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An Assessment of the Impacts of Renewable Energy Policies on the Thai Electricity Generation Sector

Supannika Wattana*, [1] and Buncha Wattana[#]

Abstract – *This paper aims to assess the implications of an increased electricity generation from renewable energy on the Thai electricity generation sector with a particular focus on energy security and CO_2 emissions mitigation potentials. For this purpose, three scenarios (REF, AEDP2015 and AEDP2018), developed in this paper, represent penetration levels of electricity generated from renewable energy. The implications have been analyzed through the application of LEAP model for the period 2018–2037. The analyses revealed that high penetrations of renewable energy would have positive impacts on the Thai electricity generation from several perspectives including improving the diversification of electricity supply, decreasing fossil fuel imports for generating electricity, less dependency on fossil fuel, environmentally friendly power generation, utilizing agricultural wastes, and build-up of local capabilities in electricity generation. Moreover, the energy transition due to disruptive innovations would make renewable energy more attractive. However, the transition would raise several challenges for the Thai electricity system, for example, capital-intensive investment, centralized electricity system, traditional regulatory framework and a lack of social involvement. In order to address the transitional challenges, the Thai government has initiated a number of policies including the upgrade of the grid to smart grid, the development of energy storage and the revision of the regulations to support local energy business. In addition to the initiation of the government's policies, this paper suggests that a structural change in the form of a separation between generation and transmission functions of the state electric utility, the development of new infrastructure and network regulation, and collaborations among stakeholders by increasing more participation and governance as well as aligning regulatory arrangement taking into account more on social objectives would provide a robust pathway to efficiently integrate renewable energy into the Thai electricity system.*

Keywords – *Alternative Energy Development Plan, electricity sector, LEAP model, renewable energy, Thailand.*

1. INTRODUCTION

Electricity is one of the most vital ingredients in meeting basic human needs, and in driving economic growth and social development. Therefore, the growth for electricity demand has constantly increased and tends to rise continuously. Between the years 2006 and 2018, electricity demand in Thailand increased annually by about 3.6%, from 127,879 GWh in 2006, to 187,823 GWh in 2018 [1]. In order to meet its growing demand for electricity, energy resources for electricity generation has been mainly from fossil fuels. For example, in Thailand, more than 70% of electricity generation in 2018 was from fossil fuels [2]. Such a high dependence on fossil fuels has, therefore, contributed to an increase in greenhouse gases emissions. In Thailand, CO_2 emissions from electricity generation over the period 2006–2018 has risen by 13 million tonnes, from 81 million tonnes in 2006, to 94 million tonnes in 2018 [3].

In recognition of the concerns about heavy reliance on fossil fuels and climate change, the Thai government has implemented policies to promote and support renewable energy. In 2015, the government has developed the Alternative Energy Development Plan (AEDP2015) for the period 2015–2036. The main objective of this plan is to increase the proportion of alternative energy, from 9,025 KTOE in 2014 to 39,402 KTOE in 2036 or 30.1 per cent of total energy consumption [4]. According to the AEDP, the proportion of electricity from renewable energy production would increase to 20% in 2036 – a double increase as compare to 2015. The installed capacity of solar, wind, biomass, biogas, waste-to-energy and small hydro is expected to grow to 6,000 MW, 3,000 MW, 5,570 MW, 600 MW, 550 MW, and 376 MW respectively. In addition, the Thai government has implemented, in 2018, a more challenging target by increasing the proportion of renewable energy in electricity generation to 33% in 2037. This new target would result in an increase in the generating capacity of solar, wind, biomass, biogas and waste-to-energy to 15,574 MW, 2,989 MW, 5,786 MW, 928 MW, and 975 MW in 2037 respectively [5]. With this background, this paper aims to assess the impacts of an increase in electricity generated from renewable energy with a particular focus on energy security and CO_2 emissions mitigation potentials. This assessment would provide an understanding about the renewable energy potential in the context of Thailand and importantly, recommend a robust pathway for supporting renewable energy in Thailand.

* Solar Energy and Energy Research Unit, Faculty of Engineering, Mahasarakham University, Kantarawichai, Mahasarakham, 44150, Thailand.

[#] Faculty of Engineering and Industrial Technology, Kalasin University, 46000, Thailand.

[1]Corresponding author:
Email: supannika.w@msu.ac.th.

2. RENEWABLE ENERGY IN THAILAND

Due to limited domestic energy supply, Thailand is heavily dependent on imported energy to meet the increasing energy demand of the country. In order to supply the growing energy demand, imported energy increased steadily, from 58.7 MTOE in 2006 to 83.1 MTOE in 2018 [2], [6]. In 2018, imported energy accounted for more than 60% of the total commercial primary energy in the country [2]. Of the total commercial energy, fossil fuels accounted for 92%, of which oil contributed 49%, followed by natural gas (33%) and coal (10%). In 2018, total final energy consumption was 89,952 KTOE, an increase of 4% in comparison with the corresponding value in 2017. Of the total final energy consumption, petroleum products had the largest share (49.3%), followed by electricity (20%), renewable energy (9.4%), coal and its products (8.2%), natural gas (6.9%), and traditional renewable energy (6.2%). It should be noted that renewable energy referred to solar, wind, hydro, biomass, biogas and waste-to-energy where as traditional renewable energy referred to fuel woods and charcoal. Electricity generation from renewable energy in 2018 was 34,730 GWh, an increase of 19.7% as compare to the year 2017. Of the total electricity produced by renewable energy, biomass had the largest share (54.8%), followed by solar (15.7%), hydro (14.5%), biogas (5.9%), wind (3.8%), waste-to-energy (3.5%) and small hydro (1.7%) [7]. CO_2 emission in 2018 was 238 million tons, of which electricity sector contributed 36%, followed by industrial sector (31%), transportation (26%) and others (7%) [3].

Being heavily dependence on imported energy and agricultural-based country, the Thai government has, therefore, a policy to support the use of renewable energy over the last two decades. In order to promote renewable energy, the Thai government has developed the first National Alternative Energy Development Plan (2004–2011) with a particular focus on production mandate for biofuels (especially biodiesel), tax and non-tax incentives, research and development supports, and public awareness promotion [8].

In 2008, the Second Alternative Energy Development Plan (2008–2022) was developed with the main target of increasing the proportion of alternative energy, to 20% of the national final energy consumption by 2022 [9]. The objectives of this plan were: a) to utilize alternative energy as a major energy substitute for imported oil; b) to increase energy security of the country; c) to promote an integrated green energy utilization in communities; d) to enhance the development of alternative energy industry; and e) to research, and develop high efficient technology for alternative energy. As noted above, the main focus of the plan was biofuel. The use of renewable energy has, therefore, had insignificant role in electricity generation over the period 2004–2012. According to DEDE [2], [10], the proportion of electricity production from renewable energy had increased slightly from 0.002% in 2004, to 3% in 2012.

A new AEDP was, however, emerged in 2012. This new AEDP (2012–2021) was developed by DEDE [11] with the main target of increasing the proportion of alternative energy, to 25% of the national final energy consumption by 2021. Under this plan, the country's planners had increased attention to support electricity production from renewable energy. For example, electricity generation from solar was expected to grow from 75 MW in 2012, to 2,000 MW in 2021. The AEDP target of wind power generation in 2021 was 1,200 MW while the existing generating capacity is 7 MW. The target of 3,630 MW for biomass to produce electricity was set to achieve AEDP in 2021 while the existing generating capacity is 1,751 MW. And, hydro, biogas and waste to energy in 2021 was expected to grow to 1,608 MW, 600 MW and 160 MW respectively. Due to a high potential of renewable energy in the country together with cost reduction in solar energy, the government has set a new target for electricity generation from renewable energy. In 2015, the Thai government has released a new Alternative Energy Development Plan (AEDP2015) for the period 2015–2036. The main objective of this plan is to increase the share of renewable energy to 30.1% of total energy consumption [4]. Under this plan, the proportion of electricity generated from renewable energy would increase to 20% in 2036 – a double increase as compare to 2015. The installed capacity of solar, wind, biomass, biogas, MSW and small hydro is expected to grow to 6,000 MW, 3,000 MW, 5,570 MW, 1,280 MW, 550 MW and 376 MW respectively. In addition, the Thai government has implemented, in 2018, a more challenging target by increasing the proportion of renewable energy in electricity generation to 33% in 2037. This new target would result in an increase in the generating capacity of solar, wind, biomass, biogas and waste-to-energy to 15,574 MW, 2,989 MW, 5,786 MW, 928 MW, and 975 MW in 2037, respectively.

3. RESEARCH METHODOLOGY

This paper employs a scenario-based approach and energy model for assessing the impacts of an increase in electricity generated from renewable energy on the electricity generation sector. In order to assess the impacts, scenarios are developed quantitatively to assess their impacts for the period 2018–2037. The development of scenarios is mainly based on the Alternative Energy Development Plan (AEDP). In this paper, three scenarios (namely REF, AEDP2015 and AEDP2018) represent penetration levels of renewable energy for electricity generation. The REF scenario reflects a situation in which the energy mix for generating electricity continue to be the same as the shares of energy resources in electricity production in 2018. The scenario represents a continuation of current trends in energy and technology mix for power generation. The AEDP2015 reflects the alternative energy planning which implemented in 2015 (AEDP2015). In the AEDP2015 scenario, there would be higher shares of renewable energy in the power sector than in the REF scenario. The AEDP2018 scenario is developed to represent the latest alternative energy targets in which the government has just implemented. For more details of each scenario, Table 1 provides an overview of the key scenario features and the target for renewable energy capacity is presented in Table 2.

To assess the energy and environmental impacts, the literature provided several methodologies including MARKAL, MESSAGE, TIMES, MAED and LEAP. Ringkjob *et al*. [12], and Bhattacharyya and Timilsina [13] provide a good review of modelling tools for energy and electricity systems. In this study, the Long-range Energy Alternative Planning (LEAP) system appears to be optimal choice due to its advantages in terms of ease-of-use, data flexibility, adaptability to different scales and policy-friendly reporting. LEAP is a static energy-economy-environment model which is maintained and supported by the Stockholm Environment Institute (SEI) [14]. This tool forecasts the electricity demand and estimates the energy and environmental impacts of each electricity scenario in terms of electricity dispatch by each power plant, fuel consumption for electricity generation by each fuel type and CO_2 emissions. LEAP is a widely used tool for energy policy analysis and climate change mitigation assessment. LEAP has been employed by several studies to assess the energy and environmental impacts [15]-[22].

Table 1. Key scenario features.

Scenario theme	Key scenario features
REF scenario	• Represent a continuation of current trends in energy and technology mix for power generation. • Natural gas maintains its position as the dominant energy resources for power production. • The share of renewable energy in electricity production would be 10% until the year 2037.
AEDP2015 scenario	• Reflects the alternative energy planning (AEDP2015). • Increasing share of renewable energy in electricity generating capacity, from 10% in 2018, to 20% in 2037.
AEDP2018 scenario	• Reflects the alternative energy planning (AEDP2018). • Significant increase in share of renewable energy in electricity generating capacity, from 10% in 2018, to 33% in 2037.

Table 2. Target for renewable energy capacity in 2037.

Renewable energy type	Generating capacity (MW)		
	Current situation[1]	AEDP2015 scenario	AEDP2018 scenario
Solar	2,849	6,000	15,574
Wind	1,504	3,002	2,989
Biomass	2,290	5,570	5,786
Biogas	382	1,280	928
Waste-to-energy	531	550	975
Small hydro	188	376	188
Hydro[2]	2,918	2,906	2,918
Total	10,662	19,684	29,358
Share of RE in electricity generation (%)	10%	20%	33%

Note: [1]Information on the generating capacity of the current situation is from Thailand Alternative Energy Situation report [7].
[2]Hydro-power in this paper refers to the generating capacity from the EGAT only.
Sources: [4], [7]

4. DATA CONSIDERATION

This study requires broad range of data including electricity consumption for various economic sectors, power generation by energy types, electricity generating capacities, electricity losses, efficiencies of power plant technologies, electricity load curve and growth for end-use electricity demand. The historical data on electricity consumption for various economic sectors, power generation by energy types, generating capacities and electricity losses is available from various Thailand Energy Balance reports and Thailand Alternative Energy Situation reports, annually published by the Department of Alternative Energy Development and Efficiency (DEDE) [2], [6]. The information on the growth for end-use electricity demand can be obtained from the Power Development Plan (PDP2018) developed by the Energy Policy and Planning Office (EPPO), Ministry of Energy (MOE) [23]. The shares of electricity capacity by each plant type (*e.g.,* steam turbine, combine-cycle, cogeneration, hydro and renewable energy) can be taken from the PDP2015 and PDP2018 [23]-[24]. The targets for renewable energy capacity including solar, wind, biomass, biogas, waste-to-energy and small hydro are available from the Alternative Energy Development Plan (AEDP2015) and AEDP2018 developed by DEDE and supplemented by EPPO and EGAT. The data on the efficiencies of power plant technologies can be taken from external sources including International Energy Agency (IEA) and Energy Information Administration (EIA) [25]-[26]. The specific information on electricity load curve for Thailand can be taken from EGAT and the relevant literature [27]-[28].

5. KEY ATTRIBUTES FOR ASSESSING SCENARIO IMPACTS

In order to achieve research objective, this paper focuses on analyzing the impacts in terms of energy security and CO_2 emissions mitigation potentials. The energy security concerns have, in the recent times, moved to the forefront of global energy policy debate. A number of studies have provided an impressive literature on the dimensions and attributes of energy security [29]-[31]. For example, Sovacool [30] has developed an energy security assessment instrument, including 20 energy security dimensions and 200 attributes that can be employed as energy security evaluation index. These attributes are, for example, diversification of energy supply, diversification of fuels for electricity, capacity margins and carbon dioxide emissions. According to UNDP [32], the notion of energy security focuses on the adequacy, availability, diversity, affordability of energy resources and their associated nonreversible environmental impacts. In order, therefore, to promote energy security, a range of measures could be implemented, for example, diversifying energy supplies, reducing energy import dependency, raising energy efficiency, maintaining adequate reserve capacity, improving energy sector governance, and making greater use of renewable resources [33]. On the basis of the reviews noted above, this paper employs four attributes, namely, diversification of electricity generation, generation technology mix, primary energy mix and carbon dioxide emissions as key indicators for assessing the scenario impacts.

6. EMPIRICAL RESULTS AND DISCUSSIONS

This paper assesses the scenario impacts in terms of diversification of electricity generation, generation technology mix, primary energy mix and CO_2 emissions for Thailand over the period 2018–2037. In order to assess the scenario impacts, annual growth for electricity demand is assumed to be 3.13% over the entire studied period. This growth is based on the PDP2018 [23].

6.1 Electricity Generation

In order to meet the growing electricity demand, power generation is expected to increase from 200 TWh in 2018, to nearly 400 TWh in 2037 for all three scenarios (as presented in Figure 1). Over the period 2018–2037, the power production from natural gas under the REF, AEDP2015 and AEDP2018 scenarios would increase by 93%, 67% and 45%, respectively. In 2037, the electricity production from natural gas in the case of the REF, AEDP2015 and AEDP2018 scenario would rise to 243 TWh, 212 TWh and 184 TWh respectively. For the period 2018–2037, the electricity generated by coal and lignite in the REF, AEDP2015 and AEDP2018 scenarios would rise by 97%, 82% and 62% respectively. In 2037, the generation of electricity from coal and lignite under the REF, AEDP2015 and AEDP2018 scenarios would increase to 74 TWh, 68 TWh and 60 TWh. From Figure 1, the power generation from renewable energy appears to increase noticeably. For example, power produced by solar in 2037 is expected to rise by about 2 times in the REF scenario, 4 times in the AEDP2015 scenario, and 15 times in the AEDP2018 scenario as compared to 2018. Moreover, the electricity generation from wind in the AEDP2015 and AEDP2018 scenarios in 2037 would be, respectively, 235% and 311% of the generation in the REF scenario. In terms of biomass, electricity produced from biomass in 2037 is expected to increase to 34 TWh in the AEDP2015 and 36 TWh in the AEDP2018 – more than three-fold increase as compared to 2018. It appears that these trends are likely to be attributed to significant penetrations of renewable energy in electricity generation in the case of AEDP2015 and AEDP2018 scenarios. It is further observed that imported electricity would also increase considerably for all three scenarios. In 2037, electricity imported from neighboring countries is expected to rise from 14 TWh in 2018, to 38 TWh in the REF scenario, 37 TWh in the AEDP2015 scenario, and 35 TWh in the AEDP2018 scenario.

Figure 2 shows that the share of natural gas in electricity production would decrease in all three scenarios. In 2037, for example, the share of natural gas for the REF, AEDP2015, and AEDP2018 scenarios would reduce by 2%, 10%, and 17%, respectively, as compared with the share in the year 2018 when natural gas accounted for 63% of total power production. Such a reduction could be attributed to the government's policy to diversify primary energy supply for power production. This is because natural gas has been major energy sources for electricity production in Thailand over the last three decades [2], [34]. According to PDP [23], the Thai government has the policy to enhance the energy security by reducing the share of natural gas in electricity production and substituting by renewable energy. In terms of coal and lignite, its share in 2037 would also decrease to 17% in the AEDP2015 scenario and 15% in the AEDP2018 scenario. In addition, the share of oil, both in the case of the AEDP2015 scenario and AEDP2018 scenario, is likely to drop to nearly 0 in 2037. These decreases are replaced by an increased share of renewable energy especially solar. For example, the share of solar in electricity generation in the case of the AEDP2018 scenario is expected to grow considerably from 2% in 2018, to 11% in 2037. Furthermore, the share of biomass would also increase from 5% in 2018, to 9% in 2037 for both in the AEDP2015 and AEDP2018 scenarios. Electricity generation from wind in the case of AEDP1015 and AEDP2018 scenarios would marginally increase from 0.4% in 2018, to 1.6% and 2.2%, respectively in 2037.

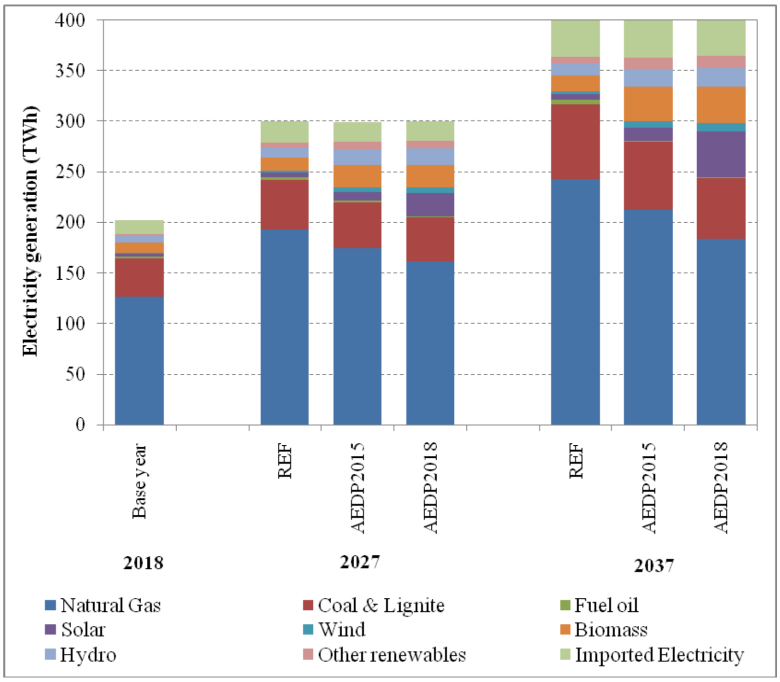

Fig. 1. Electricity generation for the period 2018–2037.

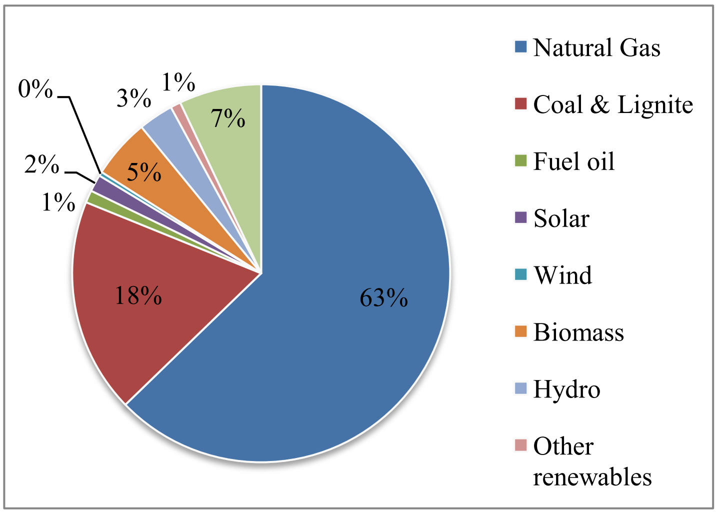

Fig. 2a. Electricity generation share by fuel type in 2018.

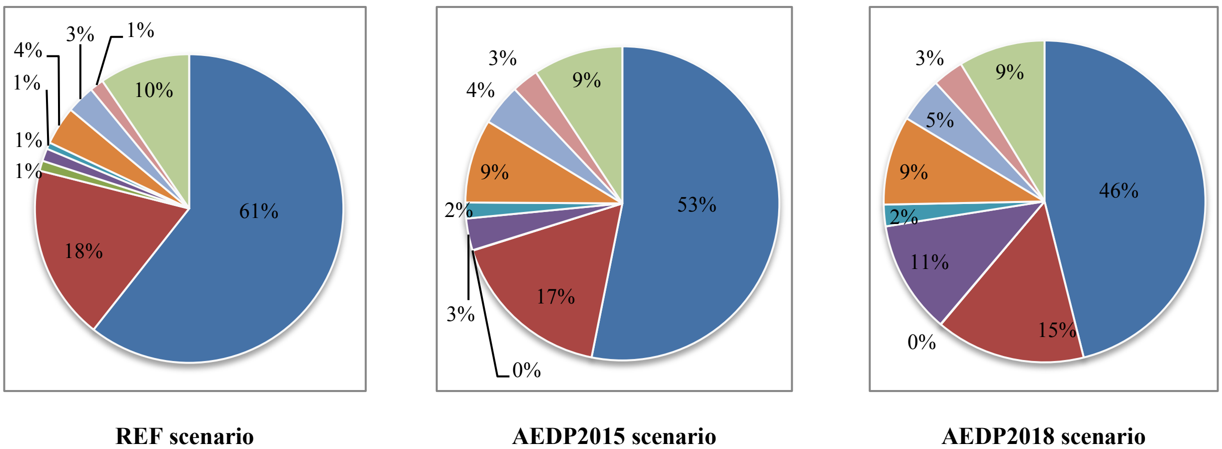

Fig. 2b. Electricity generation share by fuel type in 2037.

6.2 Electricity Generation Technology Mix

The technology mix for electricity generation under the REF, AEDP2015, and AEDP2018 scenarios is shown in Figure 3.

It is noticed from Figure 3 that the combined cycle gas-turbine (CCGT) technology is the dominant electricity generation technology in 2018 – accounting for 44% of total installed capacity. This dominant share is expected to continue under the REF scenario. It is, however, that the share of CCGT in technology mix would decrease to 30% under the AEDP2015 and 23% under the AEDP2018 scenario. This trend also accords with the government's policy to reduce the role of natural gas in the Thai fuel mix for power generation because CCGT technology could employ only one energy sources that is, natural gas. The decline in CCGT technology would be substituted by renewable energy technology, for example, solar, wind, biomass, hydro etc. According to Figure 3, the percentage share of solar technology in total generation capacity is expected to grow substantially from 6% in 2018, to 23% in 2037 in the case of AEDP2018 scenario. In addition, the share of biomass technology for the AEDP2015 and AEDP2018 scenarios would increase by 3% and 4%, respectively, as compared with the share in the year 2018. The increasing trend of renewable energy technology is further supplemented by generation technology from wind. It is revealed from Figure 3 that the share of wind technology in technology mix in 2037 is expected to rise to 4% in the AEDP2015 scenario and 5% in the AEDP2018 scenario.

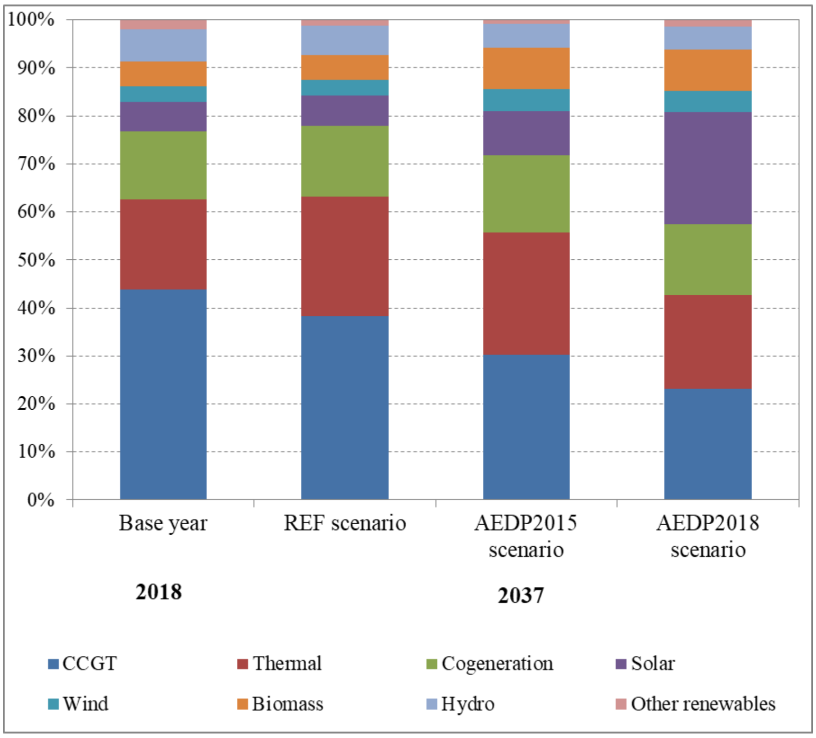

Fig. 3. Generation technology mix.

6.3 Fossil Fuels Consumption

In this section, fossil fuels consumption is employed to represent how an increase share of renewable energy in power production could contribute to a decline in fossil fuels consumption. The fossil fuels consumption for electricity generation under the REF, AEDP2015, and AEDP2018 scenarios is presented in Table 3 and Figure 4 provides the impacts of greater electricity generation from renewable energy on each type of fossil fuels.

Table 3 shows that fossil fuels inputs for power production, in the REF scenario, are expected to increase from 36,152 KTOE in 2018, to 63,993 KTOE in 2037. In 2037, the AEDP2015 scenario would contribute to a reduction of 6,710 KTOE in comparison with the REF scenario. Fossil fuels requirement in the case of the AEDP2018 scenarios in 2037 would be 13,662 KTOE less than fossil fuels requirement under the REF scenario. This is a combined effect of two changes, namely, increased share of renewable energy in electricity generation and increased power import from neighboring countries (as discussed in Section 6.1). It is further observed from Figure 4 that major contribution to a decrease in fossil fuels inputs, both in the case of AEDP2015 and AEDP2018 scenarios, would come from natural gas – accounting for more than 60% of fossil fuels supply reductions. This also corresponds with the above noted discussion in view of the decreased role of natural gas. In the case of coal and lignite consumption in 2037, it is expected to reduce by 1,387 KTOE under the AEDP2015 scenario and 3,268 KTOE under the AEDP2018 scenario (as presented in Figure 4). The declining trends in the demand for both natural gas and coal and lignite could help reduce fossil fuels imports for electricity generation. Despite the fact that fossil fuels import has been mainly from oil over the last three decades, an import of natural gas and coal has been continuously increase since 1990s [2], [6]. For example, coal bituminous has been increasingly imported from 602 KTOE in 1993, to 4,882 KTOE in 2018. Especially, natural gas import has also been rise substantially from 19 KTOE in 1998, to 13,801 KTOE in 2018. Furthermore, coal imports accounted for more than 50% of coal and lignite for power generation in 2018 whereas imported natural gas accounted for 31% of total natural gas consumption in 2018. Importantly, three quarters of total natural gas consumption has been used for electricity generation. This suggests that the penetrations of renewable energy would help improve country's energy security if one considers the fact that higher shares of renewable energy in primary energy mix would help decreasing fossil fuels imports for generating electricity and especially help improving the diversification of electricity supply.

In terms of fuel oil, it would decrease slightly to approximately 1,000 KTOE in 2037 for both the AEDP2015 and AEDP2018. This could be due to a low contribution of fuel oil to power generation (that is, less than 10% since 2000 [2], [34]) and government's strategy to maintain its role in order to diversify electricity supply as well as to deal with an emergency situation, for example, unavailability of main energy resources and supply of peak load.

Table 3. **Fossil fuels consumption for electricity generation.**

Year	REF scenario	AEDP2015 scenario Changes from REF scenario		AEDP2018 scenario Changes from REF scenario	
	(KTOE)	(KTOE)	(%)	(KTOE)	(%)
2018	36,152	-	-	-	-
2027	47,889	-4,092	-8.5	-6,977	-14.5
2037	63,993	-6,710	-10.5	-13,662	-21.3

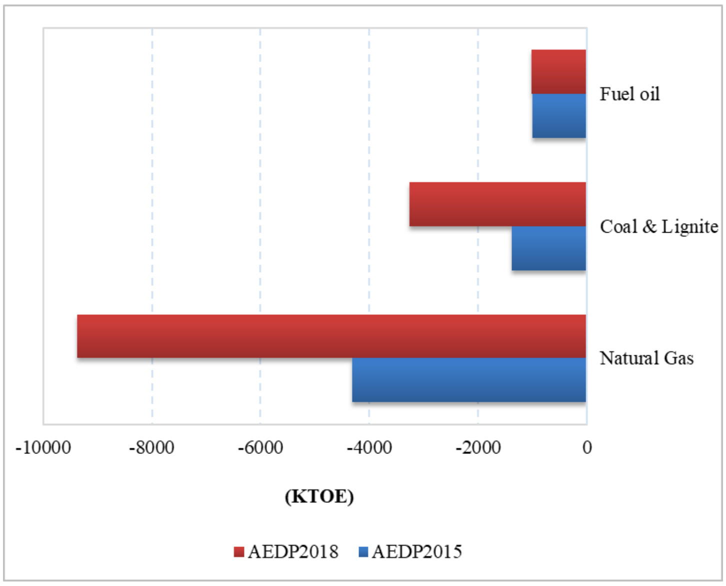

Fig. 4. Changes in fossil fuel inputs by fuel types in 2037.
Note: This figure presents the changes in fossil fuels inputs for power production under the AEDP2015 and AEDP2018 scenarios in the year 2037 as compared with the REF scenario.

6.4 CO_2 Emissions

The policy to promote the contribution of renewable energy in electricity generation sector is expected to help slow down an increase in CO_2 emissions. Figure 5 reveals that CO_2 emissions, for the REF scenario, are estimated to grow from 92 million tonnes in 2018, to 178 million tonnes in 2037, an increase of 86 million tonnes over the 2018 emission level – an average annual growth rate of 3.5%. The AEDP2015 and AEDP2018 scenarios would result in an increase of 66 and 47 million tonnes above the 2018 emission level respectively, thus resulting in an average annual growth rate of 2.9% and 2.2%, respectively for the AEDP2015 and AEDP2018 scenarios.

Figure 6 shows that the AEDP2015 and AEDP2018 scenarios would contribute to a slowdown in a rise of CO_2 emissions as compared with the REF scenario. In the AEDP2015 scenario, a reduction of CO_2 emissions in 2027 would reach 11 million tonnes, in 2037 would be higher – 19 million tonnes, as compared with the REF scenario (as shown in Figure 6). It is further observed that the AEDP2018 would result in highest CO_2 savings – 38 million tonnes in 2037, as compared with the REF scenarios. In accordance with the decrease of fossil fuels consumption, higher penetrations of renewable energy would result in higher reduction in fossil fuels inputs for electricity generation and hence lower CO_2 emissions. Such a reduction in CO_2 emissions would help enhancing the country's energy security when consider in the context of environmental sustainability dimension. According to Sovacool [30], energy security in terms of environmental dimension could refer to a number of attributes such as CO_2 emissions in aggregate, per capita CO_2 emissions and CO_2 emissions from the electricity sector.

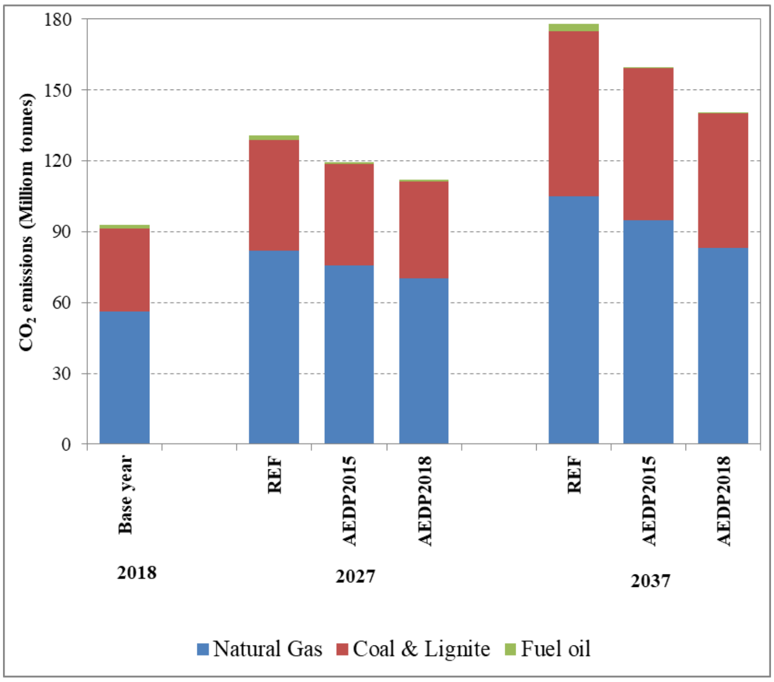

Fig. 5. CO_2 emission from electricity generation.

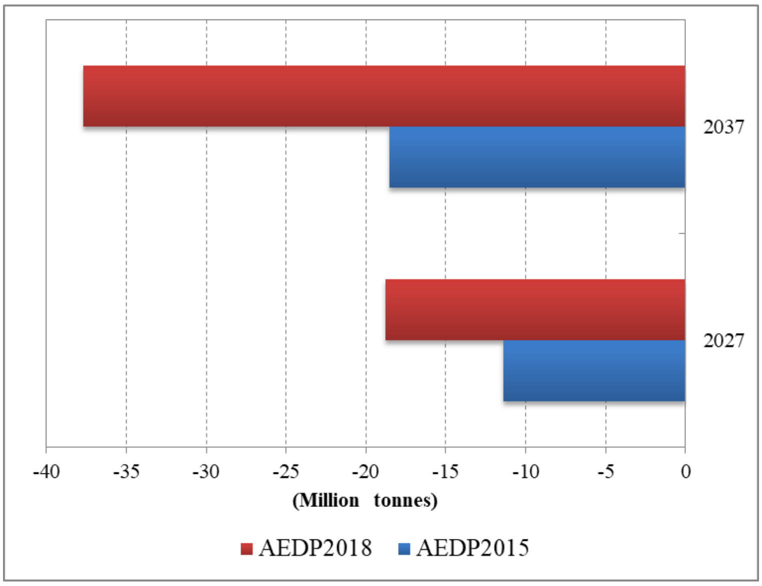

Fig. 6. Changes in CO_2 emission.

Note: This figure presents the changes in CO_2 emissions in the AEDP2015 and AEDP2018 scenarios as compared with the REF scenario.

The inference drawn from the above analyses is that high penetrations of renewable energy in the Thai electricity generation sector would provide several noticeable benefits. For example, the increasing role of renewable energy would significantly reduce the use of conventional energy resources for electricity generation. Such a reduction could further result in a decrease in an import of fossil fuels (for instance, natural gas and coal) which has currently been growing continuously due to limited domestic energy reserves. Additionally, a rise in renewable energy would help diversifying primary energy supply for power production. As discussed earlier, the declining role of natural gas in primary energy mix would be attributed to growing renewable energy trends. A decrease in fossil fuels imports together with the improvement in energy diversity would, therefore, have a beneficial impact on country's energy security. In addition, it is evident that increasing share of renewable energy in electricity production would help mitigating CO_2 emissions and therefore, provide environmental benefits – an issue of contemporary significance. Especially, it is important to note that the promotion of renewable energy use in electricity generation would help enhance the utilization of local energy resources including agricultural residues and wastes, and particularly, support the build-up of local capabilities in electricity generation. This argument gains credence if one takes note of the fact that Thailand is an agricultural-based country and therefore, it has a large amount of agricultural residues and wastes such as rice husks, bagasse, wood pellets, biogas and municipal wastes. In addition, due to the fact that the agricultural activities of the country are mostly in the countryside, electricity generation from agricultural residues would be distributed more to the regions. This would provide an opportunity to the local investors and communities to participate in the power generation from renewable energy in the form of distributed electricity generation. It appears that an increased electricity generation from local energy resources would support the development of decentralized electricity generation and hence help improve the Thai energy security in terms of decentralization dimension [30]. Despite the favorable benefits from the utilization of local energy resources, there is still a need for developing the local capability and market for renewable energy. This paper, therefore, suggest that in order to efficiently utilize these agricultural residues and wastes as well as to benefit the local economy, the Thai government should take a leading role in facilitating such development. This includes:

- The distribution of the information and benefits of the renewable energy resources among key actors including local communities and financial institutions. The local communities would know how to generate extra income from their agricultural residues and wastes. The financial institutions would gain better understanding of the renewable energy and recognize its high potential in Thailand and willing to provide financing to potential local investors; and
- The undertaking of research and development on the appropriate technologies for power generation from each type of potential domestic renewable energy sources. This would help enhance the efficient utilization of the local energy resources and, importantly, establish the country-specific energy innovation.

On the basis of the above, the policy to promote renewable energy appears to be beneficial for the Thai society. This gains more credence if one considers the fact that the electricity sector has been currently experiencing a profound disruptive transition. The transition involves a change in power system organizational structure from a fossil fuel-based, centralized and unidirectional power system with limited actors toward a renewable-based, decentralized and bidirectional power system with several actors on the supply and demand sides [35]. This would entail high penetrations of renewable power generation and a change of the power consumption patterns. However, this transition would certainly have a direct impact on the current electricity structure which was not designed to cope with the cost structure of renewable generation technologies dominated by high capital costs and very low operating costs and with the active and dynamic participation of demand in the power system operation. This could raise several transitional challenges for the Thai electricity system to adequately support and efficiently arrange the interactions between various components of the new system including renewable energy projects, energy storage system, more active electricity consumers. The challenges could be, for example capital-intensive investment, centralized electricity system, traditional regulatory framework and lack of social involvement.

- One major challenge is capital-intensive investment for renewable energy. Renewable energy projects currently require high initial capital cost but suffer from poor efficiency and hence provide a low rate of return on investment. The financial institutions would be, therefore, unwilling to finance the projects due mainly to high risks and a low rate of return on invested capital compared to fossil-energy projects. However, the declining costs of renewable energy attributed to technological advancement would attract more investments in the renewable energy projects.
- Centralized electricity system could be another challenge. Under this system, electricity produced from large-scale power plants is transported to end-users along extensive transmission and distribution networks. Few actors involve in the industry generation, operation, management and planning. Such system is not designed to support decentralized generation which is characterized by small –scale and intermittent generators like renewable energy. In order to transform the traditional power system towards the new one integrating renewable energy, additional flexibility would be required for all segments of the electricity system, for example supply-side flexibility, demand-side flexibility, flexibility from storage, well-developed grid infrastructure, and improved system operations. Therefore, future electricity system that fit for a renewable-based system should be more flexible generation, stronger transmission and distribution, more storage and more flexible demand [36]. However, increased system flexibility would require the development of new infrastructure and network regulation that support the transition to future electricity system mentioned above.
- The traditional regulatory framework could hinder the penetrations of renewable energy. The policy and regulatory framework are primarily designed to ensure supply and demand balance with the objective to minimize generation cost

while maintaining reliability and energy security. The design for policy and regulation are, therefore, configured around centralized generation technologies and to meet largely passive consumers. The energy transition would entail more actors and less passive electricity consumption. New rules and regulation are needed in order to make the power system fit for decentralized generation, smart grid infrastructure and active consumers.

- A lack of social involvement is also important. The electricity transitions in the past were almost exclusively driven by the exploitation of new energy resources and technologies without serious consideration for social and environmental consequences [37]. These transitions were also marked by top-down, highly centralized electricity system controlled by a few actors. The current transition, however, involves various cross-sector stakeholders that are more informed by public policy. Particularly, this transition would require more citizen participations and wider social acceptability. The lack of information and public awareness appears to be a major factor contributing to public resistance and opposition. Public opposition primarily arises from insufficient information regarding ecological and financial benefits, inadequate awareness of renewable energy technologies, and uncertainties about the financial feasibility of renewable installation projects. The government agencies should provide the development that enhances greater citizen participation in renewable project development. Such a development has been previously discussed in the context of local capability and market for renewable energy.

The Thai government has, so far, recognized the importance of these issues. In order to cope with the transitional challenges, the Thai government has, therefore, initiated a number of policies including supporting the upgrade of the grid to smart grid, supporting the development of energy storage, building stability for community power plants and large power plants, promoting renewable energy which has less CO_2 emissions, generate and consume power from solar, biomass, and biogas, supporting power distribution via the grid and outside of the grid, supporting building electricity balance in all regions, revising the regulations of the Energy Conservation and Promotion Fund to support the communities' energy business [38]. Against the above noted policies, it appears that much of the government's policies has been initiated with a view to provide a pathway for integrating renewable energy into the Thai electricity system, for instance, the electricity grid transition to be smart grid, the development of energy storage and support the build-up of local electricity generation. These strategies are expected to contribute to a gain in country's energy security because most strategies have been designed for supporting the domestic, diverse and local energy supplies for producing electricity, decentralized power generation and environmental sustainability.

In addition to the initiation of the government's policies to address the transitional challenges, this paper further suggests that structural reform along with regulatory reform in the Thai electricity industry should be addressed prior to starting other initiatives. This is because the current structure of the Thai electricity sector and its regulatory arrangement are unsupportable with an emergence of distributed power generation from renewable energy. For example, the current structure of the industry is in the form of Enhanced Single-Buyer (ESB) structure. Under this structure, the Electricity Generating Authority of Thailand (EGAT), which is a state generating utility, controls most of power generation and all of the transmission networks in Thailand [39]. The Metropolitan Electricity Authority (MEA) and Provincial Electricity Authority (PEA), which are state distribution utilities, buy electricity from EGAT and sell to customers. In terms of regulatory framework, Thailand's power sector is largely regulated by the government while the Energy Regulatory Commission (ERC) has the authority and duty to regulate energy industry operations in accordance with the policy framework of the government. The private sector has been allowed to participate in generation segment since early 1990s. The Independent Power Producer (IPP) program was designed for large-scale power plants. For smaller developments, the Small Power Producer (SPP) program was established to support clean electricity that made efficient use of fuel or used domestic renewable energy sources. This program allowed the projects with capacity sales up to 90 MW. Under the Power Purchase Agreements (PPAs), both SPPs and IPPs sell electricity from their generating plants to EGAT. Apart from buying electricity from the IPPs and SPPs, EGAT also purchases electricity from neighboring countries. The Very Small Power Producer (VSPP) program allowed small scale renewable energy projects of up to 10 MW to connect to the grid and sell electricity directly to MEA and PEA. The ERC has the responsibility of approving power procurement from renewable energy generation projects of the VSPPs under the Feed-in Tariff (FiT) scheme.

Based on the existing structure, EGAT – a combined national generation and transmission utility – has the responsibility of electricity generation, power purchase, system operation, electricity transmission, and bulk power supply to the distribution utilities. Further, EGAT has played, and continues to play, a dominant role in system development planning and decision making process of industry policy [39]. Such an influential role of EGAT and the strong link between generation and transmission functions of EGAT could hinder the decentralization of the Thai electricity system and lessen the attractiveness of the industry investment climate. According to Aemocha [40], "*Thailand will continue to depend mainly on EGAT for energy generation until 2037. Yet a close look at the master plan makes it obvious that advancing the renewable energy industry will rely on licensing private companies. Effective power purchasing agreement regulations are* *key. Even so, the PDP's continued emphasis on EGAT emphasizes continuing a centralized policy rather than renewable energy decentralization.*" In addition, Greacen and Bijoor [41] noted that, "*Thailand's power planning process still favors investment in new centralized, large-scale power plants. Thailand is notorious for overestimating future electricity demand. The utilities actually have a built-in incentive to overestimate power demand because their profits are set according to a "cost plus" structure, in which profits are stipulated by the government to be equal to a certain percentage of the total expenditure. This system provides an incentive for heavy investment in electricity infrastructure*". A structural change in the form of a separation between generation and transmission functions of EGAT is essential in order to provide a transparent and fair investment climate for local investors which are mainly from decentralized generation sector. This, however, needs to be cautiously considered if one takes note of the fact that EGAT has played an influential role in the Thai electricity industry since its establishment. Therefore, a recommendation of any change in its organizational structure has to be made by a consensus of the government, ERC and especially EGAT itself.

In view of the industry regulation, the regulatory framework for the Thai electricity industry has been primarily designed to support centralized electricity operation and management. For example, the industry has been centrally operated and planned by the three state electric utilities under the supervision of several government agencies. The future electricity system that fit for a renewable-based system would, however, require the development of new infrastructure and network regulation that support decentralized generation, smart grid infrastructure and dynamic consumption patterns. For instance, the implementation of new regulatory measures such as standards and codes would enhance the adoption of renewable energy projects by minimizing the technological and regulatory risk related to investments in these projects. The establishment of network regulation for transmission and distribution grid operators which provides incentives to invest in future grid infrastructure would be needed. Equally importantly, achieving successful transformation of the Thai electricity system would require collaboration among stakeholders such as state electric utilities, private investors, active and passive consumers, community and government agencies by increasing more participation and governance and aligning regulatory arrangement taking into account more on social objectives.

7. CONCLUSION

This paper assesses the impacts of an increase in electricity generation from renewable energy in terms of energy security and CO_2 emissions mitigation potentials. The assessment revealed that high penetrations of renewable energy would have positive impacts on the Thai electricity generation from several perspectives including improving the diversification of electricity supply, decreasing fossil fuel imports for generating electricity, less dependency on conventional energy sources, environmentally friendly electricity generation, utilizing agricultural and industrial wastes and residues, and build-up of local capabilities in electricity generation. Renewable energy appears even more attractive if one considers the fact that electricity sector enters to an era of disruptive innovations which entail high penetrations of renewable power generation and a change in power consumption patterns. However, the energy transition would raise several challenges for the Thai electricity system. The transitional challenges could be, for example, capital-intensive investment, centralized electricity system, traditional regulatory framework and a lack of social involvement. In order to address the transitional challenges, the Thai government has initiated a number of policies. Much of the government's policies has been initiated with a view to provide a pathway for integrating renewable energy into the Thai electricity system, for example, the electricity grid transition to be smart grid, the development of energy storage, the promotion of energy related start-ups, the revision of the regulations of the Energy Conservation and Promotion Fund to support the communities' energy business, and the build-up of local electricity generation. In addition to the initiation of the government's policies, this paper suggests that structural reform along with regulatory reform in the Thai electricity industry should be addressed prior to starting other initiatives. Firstly, a structural change in the form of a separation between generation and transmission functions of EGAT is essential to provide a transparent and fair investment climate. Secondly, in order to support the transition to a new electricity system that fit for renewable energy, the development of new infrastructure and network regulation are crucial. Lastly, achieving successful transformation of the Thai electricity system would require collaborations among stakeholders by increasing more participation and governance as well as aligning regulatory arrangement taking into account more on social objectives. This would provide a robust pathway to efficiently integrate renewable energy into the Thai electricity system.

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