Construction of Energy Demand Model in Thai Transportation Sector: A Case Study for Ethanol as Diesel Substitute

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Abstract

Energy demand model is a powerful tool to predict the trend of energy demand in the future as a result of a certain incidence of interest. Both top-down and bottom-up approaches are available but for the current focus in transportation sector, bottom-up approach is chosen. Commercially available program called Long range Energy Alternatives Planning system (LEAP) was used with necessary data, such as a number of vehicles (NV) for various vehicle types, vehicle kilometer of travel (VKT) and fuel economy (FE). Due to limited data availability and complication from various types of vehicles and fuels, certain assumptions were made in order to obtain all necessary data for calculation of total energy demand in transportation sector. Vehicle ownership models were established for all vehicle types based on vehicle classification by Department of Land Transport in Bangkok and provincial regions. VKT data for some vehicle types were taken from most recent survey in 2008 with the rest being extrapolated from survey in 1997 under certain assumptions. For FE data, further complication arose from the fuel sharing options within certain vehicle types, such as gasoline/E10/E20 for spark-ignition (SI) engine, bi-fuel with gasoline and compressed natural gas/liquefied petroleum gas (CNG/LPG), and diesel dual fuel (DDF) with CNG/LPG. All these data and assumptions were used to construct energy demand model in Thai transportation sector with validation against total energy consumption. The results showed acceptable prediction. The model was then used as a tool to investigate a case study on ethanol utilization as diesel substitute.

Keywords*:* Energy Demand Model, Long range Energy Alternatives Planning system (LEAP), Transportation Sector, Ethanol, Diesel Engine

1. Introduction

Among many oil-importing countries, Thailand has spent over one trillion baht in fossil fuel import, just to meet with energy demand within the countries. Over the past five years, a majority of the energy import lies in crude oil. In particular, the recent oil crisis in 2007 has made crude oil more expensive than the electricity. Thailand final energy consumption over the past decade has been dominated by the two economic sectors, namely transportation and industry for about 1/3 each [1]. When considering consumption per sector gross domestic product (GDP), transportation has consumed about 3-4 times than that of industry. Hence, transportation sector has long been the target of energy consumption reduction.

Within transportation sector, 3/4 of energy consumption is dominated by land transportation, with twice of diesel consumption than that of gasoline [1], as shown in Fig. 1. Table 1 shows the 2008 breakdown of vehicles in Thailand with pick-up truck, bus and truck as major consumption of diesel fuel [2]. Hence, diesel has been a core energy source of the country transportation and logistic. Various policies have been initiated and implemented in order to reduce diesel consumption, partly to justify the unbalance of gasoline/diesel consumption in order to reduce crude oil import. Despite the fact that natural gas for vehicle (NGV) and biodiesel have been promoted to reduce diesel consumption in the National Alternative Energy Strategic Plan (2008-2022), as shown in Fig. 2 [3], little has been realized that ethanol, which is deemed with higher production capacity in National Alternative Energy Strategic Plan, can be used as diesel substitute.

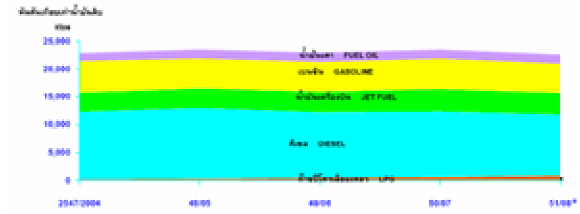


Fig. 1 History data of Thailand energy consumption in transport sector by type

Table 1: List of vehicles in Thailand by fuel type

Type	Total	Gasoline	Diesel	LPG	LPG + Gasoline	LPG + Diesel	CNG	CNG + Gasoline	CNG + Diesel	Electric	Others
Motorcycle	16,425,262	16,417,691	-	-	-	-	-	-	-	7,420	151
Passenger Cars	4,273,077	2,606,773	1,105,378	1,692	461,219	1,598	263	72,739	594	13	22,808
Pick-up Truck	4,552,284	230,351	4,237,868	2,339	44,875	3,030	173	3,201	988	8	29,451
Bus	134,225	6,924	113,242	622	4,493	141	4,482	3,662	390	45	224
Truck	771,554	627	640,643	635	162	891	7,982	31	2,279	26	118,278
Other	290,951	9,154	228,829	14,382	4,991	4	1,600	197	-	2	1,792
ALL	26,417,353	19,271,520	6,325,960	19,670	515,740	5,664	14,500	79,830	4,251	7,514	172,704

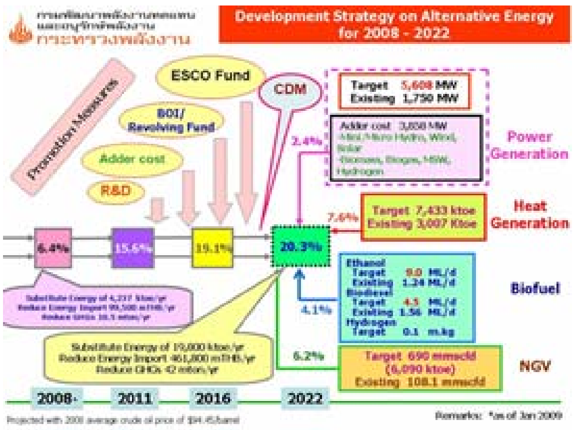


Fig. 2 Thailand Alternative Energy Strategic Plan (2008-2022)

Ethanol has been technically proved as diesel substitute in compression-ignition (CI) engine in two ways. First is low-blend of ethanol in diesel with emulsifier to be used in conventional CI engine. On the other hand, a high-blend of ethanol can be used in a modified CI engine, as have been continuously developed by Scania Company till their current 3rd-generation commercially available CI ethanol engine, as shown in Fig. 3. The present study aims to assess the possibility of using ethanol as diesel substitute by recourse to energy demand model in Thai transportation sector.

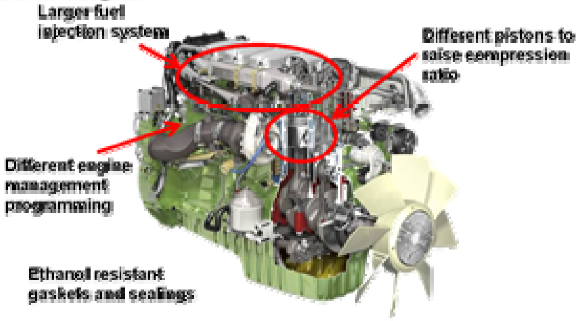


Fig. 3 Scania 3rd-generation CI ethanol engine showing necessary modification from the conventional CI engine

2. Methodology

In order to analyze energy use pattern in transportation sector with capability to predict energy demand, bottom-up approach is undertaken due to its capability in accounting for the flow of energy based on simple engineering relationship, such as traveling demand, fuel consumption and vehicle numbers. Among many others, Long-range Energy Alternatives Planning (LEAP) system will be utilized to construct the energy demand model in this study [4].

The energy demand function in transportation sector can be modeled as described in Eq. (1).

$$ED_{ij} = NV_{ij} \times VKT_j \times FE_{ij} \qquad (1)$$

where

ED_{ij} = energy demand of fuel type “i” from vehicle type “j” [liter/year]

NV_{ij} = number of registered vehicle type “j” that uses fuel type “i” [number of vehicle]

VKT_j = average distances traveled by vehicle type “j” in a year of interest [km/year]

FE_{ij} = fuel economy of registered vehicle type “j” that uses fuel type “i” [liter/km]

i = fuel type

j = vehicle type

In other words, the energy demand in the transportation sector can be determined by integrating the results over every fuel type “i” and vehicle type “j”. However, some assumptions are necessary to predict the future energy demand because the involved variables are varied with time. Firstly, the number of registered vehicle (NV) is predicted from record from Transport Statistics Sub-Division, Department of Land Transport (DLT). The data can be fitted with economic and population growth by recourse to prior works [5, 6]. However, when some necessary data like Vehicle Kilometer of Travel (VKT) is not sufficiently available, some detailed assumptions must be applied, which will be discussed later. For other data like Fuel Economy (FE), it can be extrapolated as the function of engine size, engine technology and fuel used, which are dependent on vehicle type and fuel proportion of the vehicle owner. Finally, the validation of energy demand model with the historic supply record will be shown with the preliminary scenario analysis of ethanol used as diesel substitute.

3. Model Development

3.1 Vehicle Stock Model

Vehicle types can be re-categorized from DLT classification for the purpose of LEAP calculation, as shown in the Table 2. Note that the agriculture vehicle, utility vehicle and automobile trailer are not considered in this work because they consume small fraction of energy. For each vehicle categories, three general vehicle population models were used as follows.

1. Exponential function [6]
2. Logistic Regression function [5, 7-9]
3. Combined function of the two above

where detailed functional form can be referred elsewhere [10]. Table 3 show vehicle population models (with R^2 fitting parameter) for all vehicle types in Bangkok and provincial regions.

Table 2: Vehicle re-classification in LEAP model from DLT data

A. Total vehicle under motor vehicle act		B. Total vehicle under land transport act	
MV.1 Not more than 7 passengers	PC01 passenger car	Bus	
MV.2 Microbus & Passenger Van		- Fixed Route Bus	BUS01
MV.3 Van & Pick Up	PC02	- Non Fixed Route Bus	BUS02
MV.4 Motortricycle	PC03 motor tri-cycle	- Private Bus	BUS03
MV.7 Fixed Route Taxi (Subaru)		Small Rural Bus	sBus04
MV.8 Motortricycle Taxi (Tuk Tuk)		Truck	
MV.6 Urban Taxi	PC04 taxi	- Non Fixed Route Truck	Truck01
MV.5 Interprovincial Taxi		- Private Truck	Truck02
MV.9 Hotel Taxi	PC05 Commercial rent car		
MV.10 Tour Taxi			
MV.11 Car for Hire			
MV.12 Motorcycle	PC06 Motor cycle		
MV.17 Public Motorcycle			
MV.13 Tractor	-		
MV.14 Road Roller			
MV.15 Farm Vehicle			
MV.16 Automobile Trailer			

Table 3: Vehicle population models for all vehicle types in (a) Bangkok and (b) provincial regions

(a)	N_vehicle Bangkok (GDPpCap)	R^2
PC01 private passenger car	$ln\left(\frac{VO}{0.812-VO}\right)=1.3273\,lnGDPpCap-17.8210$	0.8632
PC02 pickup	$ln\left(\frac{VO}{0.5-VO}\right)=2.2175\,lnGDPpCap-28.005$	0.7992
PC03 motor tri-cycle	$NV=16686.9 \quad yr\le 2001$ $=(unusal) \quad 2002\le yr\le 2004$ $NV=1265.6\,ln(yr-\tau)+12527 \;;\; \tau=2004$ $yr\ge 2005$	0.9681 (2005-2008)
PC04 taxi	$lnVO=2.6119\,lnGDPpCap-35.373$	0.7811
PC05 commercial rent car	$NV=-178.6\,ln(yr-\tau)+2399.4; \;;\; \tau=1988$	0.4052 (1989-1998)
PC06 motor cycle	$ln\left(\frac{VO}{0.6-VO}\right)=1.5731\,lnGDPpCap-20.2060$	0.7642
Bus01 fixed route bus	$NV=13970 \quad yr\le 1998$ $NV=3585.8\,ln(yr-\tau)+14061 \;;\; \tau=1998$ $yr\ge 1999$	0.9584
Bus02 non fixed route bus	$NV=\left(1\text{-}0.5071\cdot e^{-0.0323*(yr-\tau)}\right)\cdot\left(1786.9\,ln(yr-\tau)+6724.6\right)$ $\tau=1988$	0.9057
Bus03 private bus	$NV=\left(0.5071\cdot e^{-0.0323*(yr-\tau)}\right)\cdot\left(1786.9\,ln(yr-\tau)+6724.6\right)$ $\tau=1988$	0.7376
sBus04 small rural bus	-	-
Truck01 non fixed route truck	$NV=\left(1-0.7868\cdot e^{-0.0155*(yr-\tau)}\right)\cdot\left(20577\,ln(yr-\tau)+56314\right)$ $\tau=1988$	0.9136
Truck02 private truck	$NV=\left(0.7868\cdot e^{-0.0155*(yr-\tau)}\right)\cdot\left(20577\,ln(yr-\tau)+56314\right)$ $\tau=1988$	0.5143

(b)	N_vehicle Provincial (GDPpCap)	R^2
PC01 private passenger car	$ln\left(\frac{VO}{0.812-VO}\right)=2.5007\,lnGDPpCap-31.025$	0.8842
PC02 pickup	$ln\left(\frac{VO}{0.5-VO}\right)=2.5491\,lnGDPpCap-30.388$	0.8244
PC03 motor tri-cycle	$VO=0.0005188$	0.0041
PC04 taxi	$ln(VO)=-2.2974\,lnGDPpCap+14.4340$	0.5965
PC05 commercial rent car	$ln(VO)=1.8111\,lnGDPpCap-31.1840$	0.6464
PC06 motor cycle	$ln\left(\frac{VO}{0.6-VO}\right)=2.3609\,lnGDPpCap-26.678$	0.7021
Bus01 fixed route bus	$ln(VO)=0.2530\,lnGDPpCap-9.7824$	0.8181
Bus02 non fixed route bus	$ln(VO)=1.6778\,lnGDPpCap-26.689$	0.9533
Bus03 private bus	$ln(VO)=0.0659(yr-\tau)-10.422$ $\tau=1988$	0.9620
sBus04 small rural bus	$ln(VO)=-0.0049\,(yr-\tau)^2+0.0604\,(yr-\tau)-7.9501$ $\tau=1988$	0.8942
Truck01 non fixed route truck	$ln(VO)=0.0787(yr-\tau)-8.1426$ $\tau=1988$	0.9842
Truck02 private truck	$ln(VO)=0.3046\,ln(yr-\tau)-5.6463$ $\tau=1988$	0.9574

where

GDPpCap = GDP per capita [Baht]

Pop = Population [person]

yr = Year, which is the parameter of time

τ = Reference year

VO = fuel type

3.2 Vehicle Kilometer of Travel (VKT) Estimation

The vehicle kilometer of travel (VKT) is a parameter to reflect how heavily the considered vehicle is used. Hence, this parameter varies depending on the vehicle type and its driven area. Moreover, it should be noted that the VKT is not constant with time because the gross road distance and/or traffic condition has changed. Unfortunately, the VKT data in Thailand is not recorded on a regular basis, and the statistics survey works are not frequently conducted. To the best of authors' knowledge, there are only two rather complete survey results [11, 12]. For adaptation into current LEAP model, certain assumptions were made as shown in Fig. 3.

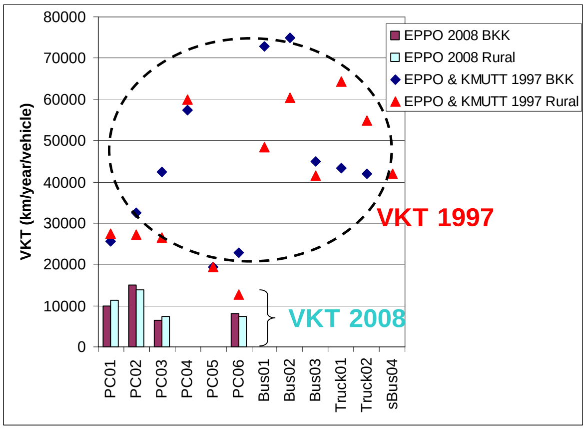


Fig. 3 Available VKT data in Thailand [11, 12]

As clearly shown in Fig. 3, the most recent survey data collected in 2008 [12] is not adequate; whereas, the more complete data in 1997 may be out of date. When comparing the data that both available in 1997 and 2008, the VKT has decreased with time, as expected. In order to get complete data for recent year, the following assumptions are applied.

- VKT is averaged out within the same vehicle type, and driving on the off-road distance is neglected in VKT
- Driving behavior of vehicle owner depends critically on available road distance and other vehicles to share the road with (traffic condition). Transportation mode change and urbanization are ignored.
- Demand for driving on the road collectively from various vehicle types at their average VKTs is satisfied by the Supply of the road distance. Hence, VKT extrapolation from 1997 to 2008 data was calculated from road surface expansion and vehicle population increase, as shown in Fig. 4.

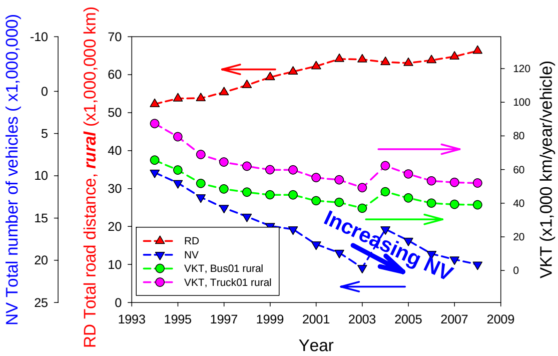


Fig. 4 VKT extrapolation over time in provincial region (only Bus01 and Truck01 are shown)

For each vehicle, the VKT values were assumed from a survey data in 2008 [12] if available. Otherwise, it will be extrapolated from survey data in 1997 [11] to base year (2006) according to the relationship in Eq. (2).

$$\frac{Rd_2}{Rd_1} = \frac{VKT_2}{VKT_1} \cdot \frac{\sum NV_2}{\sum NV_1} \qquad (2)$$

where Rd = Road distance

ΣNV = Total vehicle stock

However, the road distance change in Bangkok may be negligible compared to the vehicle population growth. The summary of VKT values are shown in the Table 4.

Table 4: Estimated VKT for Bangkok and Provincial regions

	Bangkok	Provincial region
PC01 passenger car	9,887*	11,264*
PC02 pickup	15,008*	13,746*
PC03 Motor tri-cycle	6,500*	7,475*
PC04 Taxi	39,982**	49,208**
PC05 Commercial rent car	13,407**	15,808**
PC06 Motor cycle	8,097*	7,414*
Bus01 Fixed route bus	50,746**	39,687**
Bus02 Non fixed route bus	52,168**	49,559**
Bus03 Private bus	31,301**	34,018**
sBus04 Small bus	-	34,433**
Truck01 Non fixed route truck	30,211**	52,845**
Truck02 Fixed route truck	29,128**	44,924**

*Note: *refer to survey record in 2008 [12], **estimated in this work*

3.3 Fuel Economy (FE) Estimation

Fuel economy (FE) is defined as the quantity of energy consumed in a unit of driven distance, which depends on the vehicle size, vehicle type, vehicle's powertrain technology (engine type) and fuel type used. The engine type can be classified into the spark ignition (SI, gasoline) and compression ignition (CI, diesel) engine. The distributed fuel types can also be categorized into gasoline, gasohol E10, gasohol E20, Diesel, Diesel B5, liquid petroleum gas (LPG) and compressed natural gas (CNG). Clearly, many parameters can affect FE, and certain assumption must be applied for energy demand model. A parameter, called Device Share (DS), was introduced to specify the fuel sharing when two fuel types are used, such as gasohol (gasoline and ethanol), bi-fueled CNG (gasoline and CNG) and diesel dual fuel (DDF: diesel and CNG). When CNG is used in certain vehicle types, the FE was approximated from [13, 14]. Table 5 show approximated fuel sharing percentage data from DLT records in Bangkok and provincial regions. On the other hand, Table 6 shows FE of each vehicle type in LEAP model for Bangkok and provincial regions.

Table 5: Approximated fuel sharing in Bangkok and provincial regions

(a) Bangkok	Liquid fueled engine: SI Engine*	Gasoline**	E10**	E20**	Diesel*	Liquid/gas fueled engine: Bi-fuel SI LPG*	Bi-fuel SI CNG*	DDF LPG*	DDF CNG*	Dedicated gas: LPG dedic.*	CNG dedic.*
PC01	78.16%	42.86%	56.57%	0.57%	20.38%	1.46%	0.00%	0.00%	0.00%	0.00%	0.00%
PC02	5.25%	67.95%	32.05%	0.00%	94.75%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
PC03	42.46%	79.58%	20.42%	0.00%	0.00%	17.84%	0.00%	0.00%	0.00%	37.48%	2.22%
PC04	14.01%	42.86%	56.57%	0.57%	0.00%	77.00%	7.62%	0.00%	0.00%	1.37%	0.00%
PC05	69.73%	42.86%	56.57%	0.57%	26.92%	3.35%	0.00%	0.00%	0.00%	0.00%	0.00%
PC06	100.00%	65.57%	34.43%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Bus07	1.24%	100.00%	0.00%	0.00%	94.77%	2.39%	0.00%	0.00%	0.00%	0.00%	1.60%
Bus08	0.39%	100.00%	0.00%	0.00%	99.61%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Bus09	0.80%	100.00%	0.00%	0.00%	99.20%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
sBus04											
Truck10	0.00%	100.00%	0.00%	0.00%	99.30%	0.00%	0.00%	0.22%	0.48%	0.00%	0.00%
Truck11	0.39%	100.00%	0.00%	0.00%	99.61%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

(b) Province	Liquid fueled engine: SI Engine*	Gasoline**	E10**	E20**	Diesel*	Liquid/gas fuel engine: Bi-fuel SI LPG*	Bi-fuel SI CNG*	DDF LPG*	DDF CNG*	Dedicated gas: LPG dedic.*	CNG dedic.*
PC01	68.83%	49.83%	50.17%	0.00%	30.31%	0.86%	0.00%	0.00%	0.00%	0.00%	0.00%
PC02	7.17%	67.95%	32.05%	0.00%	92.83%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
PC03	47.60%	79.58%	20.42%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	52.40%	0.00%
PC04	68.61%	49.83%	50.17%	0.00%	19.13%	12.26%	0.00%	0.00%	0.00%	0.00%	0.00%
PC05	84.01%	49.83%	50.17%	0.00%	10.18%	5.81%	0.00%	0.00%	0.00%	0.00%	0.00%
PC06	100.00%	74.56%	25.44%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Bus07	3.71%	100.00%	0.00%	0.00%	96.29%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
Bus08	24.15 %	100.00%	0.00%	0.00%	75.85%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Bus09	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
sBus04	13.32%	100.00%	0.00%	0.00%	86.68%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Truck10	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Truck11	0.00%	100.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%

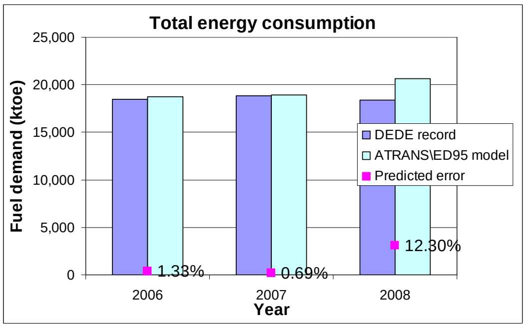
Table 6: Approximated FE of all vehicle types in Bangkok and provincial regions

(a) Bangkok km/litre and km/litre for CNG	Single fuel engine: Spark ignition engine: Gasoline	E10	E20	Diesel engine	Dedicated gas engine: LPG	CNG
PC01	10.62*	11.30*	9.85**	11.44*	9.87*	10.85*
PC02	10.00*	9.64**	9.28**	11.21*	11.57*	11.33*
PC03	10.92**	10.52**	10.13**	12.00**	9.71*	9.29*
PC04	10.58**	10.20**	9.82**	11.63**	9.83**	10.81**
PC05	11.83**	11.40**	10.97**	13.00**	10.99**	12.08**
PC06	32.77*	29.24*	-	-	-	-
Bus01	2.18**	2.10**	2.03**	2.40*	2.03**	1.86*
Bus02	2.09**	2.01**	1.94**	2.30**	1.94**	2.13**
Bus03	2.09**	2.02**	1.95**	2.31**	1.95**	2.14**
sBus04	-	-	-	-	-	-
Truck01	2.57**	2.48**	2.38**	2.83*	2.39**	2.63**
Truck02	2.22**	2.14**	2.06**	2.44**	2.07**	2.27**

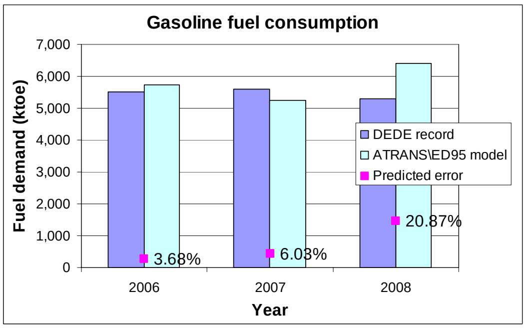
(b) Province km/litre and km/litre for CNG	Single fuel engine: Spark ignition engine: Gasoline	E10	E20	Diesel engine	Dedicated gas engine: LPG	CNG
PC01	12.28*	12.43*	11.40**	11.96*	11.03*	10.04*
PC02	11.88*	12.07*	11.02**	12.04*	11.00*	12.42*
PC03	16.16*	15.57*	14.99**	16.06**	12.18*	9.29**
PC04	12.09**	11.66**	11.22**	12.02**	11.03**	11.26**
PC05	10.82**	10.43**	10.04**	10.75**	9.87**	10.08**
PC06	25.75*	25.92*	-	-	-	-
Bus01	4.18**	4.03**	3.88**	4.15*	3.81**	3.12*
Bus02	4.37**	4.21**	4.06**	4.34**	3.99**	4.07**
Bus03	4.35**	4.19**	4.04**	4.32**	3.97**	4.05**
sBus04	4.71**	4.54**	4.37**	4.68**	4.29**	4.38**
Truck01	4.05**	3.90**	3.76**	4.02*	3.69**	2.01*
Truck02	4.68**	4.51**	4.34**	4.65**	4.27**	4.36**

4. Discussion

With all the model setup and assumption above, the validation of the model capability for base year and other years against the fuel sale record from DEDE [1] can be shown in Fig. 5.



(a)



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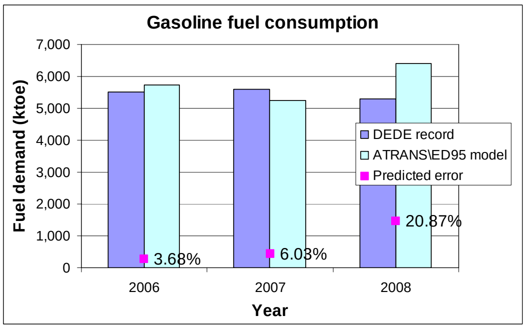
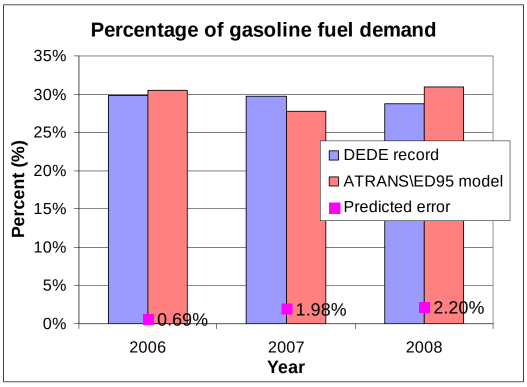


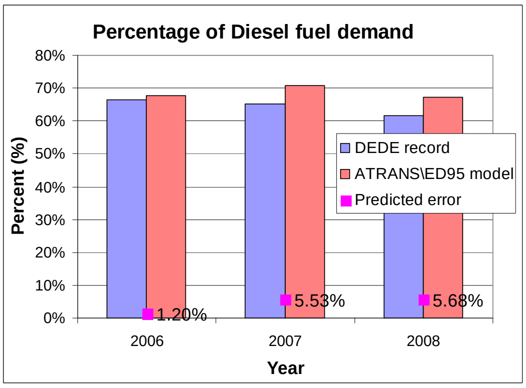
(c)

Fig. 5 Validation of energy demand model with fuel consumption in year 2006-2008 for (a) all, (b) gasoline and (c) diesel fuels

Despite the absolute difference between the model prediction and fuel sale record in Fig. 5, Fig. 6 shows better results in term of fraction of liquid fuel (gasoline/diesel) used. Further investigation into all fuels in Fig. 7 reveals that the deviation of predicted results mainly comes from the gas fractions (LPG and CNG) due to fuel switching behavior since LPG and CNG are subsidized. In addition, the registration of gas-conversion vehicles was mandated after the base year of calculation so there were some errors in the number of vehicles using LPG/CNG. However, this minor impact is beyond the scope of this work, and it is not possible to incorporate into the LEAP application.

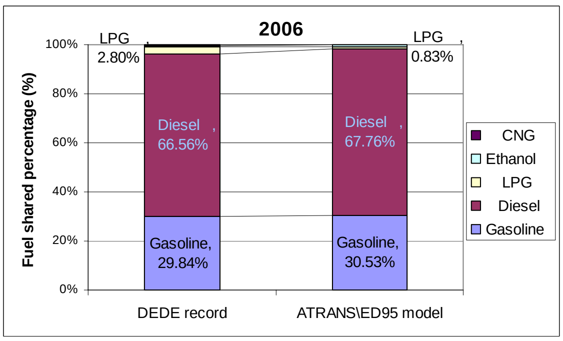


(a)

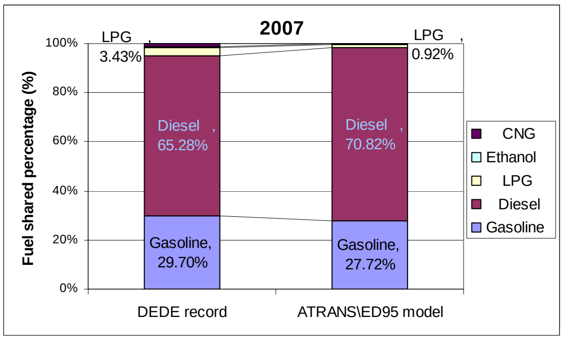


(b)

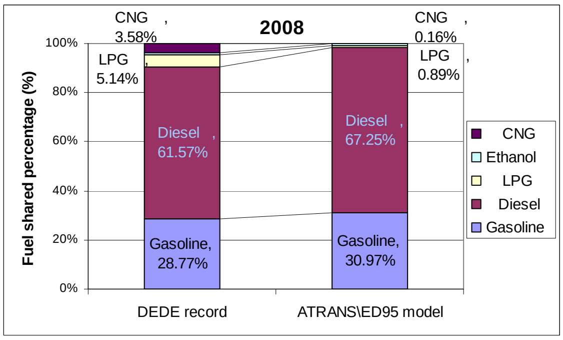
Fig. 6 Validation of energy demand model with %fuel consumption in year 2006-2008 for (a) gasoline and (b) diesel



(a)



(b)



(c)

Fig. 7 Validation of energy demand model with %fuel consumption in year (a) 2006 (b) 2007 and (c) 2008

With the Business-As-Usual (BAU) energy demand model established, scenario analysis of ethanol CI engine can be conducted to assess the potential of ethanol bus in Thai transportation sector. Fig 8 shows the predicted ethanol demand and supply in the transportation sector. The supply ethanol values refer to the predicted levels from Laoonual et al. [5], which is predicted between the year 2008 to 2018 and the target of ethanol demand from Thailand Alternative Energy Strategic Plan as 9 million liters per day in 2022 [3]. The results of ethanol demand are shown from two scenarios. First is for BAU, which reflects DLT planning to use the NGV bus in the new fixed route bus. Second is scenario A, which introduces ethanol bus (termed ED95 technology for 95% ethanol and 5% additive blend) instead of NGV in Bangkok. The technology penetrations in both cases are specified according to usual Scurve during 10 years period after 2010. It is clear that the ED95 technology is needed in order to achieve ethanol demand projected in Thailand Alternative Energy Strategic Plan.

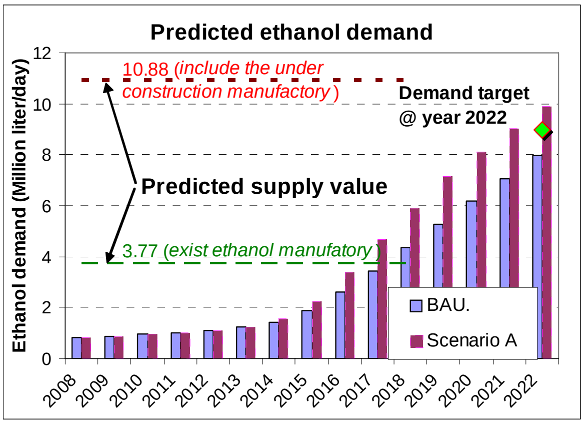


Fig. 8 Predicted ethanol demand and supply in the transportation sector

With introduction of ED95 technology, the CNG fuel consumption will be reduced by ethanol fuel substitution, which is shown in Fig. 9, as well as estimated green house gas (GHG) emission reduction cause by the fossil fuel reduction in the CO_2 equivalent scale. The GHG emissions are calculated according to the Intergovernmental Panel on Climate Change (IPCC) methodology [15]. The emissions considered here are the exhaust of mobile combustion: CO_2, CH_4 and N_2O. Eq. 3 shows the simplified calculation method while Table 7 shows the emission factor (EF) and the global warming potential (GWP) of the CNG fuel consumed.

$$EM = \sum_i EC \cdot EF_i \cdot GWP_i \qquad (3)$$

where

EM = Emission (kg CO_2 equivalence)

EC = Energy consumption (TJ)

EF_i = Emission factor of emission i (kg/TJ)

GWP_i = Global warming potential of emission i (g CO_2/g emission i)

i = Emission type, (CO_2, CH_4, N_2O)

Table 7: GHG calculation parameters of CNG fuel

CNG fuel	CO_2	CH_4	N_2O
EF (kg/TJ)	55.5	50	0.1
GWP (gCO2/g)	1	25	289

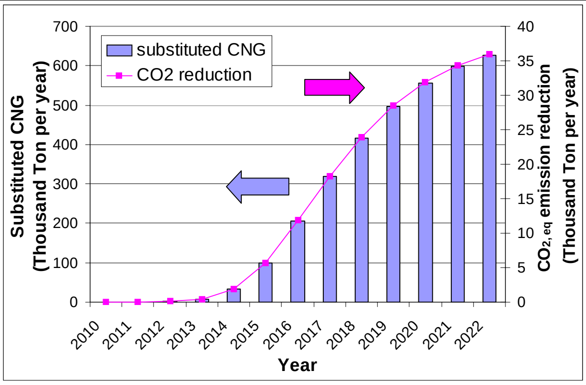


Fig. 9 Estimated reduction in CNG demand and CO_2 emission with ED95 technology

Since current consumption of CNG in Thailand still relies on import (being 25% of total consumption in 2008 at 70 billion THB [1]), introduction of ethanol bus after 10 year period can reduce CNG fuel demand by 550 thousand tons or about 4.7 billion THB per year (at recent CNG fuel price of 8.5 THB per kg). Moreover, the CO_2 emission can be reduced more than 32 thousand tons per year.

6. Conclusion

The future energy consumption in the transportation sector can be estimated by the mathematical model, which was developed in this work via LEAP model and methodology. It must be aware that the predicted results may deviate from the actual energy consumption affected by externalities such as sudden fuel price and consumer behaviors. Nevertheless, the predicted results can illustrate the energy demand trend. Within the scope of the present case study, ethanol bus technology was analyzed with the following impacts.

- To increase the ethanol demand projected by Thailand Alternative Energy Strategic Plan.
- To decrease fossil fuel consumption and increase nation energy security from domestic renewable energy resource such as ethanol.
- To decrease greenhouse gas emission by using biofuel shown by 'Well to Wheel' emission analysis.

7. Acknowledgement

The authors would like to acknowledge financial support from Asian Transportation Research Society (ATRANS), Research Project A-09/003 (www.atransociety.com)

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