Research Article

Scenario-based Assessment of Decarbonized Transport Sector in Thailand towards Carbon Neutrality 2050

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Abstract

Thailand's transport sector has been one of the highest CO_2 emitters for several decades in the country due to the excessive increase in transport service demand and the high reliance on high-carbon-intensity petroleum fuels. This article discusses the potential of CO_2 reduction in the transport sector in Thailand to achieve carbon neutrality by 2050. The Low Emissions Analysis Platform (LEAP) is adopted to estimate the future energy demand and CO_2 emission between 2020 and 2050. This study designs two main scenarios, namely the Baseline (BAS) and the Decarbonization (DEC) scenarios. The BAS scenario is developed in a business-as-usual approach with frozen technologies, while the DEC scenario is constructed as a CO_2 countermeasure by including multiple low carbon technologies such as i) improving fuel economy efficiency of engines, ii) promoting electric vehicles (EVs), iii) utilizing fuel cell electric vehicles (FCEVs), and iv) promoting mass transportation. The results indicate that by 2050, the transport sector's total energy demand will significantly increase to approximately 49,906 ktoe, with diesel, gasoline, and jet kerosene accounting for the majority of fuel consumption. In the BAS scenario, total CO_2 emissions in the transport sector are estimated to be 119,737 $ktCO_2eq$. By full implementation of the CO_2 countermeasures and low carbon technologies in the decarbonization scenario, the total carbon emission in the transport sector is estimated to be 30,582 $ktCO_2$ by 2050, which is in line with carbon neutrality pathways of Thailand. However, the nation-wide transport action plan should be developed in order to promote such sustainable transport technologies.

Keywords: Decarbonization, Transport Sector, Carbon Neutrality, LEAP model, Thailand

1. Introduction

Thailand has undergone a transformation from agricultural-based to export-oriented manufacturing economic development, resulting in rapid economic growth and becoming the second-largest economy in the Association of Southeast Asian Nations countries (Asian Development Bank [ADB], 2015). The primary driving force behind Thailand's industrialization and social development is the utilization of fossil fuels for energy supply and demand, which results in numerous environmental issues, particularly those related to carbon dioxide (CO_2). In 2020, Thailand's total CO_2 emissions amounted to approximately 248.32 million tonnes of carbon dioxide ($MtCO_2$), marking a 12.35% increase from the total emissions in 2010 (Energy Policy and Planning Office [EPPO],2021). As a member of The United Nations Framework Convention on Climate Change (UNFCCC), Thailand has committed to mitigating its medium- and long-term greenhouse gas (GHG) emissions by declaring the goal of achieving a carbon emissions peak by 2025 and nationwide carbon neutrality by 2050 (United Nations Framework Convention on Climate Change [UNFCCC], 2022).

Driven by economic and social development, the transportation service in Thailand has greatly expanded in both passenger and freight demand in the last decade. In 2020, the total number of vehicles in Thailand was approximately 41,471.35 thousand vehicles, with an average growth rate of 3.85% from 2010 (Department of Land Transport [DLT], 2024). The share of light-duty vehicles (passenger cars, motorcycles, pick-up trucks, etc.) was around 95.10%, while the share of heavy-duty buses and heavy trucks was only 3.20% and 1.70%, respectively. The total domestic demand of passenger volume in 2020 was around 610 billion passenger-kilometers (pass-km) (DLT, 2024; International Civil Aviation Organization [ICAO], 2020; Ministry of Transport of Thailand [MoT], 2009, 2018; State Railway of Thailand [SRT], 2020; World Bank, 2024), shared by road (95.92%), rail (0.62%), and air (3.46%). On the other hand, the domestic freight transport demand was 1,029 billion tonne-kilometers (tonne-km) in 2020 (DLT, 2024; ICAO, 2020; MoT, 2009, 2018; SRT, 2020; World Bank, 2024), shared by road (97.77%), water (1.88%), rail (0.25%), and air (0.10%). Furthermore, the Thai transport sector is primarily powered by a diverse range of petroleum products, including gasoline, diesel, liquefied petroleum gas (LPG), compressed natural gas (CNG), and other alternative fuels, making this sector the main contributor to the country's CO_2 emissions. In 2020, the transport sector in Thailand consumed 29,699 thousand tonnes of oil equivalent (ktoe), accounting for 38.40% of the total final energy consumption in the country, with petroleum products accounting for 95.8%, followed by natural gas at 4.1% and electricity at 0.1% (Department of Alternative Energy Development and Efficiency [DEDE], 2024). In the same year, the total CO_2 emissions from the transport sector alone were 70.58 $MtCO_2$, accounting for 28.42% of the national CO_2 emissions (EPPO, 2021). From 2010 to 2020, the amount of emissions in this sector has increased by almost 23%, from 57.48 $MtCO_2$. Considering the acceleration of economic growth (GDP and income), the rise in urbanization, and the increasing ownership of vehicles, the demand for passenger and freight transport is expected to significantly increase in the coming decades, posing a variety of energy-environmental threats. Furthermore, due to the high dependency on high-carbon intensity fuels as the major sources of transportation fuel, this sector is classified as one of the main key sectors for Thailand to impose carbon mitigation measures on. Global warming has become a major concern for the world, requiring us to impose and accelerate mitigation actions. The transport sector is one of the largest emissions contributors and is considered as one of the most difficult sectors to achieve deep decarbonization (Creutzig et al., 2015). However, it is still possible to achieve a deep reduction of carbon emissions in the transport sector if there is a clear and precise plan for the implementation of multiple transport management systems and the implications of low-emission technology in the transport sector (Limmeechokchai et al., 2024). Several articles have demonstrated the reduction of CO_2 emissions in the transport sector by employing fuel economy efficiency enhancements, adopting more efficient vehicles, and using alternative low-emission fuels such as biofuels, electricity, and hydrogen as the primary energy source for vehicles (Tsita & Pilavachi, 2017; Van der Zwaan et al., 2013). Instead, the Avoid-Shift-Improve (ASI) approach serves as an effective mitigation measure to promote low-emissions transport development (Mårtensson et al., 2023; Wimbadi et al., 2021). "Avoid" describes a reduction of travel demand, avoiding unnecessary trips, or improving the efficiency of the transport system, i.e., the utilization of transport-oriented development (TOD). "Shift" indicates the shift from a high-energy-consuming transportation mode to a more energy-saving and environmentally friendly mode and the shift from a high-carbon intensity fuel to a lower-emission fuel. "Improve" demonstrates the enhancement of fuel economy and vehicle efficiency.

Lately, greenhouse gas emissions mitigation in Thailand's transport sector has gained interest from researchers. Several research studies have explored various strategies to reduce greenhouse gas emissions, proposing four mitigation countermeasures: transport demand management, modal shift, alternative fuel utilization, and electric vehicle applications. These studies aim to demonstrate the potential and amount of GHG emissions reduction by 2050 (Chunark et al., 2015; Phoualavanh & Limmeechokchai, 2016). Besides this, Winyuchakrit et al. (2017) have discussed the effectiveness of electric vehicle utilization in terms of energy consumption reduction and GHG emissions mitigation in Thailand. Furthermore, Limmeechokchai et al. (2022) have implemented a study on decarbonizing the Thai transport sector to achieve the 2-degree Celsius goal by 2050, utilizing a combination of electric vehicles and biofuel. In addition, the alternative solution to traffic congestion by utilizing mass public transportation would provide not only environmental pollution mitigation but also other co-benefits such as reducing traveling time, minimizing fuel consumption, and reducing traffic accidents (Iamtrakul et al., 2018; Rawiwan et al., 2019). The aforementioned articles have already illustrated the long-term mitigation strategies for the transport sector; however, advancements in certain technologies, such as the use of hydrogen fuel cells for vehicle fuel, have significantly improved over time, although these articles did not mention them. Additionally, the previously mentioned research studies have not yet analyzed the possibility of achieving the goal of carbon neutrality by 2050 in Thailand through deep decarbonization implementations. In this study, we developed an energy model for Thailand's transport sector in the Low Emissions Analysis Platform (LEAP), using a bottom-up approach to determine future energy consumption and carbon dioxide emissions over a 30-year timeframe, with 1-year intervals between 2020 and 2050. This study develops two main scenarios, the Baseline (BAS) scenario and the Decarbonized (DEC) scenario, to compare future energy demand, transport system structure, and CO_2 emissions. The BAS scenario is constructed in the business-as-usual manner with frozen technology and policy, while the DEC scenario is designed as a CO_2 emissions mitigation countermeasure. The DEC scenario will incorporate various technologies and implementations, such as enhancing fuel efficiency for internal combustion engines, electric vehicles (EVs), fuel cell electric vehicles (FCEVs), and public transportation.

2. Methodology

2.1 The framework of the study

In this study, multiple procedures will be carried out, starting with the data collection on various driving factors for the transport demand, the number of fleet vehicles in the road transport mode, the demand for passenger and freight in the air, rail, and water transport, and the average fuel economy of vehicles. Furthermore, the historical data will be used for forecasting the future number of vehicles and future demand for passenger and freight transport through the multi-variable regression analysis method. Then, these data, together with the other low-carbon transport technologies, will be inserted into the LEAP model, where two main scenarios will be constructed. The Baseline (BAS) scenario is developed as the reference scenario in a frozen technology manner, while the Decarbonization (DEC) scenario is built with multiple countermeasures of action by including fuel economy efficiency improvement, alternative fuel promotion, modal shift toward mass transportation modes (trains and buses), promotion of electric vehicles, and fuel cell electric vehicles powered by hydrogen. The LEAP model will generate the results from the two scenarios, and then the conclusion and recommendations will be made. (Figure 1)

2.2 Structure of Thailand transport sector in the LEAP model

LEAP is an energy-environmental planning tool used for projecting the future energy mix and emissions through multiple scenario development. This analysis tool enables users to construct sectoral energy models, including building, transport, industrial, power, and entire energy systems (Misila et al., 2020), across a range of timeframes, from short-term to long-term studies. This study categorizes the transport sector in Thailand into four main modes: road, rail, air, and water (MoT, 2018). Each transportation mode represents the demand for passengers and freight in passenger kilometers (pass-km) and ton-kilometers (tonne-km), respectively (see Figure 2). In the road transportation modes, a variety of vehicles such as cars, vans, motorcycles, buses, and trucks operate using a variety of fuels such as gasoline, diesel, CNG, LPG, and so on. Diesel and electricity power both passenger and freight rail transports in the rail transport category, while jet kerosene serves as the sole fuel for air transport.

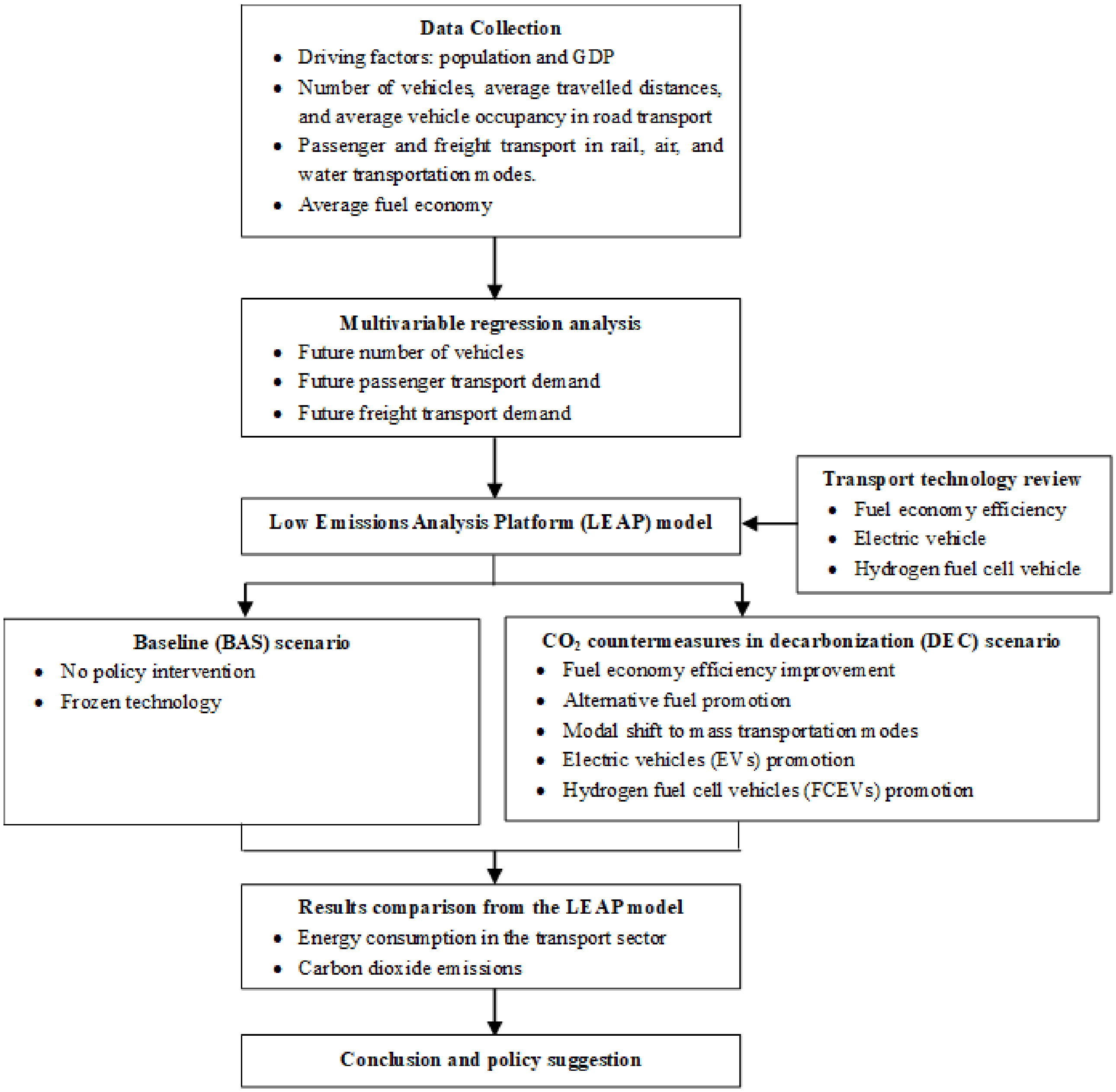

Figure 1. Flowchart of the framework of the study

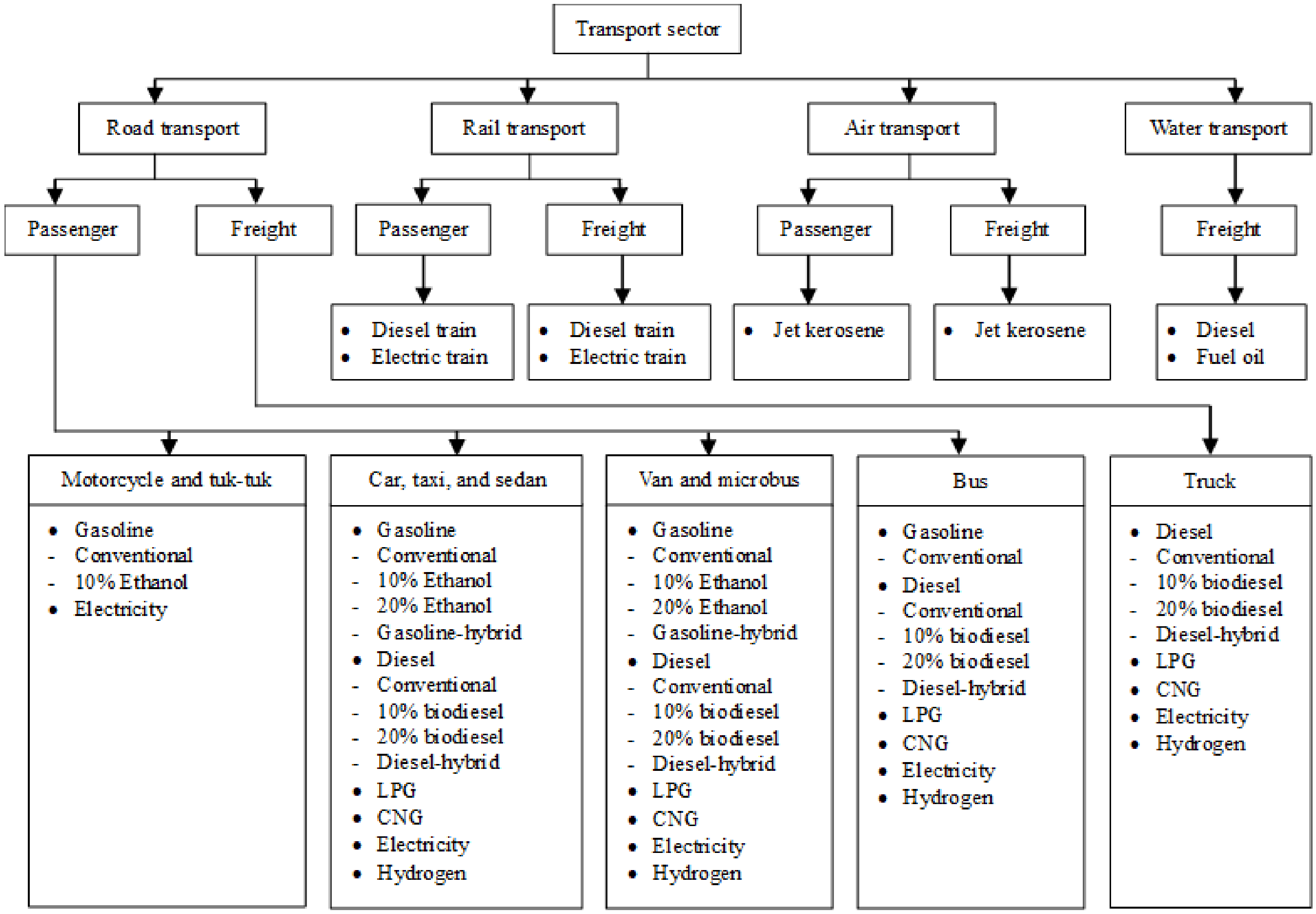

Figure 2. Structure of Thailand's transport sector in the LEAP model

Furthermore, we assume that the water transport mode primarily serves freight transport, with diesel and fuel oil serving as the dominant energy sources. In the road transport mode, the types of vehicles are grouped based on the size similarity and average fuel economy consumption similarity; therefore, in this study, it is divided into four categories as seen in Figure 2.

2.3 Data Collection and Assumptions

2.3.1 Driving Factors

The important data needed in this study consists of transport demand driving factors (GDP, income, and population), historical vehicle registration, assumptions of vehicle travelled distance, average fuel economy, average occupancy (people/vehicle and tonne/vehicle), and passenger and freight traveled per year. These data are gathered from the official statistics report and database from the Thai government websites, official international organizations, and scientific articles.

Population: Thailand's population increased from 63.88 million in 2010 to 65.56 million in 2019 and started a slight decline to around 66.19 million in 2020 (National Statistical Office of Thailand [NSO], 2021). The United Nations has conducted the world population projections and estimated that Thailand will be facing an aging society issue in the next decade (United Nations, 2024). The projection shows that the average annual growth rate of the Thai population between 2020 and 2050 is estimated to be roughly -0.25%, making a total 2050 population in Thailand to decline to around 61.32 million (see Table 1).

GDP and income: Thailand's economy is classified as a higher-middle-income country with a total GDP in 2020 of around 1,429.72 billion US dollars of purchasing power parity ($PPP) at constant 2021 U.S. dollar, a slight fall from 2019 due to the COVID-19 epidemic (World Bank, 2024). According to the Second Share Socioeconomic Pathway (SSP2) projection, Thailand's GDP will grow by 2.65% per annum between 2020 and 2050 (International Institute for Applied Systems Analysis [IIASA], 2018). The average income per capita in the country was 21.60 thousand $PPP in 2020, and it will increase to approximately 51.02 thousand $PPP in 2050 (see Table 1).

2.3.2 Estimation of Transport Demand

Road vehicle ownership estimation: Vehicle ownership in Thailand is a function of the population and income per capita (Chunark et al., 2015). Therefore, the projection of vehicle ownership is estimated by Equation 1. The coefficients of linear regression analysis in different types of vehicle projection are shown in Table 2.

$$\ln(NV_{i,t}) = a \times \ln(GDP_{cap,t}) + b \times \ln(Population_t) + c \quad \text{Equation 1}$$

Where,

$NV_{i,t}$ is the total number of vehicle types *i* in year *t*,
$GDP_{cap,t}$ is the income per capita in year *t*,
$Population_t$ is the total population in year *t*,
a is the coefficient of income per capita,
b is the coefficient of population,
c is the constant.

Passenger and freight demand estimation in road transportation: To estimate the total demand in passenger and freight transport in the road transport category, it needs to be calculated by using the following Equations 2 and 3, by using the total number of vehicles multiply with the travelled distance and average vehicle occupancy (Chunark et al., 2015).

Table 1. Historical and projection of transport demand driving factors

Items	Historical		Projections			AAGR (%)
	2010	2020	2030	2040	2050	
Population (million people)[1]	63.88	66.19	65.64	64.15	61.32	-0.25
GDP (billion $PPP at 2021$)[2]	1,147.32	1,429.72	1,868.43	2,417.47	3,128.38	2.65
Income (thousand $PPP at 2021$)[3]	17.96	21.60	28.46	37.68	51.02	2.91

Note: PPP = Purchasing Power Parity, AAGR = Average Annual Growth Rate between 2020 and 2050
Source: [1](NSO, 2021; United Nations, 2024); [2], [3](World Bank, 2024; IIASA, 2018)

Table 2. Coefficient of linear regression analysis

Type of vehicle	Coefficient a	Coefficient b	Constant c	R^2
Car, taxi, and sedan	0.5948	10.1517	-172.1735	0.9500
Van and microbus	-0.9061	1.8551	-19.5352	0.4399
Motorcycle and three-wheelers	0.2018	3.4442	-47.1722	0.8639
Bus	0.1761	6.5971	-106.5051	0.9671
Truck	-2.0815	20.4038	-333.2747	0.6074

$$TPK_{i,t} = NV_{i,t} \times TD_{i,t} \times AVO_{i,t} \quad \text{Equation 2}$$

$$TFK_{i,t} = NV_{i,t} \times TD_{i,t} \times AVO_{i,t} \quad \text{Equation 3}$$

Where,

$TPK_{i,t}$ is the total passenger (pass-km) demand of type *i* vehicle in year *t*,

TFKi, t is the total freight (tonne-km) demand of type *i* vehicle in year *t*,

$TD_{i,t}$ is the average distance travelled by type *i* vehicle in year *t*,

$NV_{i,t}$ is the total number of vehicle type i in year $_t$,

$AVO_{i,t}$ is the average vehicle occupancy (people/vehicle or tonne/vehicle) of vehicle type *i* in year *t*.

In this study, the average travelled distance of each vehicle (kilometer/year) is collected from the study of Pongthanaisawan et al. (2007), whereas the average occupancy of different types of vehicles (people/vehicle or tonne/vehicle) is collected from the study of Wongchavalidkul et al. (2016). This information is shown in Table 3.

Passenger and freight demand in rail, air, and water transportation: The projections of the volume of passenger and freight demand in these transportation modes are made by utilizing the multi-variable regression analysis approach where the GDP and population are being used as the independent variables. Therefore, results of the transport demand projections in different transportation modes in Thailand are indicated in Table 4.

Table 3. Average vehicle travelled distance and average vehicle occupancy

Type of vehicles	Average travelled distance (vehicle-kilometer/year)[1]	Average occupancy (people/vehicle or tonne/vehicle)[2]
Car, taxi, and sedan	7,500	2.10
Van and microbus	12,000	14.00
Motorcycle and three-wheelers	2,015	1.10
Bus	50,750	25.00
*Truck	57,000	25.00

Note: *the unit for truck average occupancy is defined in tonne/vehicle
Source: [1](Pongthanaisawan et al., 2007), [2](Wongchavalidkul et al., 2016)

Table 4. Historical data and projections of transport demand in Thailand

Items	Historical		Projections		
	2010	2020	2030	2040	2050
Road transportation mode					
Car, taxi, and sedan (billion pass-km)	147.92	274.31	368.54	471.73	537.11
Van and microbus (billion pass-km)	65.92	72.96	68.36	72.15	79.05
Motorcycle and three-wheelers (billion pass-km)	38.03	47.85	46.04	37.93	33.05
Bus (billion pass-km)	137.25	190.61	214.88	238.24	296.39
Truck (billion pass-km)	840.03	1,006.17	1,270.17	1,408.08	1,568.38
Rail transportation mode[1]					
Passenger (billion pass-km)	8.25	3.76	4.96	6.57	8.89
Freight (billion tonne-km)	2.95	2.62	3.42	4.42	5.72
Air transportation mode[2]					
Passenger (billion pass-km)	21.59	21.13	27.85	36.87	49.91
Freight (billion tonne-km)	2.94	0.68	0.90	1.19	1.62
Water transportation mode[3]					
Freight (billion tonne-km)	23.80	38.89	50.82	65.76	85.10

Source: [1] (MoT, 2009, 2018; SRT, 2020; World Bank, 2024), [2](ICAO, 2020; World Bank, 2024), [3](MoT, 2018; NSO, 2021)

2.4 Scenario Development

2.4.1 Baseline (BAS) scenario

The BAS scenario is developed as a reference case scenario, assuming no policy intervention and no change in technologies. Furthermore, this scenario assumes that the future share of technology and fuel economy will remain unchanged from 2020. The input data for the BAS scenario, such as the share of technology used in the road transportation mode (see Table 5), is collected from the statistics database regarding vehicle registration in Thailand, developed by the Department of Land Transport of Thailand (DLT, 2024). In terms of average fuel economy consumption of conventional fuels, biofuel (bio-gasoline and biodiesel), electricity consumption, and hydrogen consumption in different types of vehicles are gathered from various sources as shown in Table 6.

Table 5. Share of technology in the transport sector in the BAS scenario

Fuel type	Technology share in the BAU scenario (%)				
	Car	Van	Motorcycle	Bus	Truck
Gasoline	38.43	7.19	100.00	1.85	-
E10	-	-	-	-	-
E20	-	-	-	-	-
Hybrid-gasoline	0.82	-	-	-	-
Diesel	54.90	86.37	-	76.08	100
B10	-	-	-	-	-
B20	-	-	-	-	-
Hybrid-diesel	0.07	-	-	-	-
CNG	1.68	3.11	-	21.76	-
LPG	4.10	3.33	-	0.31	-
Electricity	-	-	-	-	-
Hydrogen	-	-	-	-	-
Total	100	100	100	100	100

Source: (DLT, 2024)

Table 6. Fuel economy in the road transportation mode

Fuel type	Fuel economy by type of vehicles (litre/100km)				
	Car	Van	Motorcycle	Bus	Truck
Gasoline[1]	7.85	9.71	1.71	27.92	21.00
E10[2]	8.12	10.05	-	28.90	21.7 4
E20[2]	8.24	10.20	-	29.32	22.05
Diesel[1]	6.28	7.77	-	23.45	16.80
B10[2]	6.34	7.85	-	23.69	16.97
B20[2]	6.41	7.92	-	23.92	17.14
Hybrid-gasoline[2]	4.32	5.34	-	15.36	11.55
Hybrid-diesel[2]	3.45	4.27	-	12.90	9.24
CNG[1] (kg CNG/100km)	3.50	4.33	-	12.45	9.36
LPG[1]	9.11	11.26	-	36.50	24.57
Electricity[3] (kWh/100km)	19.00	23.50	4.14	67.58	50.83
Hydrogen[4] (kgH2/100km)	0.89	1.10	-	3.17	2.39

Source: [1](Office of Transport and Traffic Policy and Planning [OTP], 2023), [2](U.S. Department of Energy [DOE], 2024), [3](Electric Vehicle Database [EVDB], 2024), [4](Duan et al., 2022)

2.4.2 Decarbonization Scenario

The DEC scenario is developed as a countermeasure against CO_2 emissions. The scenario is built by incorporating different implementations such as enhancing fuel economy efficiency, promoting electric vehicles (EVs), promoting hydrogen fuel cell vehicles (FCEVs), and modal shifting mass transportation. Furthermore, the assumptions of these implementations are made by following the existing global scenario conducted by the International Energy Agency (IEA) and other scientific studies. The assumptions of the DEC scenario are made as follows:

Fuel economy efficiency: The improvement of fuel economy efficiency for light-duty and heavy-duty vehicles in the DEC scenario is gathered from a study of the Global Fuel Economy Initiative (Global Fuel Economy Initiative [GFEI], 2020). The study has demonstrated that the mid- and long-term average fuel economy of light-duty vehicles will be able to improve by 15% in 2030 and 30% in 2050 compared to the 2020 fuel economy.

Promotion of electric vehicles: Electric vehicles (EVs) have been considered the essential technology in the decarbonized transport sector since they produce zero tailpipe emissions. In the global Net-Zero Emissions (NZE) scenario of IEA, it is indicated that to achieve the deep decarbonization goal, electric vehicles for two/three-wheelers, light-duty vehicles (passenger cars and vans), and heavy-duty vehicles (buses and medium and heavy trucks) will reach at least 90%, 85%, and 65%, respectively, by 2050 of the total vehicle fleet (International Energy Agency [IEA], 2021). Furthermore, the global NZE scenario of IEA has demonstrated that the global electric train will have a share of at least 96% of the total passenger rail transport service (IEA, 2021). Therefore, in the DEC scenario of Thailand in this study, it is assumed that the share of electric motorcycles/three-wheelers, light-duty vehicles, and heavy-duty vehicles will gradually increase to 75%, 75%, and 65%, respectively, by 2050, as shown in Table 7.

Promotion of fuel cell electric vehicles: Fuel cell electric vehicles (FCEVs) powered by hydrogen are classified as zero-emission vehicles. The study of the net zero emission 2050 roadmap for the energy sector demonstrates that the share of FCEVs in 2050 for road transportation modes such as light-duty and heavy-duty vehicles will be 10% and 20%, respectively (IEA, 2021). Hence, in this study, the share of FCEVs for light and heavy-duty vehicles in road transportation in Thailand is estimated to be 5%, respectively, by 2050 (see Table 7).

Modal shift: The global NZE scenario developed by the International Energy Agency (IEA, 2021) illustrates that global passenger transport by rail is estimated to be at least 20% of the total passenger transport in 2050 globally. Thus, in this study, the share of rail passenger transport is set be 15% of total Thailand's passenger transport demand by 2050 (see Table 8).

3. Results and Discussion

3.1 Energy Demand in the Transport Sector

The timeframe in this study is started from 2020 and projected to 2050 to illustrate the energy demand and carbon mitigation in the transport sector in Thailand. During 2020 and 2021, the impact of COVID-19 resulted in decreasing the transport sector demand and energy demand in this sector (NSO, 2023; DEDE, 2024). Then, after 2022, the demand for transport services (passenger and freight) as well as energy demand in the sector has increased. Therefore, from 2025, the service and energy demand in the transport sector in this study show a remarkable increase. Figure 3 represents the results of the total energy demand projections in the transport sector in Thailand under the Baseline (BAS) and the Decarbonization (DEC) scenarios from the LEAP model. The transport sector's energy consumption in the BAS scenario shows a significant growth between 2020 and 2050 due to the excessively increased transport demand for both passenger and freight. By 2050, the total energy demand in the transport sector is found to increase to 49,906 ktoe, a 1.76% average annual growth rate from 2020. The road transportation mode is the largest energy demand, consuming up to 83.87% of the total transport sector's energy consumption in 2050, followed by the air (10.62%), water (5.10%), and rail (0.41%) transportation modes, respectively.

Table 7. Share of transport technologies in the DEC scenario

Mode and technology		Share of technologies (%)			
		2020	2030	2040	2050
Car, taxi, and sedan	Gasoline	38.43	45.80	23.07	0.00
	E10	0.00	0.50	0.75	1.00
	E20	0.00	1.00	1.50	2.00
	Hybrid-gasoline	0.82	5.00	5.00	5.00
	Diesel	54.90	30.00	15.00	0.00
	B10	0.00	0.50	0.75	1.00
	B20	0.00	1.00	1.50	2.00
	Hybrid-diesel	0.07	5.00	7.00	9.00
	CNG	1.68	0.84	0.42	0.00
	LPG	4.10	2.05	1.03	0.00
	Electricity	0.00	8.31	41.66	75.00
	Hydrogen	0.00	0.00	2.34	5.00
Van and microbus	Gasoline	7.19	5.00	2.50	0.00
	Diesel	86.37	54.95	27.64	0.00
	B10	0.00	1.00	1.50	2.00
	B20	0.00	1.00	2.00	3.00
	Hybrid-diesel	0.00	2.00	6.00	10.00
	CNG	3.11	4.05	4.53	5.00
	LPG	3.33	2.00	1.00	0.00
	Electricity	0.00	30.00	52.50	75.00
	Hydrogen	0.00	0.00	2.33	5.00
Motorcycle and three-wheelers	Gasoline	100.00	84.00	54.50	25.00
	Electricity	0.00	16.00	45.50	75.00
Bus	Gasoline	1.85	0.00	0.00	0.00
	Diesel	76.08	76.85	38.59	0.00
	B10	0.00	2.00	2.00	2.00
	B20	0.00	2.00	2.50	3.00
	Hybrid-diesel	0.00	2.00	6.00	10.00
	CNG	21.76	10.00	7.50	5.00
	LPG	0.31	0.15	0.08	0.00
	Electricity	0.00	7.00	41.00	75.00
	Hydrogen	0.00	0.00	2.33	5.00
Truck	Diesel	100.00	85.50	48.42	10.00
	B10	0.00	1.00	1.50	2.00
	B20	0.00	1.00	2.00	3.00
	Hybrid	0.00	5.00	7.50	10.00
	CNG	0.00	1.00	5.00	10.00
	Electricity	0.00	6.50	33.25	60.00
	Hydrogen	0.00	0.00	2.33	5.00
Rail	Diesel train	75.00	60.00	42.50	25.00
	Electric train	25.00	40.00	57.50	75.00

Note: author’s assumptions

Table 8. Assumption of the modal shift and technologies in the DEC scenario

Modes	Share of passenger transport demand by modes (%)			
	2020	2030	2040	2050
Road transportation mode	95.92	92.00	87.50	83.00
Rail transportation mode	0.62	5.00	10.00	15.00
Air transportation mode	5.15	3.00	2.50	2.00
Modes	**Share of freight transport demand by modes (%)**			
	2020	2030	2040	2050
Road transportation mode	97.79	95.36	93.78	92.20
Rail transportation mode	0.25	2.67	3.84	5.00
Air transportation mode	0.07	0.07	0.08	0.10
Water transportation mode	1.89	2.00	2.40	2.70

Note: author's assumptions

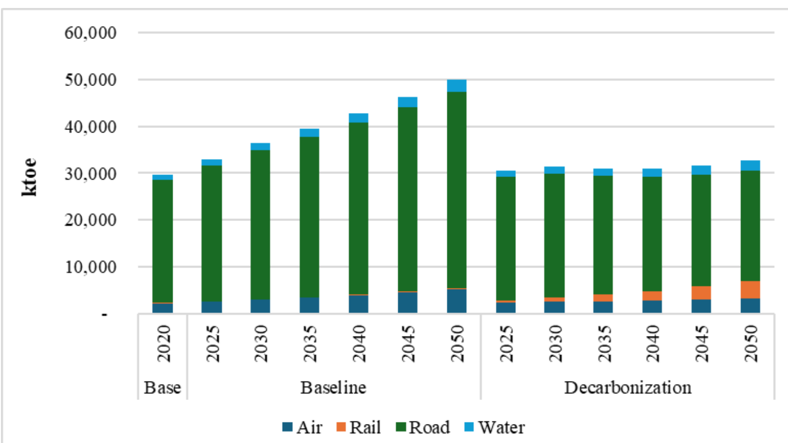

Figure 3. Energy demand in different transport modes

On the other hand, the total consumption of energy in the transport sector under the DEC scenario shows a remarkable reduction owing to the adoption of efficient low-carbon technologies such as fuel economy efficiency enhancements, shifting to mass transportation modes (trains and buses), and utilizing electric vehicles (EVs) and hydrogen fuel cell electric vehicles (FCEVs). Total energy consumption in the transport sector in the DEC2050 is estimated to be 32,777 ktoe, a 34.32% reduction compared to the BAS scenario. Additionally, the energy consumption from the mass transportation mode (rail) will have a significant growth based on the shifting from road to rail in both passenger and freight transport. The share of the total energy demand in the transport sector in 2050 under the DEC scenario is found to be 11.15% whereas the share of energy demand in the road transport is estimated to decline to 72.42%.

The comparison of fuel consumption between the BAS and DEC scenarios is illustrated in Figure 4. In the Baseline scenario, diesel and gasoline are estimated to be the two major fuel utilizations in the transport sector over the period of the study. By 2050, diesel and gasoline are projected to have a share, respectively, of 50.24% and 27.91% of the total energy consumption in the transport sector. Jet kerosene will be the third largest proportion of fuel used in this scenario, while the electricity demand in the transport sector is estimated to have only a 0.1% share in BAS2050.

Looking into the results under the DEC scenario, fuel utilization in the transport sector will have an excessive shift to low-emission fuel. The fuel composition for the Thai transport sector under the DEC scenario shows a great reliance on electricity due to the large shift to EVs in the road and rail transportation modes for both passenger and freight transport. Electricity consumption in 2050 is estimated to have a share of 57.38%, whereas the demand for diesel and gasoline will have a great reduction to approximately 11.69% and 1.87%, respectively. Furthermore, the introduction of FCEV applications in road transportation demands hydrogen fuel, and the share of hydrogen demand is projected to be around 3.19% in 2050.

This article is mainly focusing on the adoption of technology implementations such as fuel economy efficiency improvement and deployment of EVs and FCEVs, as well as shifting towards mass transportation at a highly ambitious level by utilizing the existing global scenarios conducted by the International Energy Agency (IEA) and other scientific studies. Further, in this study, the adaptation of considered technologies has not been included. Hence, some uncertainties might occur in the result analysis. Besides this, this study demonstrates only CO_2 emissions mitigation in the transport sector without considering the life-cycle assessment of carbon impacts as well as upstream effects from low-carbon transport technologies, transport infrastructure, and vehicle stocks, and low-carbon electricity for transportation (Limmeechokchai et al., 2024). Additionally, in this study, the projections of transport services demand (passenger and freight) are conducted by using the conventional methods utilizing population and GDP as the two main driving factors since they have been used in multiple research studies and are reliable. However, there are many other factors, such as land use, urban typologies, industrial characteristics, etc., that have a great impact on the travel demand in both freight and passenger logistics. Therefore, in future study, these limitations will be taken into account for the result analysis of the transport demand projections.

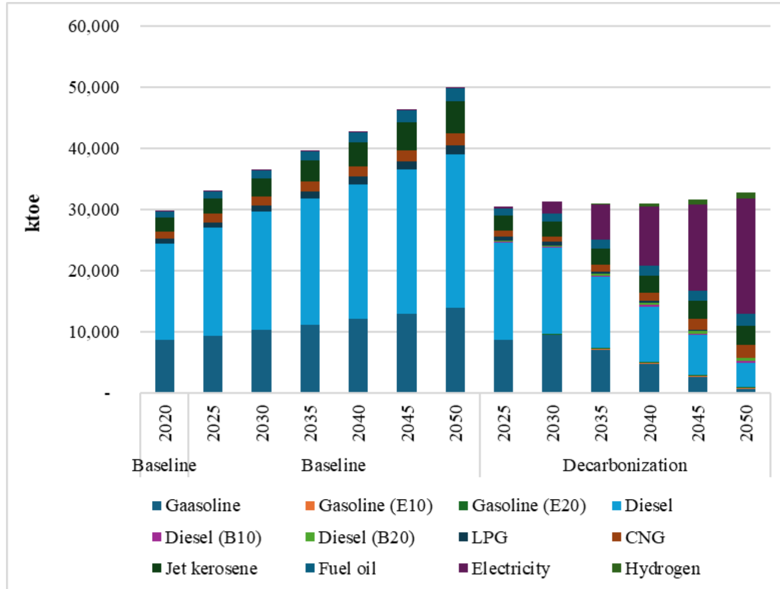

Figure 4. Energy demand by different types of fuel

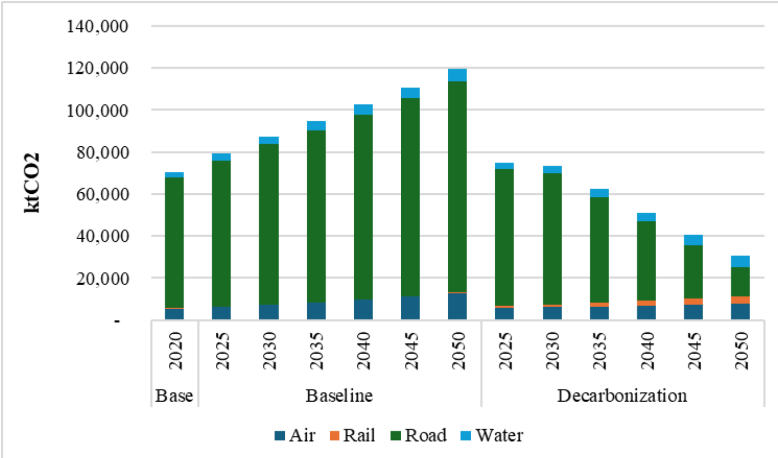

Figure 5. Carbon dioxide emissions in different transportation modes

3.2 Carbon Dioxide Emissions in the Transport Sector

The results of carbon dioxide emissions in Thailand's transport sector by different transportation modes are shown in Figure 5. In the BAS scenario, the amount of CO_2 emissions is increased in correlation with the growth of energy consumption and high dependency on high-CO_2 emission intensity fuels (see Figure 3 and Figure 4). The total CO_2 emissions in 2050 are estimated to be roughly 119,737 ktCO_2eq, a 69.66% growth compared to the total CO2 emissions in 2020. The CO_2 emissions contribution by modes in the BAS scenario illustrates that the road transportation mode will be the largest contributor by emitting around 83.74% of the total CO_2 emissions in the BAS2050, followed by the air (10.76%), water (5.17%), and rail (0.33%) transports, respectively.

The amount of carbon emissions in the transport sector is estimated to have a substantial mitigation between 2020 and 2050 in the DEC scenario. The achievement of carbon dioxide mitigation is a result of the integration of low-carbon transportation technologies in the transport system as mentioned in the DEC scenario development (section 2.4.2). The results show that the amount of carbon emissions in the transport sector in Thailand will have a peak emission by 2025 at 75,036 ktCO_2eq due to the early start of the transport sector mitigation implementations. The emissions will be gradually decreasing due to the increase in fuel economy efficiency improvement, EVs, and FCEVs penetration, together with the gradual inc rease in modal shifting to rail transportation mode towards 2050. The total emissions in 2050 are calculated to be approximately 30,582 ktCO_2eq, contributed by road transport (46.26%), air (25.42%), water (17.41%), and rail transports (10.92%), respectively.

According to the carbon neutrality 2050 target in Thailand's Long-Term Low Emissions Development Strategy (LT-LEDS), the transport sector's carbon emission is estimated to be 36,100 ktCO_2 by 2050 (UNFCCC, 2022). Nevertheless, Thailand's LT-LEDS did not clearly illustrate the technology deployment and penetration to achieve such deep decarbonization goal. Therefore, based on the findings in this paper regarding CO_2 mitigation toward 2050, total carbon emission could be mitigated to a lower level at 30,582 ktCO_2 by 2050, which represents a successful achievement of the carbon neutrality 2050 goal as mentioned in the Thailand's LT-LEDS.

4. Conclusion and Policy Suggestions

This article analyzes the potential of carbon dioxide emissions mitigation in the transport sector in Thailand by addressing the goal of achieving carbon neutrality by 2050. This study includes multiple carbon mitigation measures integrated into the transportation system in the Decarbonization (DEC) scenario, such as the improvement of fuel economy efficiency for internal combustion engine (ICE) vehicles, the promotion of EVs and FCEVs, and the shift to public transportation. The results in the Baseline scenario illustrate that the total energy demand and CO_2 emissions will significantly increase by 20,207 ktoe and 49,163 ktCO_2, respectively, compared to the 2020 level. In the Decarbonization scenario, the results show that the 2050 total energy consumption in the transport sector will be reduced by 34.32% compared to the BAS scenario. Furthermore, the amount of CO_2 emissions in the DEC scenario will gradually drop to 30,582 ktCO_2, a 69.66% reduction compared to the BAS scenario. It is indicated that the total CO_2 emissions in Thailand's transport sector in 2050 under the DEC scenario are lower than the target of carbon emissions in Thailand's LT-LEDS. Therefore, the transport sector in Thailand will be able to achieve the deep decarbonization target, which will push the country to become a carbon-neutral nation by the mid-21st century if technologies in the DEC scenario are fully adopted and implemented. Furthermore, Thailand's decarbonization in the transport sector requires tailored policies focused on incentivizing electric vehicles (EVs), enhancing public transport infrastructure, and transitioning to low-carbon fuels. Integrated strategies, such as linking energy transitions with transport electrification and urban planning, will support long-term sustainability. While challenges like funding, infrastructure, and behavioral change remain, opportunities exist through private sector involvement and regional cooperation. A holistic, multi-sectoral approach will ensure transport-related emissions reduction and achievement of its climate goals.

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CRediT Authorship Contribution Statement

Rathana Lorm: Formal analysis; data curation; Visualization; Writing – original draft.
Bundit Limmeechokchai: Conceptualization, Methodology; validation; Writing – review and editing; Supervision.

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