Renewable Energy Achievements in CO_2 Mitigation in Thailand's NDCs

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Abstract

Thailand had summited its Intended Nationally Determined Contributions (INDCs) in 2015 and ratified the Paris Agreement in September 2016. Its INDCs stated that by 2030 GHG emissions will be reduced by 20-25% when compared to the business-as-usual (BAU) scenario by using mainly domestic renewable energy resources and energy efficiency improvement. Therefore, this paper assesses the potential of greenhouse gas (GHG) emission reduction by the use of renewable energy in Thailand's INDCs and the economic impacts from GHG emission reduction. This paper employed the Asia-Pacific Integrated Model/Computable General Equilibrium (AIM/CGE). Besides the BAU scenario, four mitigation scenarios are assessed at given GHG emission levels and renewable power generation targets. Results show that Thailand's INDC can be achieved under the current renewable energy target in Thailand's Power Development Plan 2015. As a result, macroeconomic loss will be small under the light GHG reduction target; however, it will be large under the stringent GHG emission reduction target. The GDP loss ranges from 0.2% in the case of a 20% reduction target to 3.1% in the case of a 40% reduction target in 2030. Thus, the availability of land for deploying the renewable energy technologies such as solar, wind and biomass needs to be assessed.

Keywords: Renewable power generation, CO_2 mitigation, Nationally Determined Contributions (NDCs), Computable general equilibrium model

1. Introduction

The climate change issue has achieved general consensus and become a common issue [1]. The IPCC Fifth Assessment Report (AR5) concluded that human activities are the main sources of GHG emission inducing the current climate change [2]. The current emission reduction reveals significant GHG emission gaps resulting in the global mean temperature rise of 3.7-4.8^{o}C by the end of the 21st century [3]. Therefore, the AR5 proposed the global carbon emission pathway to stabilize the global mean temperature to be less than 2^{o}C compared to the pre-industrial level and to require GHG emissions to peak before 2030 [3]. The GHG emission should decrease to net-zero emissions at the end of the 21st century. However, developing countries will require time to achieve such targets [3, 4].

In order to lessen the GHG emissions while preserving both the economic growth and social development, the United Nations Framework Convention on Climate Change (UNFCCC) established an international climate agreement during the Conference of Parties (COP21) in December 2015 [5, 6]. The Parties agreed to diminish the effect of climate change through low-carbon and climate-resilient development by preparing the post-2020 climate actions, so called Intended Nationally Determined Contributions (INDCs) [5-9]. The INDCs outline the intended climate actions, particularly the climate policies related to the cooperation between the government, policy-makers and infrastructure development. The agreement also stated that the adaptation plans are also engaged. Moreover, the implementation of INDCs not only guarantees the countries' commitment but also provides insight into climate actions ambition and financial supports [7]. Thus, INDCs can become key points for improving the energy production system, preventing damage to the environment through implementation of ambitious climate policies, and providing a mechanism for low-carbon development. As of May 2016, 162 INDCs have been submitted to the UNFCCC, representing 189 countries [10]. In October 2015, Thailand submitted its INDCs to the UNFCCC, in which the GHG emissions will be reduced by 20-25%. Therefore, total GHG emissions in 2030 should be approximately 440 Mt-CO_2eq in the case of 20% reduction and 417 Mt-CO_2eq in the case of 25% reduction [11]. Figure 1 illustrates quantified GHG emission reductions obtained from energy sector (including power sector, manufacturing industry, transport sector, and commercial and residential sector), waste sector, and industrial processes and product use (IPPU) sector by 2030. Finally, Thailand ratified the Paris Agreement in September 2016.

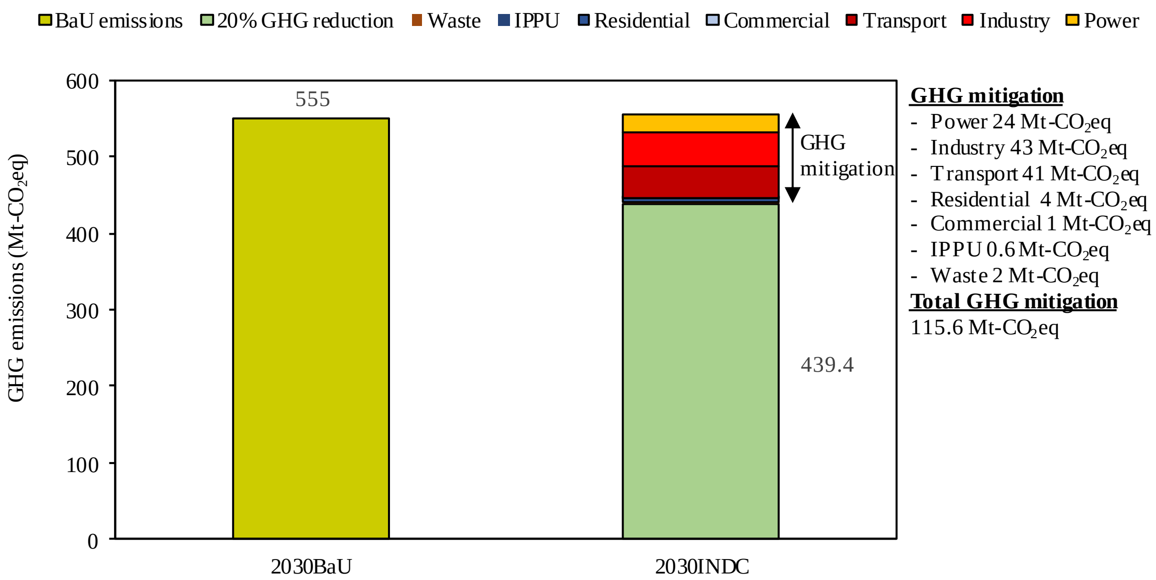

Figure 1 GHG emissions in the BaU scenario and Thailand's INDC by 2030 [11].

Several studies have focused on addressing climate change issues and INDCs through the economic development by the implementation of renewable energy. China has studied the economic aspects for achieving its INDC targets [1, 12-14]. Dai et al. (2016) examined the economic impacts of large-scale installation of renewable energy and its co-benefits in China and suggested that the renewable energy (RE) resources, and the availability and reformation of grid connectivity should be verified. Moreover, the installed capacity of RE will boost the RE manufacturing industries [15]. The economic impacts of international carbon market following the China's INDC target were investigated by Qi and Weng (2016). In addition, Mittal et al. (2016) suggested that the role of renewable energy can reduce the economic loss and that the introduction of carbon capture and storage (CCS) can be another significant technology to control the GHG emission level [16]. Furthermore, Sundriyal and Dhyani (2015) suggested that to achieve the target of 40% non-fossil fuel in its energy system by 2030, India will need 200 GW of renewable energy power plants by 2030. Altieri et al.

(2016) explored the economic impacts of concentrated solar power, solar photovoltaics and wind generation to achieve the South Africa INDCs. The gross domestic product (GDP) loss and welfare loss caused by renewable energy has been assessed for achieving the Vietnam INDCs target and establishes that renewable energy in the electricity generation sector could substantially reduce mitigation costs [4].

In the past few years, there have been limited studies in Thailand that investigated climate policies under a low carbon economy by employing renewable energy [19-26]. Thepkhun et al (2013) assessed Thailand's Nationally Appropriate Mitigation Action (NAMA) in the energy sector under emission trading scheme (ETS), and they suggest that the ETS plays a vital role in reducing GHG emissions through energy efficiency improvements and the implementation of renewable energy together with CCS technologies. Winyuchakrit et al (2016) investigated the potential of renewable energy for achieving a low-carbon economy and concluded that the adoption of available renewable energy could eliminate a tremendous amount of the GHG emissions from the industrial sector and the transport sector. Moreover, Selvakkumaran et al (2015) assessed CO_2 reduction potentials together with energy security, other air pollutants and marginal abatement cost through the low carbon pathway of Thailand.

Many studies have presented assessments of global and national mitigation measures with several low carbon measures [1, 4, 5, 9, 14-16, 18-28]. However, to facilitate a successful global climate agreement, ambitious and stringent actions on national scale are inevitable and would be valuable to be assessed. Therefore, this paper aims to analyze two research questions: firstly, the capability of GHG emission reduction scenarios through the use of renewable energy in Thailand's INDC and, secondly, the economic impact from GHG emission reduction targets. In this paper, the AIM/CGE (Asia-pacific Integrated Model/Computable General Equilibrium) model is used for the assessment. The AIM/CGE is a top down computable general equilibrium model which vastly used for assessing the macroeconomic impact of environmental policies [15, 16, 27-36].

This paper is arranged into six sections. After the introduction in section 1, section 2 reviews Thailand's power development plan 2015 (PDP2015) and Thailand's INDC. Section 3 describes the methodology and scenarios designed which gives the basic information of the AIM/CGE model and its applications for analyzing the macroeconomic impact of environmental policies. Results, including the economic impacts in all scenarios, are presented in section 4. Section 5 discusses the implication of modeling results, policy implications and limitations. Section 6 gives the conclusion of this study.

2. Thailand energy plans related to renewable energy

2.1 Thailand's power development plan 2015 (PDP2015)

Thailand launched an updated PDP in 2015. The PDP2015 considers changes in economic and infrastructure development. In 2015 the five master plans were integrated. They were PDP2015, Energy Efficiency Plan (EEP2015), Alternative Energy Development Plan (AEDP), natural gas supply plan, and petroleum management plan. The PDP2015 covers period of 2015-2036. It focuses on energy security, economy, and ecology. The average annual growth rate of GDP, estimated by the National Economic and Social Development Board, was about 3.94 percent. The PDP2015 included effects of EEP2015. The expected energy saving in the EEP2015 will be 89,672 GWh in 2036. Moreover, renewable energy such as biomass, biogas, wind and solar power will be encouraged in the AEDP2015. Investments in transmission and distribution system will help promoting renewable electricity and smart-grid development. Consequently, all plans are expected to be achieved by 2036. They are also considered as GHG mitigation actions. Therefore, such plans will not be included in the BaU scenario.

2.2 Thailand's INDC commitments under Paris agreement

On 1 October 2015, Thailand communicated its INDC to the UNFCCC. The important messages in the pledged INDC included the GHG emission reduction by 20 percent when compared to the BAU in 2030. However, Thailand's contribution will have the possibility to enlarge its reduction up to 25 percent with the sufficiency of technology development and the accessibility of technology evolution. Moreover, the financial resources and the human resources development significantly contribute the agreement [11].

3. Methodology and scenario description

3.1. AIM/CGE model

This study employs the AIM/CGE (Asia-pacific Integrated Model/Computable General Equilibrium model. Several studies employed the AIM/CGE for assessment of GHG mitigation and adaptation policies [29, 31, 32, 35-38]. The AIM/CGE is a recursive-dynamic general equilibrium model [39]. There are 42 industrial classifications (see Appendix A). Fujimori et al (2012) describes details of the model structure and mathematical formulae. This paper used a national version of the AIM/CGE model [16, 34, 40, 41].

The input parameters such as population, GDP, energy demand, the extraction cost of fossil fuels, and cost of renewable energy are exogenously given [4]. It presents energy supply and energy demand mixes, GHG emissions, and emission prices. Profit maximization is assumed for the production sectors, which is subject to multi-nested constant elasticity substitution (CES) functions and relative prices of inputs [16]. Household expenditures are assumed as a linear expenditure system (LES) function [16]. The savings come from domestic and foreign direct investment, which are given a proportion of GDP change relative to 2005. The capital formation is determined by a fixed coefficient of total investment. The Armington assumption is used for international trade [16]. In this paper, emissions of CO_2 from other sources including methane (CH_4) nitrous oxide (N_2O) and land changes are considered.

The GHG emissions constraint was specified based on the emission reduction target. When the emission constraint is added, the carbon tax becomes a complementary variable to the emission constraint, and the marginal mitigation cost is determined. In the mitigation scenario, the carbon tax affects fossil fuel prices resulting in cleaner fuels. The carbon tax also acts as an incentive to reduce non-energy-related emissions. GHG emissions other than CO_2 are weighted by their global warming potential to be CO_2 equivalent emissions as total GHG emissions. Households are assumed to receive the revenue from the carbon tax.

Costs of renewable technologies are obtained from the reports [42]. The input coefficients in the production function was changed because the output prices of these technologies were determined within the model.

3.2. Input data

The AIM/CGE model uses a Social Accounting Matrix (SAM) to calibrate the model. To precisely evaluate energy flow and GHG emissions, the CGE model is accounting not only for the original SAM but also for energy statistics. The Global Trade Analysis Project (GTAP) [43] and energy balance tables [44, 45] were used as a basis for the SAM and energy balance table. Its data were reconciled with international statistics such as national account statistics [46]. The method is described by Fujimori and Matsuoka [33]. GHG emissions and other air pollutant emissions were calibrated to EDGAR4.2 [47]. For the land use and agriculture sectors, agricultural statistics [48], land use RCP data [49], and GTAP data [50] were used for physical data. Data in 2005, as the base year, are used for model calibration.

3.3. Scenario description

To align with the obligation in COP21, the time horizon of this study is arranged in 2030 in-line with the Thailand INDC. The scenarios are designed based on the stringency of GHG emission reduction level. We performed five scenarios. One is a BaU scenario which does not have any emissions constraints. The other four scenarios are mitigation scenarios which have emissions constraints named RED1, RED2, RED3 and RED4. The mitigation scenarios are differentiated by the level of emissions reduction. The RED1 and RED2 scenarios are designed to be similar to Thailand's INDC commitment (20% and 25% GHG emissions reduction, respectively, compared to the BaU scenario). The RED3 and RED4 scenarios (30% and 40% GHG emissions reduction, respectively, compared to the BaU scenario) are considered alternative options to achieve the more stringent GHG mitigation and effects on Thailand's economy. These scenarios are already considered the EEP2015, PDP2015, and AEDP2015 to convey an impression on achieving INDC commitment.

The socio-economic indicators, including GDP and population growth, are taken from the Thailand's PDP2015 [51]. The Office of the National Economic and Social Development Board (NESDB) published the GDP growth and the population growth during year 2014-2036, including outcomes from the master plan for sustainable transport system and mitigation of climate change impacts [52]. The average GDP growth and the population

(POP) growth are expected to increase about 3.94% and 0.03% annually, respectively. Table 1 illustrates the past trend of Thailand's GDP growth rate during 2003-2017. In 2004 and 2005 the economic growth slightly declined according to high average oil prices, a reduction on subsidy in diesel fuel price, a continuous of bird flu epidemic and Tsunami impact [53, 54]. Therefore, the economic growth gradually decreased from 6.1% to 4.5% during 2004 and 2005 [54, 55]. Thai economy seemed to be severe during 2008 and 2009 due to the US financial crisis, therefore, Thai economic growth fell to -2.2% in 2009 [56, 57]. However, in the last quarter of 2009 and 2010, the economic could show a positive sign due to a recovery of global economy, thus, investors had more confident and also the expansion of export commodities [57]. Therefore, the economy grew at 7.8% by 2010 [58]. A severe flood critically affected Thai economy especially on manufacturing industries and tourism sector in 2011. Consequently, Thai economy strongly plunged by 0.1% in 2011 [59]. Thai economy did recover in 2012 which boosted the economic growth by 6.5%. Such an economic growth was mainly supported by an impact of the first-time-car-buyer scheme, the adjustment of minimum wage and the economic recovery in manufacturing products, hotels and restaurants, and construction sectors [60]. During 2013 and 2014, Thai economic growth substantially declined from 2.9% to 0.9%, respectively, according to an extended political disruption [61, 62]. However, Thai economic growth revealed positive signs during 2015, 2016 and in the first quarter of 2017, respectively. Such a recovery could be observed by; 1) the acceleration of government expenditure and investment; 2) a substantial growth in tourism sector; 3) the improvement of investor confidence; 4) the recovery of manufacturing productions; 5) high purchasing power due to low crude oil price; 6) the acceleration of farm income; and 7) the US$ 5.5 billion (equivalent to 190 billion baht, 2015 US$) [63, 64]. An averaged GDP growth rate was 3.7% during 2003-2016. Furthermore, GDP is expected to rise at 3.94%

(averaged GDP growth rate) from 2016 onwards. Such a growth rate can be achieved by transport infrastructure action plans [65].

Table 1

Thailand's GDP growth rate during 2003-2017 [53-65].

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
GDP (%)	6.7	6.1	4.5	5	4.8	2.6	-2.2	7.8	0.1	6.5	2.9	0.9	2.8	3.2	3.3

The electricity generation assumptions in both the BaU scenario and the GHG emissions reduction scenarios are shown in Tables 2 and 3, respectively. However, carbon capture and storage technologies, and nuclear power plants are excluded from this study. Fuel-oil power plants had been phased out from the electricity generation system due to the energy security, high crude oil price and public health anxiety after 2010. Currently, fuel-oil is only used for startup and testing the generation system. Furthermore, Table 3 shows that the electricity generation in the GHG emissions constraint scenarios is obviously lower than the BaU scenario (see Table 2). The reasons are as follows; 1) the electricity generation in the GHG emissions constraint scenarios included energy savings from the EEP2015 plan; 2) Thailand will import electricity from neighboring countries mainly hydro power from the Lao People's Democratic Republic; and 3) In the GHG emissions constraint scenarios, the primary energy supplies of RE sources such as biomass, solar, wind and hydro are higher than the BaU scenario. Table 2 and Table 3 show the historical data from 2005 – 2015 and the forecasted electricity generation from 2020-2030 [51].

Table 2

Electricity generation assumptions in the BaU scenario (Unit: GWh/year).

	2005	2010	2015	2020	2025	2030
Hydro power	5,821	5,528	7,088	7,898	7,863	7,558
Biomass	3,227	4,342	5,563	6,208	6,114	5,797
Solar	0	892	939	986	1,033	1,091
Wind	0	716	751	775	798	833
Coal	20,502	29,574	34,198	45,359	54,548	63,737
Fuel-Oil	9,447	47	70	70	94	106
Natural gas	101,209	119,387	151,614	167,386	198,427	235,207
TOTAL	**140,207**	**160,486**	**200,223**	**228,682**	**268,877**	**314,329**

Table 3

Electricity generation assumptions in the GHG emissions constraint scenarios (Unit: GWh/year).

	2005	2010	2015	2020	2025	2030
Hydro power	5,821	5,528	9,130	10,327	11,536	12,735
Biomass	3,227	4,342	9,752	18,273	26,793	35,320
Solar	0	892	1,843	3,403	4,964	6,532
Wind	0	716	951	1,854	2,758	3,654
Coal	20,502	29,574	34,292	40,981	47,682	54,379
Fuel-Oil	9,447	47	59	70	94	106
Natural gas	101,209	119,387	122,180	127,614	133,282	138,974
TOTAL	**140,207**	**160,486**	**178,207**	**202,523**	**227,109**	**251,594**

4. Results and discussion

4.1. The future trends of socio-economic indicators

An overview of the Thailand's socio-economic indicators and emission trajectories in Thailand during 2005-2030 is shown in Figure 2. Note that Figures 2 – 4 and 6 illustrate the historical data from 2005 – 2015 and the forecasted outcomes from 2020-2030. The population of Thailand gradually grew by 0.4% between 2005 and 2015. However, Thailand's population will increase by 0.03% and reach 70 million persons in 2030. Due to the economic development and the increment of income, GDP per capita level strongly increases in the BaU scenario without any climate policy interruption between 2005 and 2030. Thailand's per capita GDP will gradually grow to approximately 2.8 times the 2005 level in the BaU scenario. Total primary energy supply (TPES) and total final energy consumption (TFC) will augment to 136.9 million tonnes of oil equivalent (Mtoe) and 104.4 Mtoe within 2030 or equivalent to an augmentation of 1.7 times and 1.6 times, respectively (see Figure 3). Meanwhile, GHG emission will continue increasing from 383.2 million tonnes of carbon dioxide equivalent (Mt-CO_2eq) to 561.8 Mt-CO_2eq between 2005 and 2030 with an average increase by approximately 1.5% compound annual growth rate (CAGR). Figure 4 shows the energy intensity and GHG intensity under the GHG emission constraint scenarios. The energy intensity described in terms of TPES per GDP will gradually decrease. The GHG intensity represented as a ratio between GHG emission and GDP will slightly drop between 2.2 t-CO_2eq and 1.1 t-CO_2eq during 2005-2030 in the BaU scenario.

4.2. Total Primary Energy Supply (TPES)

This section presents the TPES in all GHG reduction scenarios. Economic development together with the increase in incomes results in an increase of TPES. The BaU scenario shows the highest amount of TPES in 2030 (137 Mtoe). Figure 3 shows that TPES will increase in all scenarios by 2030 when compared to 2005. The GHG reduction measures are introduced to the economy which cause the decrease of TPES under RED1, RED2, RED3, and RED4 scenarios compared to the BaU scenario. TPES in RED1, RED2, RED3, and RED4 scenarios are 126 Mtoe, 122 Mtoe, 117 Mtoe, and 105 Mtoe, respectively. The decrease in TPES under RED1, RED2, RED3, and RED4 scenarios will be 11 Mtoe, 14 Mtoe, 20 Mtoe and 32 Mtoe, respectively. RED4 scenario shows the lowest level of TPES due to the stringent GHG reduction which encourages the energy price to rise. The RED4 scenario can reduce TPES by 30% when compared to the BaU scenario in 2030. Figure 5 shows the primary energy mix under the GHG reduction scenario.

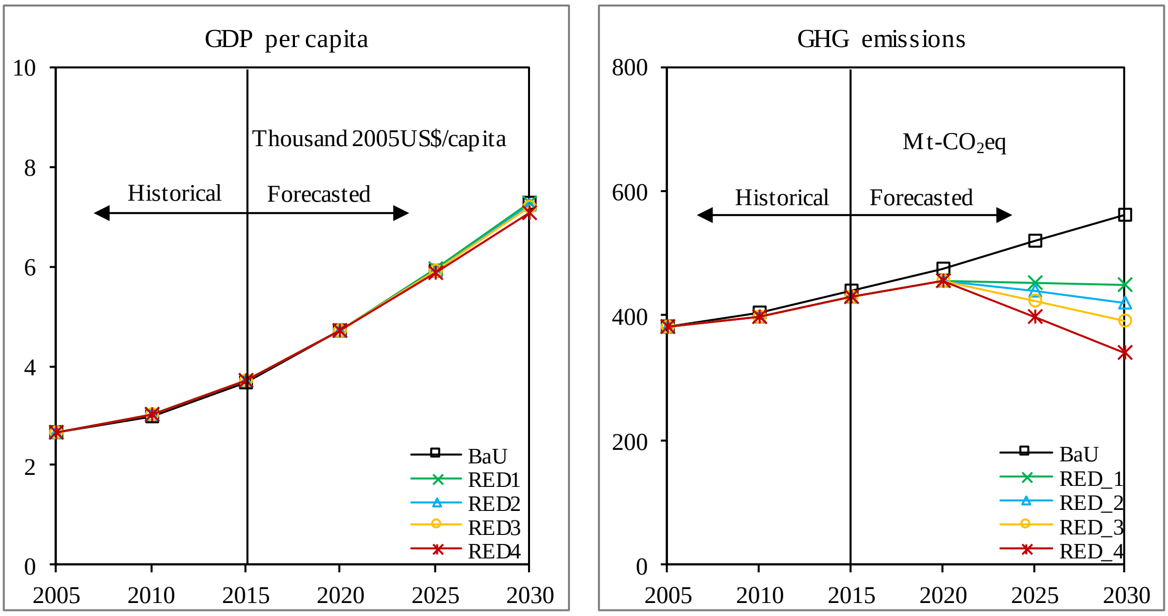

Figure 2 Thailand's socio-economic indicators and emission trajectories.

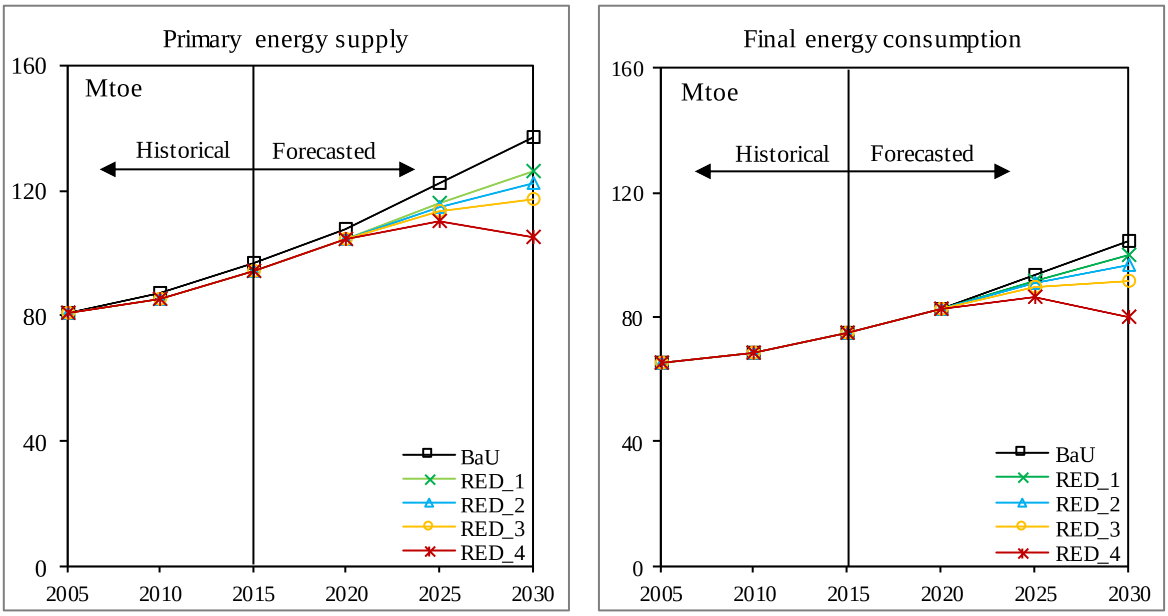

Figure 3 Thailand's primary energy supply and final energy consumption.

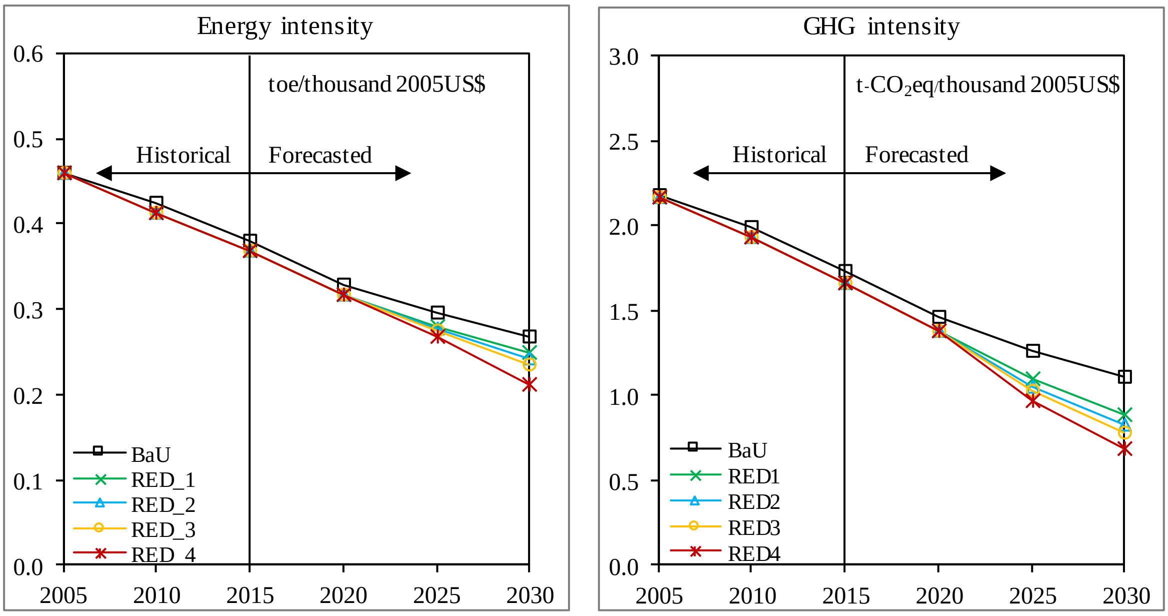

Figure 4 Energy and emission intensity.

The share of fossil fuel, particularly coal consumption, will increase without any climate policy intervention in the BaU scenario. However, with the climate policies the share of fossil fuels will diminish in the GHG reduction scenarios as illustrated in Figure 6. The share of fossil fuels (coal, crude oil and natural gas) will be reduced by 16%, 20%, 26% and 39% under the RED1, RED2, RED3, and RED4 scenarios, respectively, when compared to the 2030 BaU scenario. By contrast, the share of renewable energy will gradually drop during the study timeframe in the BaU scenario. As a result, the share of renewable energy will be decreased by approximately 10% in 2030. However, climate policy intervention will have a strong effect on energy diversification. The stringent GHG reduction levels from RE are considered after 2020 onwards according to the government policies on promotions of RE to be in line with Thailand's INDC. In the period of 2016-2019, the share of RE follows its trends during 2010-2015. Therefore, the share of renewable energy will moderately increase by 16.5%, 17.1% and 18.1% under the RED1, RED2, and RED3 scenarios by 2030, respectively. Moreover, the RED4 scenario shows the highest share of renewable energy will be 21% in 2030 (Note that the share of renewable energy indicated in this section includes solar, wind, hydro and biomass). Because Thailand is an agricultural-based country, biomass, particularly bagasse and rice husks, takes the highest share of renewable energy.

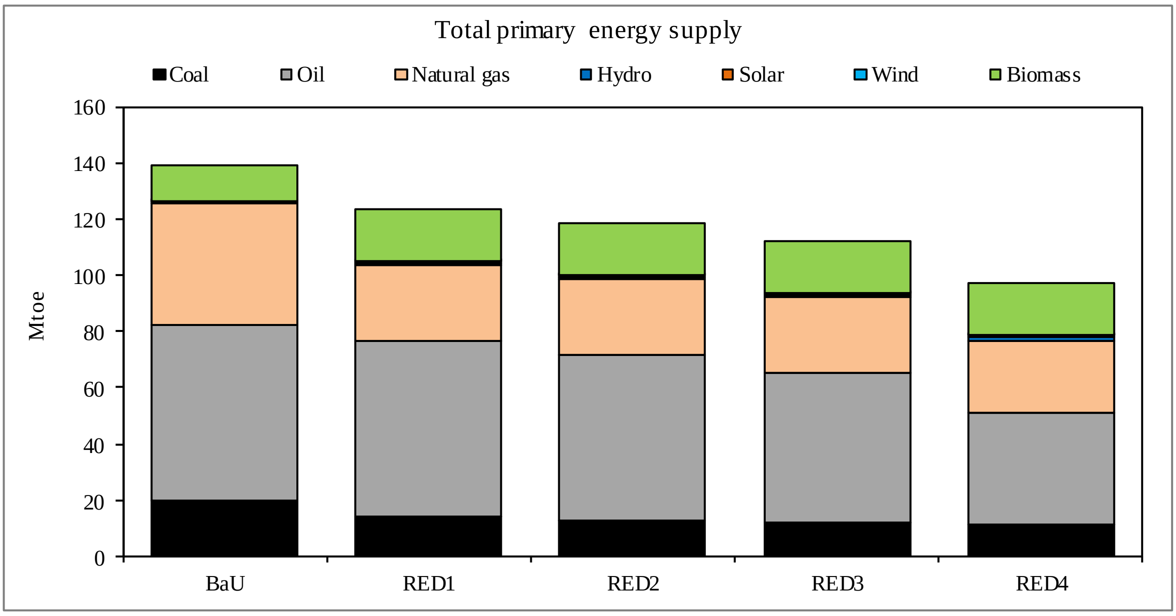

Figure 5 Primary energy mix in 2030.

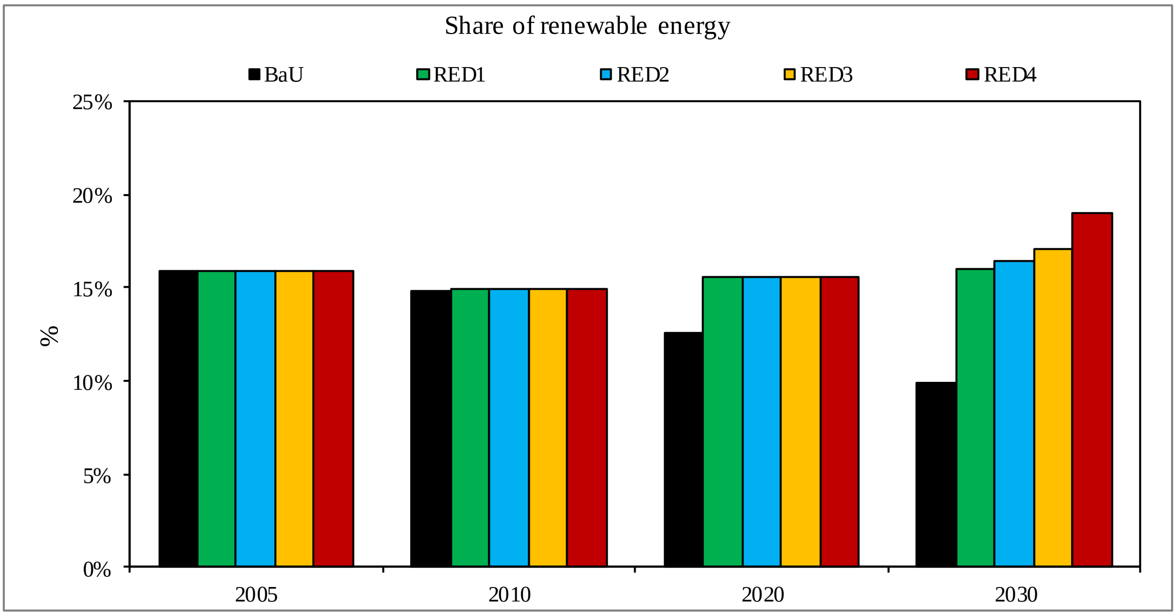

Figure 6 Share of the renewable energy.

4.3. GHG emissions

According to fossil fuel based combustion, total GHG emissions are forecasted to moderately increase to about 561 Mt-CO_2eq in the BaU scenario in 2030. The GHG emission constraints are externally given. The GHG emission pathway shows the descending trend starting from 2020 in the GHG emission reduction scenarios. The model projections show that Thailand' GHG emission will peak in 2020 (see Figure 2). The amount of GHG emission in 2020 is 456 Mt-CO_2eq in the GHG emission reduction scenarios. The RED1 scenario shows the lowest GHG emission reduction. The GHG emission can be reduced by 20% when compared to the BaU scenario in 2030. The RED1 scenario is already aligned with Thailand's INDC commitment to reduce its economy-wide GHG emissions by 20% by 2030. Furthermore, the GHG emission of the RED2 scenario in 2030 is 421 Mt-CO_2eq. The GHG emission could be reduced by 25% when compared to the BaU scenario in 2030. The corresponding commitment further mentions that the GHG emission could be reduced by 25% with sufficient international support and technology knowledge transfer. Meanwhile, the RED3 and RED4 scenarios substantially reduce the GHG emissions. Therefore, the GHG emission reduction will be reduced by almost 30% and 40% in RED3 and RED4 scenarios, respectively.

The GHG emission composition is shown in Figure 7. The GHG composition includes CO_2, CH_4 and N_2O. The CO_2 emission is the main driver of the GHG emissions. In the BaU scenario, the CO_2 emission will increase from 257 Mt-CO_2eq in 2005 to 421 Mt-CO_2eq in

2030. CH_4 and N_2O emissions represent a small portion of overall emissions in all scenarios during the study timeframe.

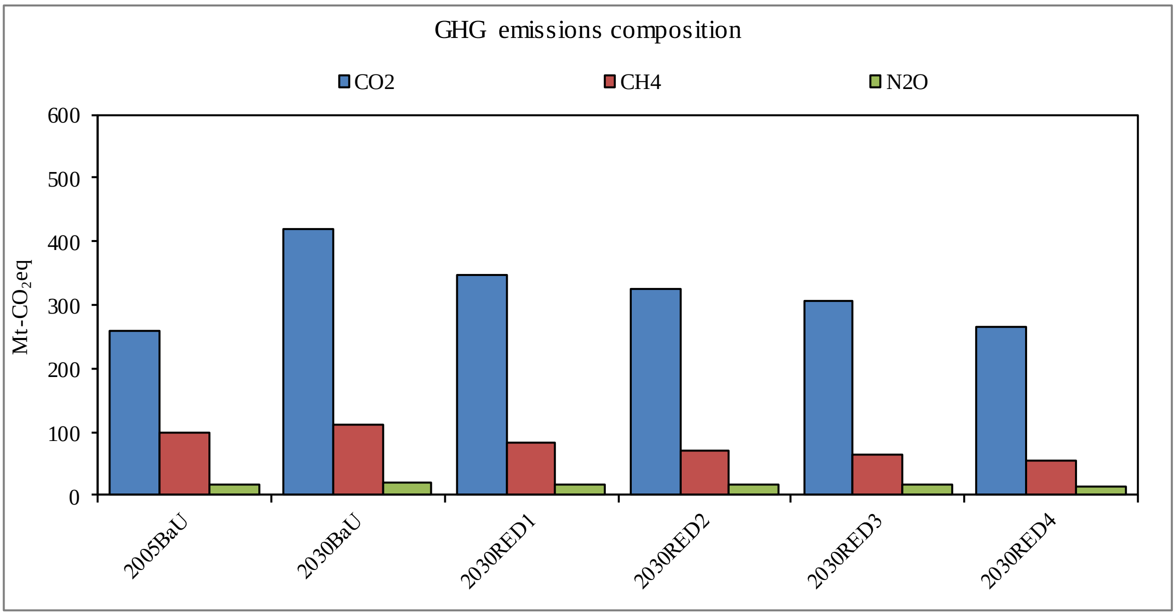

Figure 7 GHG emissions composition in 2030.

The corresponding emissions are mostly generated by fossil fuel combustion and industrial processes. The share of CH_4 and N_2O emissions remain at 15% and 4% in the RED4 scenario, respectively. The results show that the share of CO_2 emissions substantially dominates the total GHG emissions. As for the aspect of sectoral CO_2, CH_4 and N_2O emission, various sectors show the potential for GHG emission reduction as depicted in Figure 8 and 9. To align with the Thailand's INDC action plans, the electricity generation sector is a key CO_2 emission contributor (under the RED1 and RED2 scenarios). Its CO_2 emission could be reduced from 158 Mt-CO_2 to 131 Mt-CO_2 in all GHG emission reduction scenarios in 2030 when compared to the BaU scenario, and account for 34% of the CO_2

emission reduction. The industrial sector is the second largest sector of CO_2 emission reduction. The non-metallic industries and petroleum refineries are the main contributors of CO_2 emission reduction. The level of CO_2 emission reduction increases from 10% in the RED1 scenario to 48% in the RED4 scenario. The transport sector is the third largest contributor of CO_2 emissions. Results imply that the share of electric vehicles (EV) together with the electric trains tremendously increases during the stringent GHG reduction scenario. Consequently, CO_2 emissions can substantially reduce by 1%, 3%, 8% and 21% in the RED1, RED2, RED3 and RED4 scenarios, respectively. However, the CO_2 emission in the building sector will increase in the RED1 and RED2 scenarios when compared to the BaU scenario due to oil prices being cheaper than electricity prices. Thus, the consumers will use oil rather than electricity, and CO_2 emission reduction will be increased by 4%to 20% in the RED3 and RED4 scenarios, respectively.

The GHG emissions including the CH_4 and N_2O are calculated based on the global warming potential from an Intergovernmental Panel on Climate Change (IPCC). Figure 9 depicts the CH_4 and N_2O emission reduction in the RED1 scenario and the RED4 scenario in 2030 when compared to the 2030 BaU scenario. Since Thailand is an agricultural-based country, the agricultural sector will gradually reduce the CH_4 and N_2O emission ranging from 16% to 37% and 19% to 33%, respectively (see Figure 9).

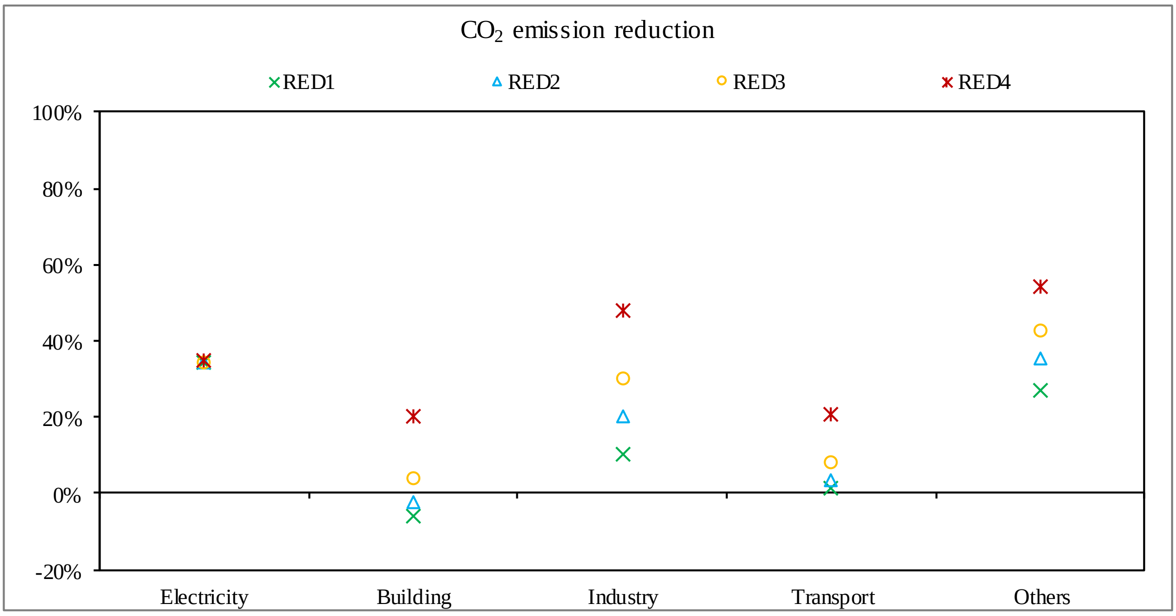

Figure 8 Sectoral CO_2 emission reduction in 2030.

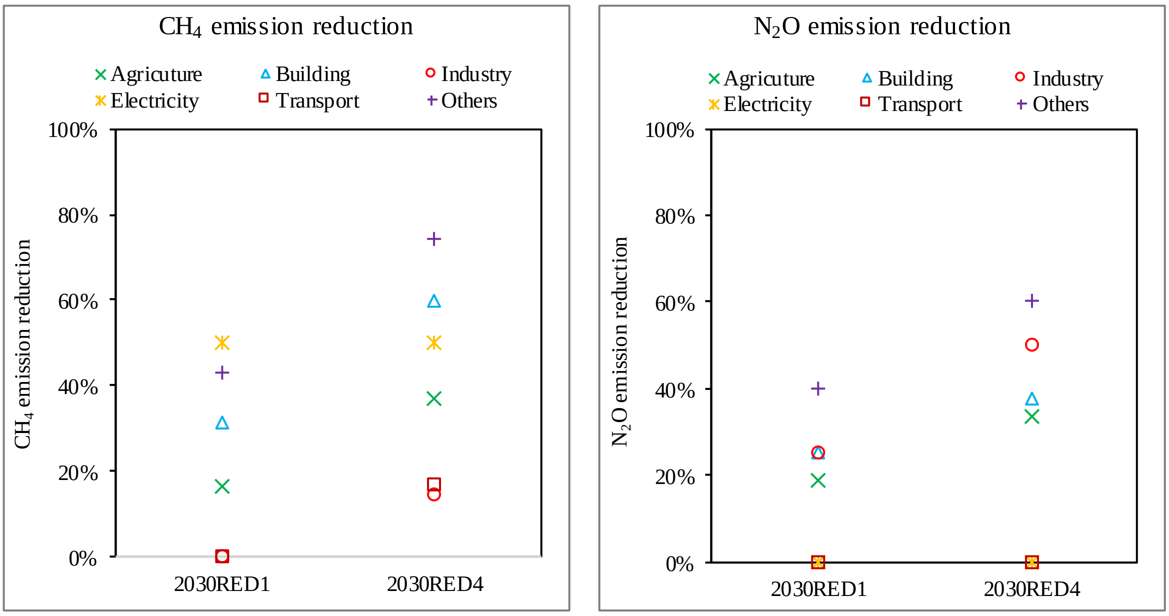

Figure 9 CH_4 and N_2O emission reduction.

4.4. Economic impacts

The AIM/CGE is a one-year step recursive dynamic general equilibrium model. The AIM/CGE is widely used for analyzing the climate change policies [4, 15, 16, 21, 27, 28, 30-37]. It can analyze not only energy consumption but also macroeconomic impacts under several environmental scenarios. Another purpose of this study is to examine the mitigation cost resulting from the GHG emission constraint scenarios. Thus, GHG price, GDP loss and welfare loss are presented in this section.

4.4.1. GHG price

Figure 10 depicts the GHG price trajectory resulting from the GHG emission reduction scenario. The GHG prices are endogenously calculated while GHG emission constraints are given exogenously. The induced emission price is directly related to the carbon-intensive sectors. The levels of the emission prices reveal the amount that should be paid for the emission activities. The emission prices not only stimulate the GHG emissions reduction activities but also encourage investment in clean technology and the low-carbon pathway. The emission price is related to the emission reduction between the BaU scenario and the GHG emission constraint scenarios. Therefore, in order to investigate the transformation from high carbon-intensive economy to low carbon-intensive economy, it is reasonable to consider the emission prices within the economy.

The aforementioned results disclose that the industrial sector will significantly reduce GHG emissions. The emission price will start to rise in 2021 when the GHG emission reduction targets are introduced. The emission prices gradually escalate through 2030. It can be seen that higher emission prices will be induced by more stringent emission reduction levels. The induced emission prices start from US$1/t-$CO_2$eq in 2021 (see Figure 10). The emission price in 2030 ranges from US\$6/t-CO_2eq to US\$16/t-CO_2eq in the RED1 and RED2 scenarios.

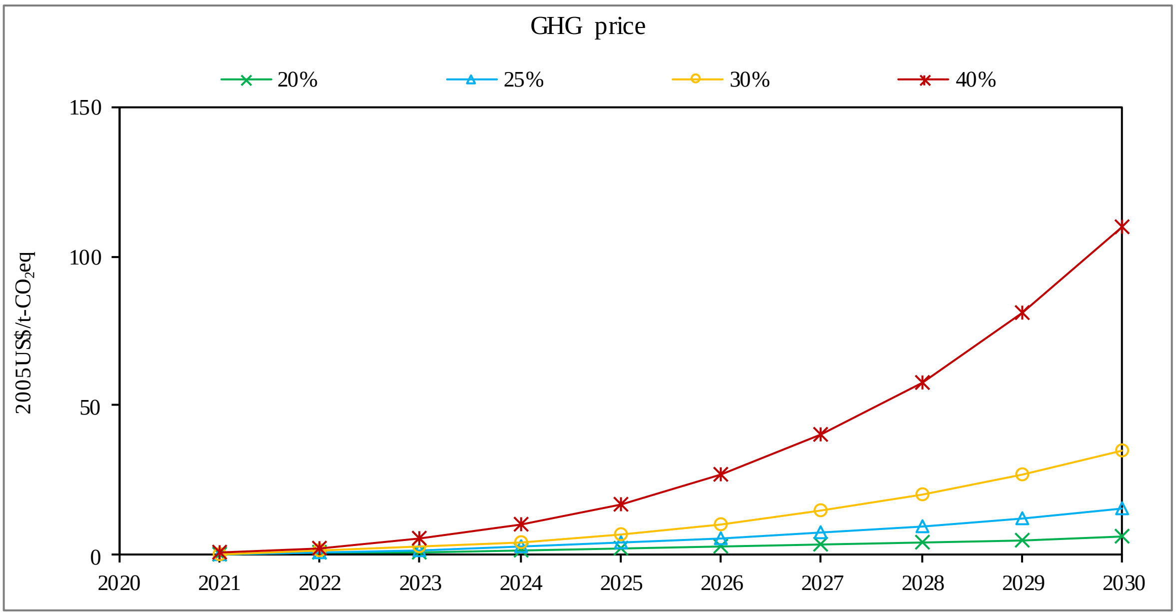

Figure 10 GHG price trajectory.

However, the emission price will rise exponentially under the RED3 and RED4 scenarios. The emission price ranges from US\$35/t-CO_2eq to US\$110/t-CO_2eq in the RED3 and the RED4 scenario in 2030. In conclusion, the CO_2 emissions in the power sector will remain constant throughout GHG emission constraint scenarios following the PDP2015. Hence, the emission price will hurt the carbon-intensive sectors, particularly in the industrial sector as observed from Figure 8.

4.4.2. GDP loss and welfare loss

Obviously, the emission prices stimulate the carbon-intensive sectors to reduce their fossil fuel combustion activities. Such emission prices directly have the adverse impacts on the economy. Consequently, GDP loss and welfare loss substantially increase while the investment in clean technologies together with low-carbon societies gradually attain greater importance. Welfare loss refers to amounts of consumers (households) need to pay for clean products and services to satisfy their living standard [66]. Thus, higher rates of welfare loss implied that households lose their income to obtain clean products and services. Obviously, welfare loss depends on stringent levels of GHG mitigation level in this study. The unit of GDP and welfare in this study are measured in billion 2005US$. Table 4 shows the GDP loss and welfare loss in 2030 under the GHG emission constraint scenarios compared to the BaU scenario. The GDP loss and welfare loss in this study are measured as relative change between the GHG emission constraint scenarios and the BaU scenario. The GDP loss substantially increases throughout the RED1 to RED4 scenarios. The GDP loss ranges from 0.2% in the RED1 scenario to 3.1% in the RED4 scenario in 2030.

Moreover, welfare loss can be investigated by the ratio between the household expenditure and government consumption in the GHG emission constraint scenarios and the BaU scenario. Imports and exports are balanced in the AIM/CGE model. Hence, the dissimilarity of GDP change in each scenario absolutely depends on the household expenditure. By contrast, the welfare loss is calculated by the fraction between the household expenditure in the GHG emission constraint scenarios and the aforementioned expenditure in the BaU scenario. Therefore, the welfare loss illustrates the surpassing amounts when compared to the GDP loss under the same GHG emission constraint scenario. Hence, welfare loss would be 0.2% to 4.2% in 2030 under the RED1 to RED4 scenarios. In conclusion, the GDP loss and welfare loss imply that Thailand will achieve a better living standard under the RED1 to RED4 scenarios. Both GDP loss and welfare loss can also reveal that there is an improvement in the end-use fuel switching, the end-use structural change, the end-use efficient appliances and the end-use behavior changes.

Table 4

GDP loss and welfare loss in 2030.

Scenario	GDP (million 2005US$)	GDP loss (%)	Welfare (million 2005US$)	Welfare loss (%)
BAU	510,404	-	360,900	-
RED1 (20% reduction)	509,648	0.2	360,144	0.2
RED2 (25% reduction)	506,992	0.7	357,488	1.0
RED3 (30% reduction)	503,414	1.4	353,910	1.9
RED4 (40% reduction)	494,623	3.1	345,119	4.2

4.5. Implication of the modelling results and limitation

The results illustrated in the previous section show the remarkable insight for achieving Thailand's INDC. Therefore, there are five key points that can be discussed from the modelling outcomes.

First, the GDP loss and welfare loss will gradually increase as shown in table 4. The RED1 scenario and the RED2 scenario imply that renewable energy for the electricity generation sector in the PDP2015 is appropriate for achieving Thailand's INDC target. Due to the fact that renewable energies can lessen the GDP loss and welfare loss, the availability of land for deploying renewable energy technologies such as solar, wind and biomass need to be evaluated to meet the GHG emission levels. Vietnam, China and India also have provided insight into the effect of renewable energy on GDP loss, welfare loss and GHG price [4, 15, 16]. Thus, increased use of renewable energy in the electricity generation sector not only makes possible the achievement of stringent GHG emission reductions, but also provides a cost-effective method for doing so. Under the RED1 scenario and the RED2 scenario, the

GHG prices of US$6 and US$16 per ton of GHG demonstrates that renewable energy, if appropriately introduced, can help achieve the Thailand INDCs. However, the installed capacity of renewable energy in the PDP2015, which is designed for 20% renewable electricity, may not be sufficient to meet higher emission reduction targets. Thus, the government should provide not only the ambitious renewable energy target but also disclose the co-benefits of renewable energy to the community. Thus, it is recommended that policy-makers should also present the investment cost, technological characteristics and return on investment to the investors for their decision making.

Second, Thailand was upgraded from a lower-middle-income country to an upper-middle-income country in 2011. Moreover, Thailand has obviously switched from an agriculture base to a major exporter in Southeast Asia with substantial economic development in the last century [67]. The people earn more income and, thus, have the capability of spending on high-quality goods which consume less energy compared to conventional ones. Additionally, the stringent GHG emission reduction levels increase the price of fossil fuel in energy-related CO_2 industries; therefore, there is a shift from high-carbon intensive commodities to low-carbon intensive commodities which can also induce the efficient technologies that will reduce the economic cost. Although these factors have important effects on energy use and GHG emissions, they are complicated to analyze in the model framework and are better explained in a quantitative way. Furthermore, NESDB reports that Thailand will become an aging society in the future, and aging people will expend more on health services for which the energy consumption and the GHG emission would be diminished.

Third, clear communication between the government and private sectors is needed to discuss how the rapid penetration of renewable energy could reduce the mitigation cost and the macroeconomic loss. Thus, the renewable energy incentive policy should be aligned with the national climate policy. The government have already launched the incentive called "feed-in tariff" mechanism. The mechanism particularly stimulates the private sector to invest in renewable energy, including small hydro power projects, grounded-mount solar farms, solar rooftops for residential buildings, wind power, biomass power plants, and municipal solid waste power plants. However, the impacts of feed-in-tariff mechanism are excluded in this analytical framework.

Fourth, the development of infrastructure, including smart grids and energy storage technologies, is another mechanism to stimulate the penetration of renewable energy. Currently, Thailand's smart grid policy plan and roadmap have been publicly disclosed. There are 3 stages of implementation; stage 1, planning and pilot projects including micro grid and other related systems and equipment from 2012-2016; stage 2, expanding the pilot projects into larger facilities covering major cities and developing efficient large-scale renewable energy and energy storage from 2017-2021; stage 3, enabling a nationwide smart grid and applying "two-way" power supply of electric vehicles. However, if smart grid and energy storage were be implemented successfully, Thailand would not only become a regional hub for distributing large scale renewable energy and energy storage, but would also encourage the renewable energy industry to establish factories in Thailand. Furthermore, such motivation would also create numerous jobs to serve such industries as already reported in the case of China [15].

Fifth, this study focuses on the Thailand INDC harmonizing the role of renewable energy targets provided in PDP2015 with the GHG emission reduction and the economic implication. The future works will include the nuclear power in the analysis since the Thai government plans to add nuclear power plants in 2035. Moreover, the carbon capture and storage shows tremendous emission reduction potential. Therefore, both technologies would play a vital role in GHG mitigation after 2030. Further studies would be covering the impacts of smart grids on renewable energy deployment and estimating the role of energy storage. The economic implication of electric vehicles is also another area for future research.

Finally, this study also investigates the CH_4 and N_2O emissions reduction under the GHG emission reduction levels. The study implies that CH_4 and N_2O emissions would be reduced in all sectors excluding the electricity generation sector. Therefore, GHG emissions reduction not only gives the sustainable development insight but also reveals the co-benefits of human health.

5. Conclusions and policy implications

This study investigates the role of renewable energy for achievement of Thailand's INDC together with the economic impacts of GHG emission reduction using the AIM/CGE model. Four scenarios for Thailand are constructed to investigate the effect of renewable energy ranging from the light GHG reduction levels to the most stringent one. Moreover, the role of renewable energy is exogenously provided in the model following the Thailand Power Development Plan 2015 (PDP2015). We can conclude that under the current power development plan, Thailand's INDC can be achieved. Furthermore, macroeconomic loss will be small under the light GHG reduction target; however, it will be large under the stringent GHG emission reduction target. Thus, to achieve the stringent GHG emission reduction conditions, government needs to promote and harmonize the availability of renewable energy and the available land with the national climate policy. Furthermore, we suggest that policy-makers also consider the impacts of distance between renewable sites and urban areas. The policy-makers should provide the length of transmission lines and visibility restrictions for the renewable energy sites.

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Appendix A

Table A1

The AIM/CGE's industrial classification.

Agricultural sectors	Energy supply sectors	Other production sectors
Rice	Coal mining	Mineral mining and other quarrying
Wheat	Oil mining	Food products
Other grains	Gas mining	Textiles and apparel and leather
Oil seed crops	Petroleum refinery	Wood products
Sugar crops	Coal transformation	Paper, paper products and pulp
Other crops	Biomass transformation (first generation)	Chemical, plastic and rubber products
Ruminant livestock	Biomass transformation (second generation with energy crop)	Iron and steel
Raw milk	Biomass transformation (second generation with residue)	Nonferrous products
Other livestock and fishery	Gas manufacture distribution	Other manufacturing
Forestry	Coal-fired power	Construction
	Oil-fired power	Transport and communications
	Gas-fired power	Other service sectors
	Nuclear power	Carbon capture service
	Hydroelectric power	
	Geothermal power	
	Photovoltaic power	
	Wind power	
	Waste biomass power	

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