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Article

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Assessment on Energy Technology Toward Carbon Neutrality Policy Using Multi-Criteria Decision Analysis: A Case of Thailand

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ABSTRACT

The assessment of greenhouse gas (GHG) mitigation technologies creates a knowledge database to support a national strategy to meet Thailand's GHG emission reduction target. Such a database also makes important contributions to the formulation of research policy and the country's broader technological development. Thailand needs a strong technological base in order to meet its national policy targets and international obligations for reducing GHG emissions, as well as to reduce the negative effects of economic activity on society and the environment and to create additional value. The goal of this study is to prioritize energy technologies so that Thailand can achieve its carbon neutrality goal by the year 2050. Multi-criteria decision making is applied with quantitative data on GHG mitigation options. Decisions are made based on the technology's readiness and level of its impact on economic, social and environmental development. Critical issues representing needs and barriers for selected key technologies are analyzed. The results indicate that solar energy and electric vehicle are selected as having the highest priority, followed by energy efficiency and other renewable energy sources. Carbon capture, utilization and storage (CCUS), green hydrogen, and carbon sinks are the last choices with high uncertainty about commercialization.

Keywords: Carbon Neutrality, Multi-Criteria Decision Analysis, Technology Prioritization, Climate Technology Assessment, GHG Emission Mitigation
JEL Classifications: D70, Q40

1. INTRODUCTION

According to the IPCC's report on mitigation of climate change (IPCC, Climate change: mitigation of climate change: summary for policy maker, 2022), emissions must peak by 2025 to limit global warming and reduce by 43% by 2030. Two possible pathways of 2 and 1.5° are still challenges in the long run. Thus, taking action on climate change has become a global goal that countries have committed to working toward. Southeast Asia (SEA) is expected to play an important role in future economic development and global climate action. The future of Southeast Asia's energy sector is in the global spotlight because of its growing population and economy. Its population has expanded by around 10% over the past 10 years, and today there are around 660 million people across the region. Southeast Asia's economy grew by around 4.2% on average each year between 2010 and 2019 (IEA, Southeast Asia Energy Outlook, 2022). Each of the ten ASEAN members has a unique character and faces different challenges in achieving sustainable energy and climate goals. Thailand is one of the leading economies that plays an important role in this region. Despite the fact that Thailand has an agricultural background, its economy is driven mainly by industrial production, tourism and services. Energy business structures are currently operated by state-owned enterprises, but this is changing to make them more competitive. This makes Thailand an interesting case study for sustainable energy and tackling climate action challenges (Wangjiraniran, 2022).

At COP26 in November 2021, Thailand set targets to reduce GHG emissions to achieve carbon neutrality by 2050 and net-zero emissions by 2065. The energy sector, which accounts for 71.65% of the national greenhouse gases inventory (MNRE, 2020), is expected to be major contributor to achieving that goal. The fact that Thailand is a middle-income country with large income gap means that the adoption of clean energy must take into the account by various factors of economy, energy cost, negatively affected stakeholder as well as social issues such as income gap, employment and etc.

In the past, studies have suggested using a marginal abatement cost curve as a decision-making tool for developing GHG mitigation strategy (Enkvist and Nauclér, 2007). However, a decision with comprehensive perspectives on multiple dimensions, including the marginal cost optimization aspect, would meet the contexts of Thailand and other emerging countries' needs. Multi-criteria decision analysis (MCDA) is also a decision tool that takes multiple criteria into account in a single analysis. In the past, it was developed and adapted for various applications, e.g., product and material design (Jahan Ali, 2013), sustainable energy (Wang, 2009) (Kumara and Sah, 2017), etc. There has also been applied for technology assessment on GHG mitigation (Subash and Desgain, 2015), (STI, 2018). A combination of MCDA and a quantitative GHG emission goal may be able to fill in the gap and help Thailand reach its carbon neutrality goal.

The objective of this study is to find out the priority of low-emission technology in the energy sector to achieve Thailand's carbon neutrality goal in 2050. With quantitative data of GHG mitigation options, multi-criteria decision making is used to make policy decisions that take multiple factors into account. Critical issues representing needs and barriers to implementing selected key mitigation technologies are analyzed.

2. METHODOLOGY

2.1. Multi-Criteria Decision Analysis

Multi-criteria decision analysis (MCDA) is a common method that combines the assessment of multiple criteria into a single analysis process. The analysis facilitates the identification and prioritization of the most feasible technologies as well as the identification of key constraints for each available option. Moreover, MCA also aids in reducing the complexity of the analysis by converting data into quantitative criteria or weighted scores. The MCA method uses weighted scores for each criterion to compare and prioritize different GHG mitigation technologies. In this study, each criterion and its score were reconsidered based on the Climate Change Technology Needs Assessment (TNA) report published by the National Science Technology and Innovation Policy Office in cooperation with the United Nations. The report was accompanied by a focus group session, where participants agreed that the most important priorities were given to (1) technology readiness and (2) impact of the technology. The results of brainstorming among experts and stakeholders on the criteria for scoring readiness and impact are shown in Tables 1 and 2, respectively. The analysis considered four criteria for technology readiness and four criteria for impact on the economic, social and environment. Both readiness and impact were given different amounts of weight.

Four selected readiness criteria are composed of:

1. Policy support (R1) represents levels of government support in terms of budget allocation, financial incentives, infrastructure investment, research and development programs, human resource, etc. Those are included in the official national plan and existing implementing actions.
2. Benefit and cost (R2) represent the level of return on economic feasibility for the end-user. It is not only about financial feasibility, but also about other co-benefits and costs, e.g., carbon reduction valuation.
3. Possibility of domestically based production and implementation (R3) represents capability for local production and innovation, including the level of technology import, feedstock, expertise, etc.
4. Social and stakeholder acceptance (R4) represents the level of acceptability among the public and end-users. It can cover various parameters for making decision of end-users, e.g., eco-friendly perception, convenience, being safe to use, etc.

Four selected impact criteria are composed of:

1. Competitiveness and value creation (I1) represent how much each technology can have an economic impact in terms of a country's competitiveness contribution and also value creation. The negative impact is also taken into account.
2. Social impact (I2) represents how much each technology can have an impact on social development. It includes creating local jobs, reducing income gap, increasing equity, etc.
3. Environment impact (I3) represents how much each technology can improve the environment by reducing air pollution, contamination, etc.
4. Estimated GHG reduction (I4) represents level of GHG mitigation potential. The result might be the combination of previous quantitative evidence and individual perceptions of GHG mitigation potential.

2.2. Key Category Analysis

Key category analysis (KCA) presents the importance of emissions and sinks. The KCA is defined as the emission sources and sinks that constitute 95% of total annual emissions when ranked from the highest to the lowest contribution. Based on the national GHG inventory for 2016 as reported in the 3rd BUR as illustrated in Table 3 (MNRE, 2020), total GHG emissions (excluding those from LULUCF) were 354.36 $MtCO_2eq$. The energy sector has been the largest contributor, accounting for 71.65%. According to the KCA, there are 16 key categories (six of which are in the energy sector) in the level assessment. Public electricity and heat production (1A1a) led the KCA in the energy sector, followed by road transport (1A3b), manufacturing industry and construction (1A2), and other sectors (1A4). These four categories make up 49% of national greenhouse gas inventory, and they are the target sectors for technology assessment in this study.

2.3. Key Technologies

In this study, GHG mitigation technologies are based on the globally available list of key technologies recommended by the IPCC technical paper on technologies, policies, and measures for mitigating climate change (IPCC, IPCC Technical Paper I - Technologies, Policies and Measures for Mitigating Climate

Table 1: Definition of scoring and weight for readiness criteria

Readiness criteria		Weight (sum=1.0)	Score				
			5	4	3	2	1
R1	Policy support	0.29	Have strong policy and regulatory support; officially announced it as a national agenda	Have policy and regulatory support officially included in the plan.	Consistent with current policy direction under consideration of regulatory support	Consistent with current policy direction without any regulatory support	Inconsistent with current policy direction
R2	Benefit and cost	0.26	Technology has a very high return on investment without any mechanisms. (Marginal cost of GHG<0)	Technology has a very high return on investment with some mechanisms (Marginal cost of GHG=0-60 USD/tCO2)	Technology has a return in investment in all levels with some mechanisms. (GHG marginal cost=60-90 USD/tCO2)	Technology is not cost effective in some levels (GHG marginal cost=90-120 USD/tCO2)	Technology is not cost effective in all levels (GHG marginal cost=90-120 USD/tCO2)
R3	Possibility of domestically based production and implementation	0.22	Very high possibility of domestic production of this technology.	High possibility of domestic production of this technology.	Possibility of domestic production of this technology.	Low possibility of domestic production of this technology.	No possibility of domestic production of this technology.
R4	Social and stakeholder acceptance	0.24	Stakeholders in all sectors accept this technology.	Government and local stakeholders accept this technology.	Government and public stakeholders accept this technology.	Only the government accepts this technology.	Stakeholders in all sectors do not accept this technology.

Table 2: Definition of scoring and weight for impact criteria

Impact		Weight (sum=1.0)	Score				
			5	4	3	2	1
I1	Competitiveness and value creation	0.18	Enhance national competitiveness with the possibility of very high value-added creation.	Contribute to national competitiveness with the possibility of high value-added creation.	With minor value-added, there is no significant impact on national competitiveness.	Have some negative impact on some economic sectors.	Have a large negative impact on the national economy.
I2	Social impact: Local employment/ income distribution/ equity	0.21	Greatly increase employment	Increase local employment	No significant impact on local employment	Have a slightly negative impact on local employment	Have a large negative impact on local employment
I3	Environment: Pollutions (air, water, contamination, etc.)	0.34	Have a positive environmental impact and reduce pollution in a broad area	Have a positive environmental impact and reduce pollution in a limited area	No significant impact on the environment, no additional pollution	Have a negative environmental impact and pollute in limited areas	Have a negative environmental impact and pollute in broad area
I4	Estimated GHG reduction	0.28	This technology can dramatically reduce GHGs.	This technology can significantly reduce GHGs.	This technology can reduce GHGs.	This technology can reduce GHGs by a small amount.	This technology can reduce GHGs by a very small amount.

Change, 1996). Some technologies will be selected for MCDA based on the following criteria: they are currently applicable in Thailand and might be useful in the future, but they are not limited to the current national plan. New technologies that are not currently in use but have the potential to be commercialized in the future are taken into account. This process is reviewed by a group of experts who play important roles in energy planning and implementation, including business entrepreneurs, scientists, and academics. A list of key mitigation technologies classified by source of GHG emission category recommended by the IPCC is shown in Table 4.

3. READINESS AND IMPACT OF GHG MITIGATION TECHNOLOGY

The results of the MCA study are presented in four categories: public electricity and heat production, road transport, manufacturing industries, construction, and other sectors. The results are as follows:

3.1. Public Electricity and Heat Production

The result of the prioritization of road transport technologies (category 1A3b) is illustrated in Figure 1, with details of selected technologies in each aspect in Figure 2.

Table 3: Key category analysis for the year 2016: approach 1 level assessment

A	B	C	D	E	F	G
Category	IPCC category	GHG	2016 Ex, t (Gg CO_2, eq)	2016|Ex, t| (Gg CO_2, eq)	Lx, t	Cumulative Total of column F
1A1a	Public electricity and heat production	CO_2	96,980.41	96,980.41	0.21	0.21
4B	Cropland remaining cropland	CO_2	−73,457.96	73,457.96	0.16	0.37
1A3b	Road transportation	CO_2	63,697.72	63,697.72	0.14	0.51
1A2	Manufacturing industries and construction	CO_2	48,769.80	48,769.80	0.11	0.62
3I	Rice cultivation	CH_4	26,639.52	26,639.52	0.06	0.67
4A	Forest land remaining forest land	CO_2	−25,117.65	25,117.65	0.05	0.73
2A1	Cement production	CO_2	17,829.34	17,829.34	0.04	0.77
1A4	Other sectors	CO_2	15,233.53	15,233.53	0.03	0.8
2B	Chemical industry	CO_2	11,163.22	11,163.22	0.02	0.83
1B2	Oil and natural gas	CH_4	10,308.03	10,308.03	0.02	0.85
1A1b	Petroleum refining	CO_2	10,229.60	10,229.60	0.02	0.87
3A	Enteric fermentation	CH_4	8,477.89	8,477.89	0.02	0.89
3F	Direct emission from managed soils	N_2O	8,425.98	8,425.98	0.02	0.91
5A	Solid waste disposal	CH_4	8,139.72	8,139.72	0.02	0.92
5D	Wastewater treatment and discharge	CH_4	7,595.01	7,595.01	0.02	0.94
4C	Land converted to cropland	CO_2	7,100.54	7,100.54	0.02	0.96

Table 4: Key mitigation technologies specified by category

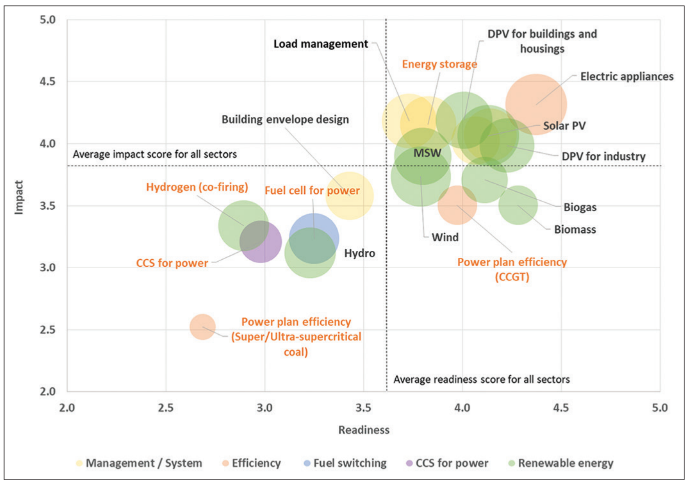
Category		Key mitigation technologies								
Management/energy efficiency		Fuel switching	Heat and power recovery	Material efficiency and recycling	CCS	Renewable energy				
						Bio-energy	Waste	Solar	Wind	Hydro
1A1	Energy industries: public electricity and heat production	Load management	Fuel cell for power	CHP	CCS for power	Biomass	MSW	Solar PV, DPV	Wind	Hydro
		Energy storage	Hydrogen (co-firing)			Biogas				
		Power plan efficiency (super/ultra-supercritical coal)								
		Power plan efficiency (CCGT)								
1A2	Manufacturing industries and construction	Energy efficiency in factory (EMS, FEMS, etc.)		Waste-heat recovery		Biomass for thermal energy	RDF for thermal energy			
						Biogas for thermal energy		Solar thermal energy		
1A3	Transport	Shared mobility	BEV/PHEV			Biofuel (1st and 2nd gen)				
		Urban planning	FCEV			CBG				
		ICE fuel economy, HEV	Electric boat			Bio-jet				
		Autonomous vehicle	Electric power train							
		Non-motorized transport								
		Mass transit (road-to-rail)								
		Freight modal shift (road-to-rail)								
		Freight modal shift (road-to-water)								
1A4	Other sectors	Building envelope design					Biogas			
		Energy management in building							Solar thermal energy	
		Electric appliances								
		Non-electric device, e.g., LPG stove, charcoal stove, etc.								

FCEV: Fuel cell vehicle

According to the findings, the top three most impactful technologies in terms of impact are: (1) electric appliances; (2) load management and energy storage; and (3) solar energy (Figure 2a). These are recognized among stakeholders as key contributions to GHG mitigation. Improving the efficiency of electric appliances has strong benefits in all dimensions. Standard labeling, namely "Number Five Label"[1], is well-known and still has potential to expand the market to cover all devices. Load management and energy storage have strong benefits in all dimensions except cost effectiveness and domestic production. Load management and energy storage, which are key parts of a smart grid and smart energy management, are currently costly and reliant on imports. However, NREL estimated that the cost of utility battery storage will be reduced by 65.4% in 2050 compared to the 2021 level (NREL, 2022). Solar energy can currently be used in a number of ways in Thailand, such as for utility-scale power generation and distributed PV in industry and buildings. The fact that solar energy is able to generate electricity only during daylight makes its impact rating lower compared to load management and energy storage. The combination of solar energy and storage is an interesting alternative for the next version of the power development plan. The levelized cost of electricity (LCOE) of utility-scale PV plus battery storage would be reduced by 45-65% in 2050, compared to the 2020 level (NREL, 2022).

1 Implemented by Electricity Generating Authority of Thailand (EGAT) and the Ministry of Energy's Department of Alternative Energy Development and Efficiency (DEDE)

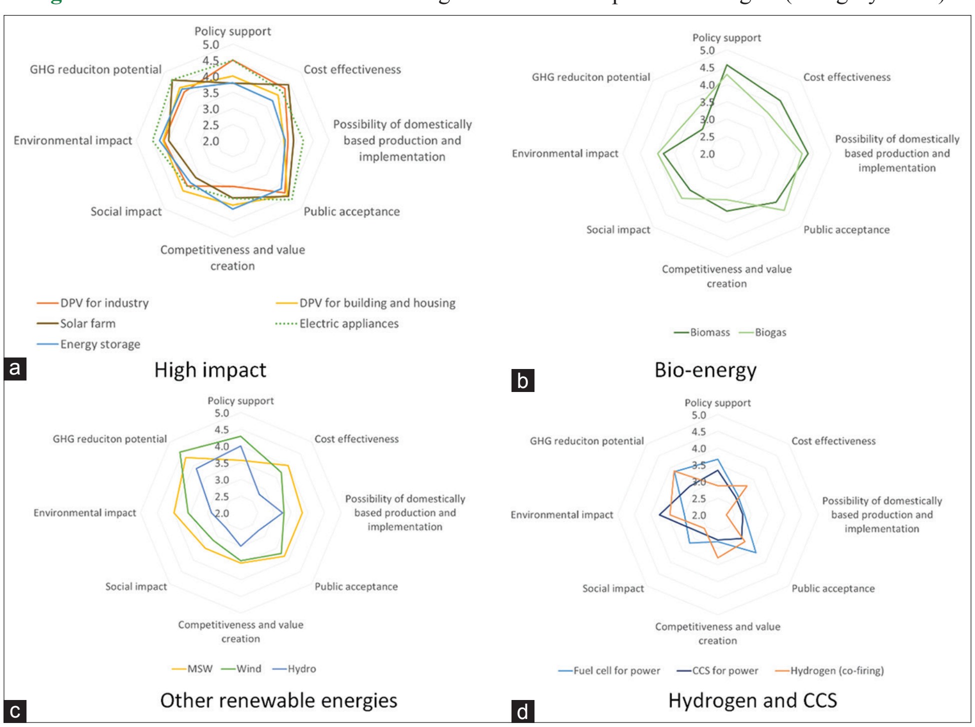
Figure 1: Prioritization of technologies in the 1A1a public electricity and heat production. Remark: Words in orange are technologies that have never been included in an official power development plan



Bio-energy for power generation, e.g., biomass and biogas technologies, can be classified by the highest readiness score, as illustrated in Figure 2b. The result indicates that the development of these renewable energies in Thailand has made progress and is ready to scale up. However, a shortage of feedstock will be a major impediment, lowering the impact score for biomass and biogas. For other renewable energy (Figure 2c), municipal solid waste (MSW) for power generation has faced issues with inefficient feedstock management. Wind power has limited average wind speed potential in Thailand. Small hydropower is applicable to only some sites.

Advanced technologies (Figure 2d), such as fuel cell power, co-firing green hydrogen, and CCS/CCUS, still have questions about technology readiness in all dimensions and are not yet able to make significant contributions in the short to medium term.

Figure 2: Assessment of selected technologies for road transport technologies (Category 1A1a)



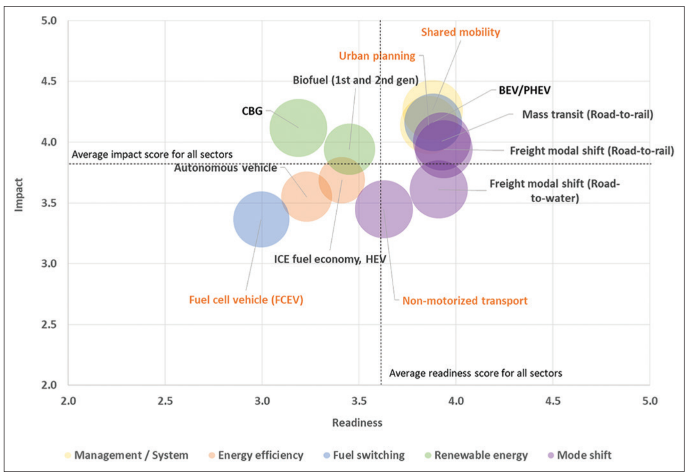
These technologies require further development and incentives for research and development.

3.2. Road Transport

The result of the prioritization of road transport technologies (category 1A3b) is illustrated in Figure 3, with details of selected technologies in each aspect in Figure 4.

The result shows that the top three highest ranked technologies in terms of impact are: 1. shared mobility; 2. electric vehicles (BEV/PHEV); and 3. urban planning (Figure 4a). Shared mobility has enormous potential. Cost reduction benefits are promising in terms of a practical business model and public satisfaction, but they would be hampered by regulatory constraints. Electric vehicles have a bright future on the market with government support, especially the 30@30 policy[2]. Urban planning is becoming more important because of projects like smart cities[3] and low carbon cities[4]. A common issue for these top three technologies is the need to improve the environment and quality of life for people, as shown by the relatively high scores for environment and social impact. In the meantime, value creation from new businesses could stimulate the macro and local economies.

Figure 3: Prioritization of road transport technologies (Category 1A3b). Remark: Words in orange represent technologies that have never been included in the previous official energy plan



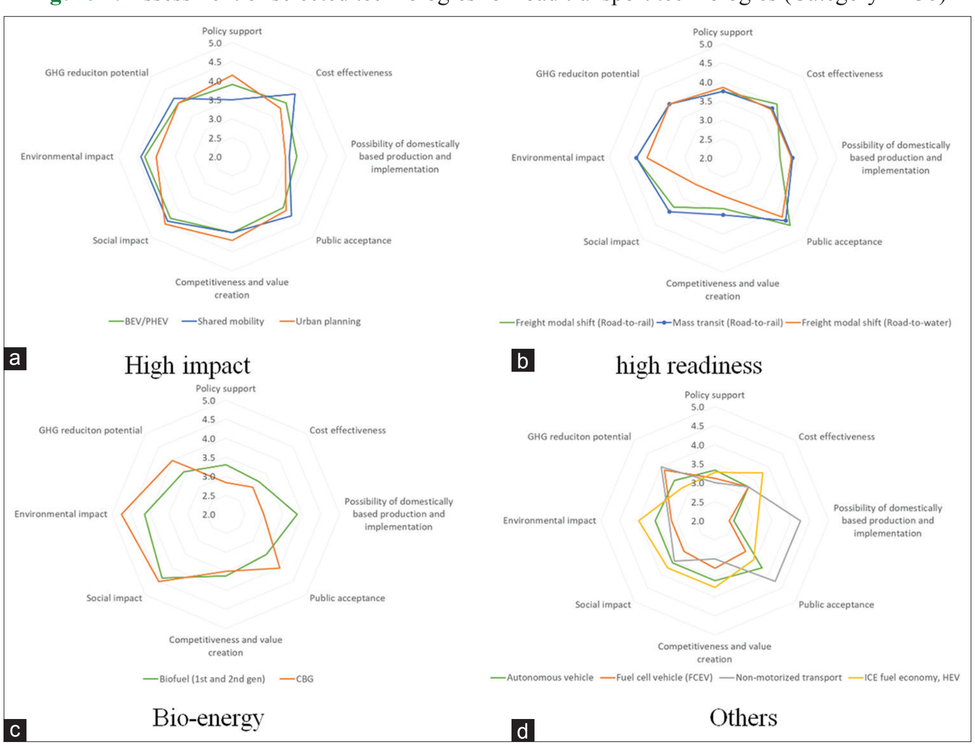
The top three technologies in terms of readiness are all related to transport mode shift, consisting of: 1. road-to-rail for freight transport; 2. road-to-rail for mass transit; and 3. road-to-water for freight transport (Figure 4b). This is thanks to public acceptance and entrepreneurs' need for an efficient logistic system. Traffic congestion and the overabundance of private vehicles in greater Bangkok and other major and tourist cities are becoming critical issues for city development. The environment and social impact are the two major advantages of mode-shift technology. Because of the limited types of bulky products and fixed waterway routes, road-to-water freight transport has a relatively low score among mode shift options. However, new businesses in the container market can be a promising model for future water transport in Thailand. It must be noted that the score of government support for mode

2 The 30@30 policy supports the target that 30 percent of vehicles made in Thailand will be zero-emission vehicles (ZEV) by 2030. The government gives tax and non-tax incentives to the automobile industry and subsidizes end-users.

3 The Board of Investment (BOI) in Thailand has set up investment incentives to encourage the development and management of "Smart City Development Projects" and to improve the quality and standard of Thailand's industrial estates and industrial zones to be able to provide smart services.

4 There are 23 municipalities participating in the low carbon city hosted by the Thailand Greenhouse gas Organization (TGO, 2022)).

Figure 4: Assessment of selected technologies for road transport technologies (Category 1A3b)



shift is relatively low compared with other aspects. This means that more incentives and investments in public transport are expected.

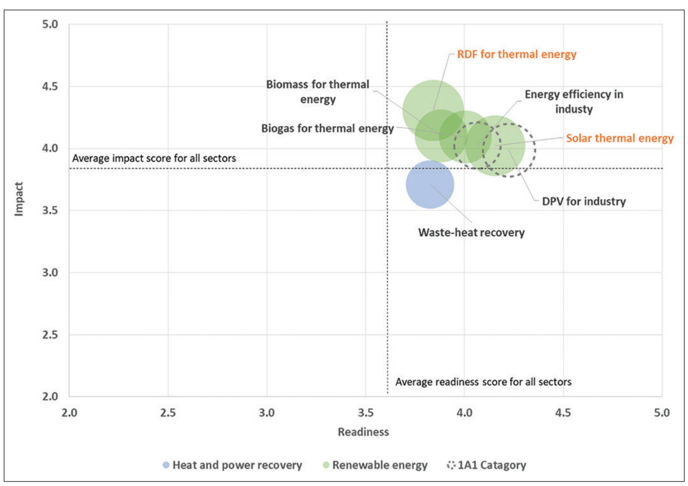
In the past, biofuel and compressed biogas (CBG) for road transport (Figure 4c) were expected to be major alternatives to fossil fuels and key technologies for reducing greenhouse gas emissions. However, their future market outlook seems gloomy due to the growth of electric vehicles. Furthermore, the cost of production is relatively high compared to oil products due to the volatility of feedstock prices. This makes biofuel an unattractive option in terms of cost effectiveness and competitiveness.

For others (Figure 4d), fuel economy improvement in internal combustion engines has lost interest since the popularity of electric vehicles. Non-motorized transportation, such as bicycles, has a strong point in terms of public needs and domestic benefit, but it has significant barriers for supporting ecosystems. Autonomous vehicle and FCEV are still far from commercialization in short-to-medium term, but they are still in a row for long run.

3.3. Manufacturing Industries and Construction

The result of the prioritization of key GHG mitigation technologies in manufacturing industries and construction (category 1A2) is illustrated in Figure 5, with details of selected technologies in each aspect in Figure 6. Electricity and fuel consumption account for the majority of GHG emissions in industry. Excluding GHG from electricity consumption, which falls under the IAI category, heating application is crucial for GHG emission contribution in the industry and construction sectors. The result shows that the top three technologies in terms of impact are: (1) refuse-derived fuel (RDF); (2) bio-energy; and (3) solar energy for thermal applications (Figure 6a). The large unrealized potential of municipal waste and the high greenhouse gas warming potential (GWP) of methane production give RDF an outstanding score on its ability to reduce GHG emissions. Bio-energy is currently used as an alternative fuel for heating in the food processing industry. A growing food industry can be a promising future for the bio-energy market. However, constraints on logistics and quality of feedstock must be considered for RDF and bio-energy heating applications in industry. Volatility of feedstock price is one of the factors that suppress the score of cost effectiveness of RDF and bio-energy. Similarly, solar thermal energy also faces difficulty competing with fossil fuels in terms of cost effectiveness. Due to the high cost of low-carbon technologies, factories decide to use liquefied natural gas in the short run to alleviate GHG emission and air pollution reduction challenges at a competitive cost. In the long term, green hydrogen for heating and carbon capture technology would be expected to take their place.

Figure 5: Prioritization of technologies in manufacturing industries and construction sector (Category 1A2). Remark: Words in orange represent technologies that have never been included in the previous official energy plan



3.4. Household and Other Sectors

The MCA of technology in other sectors, composed of commercial and residential buildings, is illustrated in Figure 7, with details of selected technologies in each aspect in Figure 8. Due to the high proportion of electricity consumption in the building and residential sectors[5], high-priority GHG mitigation technologies are located in the 1A1 category. There are energy-efficient appliances, DPV for buildings, and energy management in buildings. Less-priority options are related to heating and cooking applications, such as solar thermal energy, biogas for cooking, etc. Solar thermal energy can be used to heat water for hotels and recreation, especially in tourist areas with eco-friendly hotels that serve international tourists. Biogas can also be used to cook in the food courts and fresh markets that are all over Thailand. Using biogas for cooking not only reduces LPG usage but is also an efficient option for dealing with household biowaste. Unutilized household

5 Accounting for 92.8 percent of commercial buildings and 45.7 percent of residential buildings.

Figure 6: Assessment of selected technologies in manufacturing industries and construction sector (Category 1A2)

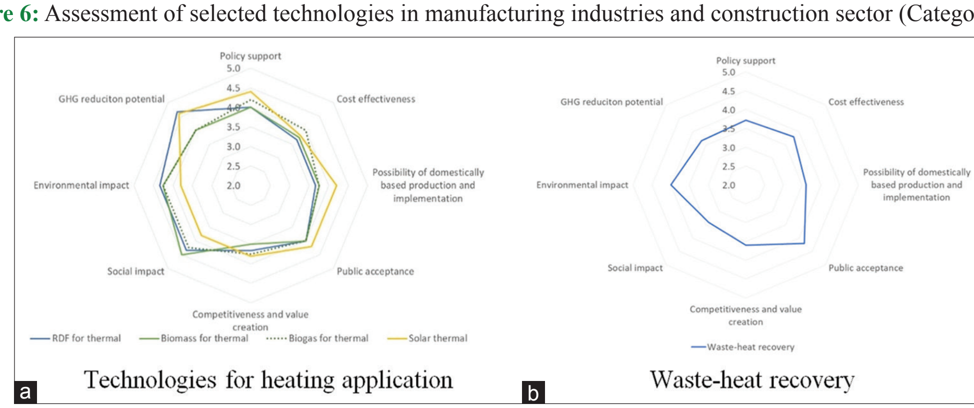


Figure 7: Prioritisation of technologies in the 1A4 other sectors. Remark: Words in orange represent technologies that have never taken into the previous official energy pla

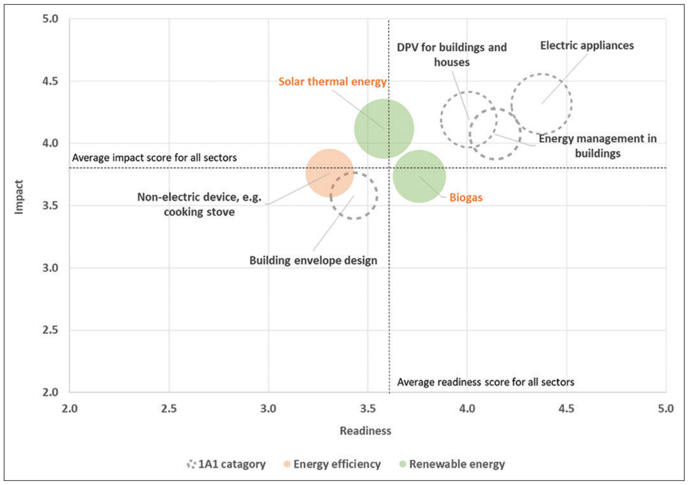
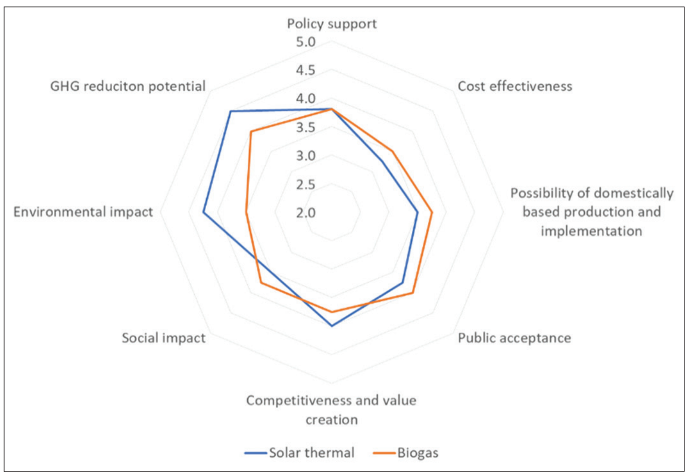


Figure 8: Assessment of selected technologies in the 1A4 sector (Category 1A4)



biowaste emits methane (CH_4), which has a global warming potential (GWP) 25 times higher than that of carbon dioxide (CO_2) (IPCC, IPCC Fourth Assessment Report, 2007).

Similar to the manufacturing industry, cost competitiveness is the major barrier for green technologies for heating and cooking.

4. POLICY IMPLICATIONS ON TECHNOLOGY PRIORITIZATION TOWARD A CARBON NEUTRALITY TARGET

In order to achieve the carbon neutrality target, a combination of quantitative data on GHG mitigation potential and the multi-criteria score of low-carbon technologies is needed to prioritize GHG mitigation technologies. The potential of selected GHG mitigation technologies is obtained from the previous continued study of Pongthanaisawan et al. Based on available data for selected technologies and assumptions proposed by that study

Figure 9: Evaluation of GHG mitigation by selected technologies

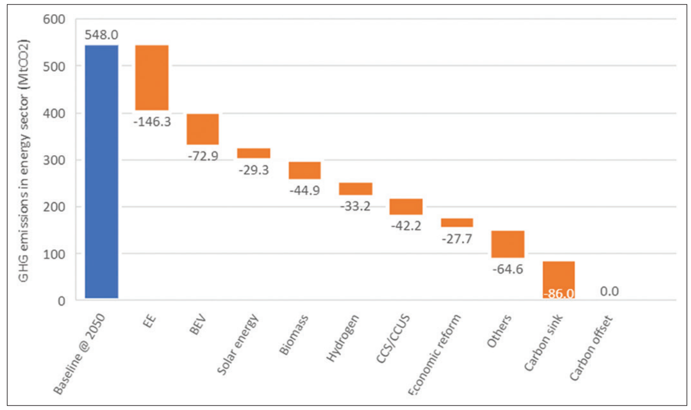
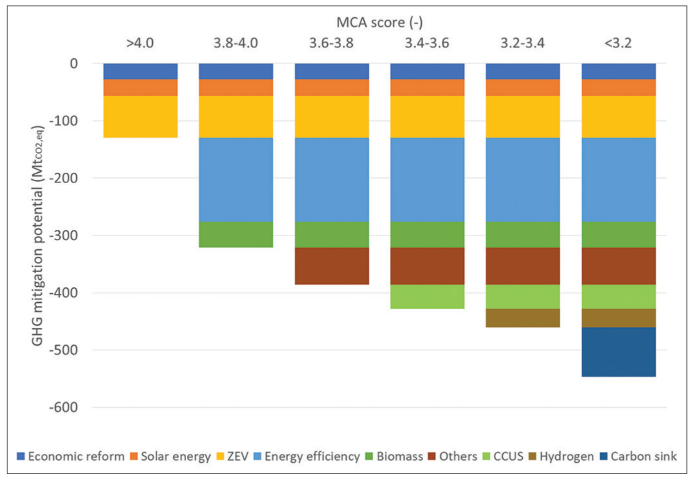


Figure 10: GHG mitigation curve with resulting multi-criteria score



(Table 5), a summary of GHG mitigation potential is illustrated in Figure 9.

The combination of quantitative data on GHG mitigation potential and a multi-criteria score is able to present technology prioritization for the carbon neutrality target, as illustrated in Figure 10. Similar to the marginal abatement cost curve, the order in which technologies are selected across the energy system is based on the average scores for readiness and impact.

It can be concluded that solar energy and electric vehicles are selected as the first priority technologies. Both of them are able to contribute 18.7% of the GHG reduction. Energy efficiency measures are diverse and have a wide score rating. Technologies related to compulsory measures, e.g., standard labeling for electric appliances and energy conservation laws in buildings and factories, have relatively high scores, while incentive measures have a lower rating. However, overall energy efficiency technologies are ranked highly. It also has the greatest potential to reduce of GHG emissions (31.8%). Bio-energy technologies are a high priority, contributing 8.2% to the reduction of GHG emissions. Concerns about feedstock availability are a major barrier to reaching potential. Other renewable energies, such as wind energy, waste-to-energy, etc., can be treated as lower priorities. Finally, CCUS, green hydrogen, and technology related to carbon sinks are placed in the lowest priority group. These technologies, which are expected to contribute more

Table 5: Summary of GHG mitigation potential from selected technologies

Selected GHG mitigation technology		Sector coverage	Key assumption
EE	- Load management - Energy efficiency in industry and buildings - Shared mobility - ICE fuel economy, HEV	1A1, 1A2, 1A3, 1A4	Energy intensity is improving by 2% annually, with expected economic growth of 3-4% annually.
BEV	- Battery electric vehicles of various types, e.g., light-duty vehicles, pickup trucks, motorcycles, public vans, buses, and trucks	1A2	100% sale of BEV by 2030-2040 (years vary depending on vehicle type)
Solar energy	- DPV in industry, building, and housing	1A1	Total installed capacity of DPV will be 32.5 GW in 2050. Peer-to-peer energy trading and energy storage are included.
	- Grid-connected solar power		A total of 24.3 GW of new installed solar power with energy storage will be added in 2050.
Biomass	- Biomass for power	1A1	New installed capacity of biomass power will be added totally 24.5 GW in 2050
	- Biomass for heating	1A2	18% of fuel mix in the industry sector will account for 5.3 Mtoe in 2050. The limited resource of feedstock is taken into account.
Hydrogen	- Hydrogen for power (co-firing) and industry through natural gas grid	1A1, 1A2, 1A3	20% blending of hydrogen in the natural gas grid and 40.6% share of natural gas in electricity generation in 2050, with decommissioning of retired plants taken into account. Total stock of 130,000 FCEVs in 2050
CCS/CCUS	- CCS and CCUS for power and industry	1A1, 1A2	Capture 80% of the CO_2 emitted from fossil-based power plants and industries.
Others		1A1, 1A2, 1A3, 1A4	Total remainder has a small amount of GHG mitigations, e.g., biogas for cooking, compressed biogas for vehicles, biofuel in transportation, small hydropower, wind power, waste-to-energy, etc.
Carbon sink	- Land (land use and land use change)	3B	Referred to the suggestion from ONEP (Office of Natural Resources and Environmental Policy and Planning [ONEP], 2022)
Carbon offset required to achieve carbon neutrality		No requirement	

Source: (Pongthanaisawan, 2023), EE: Energy efficiency, BEV: Battery electric vehicle

than 29.5% of GHG emission reduction, are considered to be at high risk of unsuccessful commercialization.

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REFERENCES

Enkvist, P.A., Nauclér, T. (2007), A Cost Curve for Greenhouse Gase Reduction. United States: McKinsey.

IEA. (2022), Southeast Asia Energy Outlook. France: International Energy Agency.

IPCC. (1996), IPCC Technical Paper I-Technologies, Policies and Measures for Mitigating Climate Change. Geneva: Intergovernmental Panel on Climate Change.

IPCC. (2007), IPCC Fourth Assessment Report. Geneva: Intergovernmental Panel on Climate Change.

IPCC. (2022), Climate Change: Mitigation of Climate Change: Summary for Policy Maker. Geneva: Intergovernmental Panel on Climate Change.

Jahan Ali., Edwards, K.L. (2013), Multi-Criteria Decision Analysis for Supporting the Selection of Engineering Materials in Product Design. Netherlands: Elsevier Inc.

Kumara, A., Sah, B. (2017), A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renewable and Sustainable Energy Reviews, 69, 596-609.

Misila, P., Winyuchakrit, P., Limmeechokchai, B. (2020), Thailand's long-term GHG emission reduction in 2050: The achievement of renewable energy and energy efficiency beyond the NDC. Heliyon, 6(12), e05720.

MNRE. (2020), Thailand Third Biannial Updated Report. Thailand: Ministry of Natural Resource and Environment.

NREL. (2022), Retrieved from NREL Transforming Energy: Available from: https://www.atb.nrel.gov/electricity/2022/utility-scale_battery_storage

Office of Natural Resources and Environmental Policy and Planning (ONEP). (2022), Long-Term Low Greenhouse Gas Emission Development Strategies (LT-LEDS). Bangkok, Thailand: Natural Resources and Environmental Policy and Planning.

Pongthanaisawan, J. (2023), Thailand energy scenario: Pathways towards carbon neutrality 2050. International Journal of Energy Economics and Policy, 13(1), 489-500.

STI. (2018), Technology Assessment for GHG Mitigation. National Science Technology and Innovation Policy Office.

Subash, D., Desgain, D. (2015), Identifying and Prioritizaing Technologies for Mitigation. Kenya: UNEP-DTU Partnership.

TGO. (2022), Available from: http://www.lowcarboncity.tgo.or.th/scaleup

Wang, J.J., Jing, Y.Y. (2009), Review on multi-criteria decision analysis aid in sustainable energy decision making. Renewable and Sustainable Energy Reviews, 13, 2263-2278.

Wangjiraniran, W. (2022), Plausible scenarios for Thai sustainable energy in 2050: Cloud and clear. International Journal of Energy Economics and Policy, 12, 357-367.