

Road Transport Energy Demand Analysis and Energy Saving Potentials in Thailand

J. Pongthanaisawan^{1,*}, C. Sorapipatana¹
and B. Limmeechokchai²

¹The Joint Graduate School of Energy and Environment
King Mongkut's University of Technology Thonburi
126 Pracha-uthit Rd., Bangmod, Tungkru, Bangkok, 10140 Thailand
Tel: (662) 4708309 ext 4147, Fax: (662) 8726978

²Sirindhorn International Institute of Technology, Thammasat University
Klong Luang, Pathumthani, 12120 Thailand

*Corresponding author: jakapong@jgsee.kmutt.ac.th

Abstract: Energy demands and CO₂ emissions in the transport sector have dramatically increased since Thailand started to transform its economy to an industrialised country. Since 1995, the transport sector has been the largest energy consuming sector in Thailand, accounting for about 38% of the total final energy consumption. Road transport, which plays an important role in economic development, consumed almost 80% of the energy consumption in the transport sector and also produced an extremely large amount of CO₂ emissions.

Because of dramatically increasing of oil price and environmental impact concern, various policy measures are sought and introduced in order to reduce energy demand and also to mitigate related emissions in this sector. The measures include efforts to increase energy efficiency

through vehicle technology options and to substitute conventional fuel by alternative fuel.

This paper presents a prediction of vehicle numbers in Thailand's road transport sector to 2020 and their implication for the energy demands and the CO₂ emissions. Non-linear vehicle ownership models derived from the gross domestic product in conjunction with numbers of annual registered vehicles were used as tools for the number of vehicles prediction. Base lines of the energy consumption and CO₂ emissions of the road transport sector in a business-as-usual (BAU) scenario were estimated by using a bottom-up or an end-use analysis method. Alternative scenarios; substitution of conventional fuel by compressed natural gas, improved fuel economy of vehicle engines by using high efficiency internal combustion engines, and the introduction of high energy efficiency hybrid vehicles, were then examined.

The resulting energy demands and the CO₂ emissions under each scenario were compared with the base line case of the BAU scenario. The reduction in energy demands and CO₂ emissions mitigation of each case show that the alternative scenarios of high energy efficiency vehicle promotion have a significant potential to reduce energy demand and mitigate emissions in this sector. Meanwhile, the promotion of compressed natural gas as alternative fuel could not reduce energy demand in the road transport sector, but it could be a substitute fuel for this sector.

Keywords: Transport Energy Policy, Energy Demand, Greenhouse Gas Emissions, Energy Substitution, Energy Efficiency Improvement.

Introduction

Energy demand and CO₂ emissions in the transport sector have dramatically increased since Thailand started to transform its economy to industrialised country. Since 1995, the transport sector has been responsible for almost 38% of total final energy consumption [1]. The transport sector is also a major contributor to environmental problems. It is estimated that about 35% of total CO₂ emissions from all economic sectors was contributed from a utilization of fossil fuels in this sector [2]. Road transport, which plays a major role in economic development, is responsible for a large share and increasing fuel use and emissions. This transport mode shared almost 80% of the total final energy consumption, increasing about 5.4% annually for the last decade.

Because of the dramatically increasing oil price and environmental impact concern, the various policy measures are sought and introduced in order to reduce energy demand and also to mitigate related emissions in this sector. The measures include substitution of conventional fuel by compressed natural gas, improvement of fuel economy of vehicle engines by using highly efficient internal combustion engines, and introducing high energy efficiency vehicles, such as hybrid cars.

This paper aims to examine the pattern and growth in the energy demand and the energy-related CO₂ emissions from an increase in the number and use of vehicles in the road transport sector. The energy demand and the emissions were derived from projections of vehicles number and use, based on the end-use analysis method. The base line business-as-usual (BAU) and alternative scenarios of fuel substitution and energy efficiency measures to reduce energy demand

and mitigate emissions will be analyzed.

Methodology

In order to forecast energy demands and their associated emissions and to analyze potentials under various scenarios for reducing energy demands and emissions, this study will be divided into three parts: travel demand estimation, estimation of energy demand and energy-related emissions, and the analysis of alternative scenarios.

1. Travel Demand Estimation

The travel demand of each vehicle is the average distance that the vehicle has traveled in one year. It can be defined as the vehicle kilometer of travel (VKT). The average distance traveled of each vehicle type used in this study is obtained from the study of Chanchaona et al. [3], as shown in Table 1. Total travel demand of vehicles is formulated from the number of vehicles and the vehicle kilometer of travel (VKT), as presented in Eq. 1.

$$TD_{i,t} = NV_{i,t} * VKT_i \quad (1)$$

where $TD_{i,t}$ is total travel demand of vehicles of type i in year t (vehicle-kilometer), NV_i is the number of vehicles of type i in year t (vehicles), VKT_i is the average vehicle kilometer of travel of vehicle type i (kilometers per year).

The number of vehicles can be estimated by employing the vehicle ownership model. The estimation of vehicle ownership was based on an econometric model relating vehicle per capita to GDP per capita [4]. A double-logarithmic function is used as a basic function of the

model. The model is developed on the basis of a time series of provincial data covering the time period from 1997 to 2005. The estimated model of major vehicle types in road transport can be presented as Eq. 2. In addition, with a different of economic characteristics of each province, the vehicle ownership modes were divided into two areas: Bangkok area and provincial area.

$$\ln VO_{i,t} = a + b \ln GDPpCap_t + t^c \quad (2)$$

where $VO_{i,t}$ is vehicle ownership of vehicle type i (vehicles per 1,000 persons) in year t , $GDPpCap_t$ is real gross domestic product per capita (1,000 baht per person) in year t , t is a time series ($t = 1$ in 1989) and a , b , c are the coefficients in the model.

The coefficients of the vehicle ownership models are presented in Table 1. The average travel distances of each type of vehicle are presented in Table 2.

Table 1. The Coefficients of Vehicle Ownership Models.

Vehicle type	Bangkok area				Provincial area			
	a	b	c	R ²	a	b	c	R ²
Sedan	-3.053	-0.085	0.266	0.93	-7.19	0.031	0.409	0.98
Microbus & SUV	-10.798	0.554	-0.135	0.24	-1.539	-0.534	0.204	0.51
Van & Pick Up	-1.296	-0.327	0.336	0.86	-5.707	0.027	0.346	0.96
Urban Taxi	-15.114	0.728	0.534	0.86	8.385	-1.829	0.216	0.80
Motorcycle	-3.653	0.004	0.236	0.28	2.348	-0.604	0.362	0.90
Fixed Route Bus	-5.19	-0.118	0.031	0.05	-4.512	-0.261	0.165	0.76
Non Fixed Route Bus	-7.575	-0.016	0.161	0.70	-14.357	0.529	0.224	0.98
Private Bus	-16.705	0.775	-0.159	0.48	-12.719	0.204	0.494	0.88
Non Fixed Route Truck	-2.871	-0.309	0.31	0.77	-23.181	1.529	0.1	0.96
Private Truck	-6.359	0.106	0.013	0.02	-4.291	-0.123	0.361	0.92

Table 2. Average Travel Distance of Vehicles [3].

Vehicle type	Average Vehicle kilometer of travel (kilometers/year)	
	Bangkok area	Provincial area
Sedan	15,634	14,071
Microbus & SUV	20,947	20,947
Van & Pick Up	17,289	17,289
Urban Taxi	61,576	61,576
Motorcycle	5,627	5,627
Fixed Route Bus	63,218	41,985
Non Fixed Route Bus	55,020	55,680
Private Bus	33,117	31,358
Non Fixed Route Truck	31,102	65,242
Private Truck	29,608	57,022

2. Estimation of Energy Demands and Emissions

On the basis of the estimated models for vehicle ownership described above and projections of population and GDP growth, forecasts of vehicle ownerships for each vehicles types can be calculated. Furthermore in order to estimate the energy demand, information on travel demand of vehicles, proportion of vehicles by fuel types and fuel economy of vehicle can be integrated. The energy demand of fuel type by each vehicle type can then be calculated by following equation:

$$ED_{ij,t} = TD_{i,t} * PV_{ij} * FE_{ij} \quad (3)$$

where $ED_{ij,t}$ represents the energy demand of fuel type j by vehicle type i (ktoe), PV_{ij} is the proportion of vehicle type i which used fuel

type j (percentage), FE_{ij} is the fuel economy of fuel type j by vehicle type i (liters of gasoline/vehicle-kilometers).

The types of fuel used in the road transport are classified into four main groups: gasoline, diesel, liquefied petroleum gas (LPG), and compressed natural gas (CNG). The proportions of fuel used in vehicles, which were obtained from Department of Land Transport [5] and Chanchaona et al., are shown in Table 3.

Table 3. Proportion of Vehicles by Fuel Types ^a[3] and ^b[5].

Vehicle Type	Proportion of Fuel Used by Vehicle (%)							
	Bangkok area				Provincial area			
	Gasoline	Diesel	LPG	CNG	Gasoline	Diesel	LPG	CNG
Sedan ^b	88.1	10.2	1.6	0.1	79.1	20.8	0.1	-
Microbus & SUV ^b	16.0	83.9	0.1	-	9.5	90.4	0.1	-
Van & Pick Up ^b	5.7	94.3	0.0	-	8.2	91.7	0.1	-
Urban Taxi ^b	22.7	0.3	73.3	3.8	79.6	18.4	2.0	-
Motorcycle ^a	100.0	-	-	-	100.0	-	-	-
Fixed Route Bus ^b	-	99.9	0.1	-	-	98.1	2.0	-
Non Fixed Route Bus ^b	-	99.9	0.1	-	-	100.0	-	-
Private Bus ^b	-	100.0	-	-	-	100.0	-	-
Non Fixed Route Truck ^a	-	100.0	-	-	-	100.0	-	-
Private Truck ^a	-	100.0	-	-	-	100.0	-	-

The energy intensity of a vehicle usually presented in terms of fuel economy. The fuel economy is the average fuel consumption of a vehicle per vehicle-distance traveled (liters of gasoline/vehicle-kilometers). The fuel economy of vehicles was also obtained from the study of Chanchaona et al. and the estimation from this study, as presented in Table 4.

Table 4. Fuel Economy of Vehicles by Fuel Types ^a Estimated by the authors and [3].

Vehicle Type	Average Fuel Economy (liters of gasoline/ vehicle-100 kilometers)							
	Bangkok area				Provincial area			
	Gasoline	Diesel	LPG	CNG ^a	Gasoline	Diesel	LPG	CNG ^a
Sedan	8.57	8.03	10.35 ^a	9.34	8.73	8.12	10.00	9.34
Microbus & SUV	8.12	7.22	9.81 ^a	8.85	8.32	8.24	10.05 ^a	8.85
Van & Pick Up	8.05	7.33	9.73 ^a	8.78	8.74	8.23	10.00	8.78
Urban Taxi	8.60	7.52 ^a	10.39	9.37	8.60	7.52 ^a	8.60	9.37
Motorcycle	4.08	-	-	-	4.76	-	-	-
Fixed Route Bus	-	9.17	12.66 ^a	9.37	-	9.17	12.66 ^a	9.37
Non Fixed Route Bus	-	9.59	13.24 ^a	9.80	-	9.59	13.24 ^a	9.80
Private Bus	-	9.54	13.18 ^a	9.75	-	9.54	13.18 ^a	9.75
Non Fixed Route Truck	-	10.87	-	11.11	-	10.87	-	11.11
Private Truck	-	12.56	-	12.84	-	12.56	-	12.84

The emissions of vehicles are the products of each type of fuel used by vehicles and their emission factors. They can be calculated by Eq. 4:

$$EM_{ijk,t} = ED_{ij,t} * EF_{jk} * GWP_k \tag{4}$$

where $EM_{ijk,t}$ is the amount of the emission of substance k from fuel type j by vehicle type i in year t (kg CO₂ equivalent), EF_{jk} is the emission factors of substance k from fuel type j in year t (kg/TJ), and GWP_k is the emission conversion factors of substance k (kg CO₂ equivalent/kg of substance).

To estimate the emissions from the energy consumption, the emission factors in this study were obtained from the Intergovernmental Panel on Climate Change (IPCC) [6], which is included in the Technology Environmental Database (TED) in the Long-range Energy Alternative Planning (LEAP) system accounting model [7]. The emissions considered are the green house gases (GHGs), such as carbon dioxide (CO₂), nitrous dioxide (N₂O), and methane (CH₄). The emission factors in

the TED module in LEAP are presented in Table 5. In addition, the quantities of GHGs cannot be expressed or compared on a mass basis alone because of the differences in the properties and nature of the gases. The IPCC then presents global warming potentials (GWPs) for each individual GHG as shown in Table 6.

Table 5. Emissions Factors Used in the Estimation [6].

Fuel Types	Emission Factors (kg/TJ of energy consumed)		
	CO ₂	N ₂ O	CH ₄
Gasoline	68.65	0.6	20
Diesel	73.3	0.6	5
LPG	62.7	-	0.03
CNG	55.5	0.1	50

Table 6. Global Warming Potential [6].

Substance	GWP (g CO ₂ /g substance)
CO ₂	1
CH ₄	25
N ₂ O	289

3. Alternative Scenarios Analysis

For policy purpose, it is necessary to analyse the potential of alternative scenarios in order to reduce energy demand and energy-related emissions. The study forecasted the energy demand and CO₂ emissions of vehicles in road transport from 2006 to 2020 by using the business-as-usual (BAU) scenario as the base case. The alternative scenarios of technology options, e.g. promotion of improved fuel economy vehicles and hybrid cars, and substitution of conventional fuel by CNG through the promotion of natural gas vehicles (NGV) are examined.

Business-As-Usual (BAU) scenario

In the BAU scenario, the numbers of vehicles were forecasted based on the GDP and the population growth. The study assumed that, from 2005 to 2020, the average annual GDP and the population growth rate were 5.5% and 0.6%, respectively, the present efficiency of vehicles and the pattern of energy utilization of vehicles were unchanged, and the ongoing projects of the mass transport system were not implemented.

Natural Gas Vehicle (NGV) scenario

Compressed natural gas (CNG) is one of the alternative fuels that could be used to replace conventional fossil fuels in internal combustion engines (ICE). The CNG can be used in both the spark ignition (SI) engine (the gasoline engine) and the compression ignition (CI) engine (the diesel engine). With CNG equipment installed, the SI engine is called the bi-fuel engine, and the CI engine is called the diesel dual fuel (DDF) engine. Because CNG is a domestic resource fuel, the Thai government, in cooperation with the PTT Public Co., Ltd., have tried to promote and implement the utilization of compressed natural gas (CNG) for the road transport vehicles. In 2003 PTT created the NGV project in road transport vehicles in the Bangkok Metropolitan area. In this project, PTT is providing and supporting the initial cost of CNG conversion equipment for vehicles which apply for the project.

Natural gas is a mixture of hydrocarbon compounds and small quantities of non-hydrocarbons existing in the gaseous phase. The natural gas typically consists primarily of methane (CH₄), the shortest and lightest hydrocarbon molecule. It also contains varying amounts

of heavier gaseous hydrocarbons – ethane (C₂H₆), propane (C₃H₈), butane (C₄H₁₀), and pentane (C₅H₁₀), acid gases – carbon dioxide (CO₂) and hydrogen sulfide (H₂S), and other gases – nitrogen (N₂) and helium (He). A comparison between the compositions of natural gas in Thailand (PTT) and standard natural gas for vehicles is presented in Table 7.

Table 7. Comparison between the compositions of standard natural gas and natural gas in Thailand [9].

Composition	US.EPA	CARB	PTT
Methane	89.0% min	88.0% min	76.26%
Ethane	4.5% max	6.0% max	6.12%
C ₃ and higher	2.3% max	3.0% max	2.90%
Oxygen	0.6% max	1.0% max	Not Available
Inert Gas	4.0% max	1.5 – 4.5%	1.86% of N ₂ , 12.86% of CO ₂

Note: US.EPA is United States Environmental Protection Agency.

CARB is California Air Research Board.

In this study, the NGV scenario considers the substitution of bi-fuel modified-engines for SI engines, such as in sedan cars and urban taxis, and the substitution of CNG dedicated engines for CI engines, such as in fixed route buses, vans and pickups in the Bangkok Metropolitan area. The penetration rate of NGV from 2005 to 2020 follows the 2005 plan of PTT, as presented in Table 8. The emission factors of different pollutants, in this study, are taken from the Technology Environmental Data (TED) module in LEAP software, in which the composition of compressed natural gas (CNG) is based on the US.EPA standard.

Table 8. Number of Natural Gas Vehicles by the 2005 plan of PTT.

Vehicle Type	Number of Natural Gas Vehicle in Bangkok Area (1,000 Vehicles)											
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Sedan	4.50	12.25	22.75	30.00	20.00	20.00	20.00	23.85	26.20	23.55	19.45	13.00
Microbus & SUV	0.40	4.10	0.50	0.50	0.50	0.50	0.50	0.49	0.48	0.46	0.46	0.43
Van & Pick Up	0.40	12.60	45.50	61.50	45.00	54.00	62.60	70.20	76.60	81.50	84.50	86.20
Urban Taxi	4.50	12.25	22.75	30.00	20.00	20.00	18.30	10.85	4.20	2.55	2.45	5.00
Fixed Route Bus	0.17	1.50	1.10	1.10	1.40	0.85	0.68	0.66	0.65	0.65	0.60	0.55
Non Fixed Route Truck	0.02	6.67	1.65	2.03	2.67	3.00	3.30	3.57	3.77	3.97	4.03	4.10
Private Truck	0.03	13.33	3.30	4.07	5.33	6.00	6.60	7.13	7.53	7.93	8.07	8.20

Fuel Economy Improvement (FEI) scenario

The fuel economy of vehicles is one of the important factors in the energy demands and emissions in road transport. In various countries, such as the United States, Europe and Japan, fuel economy standards of vehicles has been used as a mechanism in the energy conservation plan. There are three main methods for determining vehicle fuel economy standards. The first is a minimum standard value system, which all vehicles covered by this system should satisfy. The second is an average standard value system, which the average values of all vehicles covered by this system should satisfy. Finally, in the maximum standard value system, targets are set based on the value of the most energy-efficient vehicle in the market at the time of the value setting process. Currently, the most popular minimum standard value system in the world is the minimum energy efficiency standard, such as in the U.S.

In this study, the implementation of the minimum fuel economy standard program to reduce energy demand and associated emissions by the Thai government is assumed. With this program, the fuel economy of gasoline-sedan and diesel-pickup should satisfy the minimum fuel economy standard of 6.90 and 5.68 liter of gasoline per vehicle-100 kilometers, respectively.

Hybrid car (HYB) scenario

A hybrid car seems to be a promising technology for passenger cars to reduce energy demand and emissions as it is the most energy-efficient vehicle in road transportation. It presents a significant reduction of the fuel consumption and the emissions compared with conventional vehicles of similar size. Nowadays, the hybrid car is used in several advanced countries, such as in the United States, the European Union, and Japan, particularly in urban areas, in order to reduce the emissions.

In the hybrid cars scenario, we assumed that the hybrid cars will be substituted for the new conventional sedan with a market penetration rate of 15% of new sedan saturated in 2015. The period of the scenario starts from 2005 to 2020. The fuel economy of hybrid vehicle is 4.69 liter of gasoline/vehicle-100 kilometer [8].

Results and Discussion

The projections of vehicle numbers is based on the assumption of 5.5% average annual growth rate of GDP and average population

growth rate of 0.6% per year. The forecasting models predict that the total number of cars, buses and trucks will increase from 8.97 million vehicles in 2005 to 17.85 million vehicles in 2020, accounting for 4.7% average annual growth rate; whilst the number of motorcycles will increase with 2.5% average annual growth rate from 16.97 million vehicles to 24.66 million vehicles in the same period, as presented in Table 9. Private passenger transport vehicles, e.g. sedan, SUV, and pickup, are sharing about 90% of the total number of cars, buses and trucks.

From the total travel demand and the average fuel economy of vehicles, the energy demand and the energy-related emissions can be calculated. The results of this study in each scenario are presented below.

1. Business-As-Usual Scenario

In the BAU scenario, with the increasing of vehicle numbers, it is predicted that the total energy demand in road transport is expected to increase with average annual growth rate of 6.2%, from 18,530 ktoe to 45,952 ktoe in 2005 and 2020, respectively. With the high growth rate, the private passenger transport mode has the highest energy demand in this sector. Pickups have the highest energy demand in this mode, which is about 26% to 30% of the total during the study period, following by motorcycles and sedans, as presented in Table 8. In the other hand, public road transport (buses) shares only 1.4% to 2.2% of the total energy demand in this sector. Trucks, which are the major vehicles for domestic goods transport, share about 21% to 31% of total energy demand in the same period. The energy demand pattern, in addition, shows that diesel is the major fuel used in the road transport sector because it is the fuel which is used

in both passenger transport and goods transport; its share is 56% to 62% of total energy demand in this sector, as shown in Table 10.

For the environmental impact, CO₂ emissions and other GHG emissions in terms of CO₂ equivalent are expected to increase from 56,454 thousand tons of CO₂ equivalent in 2005 to 139,305 thousand tons of CO₂ equivalent in 2020, as shown in Table 11. The private passenger transport mode is also responsible for the highest share of the emissions, amounting to about 64% to 73% of total emissions from this sector. The utilization of diesel fuel, of course, produces the highest emissions, as shown in Table 12 and Table 13.

Table 9. Number of Vehicles from the Forecasting Models in the BAU Scenario.

Vehicle Type	Number of Vehicles (1,000 vehicles)											
	Bangkok Area				Provincial Area				Total			
	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020
Sedan	1,798	2,189	2,643	3,175	1,337	1,871	2,632	3,640	3,135	4,060	5,276	6,815
Microbus & SUV	354	420	494	582	254	287	300	298	607	707	794	880
Van and Pickup	959	1,231	1,547	1,911	3,340	4,318	5,476	6,829	4,299	5,549	7,023	8,739
Urban Taxi	88	124	173	238	2	1	1	1	90	126	174	238
Fixed Route Bus	19	21	22	23	57	57	55	52	77	78	78	76
Non Fixed Route Bus	8	10	11	12	16	20	23	28	24	29	34	40
Private Bus	4	5	6	8	6	7	8	9	10	12	14	17
Non Fixed Route Truck	44	49	54	59	68	100	149	221	112	149	203	280
Private Truck	78	88	98	109	541	589	626	652	619	678	724	760
Sub-Total	3,354	4,138	5,049	6,116	5,620	7,250	9,270	11,729	8,974	11,388	14,319	17,846
Motorcycle	2,398	2,938	3,552	4,244	14,576	16,263	18,376	20,411	16,974	19,200	21,927	24,655
Total	5,751	7,076	8,601	10,360	20,196	23,512	27,646	32,140	25,948	30,588	36,247	42,501

Table 10. Energy Demands by Vehicle Types in the BAU Scenario.

Vehicle type	Energy Demand (ktoe)							
	2005		2010		2015		2020	
Sedan	2,934	15.80%	4,078	17.40%	6,327	19.70%	10,151	22.10%
Microbus & SUV	742	4.00%	931	4.00%	1,239	3.90%	1,712	3.70%
Van & Pick Up	4,750	25.60%	6,438	27.50%	9,198	28.70%	13,612	29.60%
Urban Taxi	433	2.30%	652	2.80%	1,059	3.30%	1,793	3.90%
Motorcycle	3,524	19.00%	4,298	18.30%	5,830	18.20%	8,105	17.60%
Fixed Route Bus	264	1.40%	274	1.20%	286	0.90%	302	0.70%
Non Fixed Route Bus	103	0.60%	130	0.60%	175	0.50%	245	0.50%
Private Bus	41	0.20%	52	0.20%	70	0.20%	98	0.20%
Non Fixed Route Truck	572	3.10%	831	3.50%	1,353	4.20%	2,358	5.10%
Private Truck	5,167	27.90%	5,766	24.60%	6,537	20.40%	7,576	16.50%
Total	18,530		23,450		32,072		45,952	

Table 11. Emissions by Vehicle Types in the BAU Scenario.

Vehicle type	Emissions (1,000 tons of CO ₂ equivalent)							
	2005		2010		2015		2020	
Sedan	8,618	15.3%	11,985	16.8%	18,598	19.1%	29,850	21.4%
Microbus & SUV	2,287	4.1%	2,869	4.0%	3,817	3.9%	5,277	3.8%
Van & Pick Up	14,738	26.1%	19,973	28.0%	28,535	29.3%	42,232	30.3%
Urban Taxi	1,177	2.1%	1,771	2.5%	2,878	3.0%	4,870	3.5%
Motorcycle	10,497	18.6%	12,803	17.9%	17,368	17.8%	24,145	17.3%
Fixed Route Bus	820	1.5%	853	1.2%	890	0.9%	941	0.7%
Non Fixed Route Bus	320	0.6%	405	0.6%	542	0.6%	761	0.5%
Private Bus	127	0.2%	163	0.2%	218	0.2%	304	0.2%
Non Fixed Route Truck	1,782	3.2%	2,587	3.6%	4,213	4.3%	7,340	5.3%
Private Truck	16,088	28.5%	17,950	25.2%	20,348	20.9%	23,584	16.9%
Total	56,454		71,358		97,407		139,305	

Table 12. Energy Demands by Fuel Types in the BAU Scenario.

Fuel Types	Energy Demand (ktoe)							
	2005		2010		2015		2020	
Gasoline	6,641	35.80%	8,596	36.70%	12,379	38.60%	18,456	40.20%
Diesel	11,501	62.10%	14,275	60.90%	18,759	58.50%	25,929	56.40%
LPG	372	2.00%	555	2.40%	895	2.80%	1,500	3.30%
CNG	16	0.10%	25	0.10%	40	0.10%	67	0.10%
Total	18,530		23,450		32,072		45,952	

Table 13. Emissions by Fuel Types in the BAU Scenario.

Fuel Types	Emissions (1,000 tons of CO ₂ equivalent)							
	2005		2010		2015		2020	
Gasoline	19,576	34.70%	25,320	35.50%	36,441	37.40%	54,292	39.00%
Diesel	35,842	63.50%	44,493	62.40%	58,475	60.00%	80,835	58.00%
LPG	988	1.70%	1,474	2.10%	2,375	2.40%	3,982	2.90%
CNG	48	0.10%	72	0.10%	116	0.10%	196	0.10%
Total	56,454		71,358		97,407		139,305	

2. Alternative scenarios

Energy demands and emissions of alternative scenarios are presented in Table 13 and Table 14. According to the PTT plan, with the low-efficiency of NGVs, the models predicted energy demands in the NGV scenario higher than in the BAU scenario. The energy demands are expected to increase from 18,530 ktoe in 2005, to 46,102 ktoe in 2020. However, the main objective of this scenario is to introduce CNG as alternative vehicle fuel which is used to substitute the current vehicle fuels, e.g. gasoline, diesel, and LPG, because the CNG is a domestic fuel resource. Then, from the prediction model, CNG would be able to substitute about 2,308 ktoe of the conventional fuels in 2020, accounting for 5.0% of total energy demand in the BAU scenario. The private passenger transport vehicles, e.g. sedan,

pickup, SUV, and motorcycle, are still the highest energy consumer transport mode in this sector. For the emissions, the models predict that the total emissions in this scenario will increase from 55,454 to 140,309 thousand tons of CO₂ equivalent in 2005 and 2020, respectively. The emissions from this scenario are slightly more than the base case, in which gasoline and diesel are responsible for a high share of the emissions.

In the fuel economy improvement scenario, by improving the fuel economy of sedans and pickups, the energy demands are expected to increase from 18,530 to 42,158 ktoe, while the emissions from this sector would increase from 56,454 thousand tons of CO₂ equivalent in 2005 to 126,022 thousand tons of CO₂ equivalent in 2020 during the study period. The model further predicts that, in 2020, this scenario could reduce the energy demand by about 9.5% of total energy demand as well as mitigate the emissions compared with the BAU scenario. The energy demand reduction and emissions mitigation are mainly from the utilization of gasoline and diesel which account for about 10% reduction from the BAU scenario.

In the hybrid car scenario, the energy demands are expected to increase from 18,530 to 45,418 ktoe in the study period, whereas the emissions would increase from 56,464 to 137,715 thousand tons of CO₂ equivalent. The introduction of hybrid cars to replace new sedan cars would reduce energy demand and mitigate emissions up to about 1.2% of total energy demand and total emissions compared with the BAU scenario in 2020, mainly from the reduction of gasoline and diesel.

Table 14. Energy Demands and Emissions of Vehicles by Vehicle Types in Alternative Scenarios.

Vehicle type	Energy Demand (ktoe)				Emissions (1,000 tons of CO ₂ equivalent)			
	2005	2010	2015	2020	2005	2010	2015	2020
Natural Gas Vehicle Scenario								
Sedan	2,934	4,119	6,430	10,345	8,618	12,105	18,908	30,431
Microbus & SUV	743	932	1,242	1,718	2,287	2,871	3,824	5,288
Van & Pick Up	4,750	6,438	9,195	13,600	1,738	19,994	28,640	42,470
Urban Taxi	433	634	970	1,774	1,177	1,763	2,770	5,149
Motorcycle	3,524	4,298	5,830	8,105	10,497	12,803	17,368	24,145
Fixed Route Bus	264	274	286	303	820	852	885	931
Non Fixed Route Bus	103	130	175	245	320	405	542	761
Private Bus	41	52	70	98	127	163	218	304
Non Fixed Route Truck	572	829	1,344	2,336	1,782	2,578	4,179	7,264
Private Truck	5,167	5,767	6,538	7,578	16,088	17,948	20,340	23,566
Total	18,530	23,473	32,079	46,102	56,454	71,482	97,673	140,309
Fuel Economy Improvement Scenario								
Sedan	2,934	3,965	5,583	8,568	8,618	11,652	16,430	25,236
Microbus & SUV	742	931	1,239	1,712	2,287	2,869	3,817	5,277
Van & Pick Up	4,750	6,150	7,920	10,830	14,738	19,077	24,554	33,563
Urban Taxi	433	652	1,059	1,793	1,177	1,771	2,878	4,870
Motorcycle	3,524	4,298	5,830	8,105	10,497	12,803	17,368	24,145
Fixed Route Bus	264	274	286	302	820	853	890	941
Non Fixed Route Bus	103	130	175	245	320	405	542	761
Private Bus	41	52	70	98	127	163	218	304
Non Fixed Route Truck	572	831	1,353	2,358	1,782	2,587	4,213	7,340
Private Truck	5,167	5,766	6,537	7,576	16,088	17,950	20,348	23,584
Total	18,530	23,049	30,051	41,587	56,454	70,131	91,258	126,022
Hybrid Car Scenario								
Sedan	2,934	3,975	6,036	9,616	8,619	11,679	17,737	28,261
Microbus & SUV	742	931	1,239	1,712	2,287	2,869	3,817	5,277
Van & Pick Up	4,751	6,438	9,198	13,612	14,741	19,973	28,535	42,232
Urban Taxi	3,519	4,395	6,154	8,886	1,174	1,769	2,877	4,869
Motorcycle	433	557	737	1,013	10,502	12,806	17,369	24,147
Fixed Route Bus	264	274	286	302	821	853	890	941
Non Fixed Route Bus	103	130	175	245	320	405	542	761
Private Bus	41	52	70	98	127	163	217	303
Non Fixed Route Truck	572	831	1,353	2,358	1,782	2,587	4,213	7,340
Private Truck	5,169	5,766	6,537	7,576	16,091	17,950	20,348	23,584
Total	18,530	23,350	31,784	45,418	56,464	71,053	96,545	137,715

Conclusion

In this study, by using the non-linear vehicle ownership models to examine the number of vehicles in road transport in Thailand from 2005 to 2020, it was found that the numbers of cars, buses, and trucks in road transport are expected to increase from 8.95 million vehicles in 2005 to 17.76 million vehicles in 2020, accounting for 4.7% annual growth rate. Private passenger vehicles, e.g. sedan, SUV, and pickup transport vehicles share almost 90% of the total number of vehicles. Meanwhile, the number of motorcycles would increase from 17.0 to 24.7 million vehicles in the same period.

Due to the increase in the vehicles in road transport in the BAU scenario the energy demands would increase from 18,530 ktoe in 2005 to 45,952 ktoe in 2020, which share about 56.4%, 40.2%, 3.3%, and 0.1% of total final energy demand by diesel, gasoline, LPG and CNG, respectively. The emissions in terms of CO₂ equivalent in this sector would increase from 56.4 to 139.3 million tons of CO₂ equivalent in 2005 and 2020, respectively. Diesel fuel is responsible for the highest share of about 58% of total emissions in 2020.

Based on the scenario analysis, the prediction models found that, in the NGV scenario, the energy demand and energy-related emissions would exceed those in the base-case BAU scenario by about 0.1% of total energy demands because of the low energy efficiency of modified NGV. However, the CNG would be able to replace up to about 5% of the conventional fuels in the BAU scenario in 2020. In the fuel economy improvement scenario, the models found

that this scenario could reduce the energy demands and the CO₂ emissions by up to approximately 9.5% of total energy demands and emissions compared with the BAU scenario in 2020. The introduction of hybrid cars to replace new sedans, in the hybrid car scenario, would reduce energy demands and emissions by up to 1.2% of the total. The results of the analysis are presented in Table 14 and Table 15.

Table 15. Energy Demands and Emissions of Vehicles by Fuel Types in Alternative Scenarios.

Fuel Types	Energy Demand (ktoe)				Emissions (1,000 tons of CO ₂ equivalent)			
	2005	2010	2015	2020	2005	2010	2015	2020
Natural Gas Vehicle Scenario								
Gasoline	6,641	8,586	12,299	18,288	19,576	25,292	36,208	53,803
Diesel	11,500	14,214	18,432	25,139	35,842	44,303	57,455	78,370
LPG	373	403	343	300	988	1,069	909	796
CNG	16	270	1,005	2,375	48	819	3,101	7,341
Total	18,530	23,473	32,079	46,102	56,454	71,482	97,673	140,309
Fuel Economy Improvement Scenario								
Gasoline	6,641	8,473	11,611	16,826	19,576	24,961	34,204	49,544
Diesel	11,500	13,997	17,505	23,194	35,842	43,624	54,563	72,300
LPG	373	555	895	1,500	988	1,474	2,375	3,982
CNG	16	25	40	67	48	72	116	196
Total	18,530	23,049	30,051	41,587	56,454	70,131	91,258	126,022
Hybrid Car Scenario								
Gasoline	6,641	8,527	12,190	18,115	19,579	25,121	35,892	53,303
Diesel	11,500	14,243	18,666	25,750	35,849	44,394	58,184	80,275
LPG	373	555	888	1,487	988	1,466	2,354	3,943
CNG	16	24	39	66	48	72	116	195
Total	18,530	23,350	31,784	45,418	56,464	71,053	96,545	137,715

In conclusion, according to the results of this study, it has been found that the fuel economy improvement scenario and hybrid car scenario would be interesting strategies in order to reduce the energy demands and the energy-related emissions in the road transport sector. Then, the extension of the fuel economy standard to other vehicle types such as buses and trucks would be a further measure to reduce energy demand and mitigate emissions thorough the fuel economy improvement program. In addition, the measures to increase the penetration rate of hybrid cars to the market should be considered for higher energy demands and emissions reduction of road transport vehicles, especially in urban areas. However, the introduction of natural gas as an alternative fuel in this sector through the promotion of natural gas vehicles would make the energy demand and the emissions in this sector higher than in the BAU scenario. Nevertheless, the NGV scenario might be implemented in order to replace conventional fuels because it is a domestic energy resource. However, the investment in fuel supply infrastructure, i.e. re-fuelling stations, fuel pipelines, and fuel conversion kits for both SI and CI modified engine vehicles would be a serious concern because the equipment has to be imported at a very high cost.

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