climate change mitigation assessment. LEAP was developed by the Stockholm Environment Institute. The LEAP model has a flexible data structure which is not only easy to use but also rich in technical and end-user detail [13]. LEAP allows the user to analyze the technical qualification and end-use details and it includes a full area of energy systems, which are constructed as well-known from the energy carriers, optimize in transformation losses in the process and through the final energy form of end users. The output of LEAP significantly provides multifunction such as future total electricity supply and demand, the share of each fuel in the electricity supply and the CO_2 emission from power plants by each scenario that is created by the user [14].

In this study, a Business as Usual (BAU) scenario for a period of 2015-2050 is the model. In addition, three countermeasure (CM) scenarios of CO_2 mitigation, namely CM1, CM2 and CM3, are modeled along with the BAU scenario. The study mainly focuses on the electricity supply from power plants, so the electricity demand will not change in these four scenarios. The potential of renewable energy and modern technologies has been considered in this study. Thus, the purpose of countermeasure scenarios is to encourage the use of renewable and low carbon technologies. The benefit of this will be to reduce the environmental impact of coal-fired power plants. The details of each scenario will be described below.

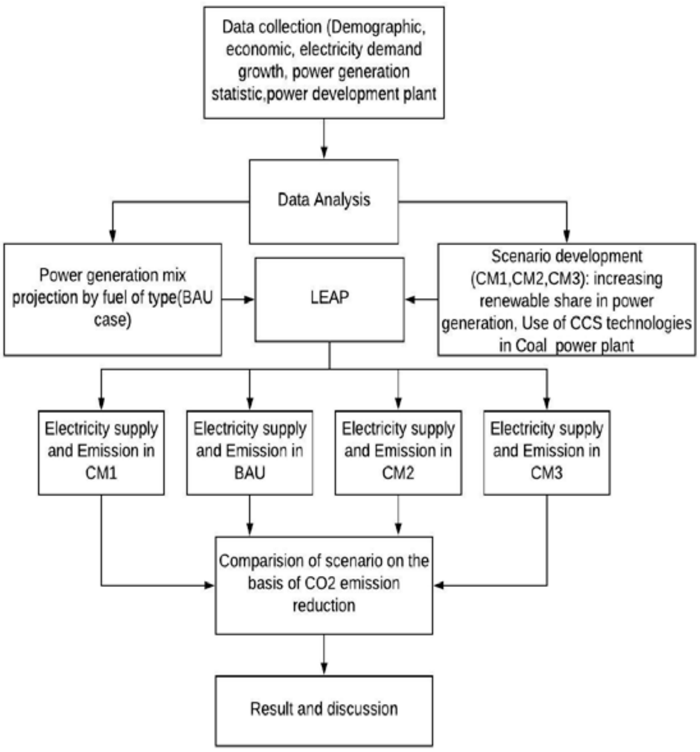

Fig. 2. Flowchart of the methodology.

3.1 Business as Usual (BAU) Scenario

In the BAU scenario, 2015 is considered the base year and 2050 as the end year. By using the concept that is mentioned above, the future electricity demand was estimated till 2050. The electricity share in this scenario is based on the Power Development Plan (PDP) of Cambodia and the study report of relevant authorities.

3.2 Countermeasure 1 (CM1)

In the CM1scenario, solar energy is proposed to have higher share than in BAU. It is considered that 5% of the total power generation will be from solar energy from 2020 to 2050. The addition of this energy source will partly replace coal-fired power plants.

3.3 Countermeasure 2 (CM2)

In this case, 5% of total power generation from biomass will be added into the power generation from 2020 till the end of this study. This new capacity will be used to replace some portion of coal-fired power plants.

3.4 Countermeasure 3 (CM3)

In this scenario, new efficient CO_2 Capture and Storage (CCS) is used in order to replace coal-fired power plants. CCS consists of 3 steps such as CO_2 capture by decarbonization of fossil fuels or separation from flue gases and other gaseous mixtures; CO_2 transportation to the storage site and CO_2 storage by injection of high-pressure supercritical CO_2 into geological formations. Normally, the efficiency to capture CO_2 is between 80% and 90%. In the CM3 scenario, 50% of coal-fired power plants will use CO_2 Capture Storage (CCS) technology from 2020 to 2050.

4. RESULTS

The electricity supply and demand, the consumption per capita, the share of renewable energy, the CO_2 emission from the power sector and the comparison in each scenario are discussed in this section.

4.1 BAU Scenario

The electricity generation mix and the CO_2 emission from the power sector in the BAU scenario are discussed in this sub-section.

4.1.1. Electricity generation mix

The total electricity demand in Cambodia is expected to increase from 4.48TWh in 2015 to 60.664TWh in 2050.

In the BAU scenario, the electricity supply in Cambodia would rely on two major sources, i.e. hydropower and coal-fired power plants. (See figure 3). The total electricity supply will expand from 4.8 TWh in 2015 to 65.9 TWh in 2050. In 2050, it is projected that the share of hydropower, coal fired power plants, solar and biomass cogeneration in total electricity generation would be 56%, 33.4%, 9.1% and 1.5%, respectively. The installed capacity in Cambodia will increase from 1,291MW in 2015 to 16,592 MW in 2050. In 2050, the share of generated capacity from hydropower, coal-fired power plants, solar and biomass cogeneration will be 51.22%, 30.52%, 8.55%, 8.25% and 1.46%, respectively.

4.1.2. Consumption per capita

The electricity consumption per capita is calculated using the estimated future population and electricity demand. The consumption per capita in 2020, will reach 547 kWh, 1,250 kWh in 2030 and 2,224 kWh and 2,755kWh in 2040 and 2050, respectively.

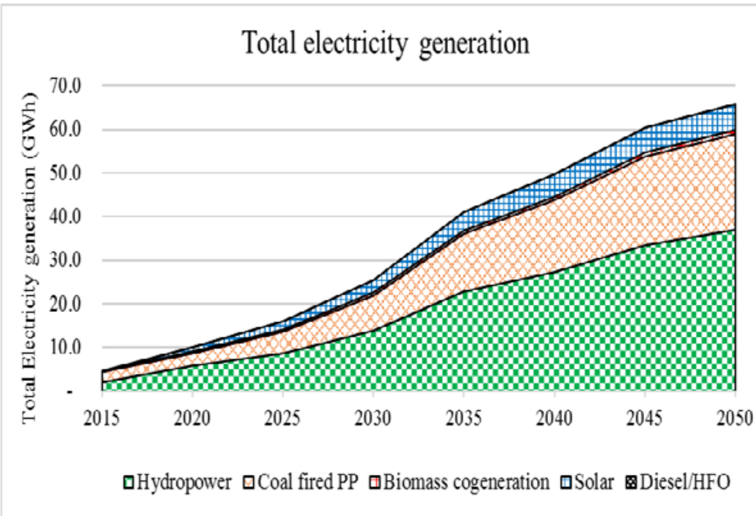

Fig. 3. Total electricity supply in BAU in Cambodia.

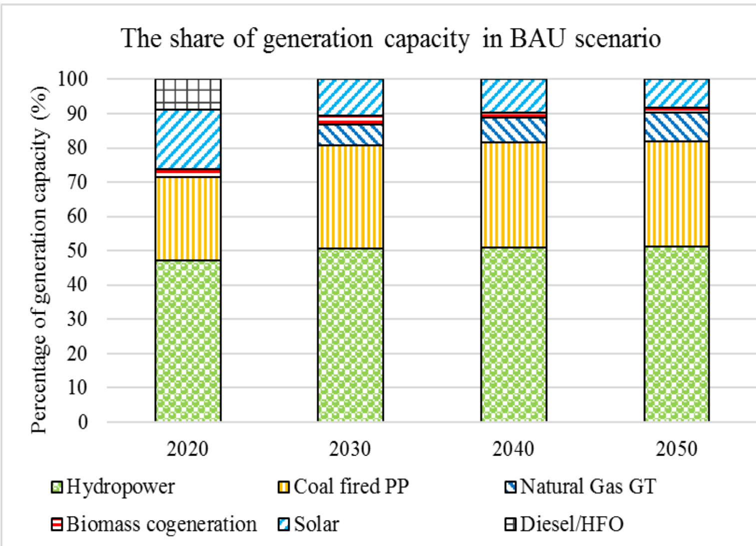

Fig. 4. The share of generation capacity in BAU scenario.

4.1.3. The CO_2 emission from the power sector

In the BAU scenario, the CO_2 emission from the power sector was determined to be 1234.4 kt-CO_{2eq} in 2016 and it is expected to reach 14683.5 kt-CO_{2eq} in 2050. In this scenario, the emissions will have an eleven-fold increase during 2016-2050.

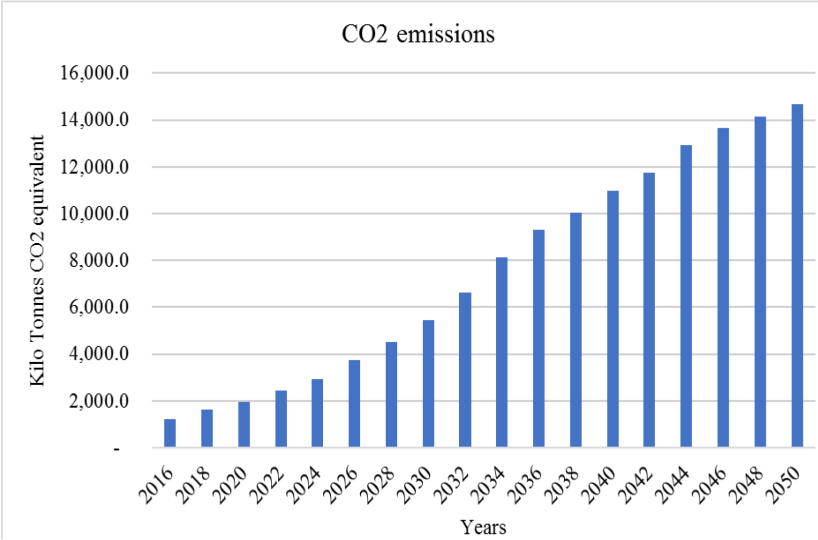

Fig. 5. CO_2 emission from the power sector in BAU scenario.

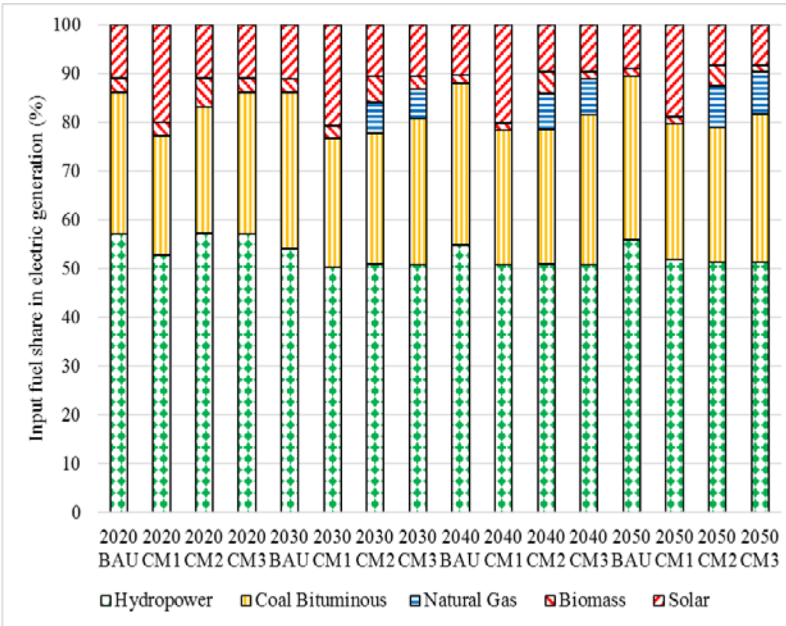

Fig. 6. Generation mix in all scenarios.

4.2 Electricity Generation Mix and CO_2 Emissions in Countermeasure (CM) Scenario

The electricity generation mix and emission from three scenarios, namely Countermeasure 1 (CM1), Countermeasure 2 (CM2) and Countermeasure 3 (CM3), are explained in this sub-section.

4.2.1. Electricity generation mix

a. Countermeasure 1 scenario (CM1)

In this scenario, the electricity generation is expected to increase to 67.4 TWh in 2050. The share of electricity generation from hydropower, coal-fired power plants, solar and biomass would be 51.92%, 27.8%, 19% and 1.28%, respectively.

b. Countermeasure 2 scenario (CM2)

In this case, total electricity generation will expand from approximately 6 TWh in 2016 to 70.1 TWh in 2050. The share of electricity generation from hydropower, coal-fired power plants, natural gas, solar and biomass will be 51.35%, 27.53%, 8.55%, 8.27% and 4.3%, respectively.

c. Countermeasure 3 scenario (CM3)

In the CM3 scenario, the consumption of electricity generation is the same as in the CM2 scenario (70.1 TWh) in 2050, while the share of electricity generation is different. The result shows that the shares of electricity generation from hydropower and coal-fired power plants will be 51.21% and 30.52%, while 8.55%

will be attributed to natural gas followed by solar and biomass with shares of 8.27% and 1.45%, respectively.

4.2.2. CO_2 emission

a. Countermeasure 1 scenario (CM1)

In CM1, by promoting solar energy into the power sector, CO_2 emission from fuel input will be around 12479.2 kt- CO_2eq. It is noticed that CO_2 emission in this scenario will be 15% less than emissions from BAU in 2050.

b. Countermeasure 2 scenario (CM2)

In the CM2 scenario, 5% of total electricity generation will come from biomass, which will partly replace coal-fired power plants. This replacing will result in the reduction of CO_2 emission from conventional coal-fired power plants. In CM2, the total CO_2 emission will be 12,851.8 ktCO_2eq in 2050. The CO_2 emission in the CM2 scenario will be 12.47% lower than the emission from the BAU scenario.

c. Countermeasure 3 scenario (CM3)

In the CM3 scenario, the electricity supply in 2050 will reach 70.1TWh and the share of renewable energy will be 60.9%. The total CO_2 emission from power sector will be 8,075.9 kt-CO_2eq in 2050. The CO_2 emission in this scenario is significantly lower than emission from BAU 45%.

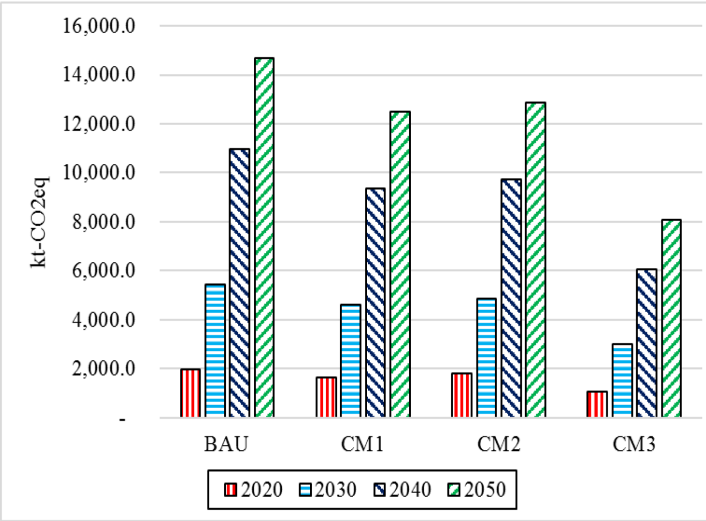

Fig. 7. Total CO_2 emission in all scenarios in the power sector.

6. CONCLUSION

As a developing country, Cambodia is facing the impact of the climate change. Some studies regarding the low CO_2 emissions emitted from the power sector have been done by the relevant authority and the private sector. In addition, the potential of renewable energy and efficient technologies are crucial in the long-term electricity planning to reduce GHG emissions. It is found that the electricity supply in the BAU, CM1, CM2, and CM3 will be 65.9TWh, 67.4TWh, 70.1TWh and 70.1TWh, respectively, in 2050. In addition, the CO_2 emission in the CM3 will be 8,075.9 kt-CO_{2eq} while it will be 12,479.2 kt-CO_{2eq} in the CM1 and 12,851.8 kt-CO_{2eq} in the CM2 in 2050. Results show that the CM3 scenario has the highest reduction potential when compared with the BAU scenario. In conclusion, efficient technologies and renewable energy provide many merits in terms of reducing CO_2 emission from the environment. The power plants with CO_2 Capture Storage technologies also offers high potential in reducing emissions. Moreover, research and improvement are needed regarding the government plans in order to fulfill electricity demand by promoting renewable energy and efficient technology in Cambodia.

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