Achievement of Paris Agreement in selected Greater Mekong Sub-region Countries: Analyses of Renewable Electricity and Emissions Gap

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A R T I C L E I N F O

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A B S T R A C T

This paper presents GHG mitigation potential through renewable electricity in the four GMS countries, namely Cambodia, Lao PDR, Thailand, and Vietnam in view of the Intended Nationally Determined Contributions (INDCs). The analysis tool is the Low Emission Analysis Platform (LEAP) model. The INDCs of these countries aim at GHG emissions mitigation in 2030, based on improvement of energy efficiency and renewable electricity generation, in the range of 177-339 Mt-CO2eq compared to the business-as-usual (BAU) scenario. However, only Thailand has tangible NDC roadmap 2030. In this paper, two scenarios are considered. They are the BAU scenario and the Renewable Electricity (RE) scenario. This study highlights emissions gap in the selected GMS countries using effort-sharing approaches based on the 2-degree targets in 2050: grandfathering (GF), immediate per capita convergence (IEPC), per capita convergence (PCC), and greenhouse development rights (GDR). Results indicate that the reduction of GHG emissions in power generation is estimated to be 110.1 Mt-CO2eq by 2030 in the RE scenario for the four countries. The GDR approach allows for larger cumulative carbon budgets for Cambodia, Lao PDR, and Thailand except for Vietnam than other three approaches. Nonetheless, emissions remain in a wide gap to reach the 2-degree goal of the Paris Agreement.

1. INTRODUCTION

The emissions of greenhouse gas (GHG) are found to be the principal causes of climate change [1]. GHG emissions need to be mitigated to restrict climate change mitigation. In 2015, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) joined hands to adopt the Paris Agreement (PA) at the 21st Conference of the Parties to hold the global temperature rise level well below 2°C, preferably to 1.5°C by 2100 [2]. Under the PA, the Party needs to submit its INDCs to the UNFCCC which then becomes NDCs when ratified. It is the Party's commitment to limit GHG emissions [3].

The selected countries in the GMS region, namely Cambodia, Lao PDR, Thailand, and Vietnam had communicated their INDCs aiming at GHG emissions reduction. The INDC of Cambodia sets to reduce the national GHG emissions of 3.1 Mt-CO_{2eq} by 2030 [4]. On the other hand, Lao PDR did not mention its GHG emissions mitigation target in its INDC [5]. In Thailand's INDC, nation-wide GHG emissions would be reduced by 20%-25% by 2030 [6]. According to the INDC of Vietnam, 8% (under domestic mitigation actions) and 25% (under supported condition) of GHG emissions are expected to be cut down by 2030 [7]. Table 1 presents sectoral GHG mitigation under INDCs of the four countries.

Table 1. GHG emissions reduction in 2030 under NDCs (Unit: Mt-CO_2eq) [4]-[8]

Sector	KHM	LAO	THA	VNM
Energy	1.8	-	113	29-66
Manufacturing	0.727	-	-	-
Agriculture	-	-	-	6-46
Transport	0.39	-	-	-
Waste	-	-	2	4-20
IPPU	-	-	0.6	-
LULUCF	-	-	-	22-68
Other	0.155	-	-	-
Sub-total	3.072	-	111-139	63-197
Total	177-339			

Note: KHM: Cambodia, LAO: Lao PDR, THA: Thailand, VNM: Vietnam, LULUCF: Land Use, Land-Use change and Forestry

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There are several studies on energy policies related to the INDCs in the Southeast Asian countries. Tri Vicca Kusumadewi, et al. assessed the GHG mitigation in Thailand's power sector by promotion of the use of renewable energy [9]. Vietnam can easily achieve its NDCs aiming at the energy sector. The study concluded that Vietnam could even level-up the target in the energy system by the use of alternative energy sources [10]. Beni Suryadi and Sanjayan Velauthaam stated that Cambodia and Lao PDR are moving toward the INDC achievement through the low-carbon energy [11]. Several existing studies have been done on the power sector or energy sector in the individual country within the GMS countries. On the other hand, this study focuses on the power sector in the view of their NDCs.

The national energy plans in the GMS countries are different. They contain specific goals and objectives. The timelines of policies are in line with the NDCs while others are not. Moreover, Thailand is the only country within the four GMS countries to have a specific roadmap for the NDC which leads to the existence of uncertainty in the GHG emissions in the four countries. Therefore, this study estimates GHG emissions reduction in the four countries in view of the NDCs through renewable electricity in the power sector. To achieve this objective, the Low Emission Analysis Platform (LEAP) was employed. The two scenarios namely, the BAU scenario and the Renewable Electricity scenario were developed. This study is extended from the two papers [12],[13].

This paper consists of six parts. This section is the introduction. The second section reviews the power generation situations. The third section presents the concept of effort-sharing approaches. The fourth and fifth section discusses the methodology and results, respectively. The sixth section gives the conclusions.

2. THE SITUATION OF THE POWER SECTOR

2.1 Electricity Demand and Supply

The power sector within the four countries has seen great improvements during 2005-2015. The electricity demand in the four countries is estimated to have increased from 170 TWh in 2005 to 325 TWh in 2015. Similarly, the electricity supply in these countries increased by about two times in 2015 when compared to 193.3 TWh in 2005 [14]-[18]. Coal, natural gas, and hydro energy are the dominant sources of electricity generation within the GMS countries.

2.2 GHG Emissions

Due to the high reliance on fossil fuels for power generation, GHG emissions in the power sector of these four countries shoot up from around 109.7 Mt-CO_2eq to 186.4 Mt-CO_2eq during 2005-2015 [19]. Thailand emits the most emissions in the power sector which account for approximately 59.2% among the four countries in 2015. The GHG emissions in Vietnam and Cambodia account for 39.5% and 1.3% respectively. The GHG emissions from power generation in Lao PDR are not available [19].

2.3 Renewable Energy Potential

The four countries have high potential of renewable energy as listed in Table 2. A substantial portion of the RE resources such as solar, hydro, wind, biomass, and geothermal are not yet tapped.

Table 2. Potential of renewable energy for electricity generation (Unit: TWh/y, *Unit: MW) [20]-[27]

	KHM	LAO	THA	VNM
Hydro*	10,000	26,000	15,155	35,000
Biomass	15.89	7.02	136.4	373.9
Geothermal*	-	-	-	300-400
Wind	154	1112	899	64.35
Solar	11.9	11.7	33.4	18

Note: KHM: Cambodia, LAO: Lao PDR, THA: Thailand, VNM: Vietnam

2.4 Renewable Energy Related Policies

Different renewable energy-related policies have been issued in the GMS. For instance, the Royal Government of Cambodia initiated the National Policy Strategy and Action Plan on Energy Efficiency in Cambodia in 2013 and the Power Development Plan (PDP) in 2015. The Renewable Energy Development Strategy in Lao PDR was issued in 2011 and the National Energy Efficiency and Conservation Policy towards 2030 was issued in 2016. Thailand announced the Power Development Plan 2015 (PDP2015), the Alternative Energy Development Plan 2015 (AEDP2015), and the Energy Efficiency Plan 2015 (EEP2015). Thailand revised these plans in 2018. However, this study employs the plans announced in 2015 due to the availability of information. Vietnam issued the Decision 2068/QD-TTg for the approval of the Viet Nam's renewable energy development strategy in 2030, and the Decision 14318/QD-BCT for the approval of the restructuring power sector, and the Decision 428/QD-TTg for the approval of the revised national power development plan.

3. EFFORT SHARING

The report on emissions gap 2020 of the United Nations Environment Programme (UNEP) stated that to limit the mean global temperature rise to well below 2^{o}C by 2100, the annual world emissions in 2030 need to be reduced by 15 Gt-CO_2eq lower than the pledged unconditional NDCs and 32 Gt-CO_2eq lower for the 1.5℃ target [28].

It implies that each country in the world needs to contribute much more effort to fill the gaps to ensure the possibility of reaching targets of the Paris Agreement. The effort sharing must consist of fairness so that participation from each country is ensured. Yet, there is no generally accepted way of describing or assessing a fair and ambitious country mitigation commitment [29].

Various effort-sharing approaches in various parts of the world were suggested based on the principles of equity, which are the common concepts of distributive equality. In Europe, the European Union (EU) issued legislations called Effort Sharing Decision (ESD) and Effort Sharing Regulation (ESR) in 2009 and 2018 respectively [30]. The binding national GHG targets of the EU's members would reach a 10% reduction by 2020 in the ESD whereas, in the ESR, the binding targets would reach a 30% cut by 2030 when compared to 2005. Under both legislations, every member state in the EU has a different annual GHG emission target for the periods 2013-2020 and 2021-2030 respectively.

To ensure fairness on the reduction targets of each member of the EU, the EU allocated the targets based on the Member States' gross domestic product (GDP) per capita compared to the EU average GDP per capita [30]. Höhne et al. compared an extensive number of studies on the GHG reduction targets using effort sharing in 2014 and stated that the four most common effort-sharing approaches are based on responsibility, capability, equality, and cost-effectiveness [31]. Several effort-sharing approaches have been suggested such as the equal per-capita distribution of cumulative emissions, common but differentiated responsibilities, grandfathering, immediate per capita convergence, per capita convergence, equal cumulative per capita emissions, ability to pay, greenhouse development rights, constant ratio, equal per capita, and capability [32]-[35].

4. METHODOLOGY

4.1 LEAP Model

The Long-range Energy Alternative Planning (LEAP) System model is a scenario-based modeling tool developed by the Stockholm Environment Institute. In 2020, its name was changed to "Low Emissions Analysis Platform (LEAP)" [36]. The LEAP is widely used to estimate the trend of energy demand and supply, emissions, and impacts of policies [37]. LEAP has been adopted in various research to assess the energy production, emission inventories, and environmental costs, using different user-specified scenarios [21]. The LEAP model provides a versatile, user-friendly data framework and is also well-provided with technical and user information [37]. At least thirty-two countries used LEAP as a framework for their INDCs to establish energy and pollution scenarios [37]. LEAP is appropriate for assessment of GHG mitigation. Thus, in this study the LEAP model is employed to assess the potential of renewable electricity and GHG emissions reduction in power generation in Cambodia, Lao PDR, Thailand, and Vietnam.

4.2 Scenario Description

The timeline of this study is taken as 2015-2030, of which 2015 is considered as the base year of the study. This study develops the business-as-usual (BAU) scenario and the renewable electricity (RE) scenario. In the BAU scenario, the previously adopted power development plans of each country remain unchanged. In addition, no GHG emissions mitigation constraints will be added to this scenario if it was not included in the power development plan. On the other hand, the RE scenario considers the new power development plan along with the renewable energy-related policies that can be applied to the power sector. The purpose of the RE scenario is to encourage more renewable energy usage in the power sector, and to assess the potential of renewable electricity and GHG mitigation. In addition, the new power development plans in the RE scenario include energy efficiency measures.

For Cambodia, the RE scenario considers the inclusion of the National Policy Strategy and Action Plan on Energy Efficiency in 2013. The RE scenario for Lao PDR includes the Renewable Energy Development Strategy in Lao PDR and the National Energy Efficiency and Conservation Policy towards 2030. The RE scenario also considers the PDP2015, AEDP2015, and EEP2015 for Thailand. For Vietnam, the RE scenario takes into consideration the Decision 2068/QD-TTg and the Decision 428/QD-TTg.

4.3 Emissions Gap

The emissions gap analysis presents the gaps between the GHG emissions pathways of the Paris Agreement and the GHG emissions level of the Southeast Asian countries. The emissions gap in this study is highlighted in eight different scenarios: NDC-U, NDC-U-DOU, NDC-U-TRI, NDC-C, NDC-C-DOU, NDC-C-TRI, 2D2050, and 1.5D2050. The data of the emissions gap highlighted in this study do not include the emissions of LULUCF. The description of each scenario is presented in Table 3.

The necessary data for the baseline scenario until 2030 is collected from the official NDC documents, the AIM/CGE 2.1 model in Shared Socioeconomic Pathways (SSP) scenarios, and other reports [38]-[44]. The data from 2031 onward are determined using the Immediate Per Capita Convergence method adopted in this study. The data of the 2D2050 and 1.5D2050 scenarios of Southeast Asian countries are determined based on the global emissions pathways from the AIM/CGE 2.1 model in SSP scenarios using the Immediate Per Capita Convergence method [46]. The data for the NDC-U and NDC-C scenarios are taken from the official NDC documents [38]-[44].

Table 3. Descriptions of emissions gap scenarios

Scenario	Description
Baseline	Follows the BAU emissions (exclude LULUCF) of the NDCs documents until 2030. After 2030 onward, data are assumed.
NDC-U	Follows the targets of the official NDCs in 2030. The percentage targets are assumed to stay the same in 2050.
NDC-U-DOU	Follows the targets of the official NDCs in 2030. The percentage targets are assumed to be doubled in 2050.
NDC-U-TRI	Follows the targets of the official NDCs in 2030. The percentage targets are assumed to be tripled in 2050.
NDC-C	Follows the targets of the official NDCs in 2030. The percentage targets are assumed to stay the same in 2050.
NDC-C-DOU	Follows the targets of the official NDCs in 2030. The percentage targets are assumed to be doubled in 2050.
NDC-C-TRI	Follows the targets of the NDCs in 2030. The percentage targets are assumed to be tripled in 2050.
2D2050	This scenario indicates the emissions pathway of the 2°C goal of the Paris Agreement.
1.5D2050	This scenario indicates the emissions pathway of the 1.5°C target.

4.4 Effort Sharing for Selected GMS Countries

This study adopts four different effort-sharing approaches, namely, grandfathering (GF), immediate per capita convergence (IEPC), per capita convergence (PCC), and greenhouse development rights (GDR) to determine the carbon budgets for the selected GMS countries. Table 4 shows the descriptions of the four approaches.

The GF approach is believed to be a fair choice for developing countries [29]. The GF and PCC approaches are cost optimization approaches for most countries [34]. The IEPC stands on the equality concept which prioritizes human rights in atmospheric space. This concept is decently fair in terms of humanity and the value of all humans [34]. The GDR approach allocates large budgets to the developing countries which makes it suitable for the developing countries since reducing emissions affects the economic development of the countries. In contrast, this approach is not preferable if applied to the industrialized countries which have already emitted a substantial portion of the world's emissions. Thus, this study adopts the GF approach, IEPC approach, PCC approach, and GDR approach from the study of van den Berg et al. to determine the carbon budgets (CO_2 emissions only) for the selected GMS countries based on the 2°C goal of the Paris Agreement, and 1.5°C target.

Table 4. Descriptions of effort-sharing approaches

Approach	Description
Grandfathering	GF is based on “acquired rights” justified by custom and usage. Carbon budgets are allocated based on based-year emission shares.
Immediate per capita convergence (IEPC)	IEPC approach aims at equal individual rights to atmospheric space. Carbon budgets are allocated based on population shares during a certain period.
Per capita convergence (PCC)	PCC is based on the equity principle of sovereignty and equality. Carbon budgets are allocated based on emission shares and population shares.
Greenhouse development rights (GDR)	GDR is based on equity principle of responsibility and capability. Carbon budgets are based on the responsibility-capacity index including the per capita GDP and the income distribution.

Required datasets such as the baseline global carbon budgets are taken from the AIM/CGE 2.1 model in the CD-LINKS Database [45]. Historical and future baseline emissions data (excluding LULUCF) are based on the SSP2 scenario of the study of Gütschow et al. [46]. The requisite LULUCF emission data are estimated based on historical data, future forest land-area, and the future population of each country. The Responsibility-Capacity Index (RCI) values are obtained from Kemp-Benedict et al. [47]. Because of the small number of emissions emitted in the past within the four countries, the RCI values of Cambodia and Lao PDR stand on the setting of zero percent responsibility for the historical emissions. For Thailand and Vietnam, the RCI values are taken based on 10 percent responsibility for the historical emissions. The RCI values of the four countries are assumed to stay constant from 2030 until 2050.

5. RESULTS

5.1 Electricity Demand

Total electricity demand in the four GMS countries in the RE scenario would drop by approximately 9.34% by 2030 compared to the BAU. It is due to energy efficiency measures in the new energy plans. Vietnam makes up 62.6% of total electricity demand in the RE scenario by 2030 while Lao PDR would cover only about 1.5%. Figure 1 represents the total electricity demand in the four countries in the BAU and the RE scenarios. In 2015, the electricity demands in Cambodia, Lao PDR, Thailand, and

Vietnam were 335.4 kWh/capita, 637 kWh/capita, 2618 kWh/capita, and 1505 kWh/capita, respectively. By 2030, under the BAU scenario, the numbers would increase to 1048 kWh/capita, 1611 kWh/capita, 4991 kWh/capita, and 4835 kWh/capita accordingly. In the RE scenario, the electricity demand per capita in Cambodia would decrease from that in the BAU by approximately 15% in 2030 while the demand per capita in Lao PDR and Thailand would decrease by 10% and 77% respectively. On the other hand, the electricity demand per capita in Vietnam in the RE scenario in 2030 would slightly increase from that in the BAU scenario which will be accounted for 0.5%. Figure 2 demonstrates the electricity demands during 2015-2030.

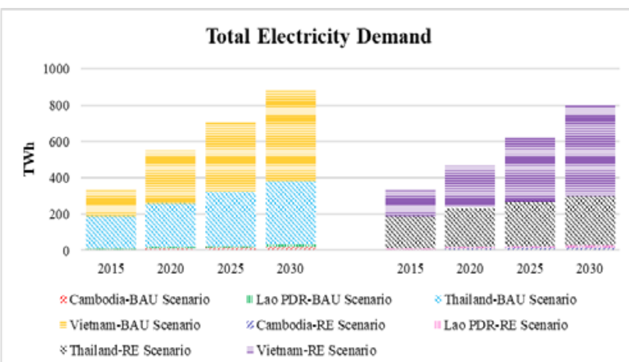

Fig. 1. Total electricity demand in the BAU and RE scenarios.

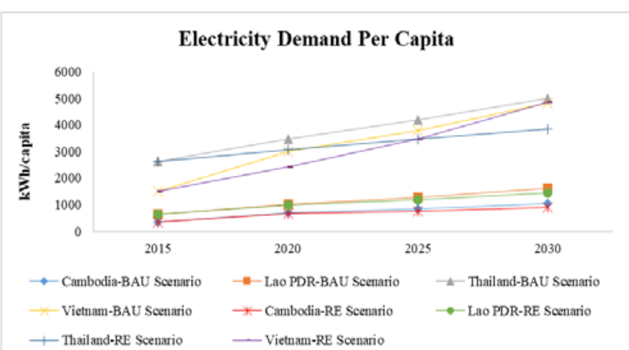

Fig. 2. Per capita electricity demands in the BAU and RE scenarios.

5.2 Electricity Supply

Like the electricity demand, the electricity generation in those countries would be decreased by 8.23% in the RE scenario by 2030 compared to the BAU. Figure 3 shows total electricity generation in the four countries during 2015-2030. The dominant source of electricity generation in 2015 is natural gas and coal. In the BAU scenario, coal, hydro, and natural gas would sum up to a total share of 85.84% of all the sources for electricity generation in 2030. Figure 4 shows total electricity generation in the BAU by types of sources.

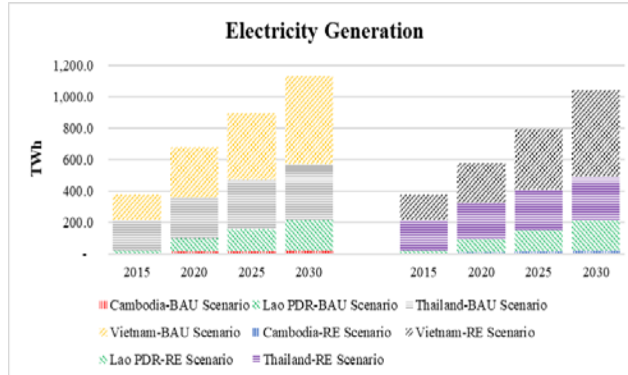

Fig. 3. Total electricity generation in the BAU and RE scenarios.

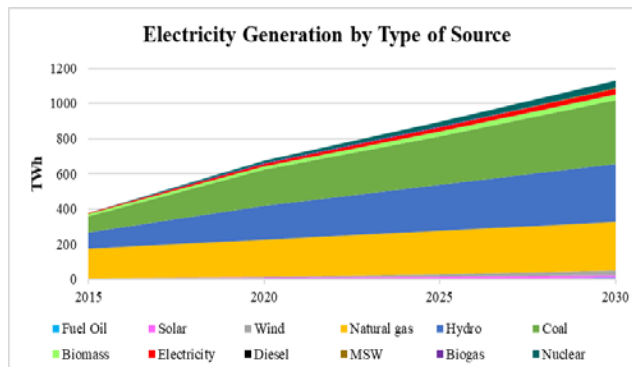

Fig. 4. Total electricity generation by types of sources in the BAU scenario.

However, hydro would be the main source of power generation accounting for a share of 35.2% in total of electricity generation. In the RE scenario, the share of renewable energy including hydro would increase from 28.2% in 2015 to 49.8% in 2030. Natural gas and coal would sum to a total share of 47.6% in 2030. Figure 5 illustrates total electricity generation by types of sources in the RE scenario during 2015-2030. Please note that the term electricity presented in Figure 4 and Figure 5 indicates the imported electricity.

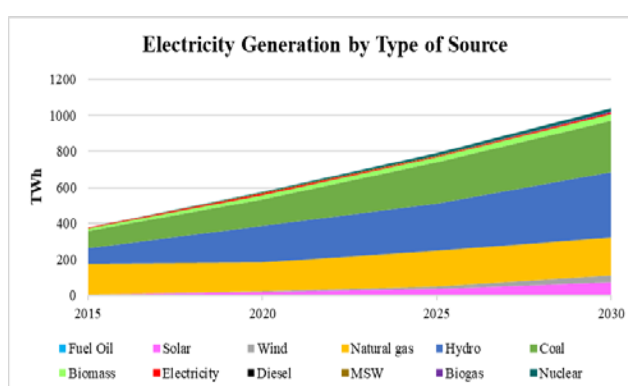

Fig. 5. Total electricity generation by types of sources in the RE scenario.

5.3 GHG Emissions in the Power Sector

In the RE scenario, GHG emissions from emission sources in the power sector in 2030 would be mitigated by about 24.1% compared to the BAU. Figure 6 presents GHG emissions from power generation during 2015-2030 in the BAU scenario and RE scenario. Table 5 illustrates the comparison of GHG emissions reduction between the RE scenario and the NDCs targets.

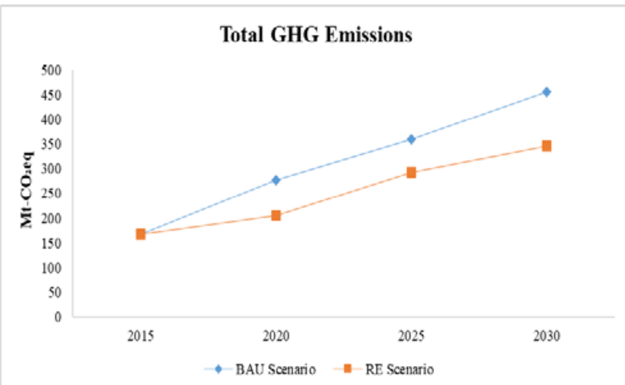

Fig. 6. Total GHG emissions from power generation in the selected years.

Vietnam is the major contributor of GHG emissions in the power sector in both the BAU and RE scenarios. Vietnam would reduce approximately 47 $Mt\text{-}CO_2eq$ of GHG emissions from power generation in the RE scenario compared to the BAU scenario in 2030. Vietnam would have a share of 70.1% among the total GHG emissions while Thailand would cover 26.7% in the RE scenario. Thailand would reduce about 36.4% of GHG emissions in the RE scenario. Cambodia and Lao PDR would cover 6.4% and 3.5% respectively of the GHG emissions in 2030. Figure 7 shows GHG emissions by country from 2015 to 2030 in the BAU and RE scenarios.

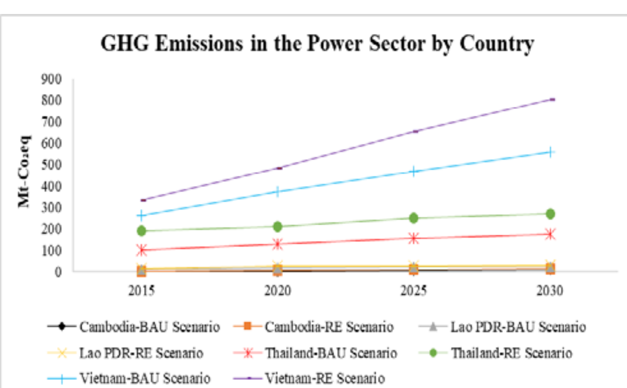

Fig. 7. Comparison of GHG emissions from power generation in the BAU and RE scenarios.

Table 5. GHG emissions reduction in RE scenario and NDCs targets

Year	RE scenario	Targets in NDCs
2030	110.1 $Mt\text{-}CO_2eq$	177-339 $Mt\text{-}CO_2eq$

5.4 Emissions Gap in Southeast Asian Countries

Total GHG emissions in all Southeast Asian countries in the BAU would be approximately 4.91 $Gt\text{-}CO_2eq$ and 5.83 $Gt\text{-}CO_2eq$ by 2030 and 2050, respectively. Even after considering the full achievement of the NDCs targets, both the unconditional and condition targets, the emissions gap to reach the 2°C pathway would still be big. The gaps are even bigger for Southeast Asian countries to reach the 1.5°C emissions pathway.

As shown in Figure 8, the emissions gap between the NDC-U and the 2D2050 and 1.5D2050 scenarios would be 2.4 $Gt\text{-}CO_2eq$ and 2.9 $Gt\text{-}CO_2eq$ in 2030, respectively. The emissions between the 2D2050 and the NDC-C-DOU and the 1.5D2050 and the NDC-C-DOU in 2050 would be 1.71 $Gt\text{-}CO_2eq$ and 2.52 $Gt\text{-}CO_2eq$, respectively. Even considering tripling the NDCs targets in 2050 in the NDC-C-TRI scenario, there exists gaps to reach the 2D2050 and the 1.5D2050 of 0.33 $Gt\text{-}CO_2eq$ and 1.14 $Gt\text{-}CO_2eq$ in 2050, respectively.

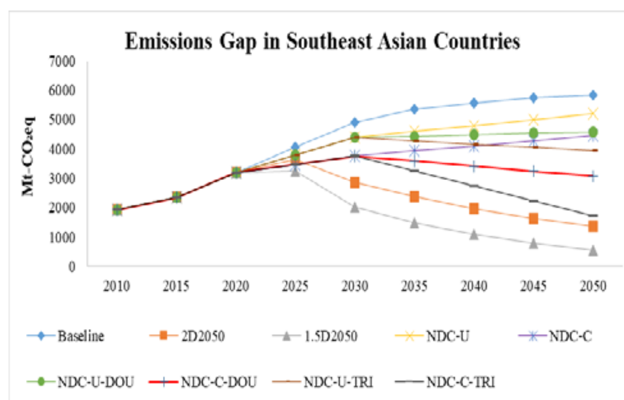

Fig. 8. Emissions gap in Southeast Asian countries

5.5 Emissions Gap in GMS

The focus of the emissions gap in the four GMS countries shows similarity to the emissions gap in Southeast Asian countries as presented in Figure 9. Noticeably, the emissions gaps in these countries between the 2D2050 and the NDC-U scenarios, and the 1.5D2050 and the NDC-U scenarios are accounted for 632.1 $Mt\text{-}CO_2eq$ and 874.8 $Mt\text{-}CO_2eq$ in 2030, respectively. In the NDC-C scenario, the emissions gap to reach the 2D2050 and 1.5D2050 scenarios in 2030 would be 416.1 $Mt\text{-}CO_2eq$ and 658.8 $Mt\text{-}CO_2eq$, respectively. When extending the NDCs targets in 2050 in the NDC-U-DOU and NDC-U-TRI scenarios, the emissions pathways of these scenarios would still not reach the pathways of the 2°C goal and 1.5°C target in 2050. The gaps indicate that if the targets in the NDCs were to be increased from 2030 onward, the targets would need to be higher than three-fold of the 2030 targets of the NDCs to reach the 2℃ emissions pathways in 2050.

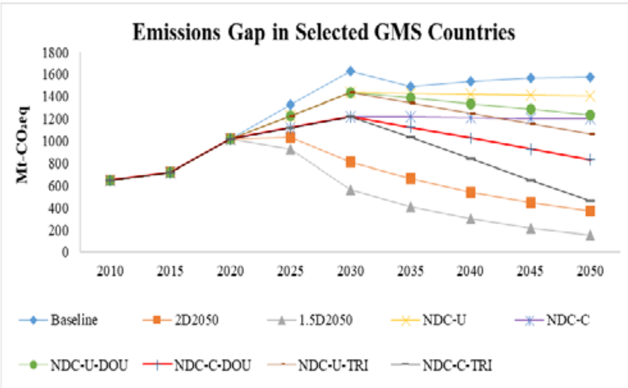

Fig. 9. Emissions gap in selected GMS countries.

5.6 Carbon Budgets for Selected GMS Countries

5.6.1 Carbon Budgets Based on the 2℃ Target

Results of the four GMS countries suggest that the total cumulative carbon budgets in the IEPC approach of the four selected countries will be bigger than the other three approaches during 2011-2050. Lao PDR would be given the smallest cumulative carbon budget when compared to Cambodia, Thailand, and Vietnam under the IEPC approach. This is because Lao PDR has the smallest population among the four countries and Lao PDR was the least CO_2 emitter in the past among the four countries.

The carbon budgets by 2050 relative to 2010 carbon emissions of the four countries under the GDR approach would be approximately 92.3%, 269.2%, 36.3%, and 42.3% respectively as can be seen from Figure 10. Lao PDR will be allowed to emit more CO_2 by 2050 because Lao PDR has the smallest RCI values compared to the other three countries.

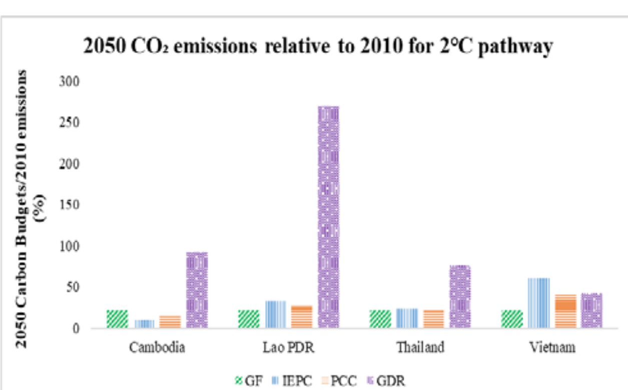

Fig. 10. Carbon budgets including LULUCF of effort-sharing approaches in 2050 relative to 2010 emissions.

Note: The carbon budgets are presented as a percentage of carbon dioxide emissions in 2010.

Figure 11 presents the cumulative 2011-2050 carbon budgets including LULUCF relative to the 2010 carbon emissions for the selected GMS countries based on the 2°C emission pathway. The cumulative carbon budgets during 2011-2050 based on the 2℃ goal of the Paris Agreement of the four GMS countries in the GDR approach would be 5.26 Gt-CO_2eq, 1.1 Gt-CO_2eq, 10.11 Gt-CO_2eq, and 4.14 Gt-CO_2eq, respectively. Vietnam would be allowed for the most cumulative carbon budget during 2011-2050 in the IEPC approach because of its huge population. However, in the GDR approach, Thailand would have the biggest cumulative carbon budget during the same period because Thailand emits the most CO_2 emissions in the past.

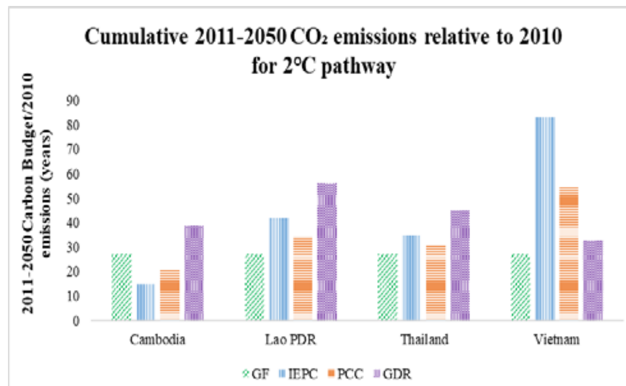

Fig. 11. Cumulative carbon budgets including LULUCF relative to 2010 based on the 2℃ target.

Notes: Cumulative carbon budgets (2011-2050/2010 carbon emissions) are based on the 2°C goal and are expressed in emission years (i.e., the cumulative carbon budgets during 2011-2050 is equal to the amount of 2010 emissions emitted constantly throughout the years that are expressed in the graph).

5.6.2 Carbon Budgets for Selected GMS Countries Based on the 1.5℃ Target

Based on the 1.5℃ target, the total cumulative carbon budgets including LULUCF during 2011-2050 of the four countries in the GF, IEPC, PCC, and GDR approaches would be 11.68 Gt-CO_2eq, 18.21 Gt-CO_2eq, 14.94 Gt-CO_2eq, and 18.7 Gt-CO_2eq, respectively. In the GF approach, Thailand would have the largest carbon budget during 2011-2050 based on the 1.5℃ emissions pathway followed by Cambodia and Vietnam while Lao PDR has a smallest value. In the IEPC, Vietnam would have the largest cumulative carbon budget and would be followed by Thailand, Cambodia, and Lao PDR. Figure 12 illustrates the cumulative carbon budgets during 2011-2050 for the selected GMS countries based on the 1.5℃ target under various approaches.

Similar to the cumulative carbon budgets based on the 2℃ emissions pathway relative to the 2010 CO_2 emissions, the IEPC approach would allow Vietnam to have the largest cumulative 2011-2050 carbon budgets based on the 1.5°C emissions pathway relative to the 2010 CO_2 emissions (see Figure 13). It can be noted that the GDR approach would allow for the most cumulative carbon budgets for Cambodia, Lao PDR, and Thailand when compared to the effort-sharing approaches. In contrast, only Vietnam would have the smallest cumulative carbon budget compared to the three other approaches during 2011-2050.

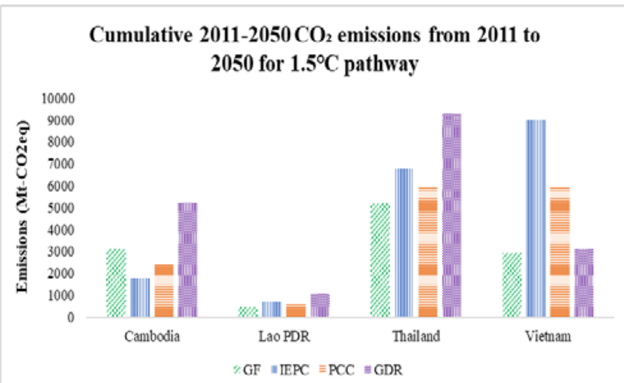

Fig. 12. Cumulative carbon budgets including LULUCF of effort-sharing approaches based on the 1.5°C pathway.

Notes: Cumulative carbon budgets (2011-2050 carbon emissions) are based on the 1.5°C target and are expressed in Mt-CO_2eq.

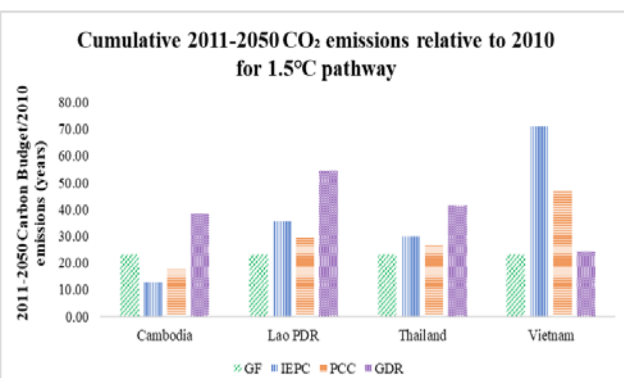

Fig. 13. Cumulative carbon budgets including LULUCF relative to 2010 based on the 1.5°C target.

Notes: Cumulative carbon budgets (2011-2050/2010 carbon emissions) are based on the 1.5°C target and are expressed in emission years (i.e., the cumulative carbon budgets during 2011-2050 is equal to the amount of 2010 emissions emitted constantly throughout the years that are expressed in the graph).

6. CONCLUSION

This study presents potential of RE and GHG mitigation in power generation in the four GMS countries under the pledged NDCs within 2030. Total GHG emissions in the four countries would be mitigated by 110.1 Mt-CO_2eq compared to the BAU scenario in 2030. Thus, approximately 62% of GHG emissions targets can be achieved. It is recommended that governments revise their national master plans to promote renewable energy. Additional studies should be considered for the feasibility of advanced climate measures such as carbon capture and storage (CCS) and smart grids.

The emissions gap in Southeast Asian countries shows that the full achievement of current NDCs targets would not be enough for the countries to reach the 2°C target of the Paris Agreement nor the 1.5°C emissions pathway. The emissions gap in the selected GMS countries between the NDC-U and NDC-C scenarios and the 2D2050 scenario would be 632.1 Mt-CO_2eq and 416.1 Mt-CO_2eq respectively in 2030. The gaps in 2050 would be 1.03 Gt-CO_2eq and 0.83 Gt-CO_2eq, respectively. When the targets in the NDC-C scenarios in 2030 are tripled in 2050, the emissions gap to reach the 2D2050 and 1.5D2050 scenarios would be 89.9 Mt-CO_2eq and 309.1 Mt-CO_2eq respectively in 2050. The emissions gap indicates that if the current NDCs targets were to be increased from 2030 onward, the targets would need to be three-fold higher than the 2030 targets of the NDCs to reach the 2°C target in 2050.

Regarding the emission pathways, there are no any official effort-sharing approaches to determine the fair mitigation contribution which leads to the existence of various approaches within the research community. However, the efforts still can be viewed. For this study, the cumulative carbon budgets, including emissions from LULUCF, during 2011-2050 based on the 2°C goal of the Paris Agreement for the selected countries under the IEPC approach are the biggest among the four approaches adopted in this study whereas the smallest carbon budgets for the four countries are found in the GF approach. Similarly, based on the 1.5°C target, the GF approach would allow for the smallest cumulative carbon budgets. On the contrary, unlike the carbon budgets based on the 2°C emissions pathway, the approach that would allow for the largest carbon budgets based on 1.5°C target during the same period would be the GDR approach.

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