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Article

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Plausible Scenarios for Thai Sustainable Energy in 2050: Cloud and Clear

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ABSTRACT

This study's goal is to illustrate future energy scenarios for Thailand in the year 2050: Cloud and Clear scenarios. Cloud depicts a scenario of an economy driven mainly by value-based industrial manufacturing. Security of energy supply is prioritized, with an emphasis on environment concerns and GHG emissions. Energy industry is dominated by incumbent businesses, which play important role in energy transition. Clean energy is gaining more market share, but fossil fuels remain the primary source of energy. Clear reflects the new economy driven by new S-curve businesses. Energy sustainability became first priority for national policy. Diverse options for end-users are available for self-management. New players can be competitor in Thai energy industry. Clean energy became one of the main energy sources. The quantitative results show that owing to the pandemic's impact, short-term energy demand and GHG emissions decrease dramatically, then rebound and split into two scenarios: uptrend for Cloud and downtrend for Clear. Pathway to sustainable energy is revealed in Clear scenario. Peak energy demand can be reached within 2030. The peak of GHG emissions has already passed and will be approaching to the level of 2DC pathway. Therefore, more actions are required to achieve the ambitious goal of 1.5C.

Keywords: Plausible Scenario, Sustainable Energy, Energy Model, Prosumer, Energy-Related GHG
JEL Classifications: Q41, Q47, Q48

1. INTRODUCTION

Sustainable development goals have become a key role of modern energy business strategy. Corporations have to be responsible for the society and environment along with their core businesses. However, complex relationship between surrounding factors and their high uncertainty may impede the achievement of sustainable development. Using a variety of tools with different characters can help decision-makers to handle uncertain situations. Shell explores plausible scenarios for global energy sustainability and achieving the goal of Paris Agreement. Three scenarios are proposed: Islands, Waves and Sky 1.5. Narratives of the three scenarios are given with the quantitative modelling results under uncertainty of various factors, e.g. economic survival, national role on climate policy, technology disruption.

Southeast Asia is expected to play larger role in the world's future development. It contributes more than 6% of global GDP, 9% of global population and 5% of global energy demand (IEA, ASEAN energy outlook, 2019). Each of the ten ASEAN countries members has its own character and has different challenges in achieving sustainable development goal. Thailand is one of the leading economies that plays an important role in this region. Although, Thailand has an agricultural background, its is driven mainly by industrial production, tourism and services. Energy business structure is still in the hands of state-owned enterprises. All of these make Thailand an interesting case study for sustainable energy challenges. There have been previous studies on sustainable energy in Thailand. Most of them are based on specific goal and boundary. Example of previous studies area study of energy technology alternatives towards the greenhouse gas targets (Rajbhandari and Limmeechokchai, 2020; Misila et al., 2020), bio-economy and land-water-energy NEXUS (Silalertruksa and Gheewala, 2019), energy transformation and disruption on power system (Wangjiraniran et al., 2017), and sustainable energy in transport.

The objective of this study is to illustrate future energy scenarios for Thailand in the year 2050, namely Cloud and Clear scenarios. Linkage between factors related to sustainability is explored. Based on STEEP framework, scenario stories on uncertainty of social, technology, economic, environment and political aspects on STEEP framework are described. Quantitative data is analyzed by using energy accounting model. Scenario stories are derived into quantifiable parameters. Assumptions related to economic restructuring, decentralized bargaining power, bio-economy, pollution control and climate action policies are analyzed. Data from 2018 is used as a base year to avoid unusual pandemic event. However, updated figures on economic activity downturn and recovery due to pandemic during 2019-2021 are monitored and taken into calculation.

2. SCENARIO

Plausible scenarios proposed in this study are derived based on the foresight technique. In general, foresight is a view of the future based on a variety of surrounding factors and perspectives. As a result, determination of driving forces and critical uncertainty factors are the key point to differentiating future outlooks. Nakapreecha et al. presented a set of variables affecting the sustainability of the Thai energy business. It was found that climate policies, clean disruptive technologies, and changes in people's lifestyles are identified as critical uncertainty factors. In addition, there are also studies that identify other crucial factors affecting energy systems. For example, Wangjiraniran et al. highlighed the impact of structural changes on energy systems, particularly in term of energy efficiency. Factors in agricultural resource allocation (Silalertruksa and Gheewala, 2019) and the increase of energy vehicles may affect biofuel demand. Recently, Thai Ministry of Energy announced the needs to step up its efforts to achieve its net-zero goal and reduce carbon emissions (BangkokPost, 2021).

Based on driving forces from the aforementioned literatures, two scenarios namely "Cloud" and "Clear" are proposed in this study. Definition and relationship of scenario stories under STEEP framework are described in Table 1.

3. METHODOLOGY FOR ENERGY MODELLING

A scenario-based energy accounting model, i.e. LEAP (Low Emission Analysis Platform) (SEI, 2021), was applied for creating long-term future scenarios. It is especially designed for balancing energy systems with an integrated environmental database. Emission factors are mostly based on the recommendation of the Intergovernmental Panel on Climate Change (IPCC). In this study, modelling approach for balancing energy demand and supply is based on previous publication proposed by Wangiraniran et al., 2017. Figure 1 illustrated modelling structure for energy accounting model, based on value-chain of energy system in Thailand.

In the demand module, sectoral energy demands are independently derived from key drivers, e.g. economic and demographic parameters, and sectoral energy intensities. In the transformation module, the demand for each fuel can be met by current production capacity. Primary resource is withdrawn by the required feedstock during the transformation process. The energy system is balanced by exporting surplus energy and importing energy in short supply. Under this scheme, energy-related greenhouse gases (GHGs) will be evaluated endogenously based on energy consumption at each stage with the tier 1 emission factor, then be integrated into the Technology Database (TED). Based on available data, the analysis is disaggregated into a hierarchical structure, comprising six major energy-related sectors aligned with the socio-economic and energy database (DLT, 2018). Activities in transportation and industrial sectors are disaggregated by mode of transportation and sub-industries, respectively. The remainders are considered as an aggregation. Modelling structure is based on the national energy database classified by International Standard Industrial Classification (ISIC) and Thailand Standard Industrial Classification (TSIC).

3.1. Final Energy Consumption

Final energy consumption in the industrial, commercial and agricultural sectors depends highly on the economic situation (IEA, 2020). Hence, it is evaluated by the product of sectoral/ sub-sectoral value-added and energy intensity in each branch of economic sectors. In the residential sector, number of households is a major driver of fuel consumption (Kleebrang et al., 2017; Tanatvanit et al., 2003). Depending on the scenario, substitution of traditional fuel with modern energy is assumed to represent future pattern of energy use. Prosumer penetration, e.g. distributed photovoltaics (DPV), is directly taken into the net electricity load calculation in the demand module, reflecting self-generation and peer-to-peer power trading. Energy demand in the transportation sector is estimated using a stock turnover analysis presented by Pongthanaisawan et al. in a previous study (Pongthanaisawan and Wangjiraniran, 2019). Firstly, vehicle stock is calculated based on annual sale and survival rates for various vehicle types, such as light duty vehicle, motorcycle, commercial van, bus, and truck. Fuel consumption is estimated by the combination of vehicle stock, travel demand and fuel economy of each type of vehicle.

3.2. Transformation Module

3.2.1. Power generation

In order to determine the requirement of power supply, peak power demand is evaluated using the electricity demand from the final consumption model and the average load factor. In this study, the national plan is used to designate the entire power supply option. Exogenously input includes installed capacities of new and retired

Figure 1: Modelling structure for energy accounting model in Thailand

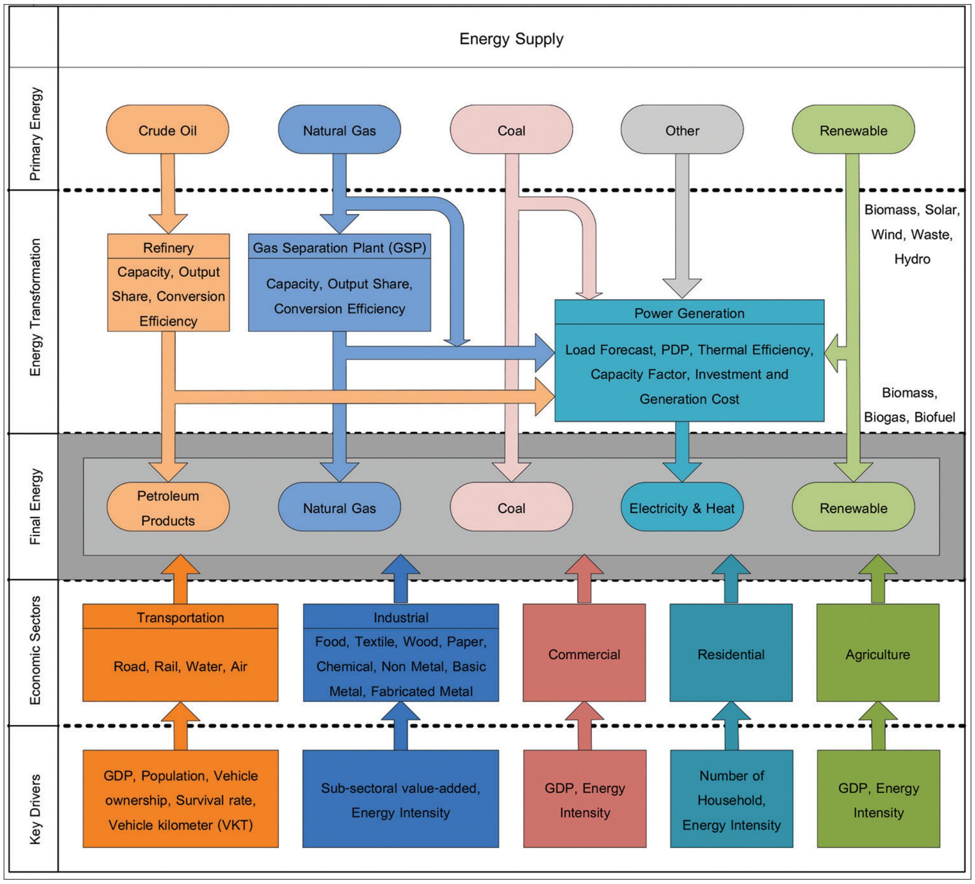


Table 1: Definition of cloud and clear scenario

Driving forces		Cloud scenario	Clear scenario
Social	Lifestyle and perception on environment concern	As society enters the digital age, economic concerns take priority over environmental concerns	Society gives attention to environmental concerns. Clean technologies and low-carbon products are preferentially chosen widely.
	Decentralized bargaining power	State enterprise continue to be a major energy supplier and play a key role in the implementation of smart energy. End-users have limited choice of energy supply. Market of prosumer mainly covers only industrial and commercial users.	The energy business becomes more competitive as a result of new opportunities created by smart technologies. New players have larger market share for energy supply services. Consumers have diverse options for energy supply and self-management. Market of prosumer is extended to residential users
Technology	Clean disruption	Thailand's market for clean disruptive technologies is expanding at a slower rate speed than developed countries. It is due to power business structure and rigid contractual constraints.	Clean disruptive technologies are expected to accelerate in the near future and play a critical role for in the energy system by 2050.
Economic	Economic and industrial restructuring	Thailand's future economy is driven by value-based economy, focusing on the first S-curve, i.e., food for the future, smart electronics, and next-generation automotive.	Economic is driven mainly by high value-based economy, focusing on the first and new S-curve, i.e., digital economy, medical hub, aviation and logistics, biofuel and biochemical, and automation and robotics.
	Bio-economy	Target of bioenergy usage is assessed based on the maximum potential.	Proportion of resource consumption will be more balanced between high-value products and energy use.
Environment	GHG mitigation	GHG migration options can be achieved as committed under the current nationally determined contributions (NDC).	More attempts are required beyond the NDC commitment.
	GHG Emission control	GHG emission control is on voluntary basis.	GHG emission control is on mandatory approach.
Politic	National energy policy	Policies on clean and smart energy are already in place, with an emphasis on energy security. Moderate attempt on GHG mitigation is proposed in NDC.	Sustainability with target beyond the NDC become the priority for national agenda.

power plant, as well as the feedstock required for each process. In power generation module, peak load demand can be evaluated directly by the product of electricity demand and the assigned load duration curve. Additional capacity of power generation technology can be calculated based on the merit order with the constraint of the planned reserve margin. Primary resource is withdrawn by the required feedstock during the transformation process. Moreover, targets of electricity import and export are included in the power purchase planning. As a result, total generation cost and environmental impact can be calculated from the electricity generation process by individual technology. The simulation structure is summarized in Figure 2.

3.2.2. Petroleum refinery and gas separation plant

The assessment of oil and gas production for oil refineries and gas separation plants starts with the demand for refined oil and natural gas in the demand module by sector, including the requirement for fuel for energy processing (e.g. natural gas for power generation). Then, supply options, consisting of domestic production, import and export, are prioritized. Due to the limited domestic crude oil resources, the amount of crude oil imported for oil refineries is depend on the demand for oil products. For natural gas, input of domestic wet gas is prioritized for gas separation plant. Existing and future expanded capacity is the constraint for domestic production in term of distillation capability. Additional imports and exports are calculated from the residual of domestic production. Schematic diagram for petroleum refinery and gas separation plant is illustrated in Figure 3.

4. KEY ASSUMPTIONS

4.1. Macro-economic and Economic Restructuring

It is known that macroeconomic parameters are crucial for energy demand and supply outlook. In this study, economic growth is

Figure 2: Modelling structure for power supply options

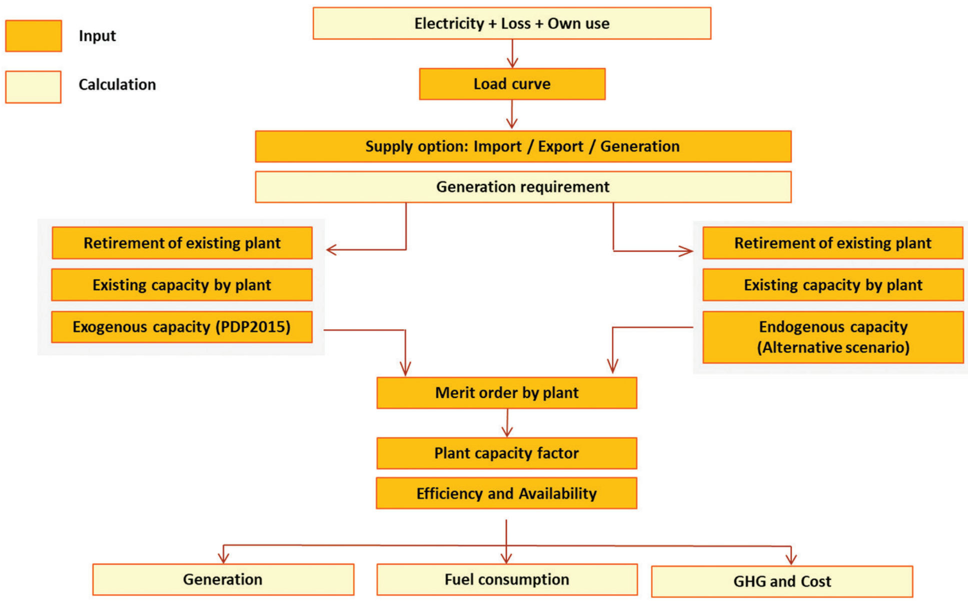
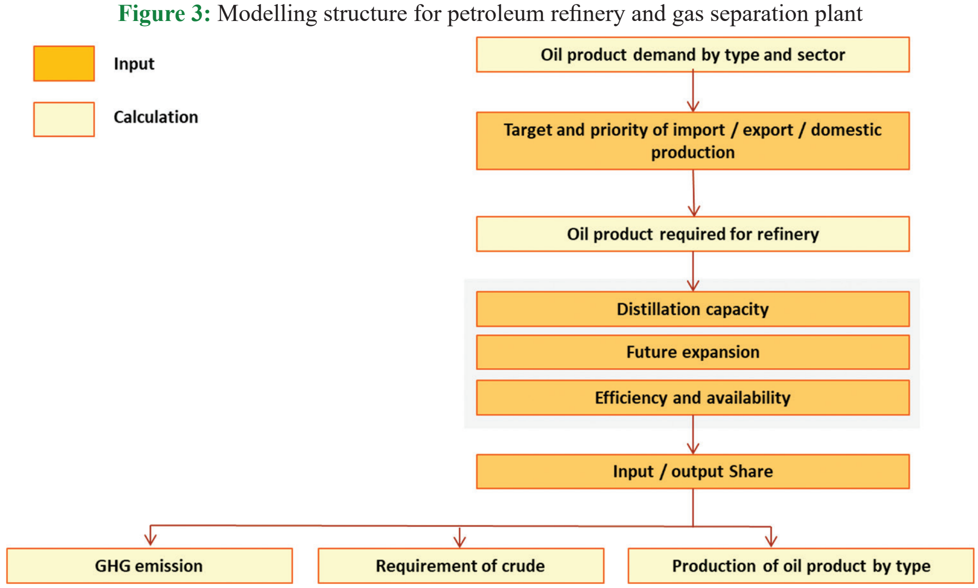


Figure 3: Modelling structure for petroleum refinery and gas separation plant



assumed to be 3-4% per annum, which is a desirable target for long-term sustainability. However, the slowdown of economic activity in 2020-2021 due to pandemic impact is also taken into the consideration (–6% in 2020 and +2% in 2021). The GDP is expected to recover after 2022. This projection is applied to both Cloud and Clear scenarios.

For Cloud scenario, it is assumed that the economic structure shifts slightly from 2018 (Figure 4a). According to the official plan on promoting value-based economy, food for the future, agricultural and biotechnology, smart electronics, affluent medical and wellness tourism have been identified as five first S-curve promising sub-sectors. As a result, the industry has a higher economic share than the commercial sector, as illustrated in Figure 4b.

For Clear scenario, more ambitious attempts on new S-curve are made. Additional new S-curves in biofuel and biochemical, digital economy, medical hub, automation and robotics, aviation and logistics are expected to expected drive long-term sustainable growth. This will result in an increase in the share of lower-energy intensive services, in comparison to the industrial sector (Figure 4c).

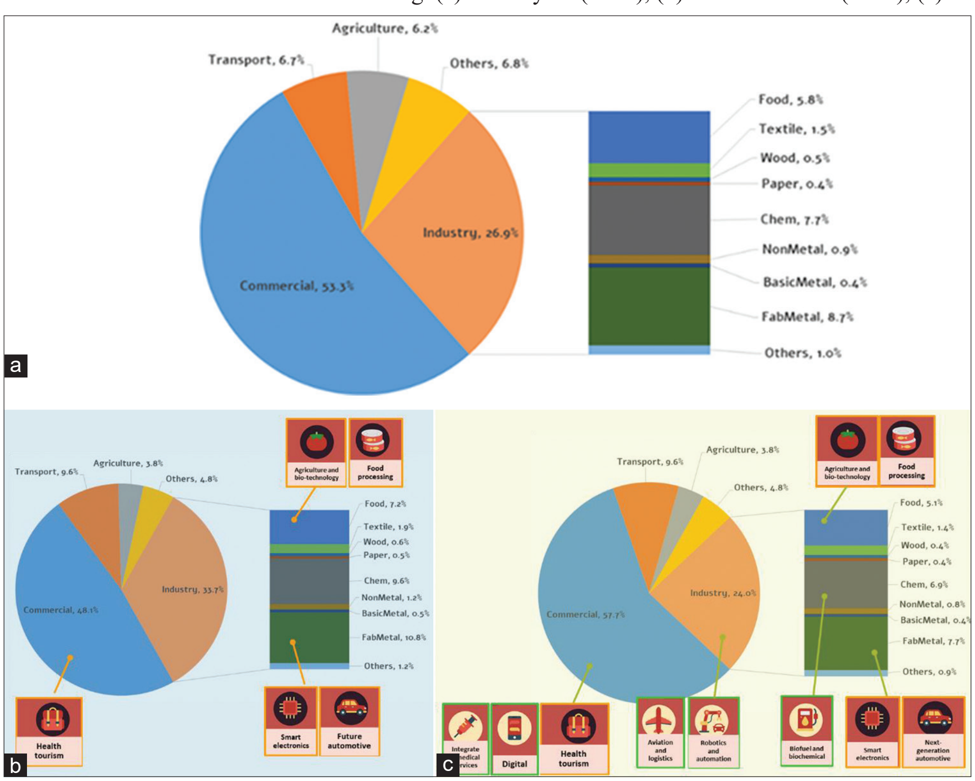
4.2. Decentralized Bargaining Power

Power market structure in Thailand has been evolved from a state-owned enterprise to a more competitive one (Ministry of Energy, 2021). Most of the changes occur at the generation level. There are still a limited range of choice for end-user consumers. Development of clean disruptive technologies, such as DPV, smart appliances, and energy storage provide a variety of options for consumer. This megatrend could bring a significant change in power market structure. However, such change may have to confront uncertainty due to regulatory barriers.

For the Cloud scenario, such change continues to occur at a slow pace. State enterprise still be a major energy supplier and play a key role to in the implementation of smart energy. Although, the state tries to support new players, they are impeded by the existing market and contractual structure. However, with cheaper technologies, the prosumer market continues to grow because it does not required power purchase from the national grid. Prosumer market covers only industrial and commercial users. Under this hypothesis, it is assumed that more than 11.4 GW of DPV will be installed by 2050 (TDRI, 2019). Demand response is still in the initial state. End-users contributed at least 500 MW in demand response project (EPPO and ERI, Study on demand response business in Thailand (in Thai), 2019). The major end-users are large and medium factories as well as commercial buildings, in which the investments are considered to be worthwhile.

In the Clear scenario, power balance shifts rapidly. Intensive policies and rapidly changing technology makes a market grows by leaps and bounds. The energy sector becomes more competitive as a result of new opportunities created by smart technologies. Self-dependency and prosumers have a larger market share in the energy supply service. Under this hypothesis, it is assumed that more than 35 GW of DPV will be installed by 2050(TDRI, 2019). Demand response is widely used in the market platform, accounting for more than 1250 MW (EPPO and ERI, Study on demand response business in Thailand (in Thai), 2019). Apart from the aforementioned commercial scale, the residential sector is another key segment in the long-term growth of prosumer market. Some of them will be equipped with energy storage. Thus, they can manage energy on their own (Figure 5).

Figure 4: Assumption of economic and industrial restructuring. (a) Based year (2018), (b) Cloud scenario (2050), (c) Clear scenario (2050)



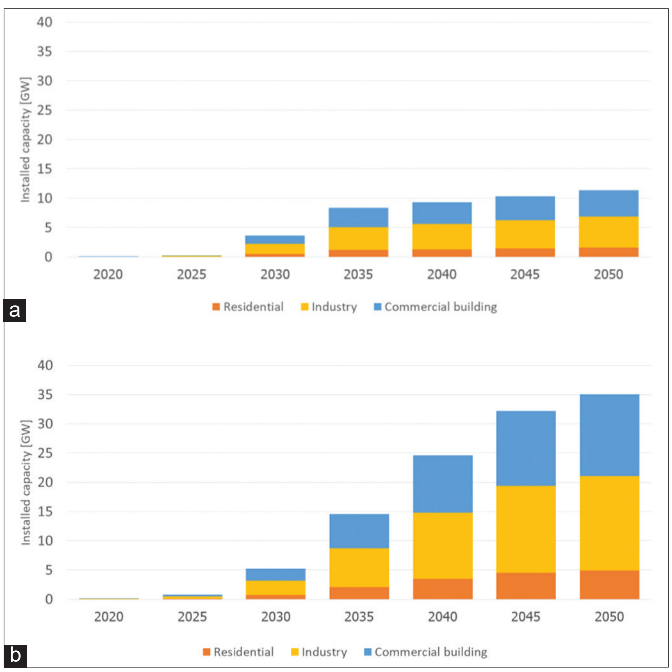
4.3. Bio-economy

Agriculture employs a substantial percentage of Thailand's workforce, accounting for 40% of the total population (DEPA, 2021), but it contributes <10% of the country's overall GDP. Over last decade, population has noticeably immigrated to the urban city. This caused a significant slowdown in agricultural activities. However, the epidemic could result in long-term immigration changes (BOT, 2021). Agricultural resources and bio-economy may play an important role in the economic sustainability. Prioritizing resource use is a key factor, that will influence future biofuel growth.

In the Cloud scenario, biofuels are promoted to replace fossil fuels. According to the office plan (DEDE, 2018), biofuel usage is assessed based on the maximum potential of feedstock supply. The primary target of biofuel demand is the land transportation sector. A target of 7 million liters per day of bio-ethanol and 6.5 million liters per day of biodiesel has been set for 2030, as illustrated in Figure 6a.

In the Clear scenario, the proportion of resource consumption will be more balanced between high-value products and energy use. With the downward trend in energy consumption, this scenario requires less biofuel blending in oil than the Cloud scenario, as illustrated in Figure 6b. Biofuel can also be used to replace jet fuel replacements as sustainable alternative fuel (SAF), corresponding to measures of Carbon Offsetting and Reduction Scheme for International Aviation (COSIA). In this case, it is assumed that 10% of the SAF is blended with jet fuel.

Figure 5: Estimated installed capacity of DPV. (a) Cloud scenario, (b) Clear scenario



4.4. GHG Reduction and Environment Protection

As a result of the Paris agreements, all countries are obliged to contribute to reducing greenhouse gas emissions. Energy efficiency (EE), renewable energy (RE), and waste-to-energy are found to be key solutions for minimizing GHG emissions in the energy sector. The aforementioned GHG mitigation measures also create a co-benefit of environmental protection.

Access to clean cooking is one of the crucial factors to tackle household air pollution from cooking smoke, especially in Southeast Asia, where charcoal and wood are widely used widely for cooking. Thus, a cleaner cooking solution based on switching from traditional energy to modern energy has to be taken into account.

Electric vehicle (EV) is another option to help minimize the impact of air pollution in urban areas. As the impact on GHG emissions by EVs remains unclear, the focus is on the power source used in electricity generation. Thus, decarbonization in the power sector must be implemented. The rise of variable renewable energy (VRE) and EVs may affect power system management over time. Therefore, power system flexibility must be considered.

Details of GHG mitigation and environmental protection assumptions for the Cloud and Clear are described in Table 2.

5. RESULTS

5.1. Final Energy Demand

According to the assumptions, the results of the final energy demand analysis of the Cloud and Clear scenarios are shown in Figure 10.

In the Cloud scenario, short-term final energy demand will be affected by the pandemic, but the medium and long-term demand

Figure 6: Intermediate calculation of estimated biofuel consumption in road transportation. (a) Cloud scenario, (b) Clear scenario

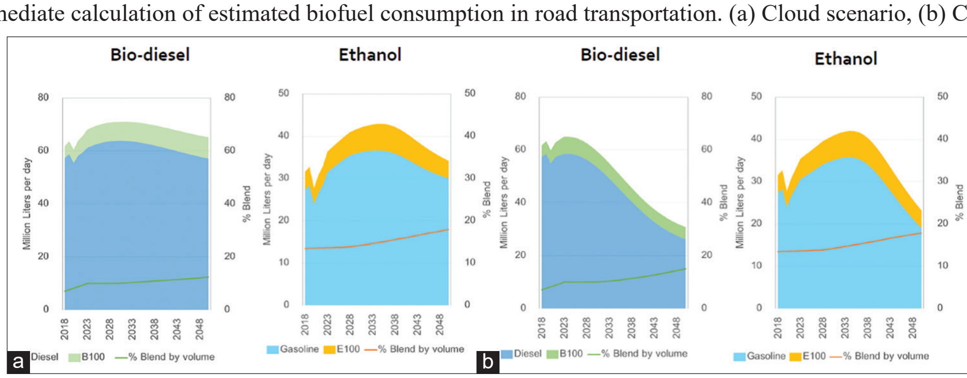
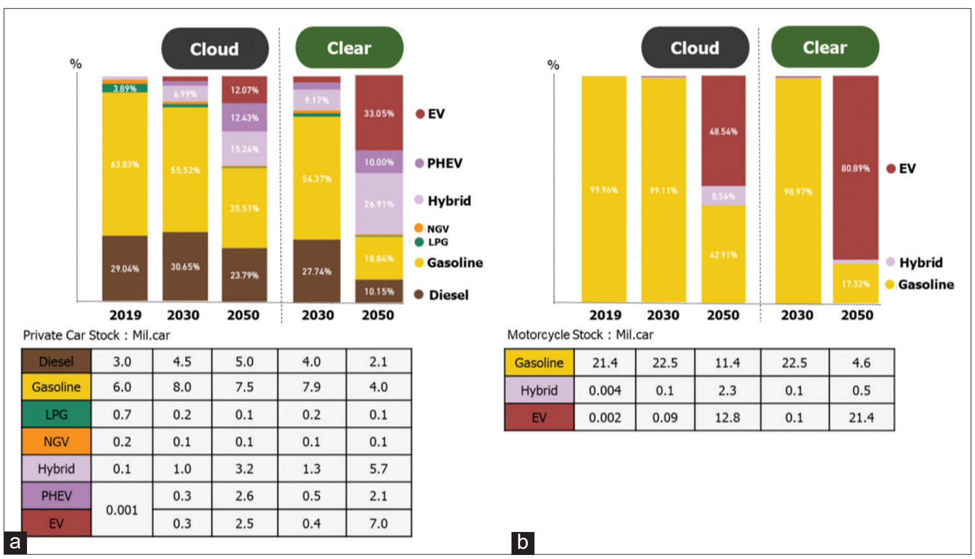


Table 2: Assumptions of GHG mitigation and environmental protection

Parameter	Cloud scenario	Clear scenario
Energy efficiency	Energy efficiency will be improved, resulting in a 1.5% reduction in energy intensity per year.	Energy efficiency will be dramatically improved, resulting in a 2.9% reduction in energy intensity per year (IEA, 2019).
Renewable energy	Renewable energy accounts for 30% of final energy demand.	With the downward trend in energy consumption, but similar level of RE usage to the Cloud scenario, the proportion of RE is expected to increase in the Clear scenario.
Waste-to-energy	Waste-to-power capacity is approximately 400 MW in 2037 (DEDE, 2018), and will increase to 900 MW in 2050.	Waste-to-power capacity is approximately 1,900 MW in 2050.
Clean cooking	Traditional fuel is replaced by liquefied petroleum gas (LPG) and electricity. The ratio of traditional fuel to modern energy will shift from 0.73:0.27 in 2018 to 0.66: 0.34 in 2050.	Traditional fuel is replaced by modern energy and new RE. The ratio of traditional fuel to modern energy to new RE is 0.34: 0.54: 0.12 in 2050.
Zero emission vehicle	In 2050, vehicle stock of EVs and plug-in hybrid electric vehicles (PHEVs) is 5.1 million for light duty vehicles and 12.8 million for electric motorcycles [Figure 7].	In 2050, vehicle stock of EVs and PHEVs is 9.1 million for light duty vehicle and 21.4 million for electric motorcycles [Figure 7].
System flexibility responding to load variation	The load duration curve does not differ significantly from the current one due to low penetration of the VRE and EV. Load duration curve does not change from 2019 [Figure 8].	High penetration of the VRE and EV have significantly affects the load duration curve. In order to cope with that change, power system flexibility, e.g., energy storage and flexible grid infrastructure, will be adopted to flatten the curve. [Figure 8]
Decarbonization in power	Decarbonization in power generation relies on the power development plan. In 2050, total installed capacity of power generation will be 76.5 GW, with gas accounting for 61.6%, hydropower for 5.1%, coal for 0.2%, RE for 27.7%, and others for 5.4% (Figure 9a).	Decarbonization in power generation is driven by new policy direction. Additional capacity is available for renewable energy. Gas power plants and energy storage (approximately 20 GW) are required to maintain reliability of central system. There will be no new coal power plant added to the system. In 2050, total installed capacity of power generation will be 44.8 GW, with gas accounting for 45.4%, hydropower for 8.8%, 45.0% for RE, and 0.8% for others (Figure 9b).

Figure 7: Intermediate calculation of vehicle stock by fuel type in road transportation. (a) Light duty vehicle, (b) Motorcycle



will increase as a result of long-term economic activity expansion, especially the industrial sector. Industrial production is expected to be a key driver for the country's long-term economic growth. The results also show that Thailand's energy demand depends strongly on the industry and transportation sectors. Looking forward to 2050, it can be foreseen that the share of energy consumption in the industrial sector is much higher than the transportation sector's. This trend is mainly driven by promising growth in industrial production activities. Improvements of energy performance are continually being made, but the potential is getting narrower. Energy conservation laws for factories have been in place for a long time (EPPO, Energy Conservation Promotion Act B.E. 2535 (1992)). This brings limited energy conservation potential for large factories. In the meantime, there is still a lot of potential for energy efficiency in the transportation sector, e.g., fuel economy improvement, shared mobility and road-to-rail mode shift.

In the Clear scenario, the recovery of energy demand in the short-term after the pandemic can be observed, but the long-term trend has shifted to the downside. Peak energy demand is expected in 2030. The end-of-year energy demand is expected to be at the same level of the current situation. Decoupling of energy demand and economic activities is likely to occur under the given assumptions.

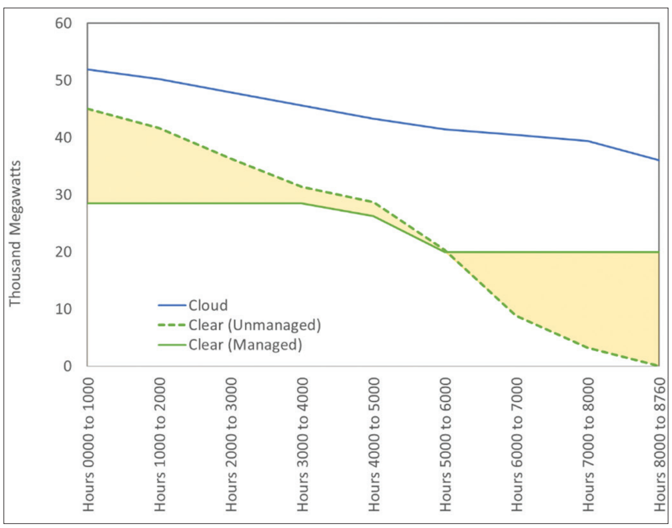
Structural change in the economic and industrial sectors with rapid development of clean technologies will be the crucial factor in flattening the demand curve. The value-based economy can unlock the potential of energy efficiency, especially in the industrial sector. Almost half of the energy demand in industry is reduced compared to the Cloud scenario. Moreover, an increase in consumer choice leads to self-management, resulting in maximum efficiency attainment.

5.2. Primary Energy Supply

According to the assumptions, the results of the primary energy supply analysis of the Cloud and Clear scenarios are shown in Figure 11.

In the Cloud scenario, the short-term final energy demand will be affected by pandemic, but it will rebound and continue to rise in the medium and long-term. Primary energy supply growth (CAGR = 0.79%) is slightly slower than final energy demand growth (CAGR = 1.16%). The difference can be explained by the improvement of energy efficiency in the transformation process.

Figure 8: Average load duration curve influenced by DPV and EV



Fossil fuels still play an important role, but their share is slightly reduced (86% in 2018 to 80% in 2050). Natural gas is the only fossil fuel that continues to increase, while coal and oil will slightly decrease. Renewables have continuously increase in popularity and will play a larger role in the fuel mix in 2050 (20% in 2050). This is a result of government policies, especially the proportion of fuel mix in electricity generation according to the power development plan (PDP 2018 rev1).

In the Clear scenario, the recovery of energy demand after pandemic can be observed in the short-term, but the long-term trend will shift to the downside. Peak energy demand is expected to occur around 2028-2030. The end-year energy demand is expected to be at the same level of current situation. The share of fossil fuel will decrease significantly (84% in 2018 to 65% in 2050). Coal is being phased out and will be completely gone by 2050. Oil consumption declines due to the replacement of internal combustion engine (ICE) vehicles with electric vehicles. However, oil consumption will not reduce rapidly due to the high survival rate of vehicles. Gas consumption tends to be stable due to the efficient load management, including a decentralized power system. New gas plant is postponed, corresponding to the delay in load requirement. Renewable energy is becoming more prevalent and will account for the majority of the fuel mix (29% in 2050).

5.3. Energy Balance

Energy balance snapshots for the Cloud and Clear scenario in 2018 and 2050 are shown in Figure 12.

In 2018, fossil fuels can be observed as major sources of energy in Thailand's energy system. Refined oil is produced mainly from domestic refineries. Under limited domestic resources, the country needs a high level of crude oil imports. Therefore, some of the excess refined oil are exported. Natural gas is mainly used in the electricity generation. It is also used as final energy in the industrial and transportation sectors. The majority of natural gas can be produced locally (70%). The rest is imported through pipelines from Myanmar and LNG shipping from other nations. Coal can be

Figure 9: Intermediate calculation of installed capacity requirement. (a) Cloud scenario, (b) Clear scenario

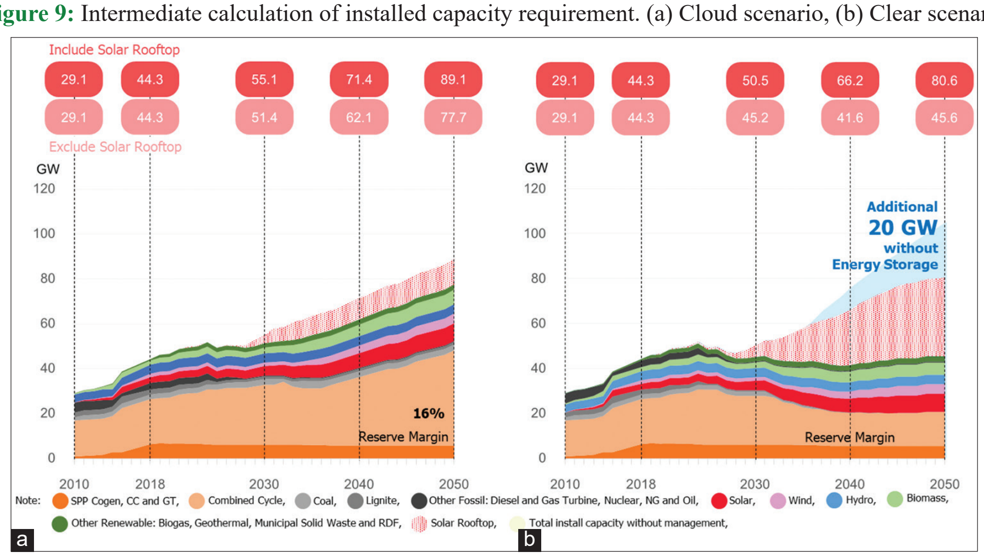


Figure 10: Final energy demand

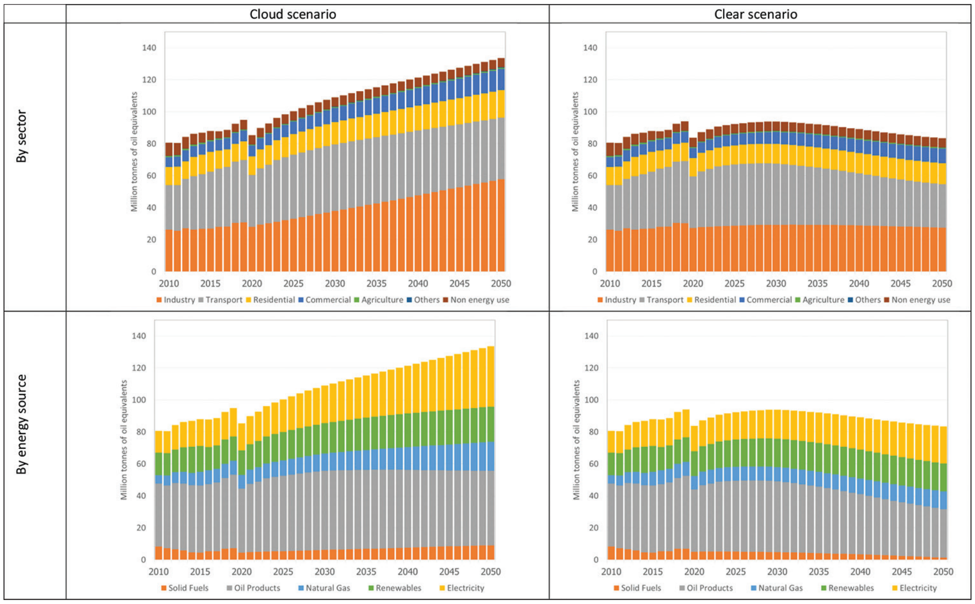
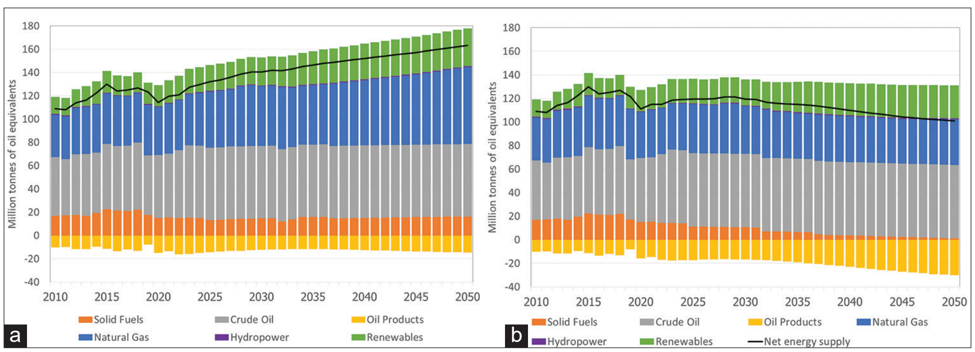


Figure 11: Primary energy supply. (a) Cloud scenario, (b) Clear scenario



produced domestically in the form of lignite. Imported coal take majority in the electricity generation and industrial heat processes. In summary, Thailand is heavily reliant on energy imports, which account for 51.5% of total energy supply.

Although the Cloud shows the success of the existing policies on energy efficiency and renewable energy in 2050, there is still a large gap in sustainability goal. Growing economic activities increase dependence on fossil fuels. The pandemic does not change the long-term situation. This led to a significant increase in import levels, up to 77.4% of total energy supply in 2050. It can be seen that the majority of oil, coal, and natural gas supplies are mostly imported. Domestic production of renewable energy cannot keep up with rising fossil fuel demand.

In the Clear scenario, the slowdown in energy demand relieves the strain on energy supply. But such trend only slows down the rate of energy imports as it is still considerable (68.8% of total energy supply in 2050). Most of the oil, coal and natural gas are still imported, though at a lower rate than in the Cloud scenario. In summary, reliance on energy imports is inevitable within the study period. If the downtrend continues, there is a chance for self-sustainability of energy in the long run.

5.4. Energy-related GHG

The results of energy-related GHG emissions are illustrated in Figure 13. In the Cloud scenario, GHG emissions increase in parallel with the growth economic activities, but at a slower rate. Such trends show continuous improvement in efficiency of GHG mitigation measures, although they still fall short of the Paris Agreement's target. On the other hand, the decoupling of GHG emissions and economic activity is clearly seen in the Clear scenario. The findings also show that the peak of GHG emissions in the Clear scenario has already passed. It is believed that the pandemic is one of the major contributors to this incident. The GHG emissions are expected to reach the level of 150-160 Mt_{CO2} in 2050, which is the level that corresponds to the Paris Agreement's goal. Rajbhandari (Rajbhandari & Limmeechokchai, 2020) suggested, in order to meet the Paris Agreement's 2DC and 1.5DC targets, Thailand's energy-related GHG emissions in 2050 should be at 280-300 Mt_{CO2} and 80-100 Mt_{CO2}, respectively. Therefore, if the conditions and actions in Clear can be met, Thailand will be able to achieve at least the target of the 2DC pathway. However, to achieve the more ambitious goal of 1.5DC, additional efforts must be required, especially the adoption of new technologies that are not yet commercially available.

Figure 12: Energy accounting for demand and supply system in Thailand. (a) 2018, (b) Cloud scenario (2050), (c) Clear scenario (2050)

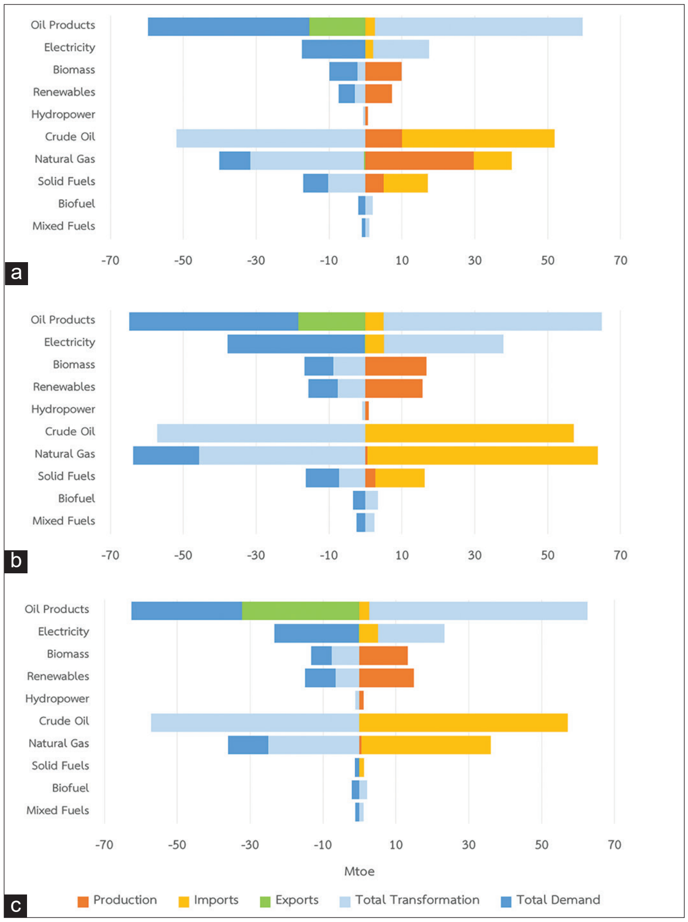
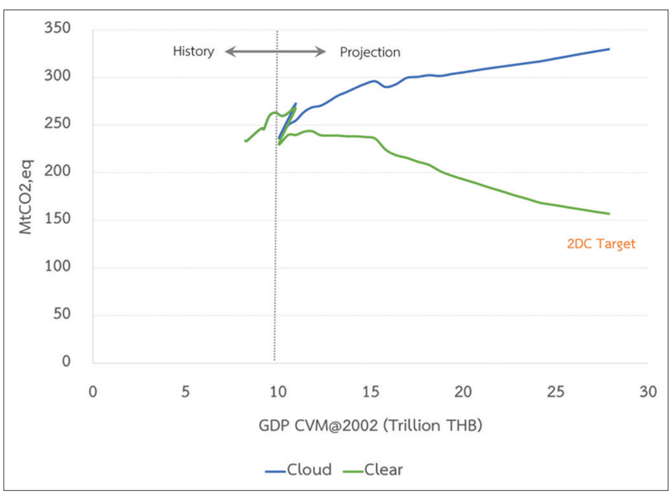


Figure 13: Relationship between the calculated energy-related GHG emissions and the gross domestic product (GDP)



6. CONCLUSION

This study focuses on exploring plausible energy scenarios by considering all aspects of economic, social, and environmental requirements. Two scenarios are proposed to represent future situations, in which different factors are connected to different conditions. Key findings are as follows.

In the Cloud scenario, achieving existing plans is insufficient to achieve long-term energy sustainability. Existing economic and industrial structures do not allow energy efficiency to reach its full potential. The limitation of choices for end-users is a barrier to allowing people to manage power on their own. This causes the burden of having to supply more power sources. Uptrend energy demand widens the energy self-sufficiency gap. It is also impossible to achieve the moderate goal of 2DC.

For the Clear scenario, various actions, e.g. a new value-based economy, power shift to prosumers, and clean disruption, can reduce energy demand and GHG emissions in a direction that leads to energy sustainability. Energy peak can be reached within 2030. Although, reliance on energy imports is inevitable within the study period; if the downtrend is maintained, there is a chance for self-sustainability of energy in the long term. The peak of GHG emissions has already passed and the situation is approaching the level of 2DC target. It must be noted that this scenario is based on commercially developed technologies. The country still has potential to achieve the more ambitious goal of 1.5DC by applying more advanced technologies, e.g. hydrogen technology, as well as carbon capture, utilization and storage.

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