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Possibility of Ethanol Usage as Diesel Substitutes in Thai Transportation Sector

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List of Abbreviations and Acronyms

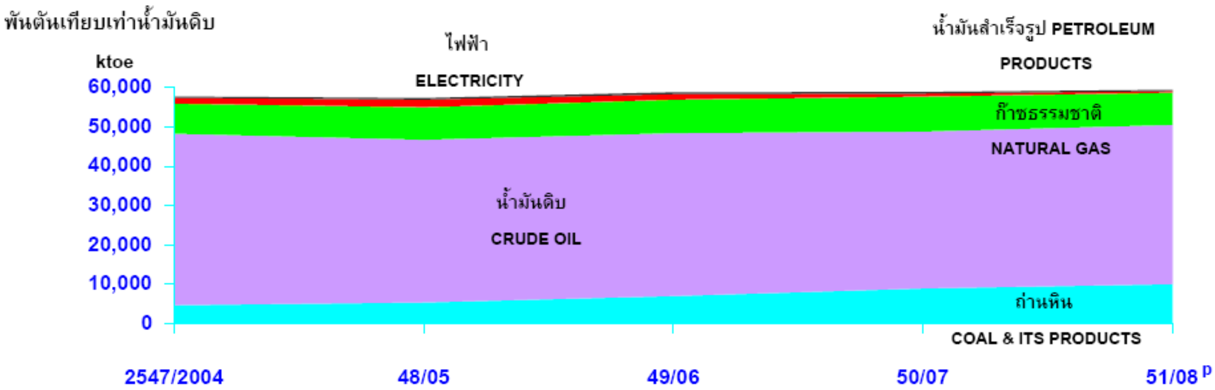
ASIF	Activity (A), Mode Share (S), Fuel Intensity (I) and Fuel Choice (F)
BAU	Business-As-Usual
BEST	Bioethanol for Sustainable Transport
CI	compression-ignition
DEDE	Department of Alternative Energy Development and Efficiency, Ministry of Energy (Thailand)
DOT	Department of Transport
E10	Ethanol-blended gasoline at 10% v/v
E20	Ethanol-blended gasoline at 20% v/v
E85	Ethanol-blended gasoline at 85% v/v
EC	Energy consumption (TJ)
ED	Energy demand
EEV	Enhanced Environmentally-friendly Vehicle
EF_i	Emission factor of emission i (kg/TJ)
EGR	Exhaust gas recirculation
EM	Emission (kg CO_2 equivalence)
EPPO	Energy Policy and Planning Office
EU	European Union
FE	Fuel economy
FFV	Flex-fuel vehicle
FP	Framework Programme
GDP	Gross domestic product
GHG	Greenhouse gas
GWP_i	Global warming potential of emission i (g CO_2/g emission i)
HP	horsepower
i	Emission type (CO_2, CH_4, N_2O)
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
ktoe	Kilotonne of oil equivalent
LPD	Liter per day
LPG	Liquefied Petroleum Gas
MMscfd	Million Standard Cubic Feet per Day of gas
MW	Megawatts
NEPC	National Energy Policy Council
NESDB	Office of the National Economic and Social Development Board

NGV	Natural gas for vehicle
NV	Number of vehicle
OAE	Office of Agricultural Economics, Ministry of Agriculture and Cooperatives (Thailand)
OCSB	Office of the Cane and Sugar Board, Ministry of Industry (Thailand)
PCD	Pollution Control Department, Minister of Natural Resource and Environment (Thailand)
R&D	Research and development
RD	Road distance
RPM	Revolution per minute
SEI	Stockholm Environment Institute
SI	spark-ignition
THB	Thai Baht
TRF	Thailand Research Fund
US	United States of America
VKT	Vehicle Kilometer Traveled
VO	Vehicle population per capita
yrs	Years

CHAPTER I INTRODUCTION

1.1 Rationale

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, Fig. 1(a) clearly illustrates the trend of energy import over the past five years, where a majority of the import lies in crude oil. In particular, the recent oil crisis in 2007 has brought crude oil to be the most expensive imported energy prices surpassing the electricity cost, as shown in Fig. 1(b) [1].



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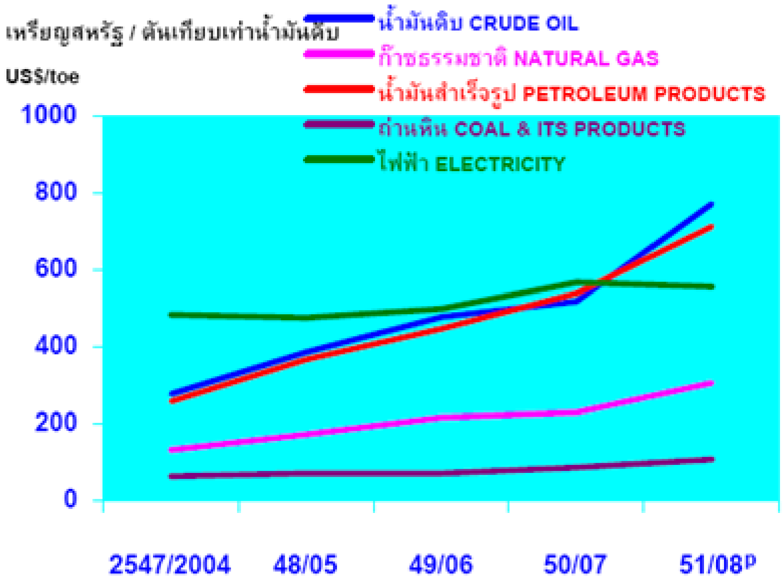

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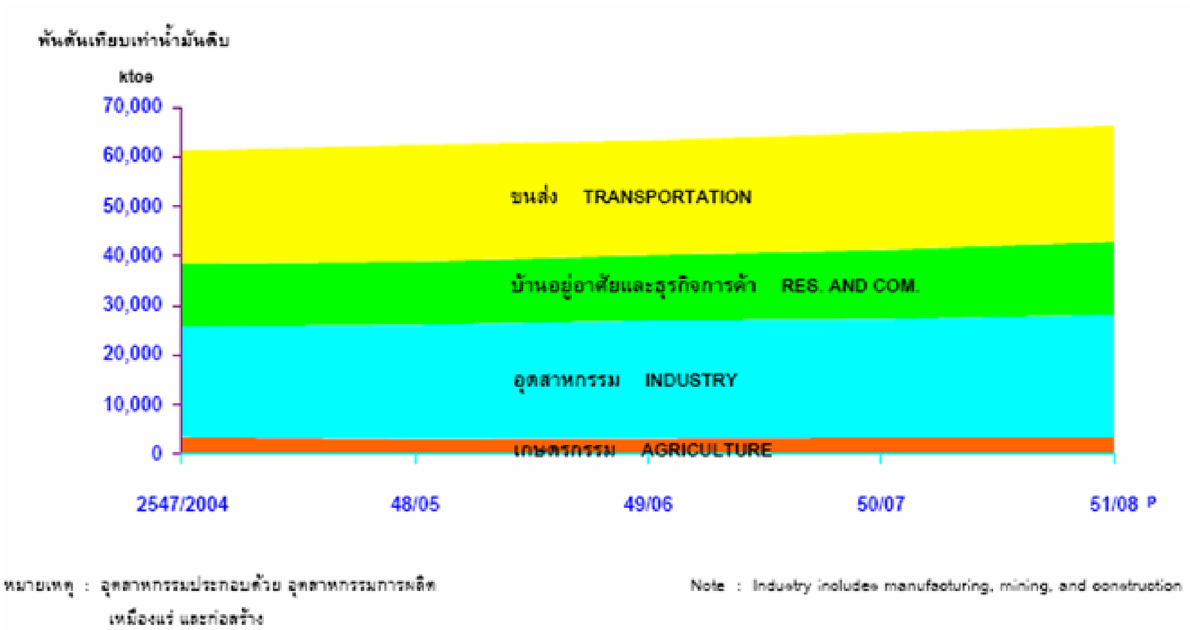
Fig. 1 Thailand energy import (a) quantity and (b) price over the past five years

Over the past decade, Thailand Final Energy Consumption has been dominated by the two economic sectors, which are transportation and industry for about 1/3 each, as shown in Fig.

2(a) [1]. When considering consumption per sector GDP, transportation is the greatest, about 3-4 times that of industry, as shown in Fig. 2(b). Hence, transportation sector has long been the target to reduce energy consumption. Within transportation sector, it is dominated by ground transportation, with about ¾ fraction. Furthermore, the transportation sector has consumed diesel about twice as much gasoline, as shown in Fig. 2(c). 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. NGV and biodiesel are two main substitutes to diesel fuel in transportation sector with clear target projected in the National Alternative Energy Strategic Plan (2008-2022). The goal is to achieve 20% of energy consumption from alternative sources, e.g. biomass power/heat generation, biofuel and NGV, as shown in Fig. 3.



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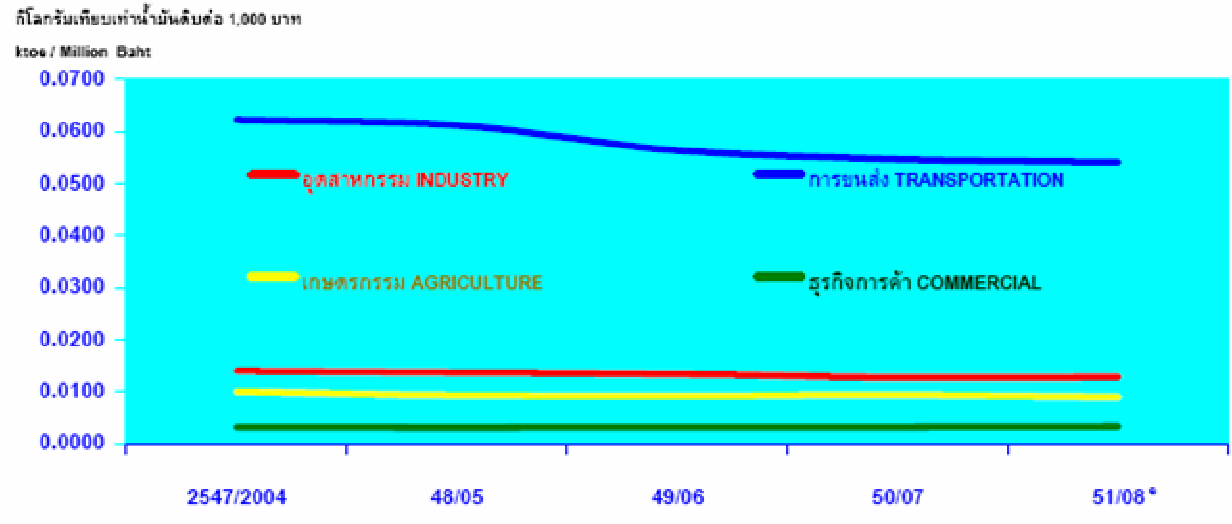

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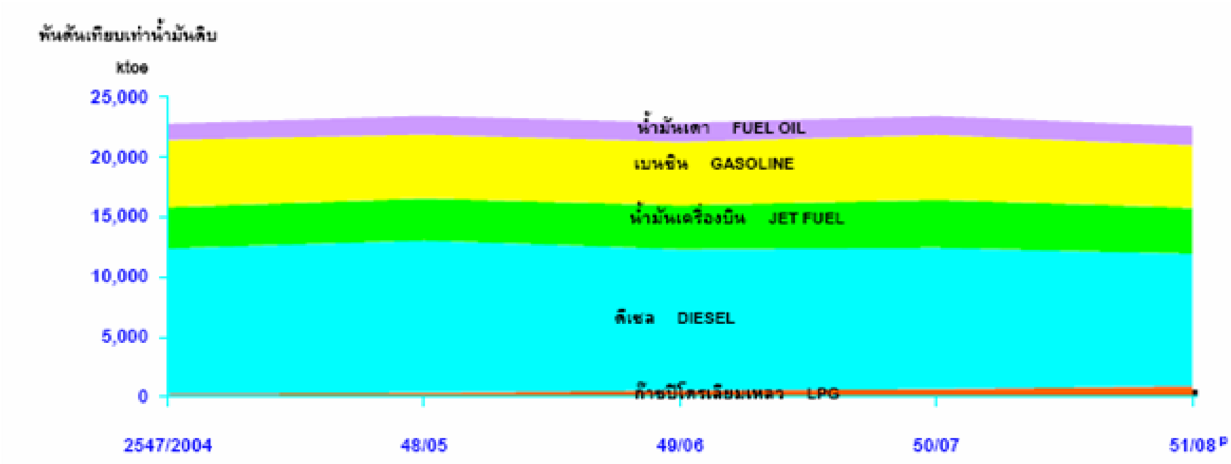
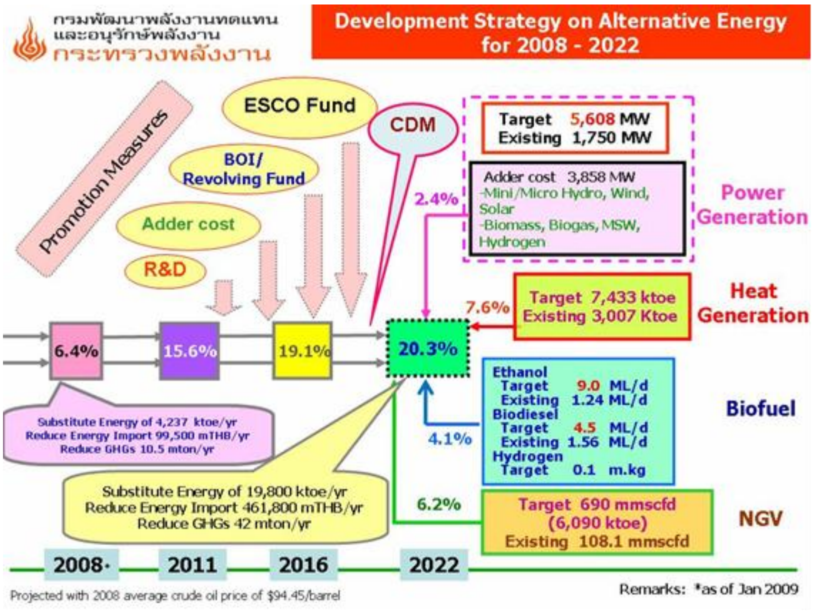


(c)

Fig. 2 History data of (a) final energy consumption by economic sector, (b) sector energy consumption per sector GDP by economic sector and (c) 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



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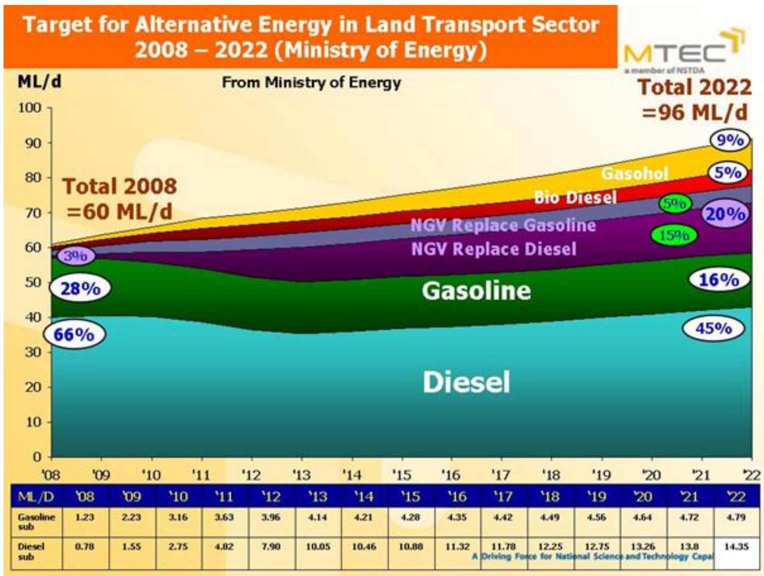


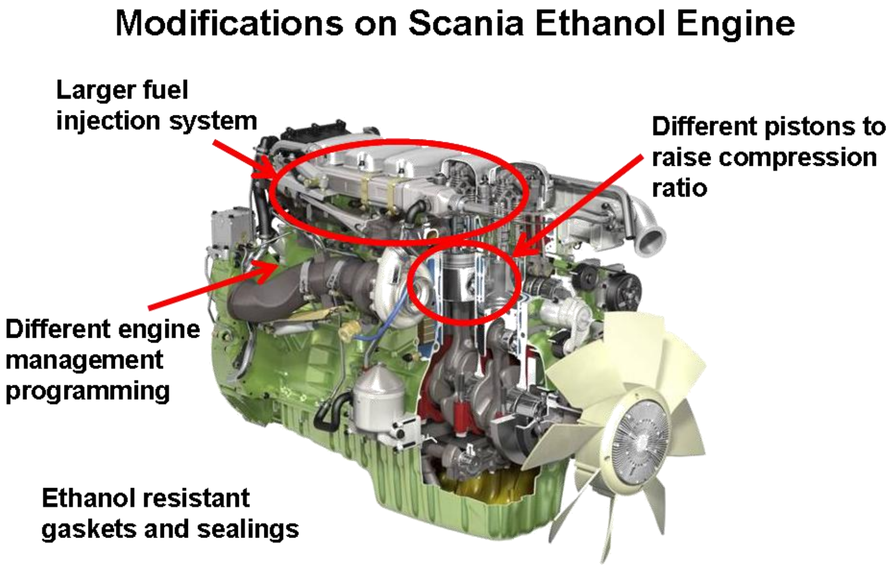
(b)

Fig. 3 (a) Thailand Alternative Energy Strategic Plan for 2008-2022 with (b) detailed breakdown of transport fuel projection

However, the higher volume target for ethanol production in 2022, which results from the more probable feedstock availability in the future, will further widen the unbalance between diesel and gasoline consumptions since ethanol is conventionally used in blending with gasoline in the form of gasohol E10 (ethanol: gasoline = 10:90 by volume), E20 (ethanol: gasoline = 20:80 by volume) and E85 ethanol: gasoline = 85:15 by volume. While NGV and biodiesel have been planned as diesel substitute, their amounts are still not as large to lessen the diesel-gasoline unbalance. Fortunately, bioethanol has been technically proved as diesel substitute in compression-ignition (CI) engine, despite the conventional knowledge that ethanol is usually used in spark-ignition (SI) engine due to its high octane

number. Among others, Scania Company has been conducting research for using ethanol in CI engine for the past few decades with the current 3rd-generation CI ethanol engine commercially available, as shown in Fig. 4(a), which has been modified from the regular CI diesel engine, as shown in Fig. 4(b). For instances, larger fuel injection system is required to match up the heating value usually obtained from fossil diesel, as well as higher compression ratio to both increase the thermal efficiency and cope with the high octane nature of ethanol. Of course, certain gaskets and sealings, which are exposed to ethanol, need to be changed to the ethanol-resistant kinds. Scania has commercialized this specially developed ethanol CI engine in the City Bus, as shown in Fig. 4(c). In addition to Sweden, Scania ethanol buses have been tested in Brazil, China, Germany, Italy, Netherlands, Norway Spain and UK under EU FP-7 co-finance project BEST (BioEthanol for Sustainable Transport) and other initiatives, as shown in Fig. 4(d). In addition to Scania, SAAB has also worked on ethanol CI passenger car, as shown in Fig. 4(e).

(a)



(b)

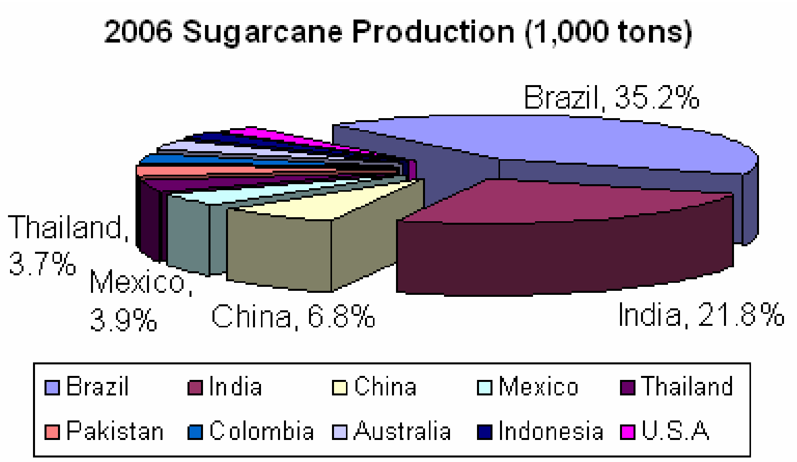
(c)

(d)

(e)

Fig. 4 (a) Scania 3rd-generation CI ethanol engine showing (b) necessary modification from the regular CI diesel engine, with (c) the commercial ethanol bus currently commercially available in the market. Outside Sweden, the ethanol bus has been tested under (d) BEST initiative with (e) SAAB as a partner for ethanol-powered diesel passenger car.

For sustainable promotion of ethanol utilization in transportation sector, the feedstock must be considered, planned and secured with supporting processing capacity. Fig. 5 illustrates that Thailand is among the world leaders in both sugarcane and cassava production, which are ethanol feedstock [3]. Furthermore, Table 2 shows the list of all ethanol plants in Thailand, both actively processing and in-planning [4]. However, successful implementation of new technology requires reliable feasibility study. Hence, the present investigation aims to assess possibility of using ethanol as diesel substitute in transportation sector.



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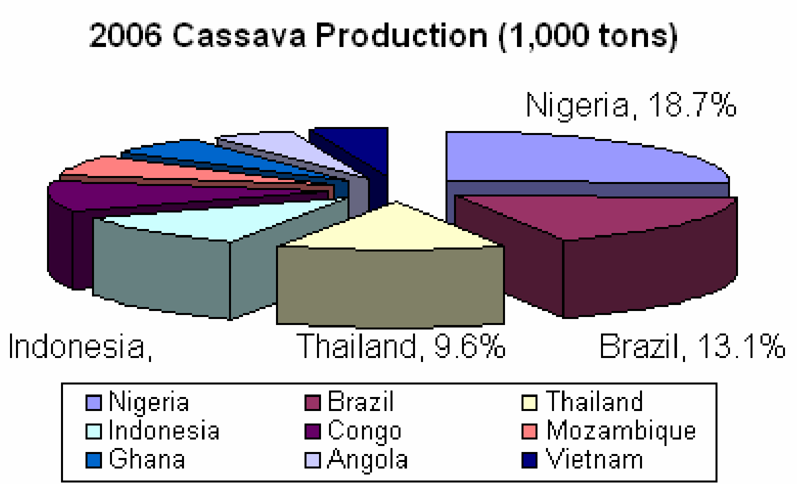


(b)

Fig. 5 2006 world (a) sugarcane and (b) cassava production

Table 2: Lists of ethanol plants in Thailand

	Companies	Installed capacity (L/d)	Feedstock	Province
	In production (Jun 09)	2,275,000		
1	Pornwilai International Group Trading†	25,000	Molasses/Cassava	Ayuttaya
2	Thai Alcohol	200,000	Molasses	Nakhon Pathom
3	Thai Agro Energy	150,000	Molasses	Suphanburi
4	Thai Nguan Ethanol	130,000	(Fresh) Cassava	Khon Khen
5	Khon Khen Alcohol	150,000	Molasses	Khon Khen
6	Petrogreen (Chaiyabhum)	200,000	Molasses/ (Sugarcane)	Chaiyabhum
7	Petrogreen (Kalasin)	200,000	Molasses	Kalasin
8	Thai Sugar Ethanol	100,000	Molasses	Karnchanaburi
9	K.I. Ethanol	100,000	Molasses	Nakhon Ratchasima
10	Akekarat Pattana‡	200,000	Molasses	Nakhonsawon
11	Thai Rungruang	120,000	Molasses/(Bagasse)	Saraburi
12	Ratchaburi Ethanol	150,000	Cassava	Ratchaburi
13	ES Power§	150,000	Cassava/Molasses	Sarkaew
14	Maesawd Clean Energy	200,000	Sugarcane	Tak
15	Sapthip*	200,000	Cassava	Lopburi
	Under construction	1,700,000		
1	IEC Business Partner#	150,000	Cassava	Rayong
2	Farkwanthip#	60,000	Cassava	Prachenburi
3	TPK Ethanol	340,000	Cassava	Nakhonratchasima
4	Sima Inter Product	150,000	Cassava	Chasengsao
5	P.S.C. Starch Product	150,000	Cassava	Chonburi
6	Double A Ethanol	500,000	Cassava	Sarkaew
7	Boon Anek	350,000	Cassava	Nakhonratchasima
8	Impress Technology	200,000	Cassava	Chasengsao

†Now producing acetic acid instead
‡Producing hydrous ethanol (95%)
§Produce from cassava in Oct 09
*No production until Oct 09
#IEC Business Partner and Farkwanthip had completed plant construction but not yet operating.

1.2 Objectives

In order to assess possibility of using ethanol as diesel substitute in transportation sector, the present investigation aims to

1. **Construct a database model for energy consumption in transportation**
2. **Analyze above model for various scenarios to reflect different levels of diesel substitution by ethanol**
3. **Assess technical-economical feasibility of using ethanol as diesel substitute in transportation sector**

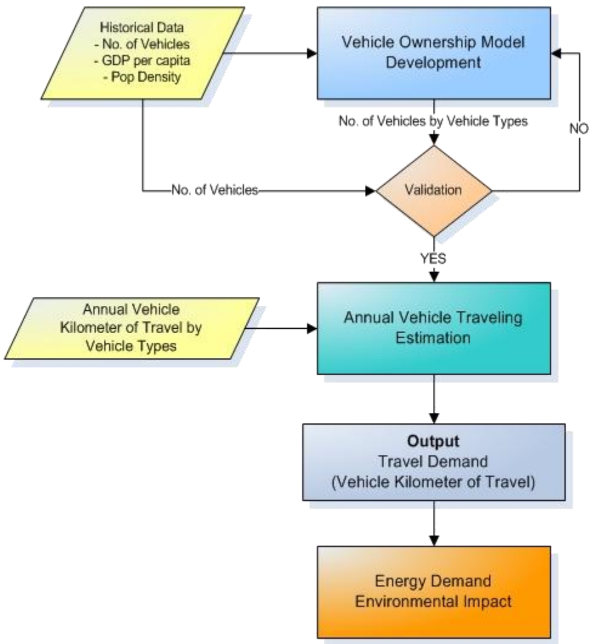
1.3 Methodology

In order to analyze energy use pattern in transportation sector with capability to predict energy demand, bottom-up approach, rather than top-down approach, is undertaken due to its capability in accounting for the flow of energy based on simple engineering relationship,

as detailed in Table 3 [5]. Inputs of traveling demand, fuel consumption and vehicle numbers from various types into the bottom-up model can yield the estimation of energy demand, as schematically shown in Fig. 6 [6]. Among many others, Long-range Energy Alternatives Planning (LEAP) system will be utilized to construct the energy demand model in this study.

Table 3: Differences between top-down and bottom-up approach in energy model

Top-down	Bottom-up
Use aggregated economic data	Use detailed data on fuels, technologies and policies
Assess costs/benefits through impact on output, income, GDP	Assess costs/benefits of individual technologies and policies
Implicitly capture administrative, implementation and other costs.	Can explicitly include administration and program costs
Assume efficient markets, and no "efficiency gap"	Do not assume efficient markets, overcoming market barriers can offer cost-effective energy savings
Capture intersectoral feedbacks and interactions	Capture interactions among projects and policies
Commonly used to assess impact of carbon taxes and fiscal policies	Commonly used to assess costs and benefits of projects and programs
Not well suited for examining technology-specific policies.	



				Energy demand module			
Sector	**Sub-sector**	**End-use**	**Device**	**Energy intensity**			**Energy demand**
Transport sector (vehicle)	Transport mode (per cent)	Modal split (per cent)	Vehicle kilometer of travel (kilometer)	Type of fuel used (per cent)	Fuel economy of vehicle (GJ per veh-km)	⇨	Scenario analysis (GJ or ktoe)

Fig. 6 Flow of bottom-up energy demand model

From previous study [7], relevant energy transport database framework from vehicles, traffic, energy usage and socio-economic data has been laid out. Important factors for energy demand in transportation have been identified following "ASIF" principles, namely Activity (A), Mode Share (S), Fuel Intensity (I) and Fuel Choice (F) [8]. Unlike US [9] or UK [10] where transportation energy statistics are well documented by a single governmental authority, data gathering methodology from various Thai organizations must be established with certain assumptions if the data is not available. Once the model is developed and well calibrated the past history data, Business-As-Usual (BAU) reference case will be constructed based on the proper choice of base year. Various scenarios of diesel substitution by ethanol will be analyzed to assess economical feasibility. Furthermore, technical feasibility must be assessed in term of technological supporting infrastructure. Detailed approach will be discussed in the next Chapter.

CHAPTER 2 LITERATURE REVIEW

2.1 LEAP System

The choice of bottom-up energy model approach in the present study is Long-range Energy Alternatives Planning (LEAP) system, developed by Stockholm Environment Institute (SEI) and freely available for non-profit organization [6]. LEAP modeling capabilities are highlighted as follows, with the calculation flows shown in Fig. 7.

- **Energy Demand**
  - **Hierarchical accounting of energy demand (activity levels x energy intensities).**
  - **Choice of methodologies.**
  - **Optional modeling of stock turnover.**
- **Energy Conversion**
  - **Simulation of any energy conversion sector (electric generation, transmission and distribution, CHP, oil refining, charcoal making, coal mining, oil extraction, ethanol production, etc.)**
  - **Electric system dispatch based on electric load-duration curves.**
  - **Exogenous and endogenous modeling of capacity expansion.**
- **Energy Resources:**
  - **Tracks requirements, production, sufficiency, imports and exports.**
  - **Optional land-area based accounting for biomass and renewable resources.**
- **Costs:**
  - **All system costs: capital, O&M, fuel, costs of saving energy, environmental externalities.**
- **Environment**
  - **All emissions and direct impacts of energy system.**
  - **Non-energy sector sources and sinks.**

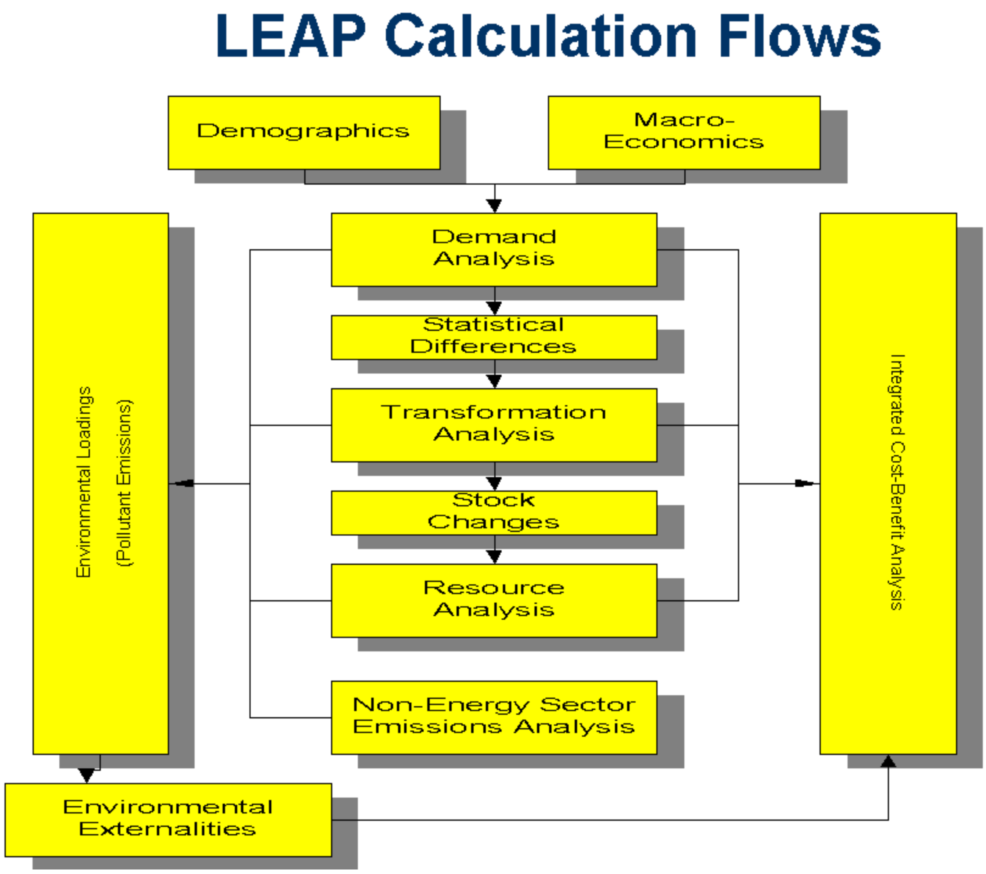
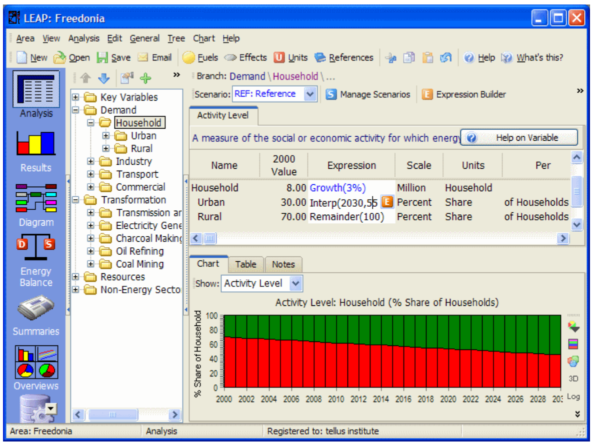


Fig. 7 LEAP calculation flows

In brief, LEAP system mainly deals with energy demand, energy conversion/transformation and energy resource, with optional analyses on cost and environment. The model is based on accounting of energy flow with spreadsheet functionality, with the selected appearance shown in Fig. 8.

- **The *Analysis View* allows user to create data structures, enter data, and construct models and scenarios in all demand, transformation and resource, as shown in Fig. 8(a)-(c).**
- **The *Results View* allows user to examine the outcomes of input scenarios as charts and tables, as shown in Fig. 8(d).**
- **The *Diagram View* allows user to track the flows of energy.**
- **The *Energy Balance View* allows user to output standard table showing energy production/consumption in a particular year.**
- **The *Summary View* allows user to output cost-benefit comparisons of scenarios and other customized tabular reports.**
- **The *Overviews* allows user to group together multiple "favorite" charts for presentation purposes, Fig. 8(e).**
- **The *TED View* allows user to access Technology and Environmental Database complied with technology characteristics, costs, and environmental impacts of approximately 1000 energy technologies.**

- **The *Notes View* allows user to document and reference own data and models.**



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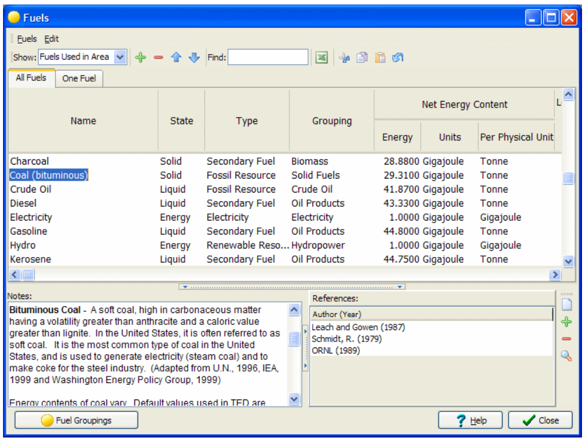

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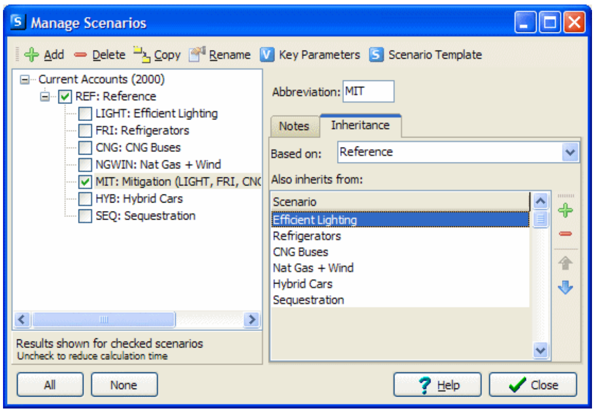

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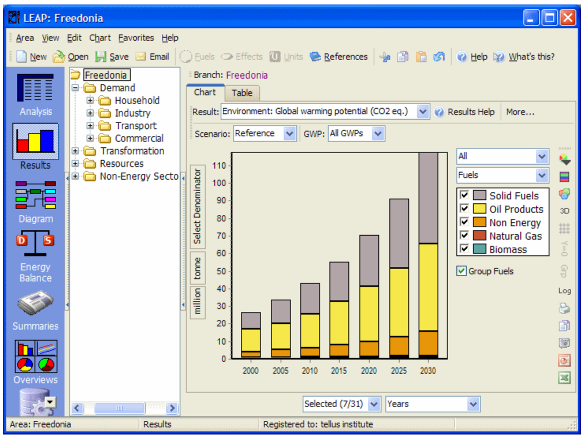

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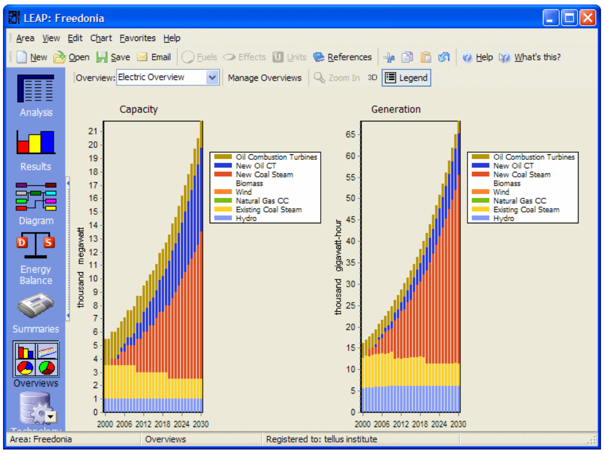


(e)

Fig. 8 Overview of LEAP system showing (a) Analysis View, (b) Fuel data customization, (c) Scenarios customization, (d) Result View and (e) Overview of interested results

As shown in Fig. 6 and Fig. 7, the analysis of ethanol utilization as diesel substitute can be divided into the following steps.

2.1.1 Ethanol Demand Model

In order to quantify and predict the ethanol consumption in transportation sector, especially as diesel substitute, certain assumptions must be made to

1. **estimate the number of vehicles,**
2. **estimate the distances traveled by vehicles,**
3. **estimate the energy demand**

First, the number of vehicles can be estimated by realizing the past data and trend of vehicle growth in a mathematical model, often called "Vehicle Ownership Model", which can be modeled as the S-Curve logistic function of GDP per capita and population density. An example of such function is [11]

$$\ln\left(\frac{S-VO}{VO}\right) = a + b\ln GDPpCap + c\ln PopDen$$

where VO **= Vehicle occupancy (number of vehicle/1,000 population)**

S **= Saturation level of VO (number of vehicle/1,000 population)**

GDPpCap = GDP per capita (THB/person)

PopDen = Population density (person/sq. km)

a, b and c = coefficients from curve fitting with historical data

Second, the distances traveled by all vehicles can be estimated from the product between the Vehicle Kilometer Traveled (or VKT) of each vehicle type and number of that vehicle type, under the assumption that vehicle of the same type but different fuel travels the similar average distance.

$$TD_{ij} = NV_{ij} \times VKT_{j}$$

where TD_{ij} **= distances traveled by vehicle type "j" with fuel type "i" (km)**

NV_{ij} **= number of registered vehicle type "j" that uses fuel type "i" (number of vehicle)**

VKT_{ij} **= average distances traveled by vehicle type "j" (km)**

Last, the energy demand can be estimated from the product between the distance traveled by vehicle and the average fuel economy.

$$ED_{ij} = TD_{ij} \times FE_{ij}$$

where ED_{ij} **= energy demand of fuel type "i" from vehicle type "j" (liter)**

TD_{ij} **= distances traveled by vehicle type "j" with fuel type "i" (km)**

FE_{ij} = fuel economy of registered vehicle type "j" that uses fuel type "i" (liter/km)

2.1.2 Scenarios Definition

As previously mentioned, the present study focuses on the utilization of ethanol as diesel substitute in transportation sector. Underlying assumption are the fixed economic growth (that would reflect the vehicle growth), and the fixed population growth throughout the period of study. The Busines-As-Usual reference case assumes there is no usage of ethanol as diesel substitute but the usage of ethanol as gasoline substitute still continues as previously. For the scenarios analyses, three additional cases pursued are defined as follow.

1. **Existing technology case for ethanol city bus:**
   - **Assume initial introduction of ethanol bus to Bangkok Mass Transit Authority**
   - **Balance ethanol supply and demand while considering other diesel substitute like biodiesel and NGV**
   - **Evaluate necessary investment vs. saving/benefit gained**
2. **Emerging technology case for ethanol coach bus/pick-up truck**
   - **Assume future market penetration of emerging technology in two sectors (coach bus/pick-up truck)**
   - **Balance ethanol supply and demand while considering other diesel substitute like biodiesel and NGV**
   - **Evaluate necessary investment vs. saving/benefit gained**
3. **R&D case for funding research project to develop indigenous technology**
   - **Assume budget spent on developing indigenous technology for utilizing ethanol as diesel substitute**
   - **Balance ethanol supply and demand while considering other diesel substitute like biodiesel and NGV**
   - **Evaluate necessary investment vs. saving/benefit gained**

Note that specific assumption for each scenarios will be discussed among experts in the field to obtain most probable and realistic definitions.

2.1.3 Demand/Supply Analysis for stakeholders' impact

The demand analysis must be considered under the constraint of supply, especially for the production capacity of ethanol and the future trend. For future production of ethanol, three studies of OCSB [12], OAE [3] and Sriroth et al [13] are used as a supply benchmark for ethanol production limit from all possible resources, namely molasses, sugarcane juice and cassava, as shown in Fig. 9. Note the ethanol conversion rate from different feedstock shown in Table 4.

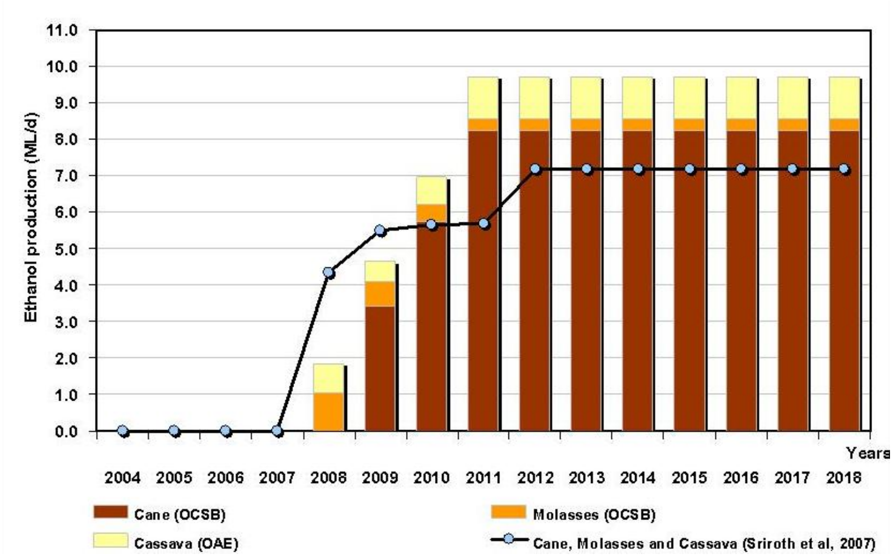


Fig. 9 Estimated ethanol production in Thailand

Table 4: Ethanol conversion from various feedstock

Type of feedstock	Ethanol conversion rate (liter of ethanol/ton of feedstock)
Sugarcane	70
Molasses†	260
Cassava	165

†Under the assumption that 1 ton of sugarcane juice yields 45 kg. of molasses

In term of related stakeholder to evaluate the fiscal impact in the scenarios analysis, four groups are categorized as follows.

1. **Feedstock and ethanol production stakeholder**
2. **Based fuel stakeholder**
3. **Automotive stakeholder**
4. **Policy and planning stakeholder**

2.2 Energy Database Framework for Transportation Sector in Thailand

Currently, there is no single governmental authority in Thailand that has complete necessary transportation energy database available despite many research efforts in this field [7]. Crucial data are still scattered in various authorities according to the responsibilities and interests of specific organizations, as shown in Table 5.

Table 5: Some relevant transportation energy data in various organizations

Governmental Authority	Kind of transportation energy data
Ministry of Transport	
Department of Land Transport (DLT) [2]	Number and category of registered vehicles for the purpose of vehicle tax
Office of Transport and Traffic	Traffic volume, accident record, socio-economic impact,

Policy and Planning (OTP) [14]	commodity logistics and related statistics for the purpose of national transportation policy planning
Ministry of Energy	
Energy Policy and Planning Office (EPPO) [15]	National energy plan and policy for all sectors including transportation
Department of Alternative Energy Development and Efficiency (DEDE) [1]	Thailand annual energy situation including all statistics for energy import/usage/export in all sectors
Department of Energy Business (DOEB) [16]	Fuel regulatory authority (trading and specification) in Thailand
Ministry of Natural Resources and Environment	
Pollution Control Department (PCD) [17]	Fuel consumption and emission information for the purpose of air quality control
Ministry of Industry	
Thai Industrial Standards Institute (TISI) [18]	Regulatory authority for standard of all industrial commodities, including vehicle emission

In order to construct predictive energy model in transportation sector, all relevant energy database reviewed are categorized into four groups as follows.

1. **Vehicle related database, which deals with vehicle energy consumption and environmental impact information, such as number of vehicle, fuel economy and emission factor**
2. **Traffic related database, which deals with travel demand management, such as vehicle kilometer traveled (VKT), travel mode share and vehicle occupancy rate**
3. **Socio-economic related database, which deals with energy consumption pattern and trend, such as GDP, household income and population growth**
4. **Fuel related database, which deals with fuel-specific information, such as types of available fuel, fuel quality and impact on utilization**

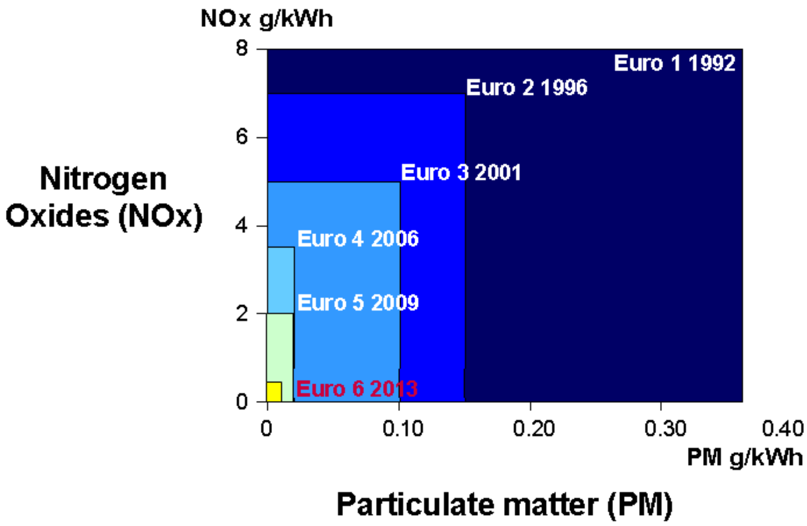
For the scope of current study, where ethanol is assessed as diesel substitute, the energy model can be constructed as shown in Fig. 4 with the following details.

Table 6: Necessary data for construction of energy demand model

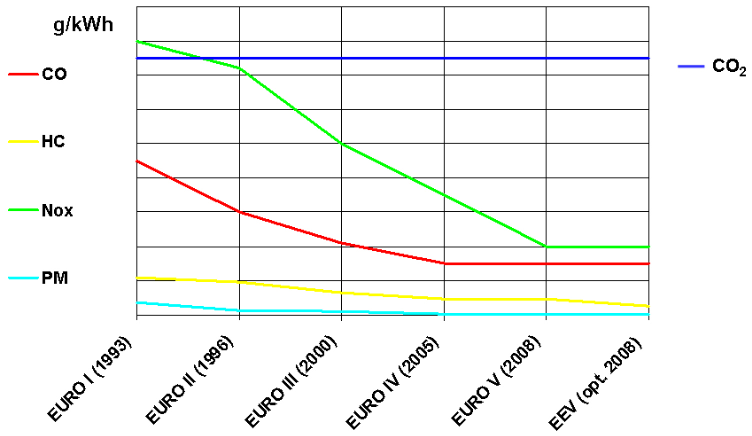
Data	Available data form	Source
For prediction of number of vehicles		
Numbers of registered vehicles	Annual statistics of registered vehicles by classification, fuel and area	DLT [2]
Numbers of population and GRP	Population growth and GRP history/trend	NESDB [19]
For prediction of traveling amount		
VKT	Average distances traveled of vehicles by type	Chanchaona et al [20]
For prediction of energy demand in transportation sector		
Fuel consumption by vehicle type	Fuel consumption of various fuel types by classified vehicles according to DLT	DLT [2]
Fuel economy by vehicle type	Fuel economy of various fuel types by classified vehicles according to DLT	Chanchaona et al [20]

2.3 Technical specification of Scania ethanol engine

Scania has long belief in development of ethanol-powered diesel engine for the past few decades since ethanol is still considered vastly available, and economically feasible as fossil substitute in the near future. There exist many automotive companies that have continuously developed Flex-Fuel Vehicle (FFV) to allow ethanol usage as gasoline substitute in SI engine. However, only Scania has focused on ethanol as diesel substitute in CI engine since much of the transportation and logistic still heavily relied on more powerful diesel engine technology. Ethanol is considered not only for energy security for the foreseeing fossil fuel depletion, but also for environmental purposes, such as cleaner emission and CO_2 neutral life cycle. With the stringent EU emission legislation, only the conventional emissions (CO, HC, NOx and PM) are regulated, leaving the CO_2, a major GHG, uncontrolled, as shown in . With ethanol consumption as transportation fuel, CO_2 emission will also be suppressed.



(a)



(b)

Fig. 10 EU emission regulation for (a) NOx vs PM and (b) all regulated emissions (CO, HC, NOx and PM) with reference to unregulated CO_2 emission

The first ethanol CI engine was developed with an aim for city bus in order to improve the air quality in the metropolitan area by firstly the more complete combustion of ethanol fuel and secondly less individual passenger cars to be used, as illustrated in Fig. 11. As shown in Fig. 4, the ethanol CI engine was modified from the diesel engine with the technical specification shown in Table 7. Note that Scania is closely collaborating with Sekab, who prepares additive for blending ED95 to be used with Scania ethanol engine. The additive acts as cetane improver to overcome the high-octane nature of ethanol blended at 95%. It is worth noted that it is hydrous ethanol (95% purity ethanol), not anhydrous ethanol (99.5% purity ethanol), that is used in blending ED95 fuel. Table 8 shows the content of ED95 fuel, supplied by Sekab.

Table 7: Technical specification of Scania ethanol CI engine

Specification	Details
Model	DC9 E02 270 Euro-5 EEV engne
Fuel	Ethanol ED95
Cyliner displacement	9 liter, 5 cylinder
Max power	270HP (198 kW) at 1,900 rpm
Max torque	1,200 Nm at 1,100-1,400 rpm
Fuel injection system	EDC, PDE Unit Injector
Bore x Stroke	127 mm x 140 mm
Compression ratio	28:1
Emission control system	EGR
Emission quality	Euro 4 EEV

Table 8: Technical specification of Scania ethanol CI engine

Component	Unit	Amout
Hydrous 95% ethanol	% by weight	92.2
Ignition improver	% by weight	5.0
Denature†	% by weight	2.8
Corrosive inhibitor	ppm	90
Color		Red

†By Swedish law, denature substance is mainly MTBE with some Isobutanol

With strong support from the City of Stockholm, all city bus operation is targeted to run on renewable fuel (ethanol or biogas) at the increasing fractions: 25% in 2006, 50% in 2012 and ultimately 100% in 2025. Of course, necessary maintenance and period check-up are the key for smooth operation of city bus powered by ethanol. Fig. 12 shows the comparisons of operating cost structure for 12-meter city bus that runs on ethanol and biogas with reference to diesel. It is clear that ethanol bus is not much different from the diesel bus in terms of capital cost but has higher costs on repair, maintenance and fuel, with much saving on the road tax.

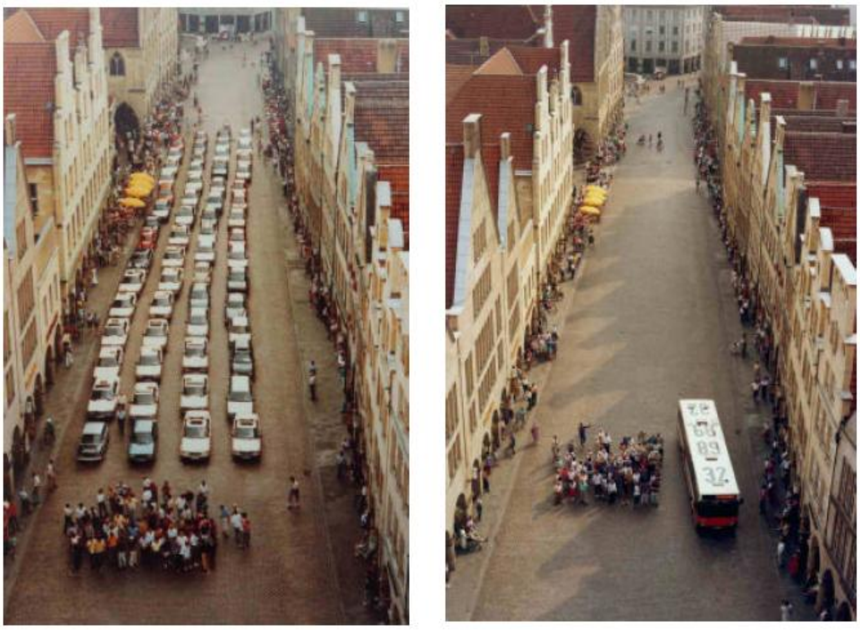


Fig. 11 Scania campaign to promote the usage of city bus as opposed to individual passenger cars to improve the air quality in the metropolitan

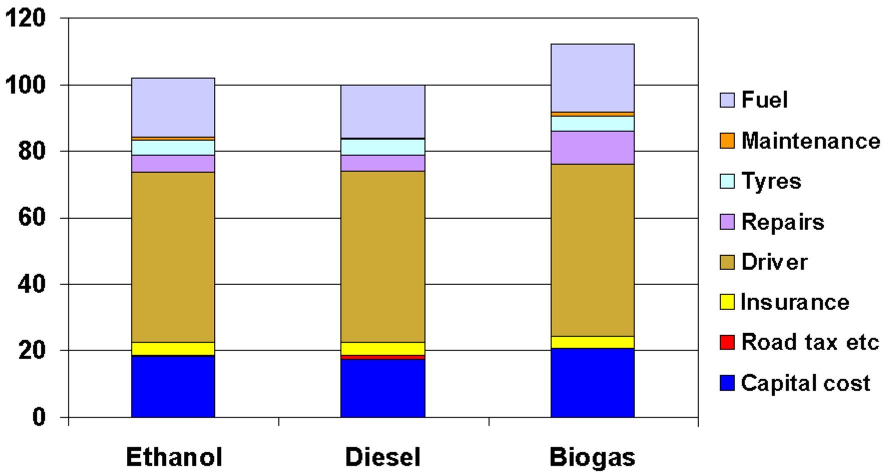


Fig. 12 Comparison of operating cost structure for Scania ethanol, diesel and biogas 12-meter buses

In summary, all technical specifications of Scania ethanol CI engine, as well as over 20 years of testing and economical data collection, will be taken into consideration of developing the energy model, with some modification to suit the environment in Thailand.

2.4 Environmental Impact

With introduction of bio-fuel and substitution of fossil fuel, the greenhouse gas (GHG) emission can be reduced by recourse to "Well to Wheel" emission analysis. The GHG emission for the transportation sector is calculated in the CO_2 equivalence scale. It is calculated according to the Intergovernmental Panel on Climate Change (IPCC) methodology [21]. The relevant emissions considered are typical exhaust gases from

mobile combustion: CO_2, CH_4 and N_2O. Furthermore, the methodology to calculate the GHG emission can be simplified as shown in the equation below while Table 9 and Table 10 show the emission factor (EF) and the global warming potential (GWP) of some fossil, respectively [22].

$$EM = \sum_i EC \cdot EF_i \cdot GWP_i$$

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 9: Emission factors for some fossil fuel [22]

Fuel types	Emission factors (kg/GJ of energy consumed)		
	CO_2	CH_4	N_2O
Gasoline	68.65	20	0.6
Diesel	73.30	5	0.6
LPG	62.70	0.03	-
CNG	55.50	50	0.1

Table 10: Global warming potential of emission i [22]

Substance	GWP (g CO_2/g substance)
CO_2	1
CH_4	25
N_2O	289

CHAPTER 3 RESEARCH PLAN

3.1 Project Schedule

Table 11 shows the project planning schedule, which can be divided into four steps. The first step is to collect necessary data for the transport energy model, which has been preliminarily established previously [7, 11]. The second step is to construct and/or update the LEAP model with validation of the BAU with historical data. The third step is to perform the scenarios analysis to assess feasibility and impact of ethanol utilization as diesel substitute. Finally, the fourth step is to prepare for the final report and presentation at 3rd ATRANS symposium on 2-3 September 2010.

All project members will meet once a month to discuss the technical results performed by project research assistant, and directions of the project. At the end of the first three steps (labeled Project meeting 1, 2 and 3 in Table 11), roughly every three months, the progress report will be presented to the advisors to further seek guidelines and comments of the results and future direction.

Table 11: Project planning schedule

Tasks	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Inception report due **(1 Nov)**												
I. Data collection												
Identify & obtain necessary data for the model (interview if necessary)												
Project meeting 1												
Progress report presentation **(29 Jan)**												
II. LEAP model construction												
Construct & validate LEAP model with BAU												
Project meeting 2												
Interim report submission **(30 April)**												
III. Scenarios analysis												
Analyze various scenarios to assess economical feasibility/impact of diesel substitution by ethanol												
Assess technical feasibility of ethanol usage in CI engine												
Project meeting 3												
Final presentation **(27 Aug)**												
IV. Final report												
ATRANS symposium **(2-3 Sep)**												
Final report submission **(31 Oct)**												

3.2 Project Expenditure

Table 12 shows the breakdown of the project expenditure, which is mainly composed of the participation of the members (monthly) and advisors (3 times for project duration). Two

research assistants (RAs) will be employed on the part time basis. The first RA will be employed for three months so that he can transfer the setting of the previous LEAP model [7, 11] to the second RA, who will be employed for the whole project to be the main contact point. Necessary expenses such as transportation to gather data and office/computer supply are included. The project aims to present the preliminary result at a conference upon approval from ATRANS. Lastly, the expenses of secretariat's participation and report publishing are included.

Table 12: Project expenditure (revised as of April 2010)

No	Description	Unit cost	#	Sub Total
1	Project leader (3,000 THB/month x 12 months)	3,000	12	36,000
2	Members participation in project meeting (1,000 THB/day x 3 persons x 12 days)	3,000	12	36,000
3	Advisors participation in project meeting (1,000 THB/day x 5 persons x 3 days)	5,000	3	15,000
4	Research assistant (part time at 200 THB/hr x 4 hrs/day x 10 days/month) for 3 months (master degree level)	8,000	6	48,000
5	Research assistant (part time at 200 THB/hr x 5 hrs/day x 20 days/month) for 12 months (master degree level)	20,000	12	240,000
6	Transportation for data gathering and interview	15,000	1	15,000
7	Office & computer supply	16,000	1	16,000
8	Presentation in a conference	60,000	1	60,000
9	Secretariat's participation	10,000	1	10,000
10	Report publishing	50,000	1	50,000
			Total	**526,000**

CHAPTER 4 ENERGY DEMAND MODEL SETUP

4.1 Database Framework

From Section 2.1.1, the energy demand function can be modeled as follows.

$$ED_{ij} = NV_{ij} \times VKT_{j} \times FE_{ij} \quad (I \text{ is fuel type, j is vehicle type})$$

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_{ij} **= average distances traveled by vehicle type "j" [km/year]**

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

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, which will be explained in the Section 4.2. However, when some necessary data like Vehicle Kilometer of Travel (VKT) is not sufficiently available, some detailed assumptions must be applied, which will be explained in the Section 4.3. 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, to be explained in the Section 4.4. Finally, the validation of energy demand model with the historic supply record will be shown in the Section 4.5.

4.2 Vehicle Population Model

Following [7, 11], the vehicle types can be re-categorized from DLT classification for the purpose of LEAP calculation, as shown in the Table 13. It is shown that the "Bus" and "Truck" vehicles under Land Transport Act and the "Van & Pickup" (MV. 3) vehicle under Motor Vehicle Act are not re-categorized due to a need to obtain detailed energy demand calculation for these diesel consumed vehicle under the scenario definition specified in Section 2.1.2. Meanwhile, other vehicle types are re-categorized based on its characteristics such as the vehicle's powertrain, utilization etc. (that would reflect FE, VKT). Note that the agriculture vehicle, utility vehicle and automobile trailer are not considered in this work because they consume small fraction of energy.

Table 13: 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 & Pickup	PC02 pickup	- Non Fixed Route Bus	Bus02
MV. 4 Motor tri-cycle	PC03 motor tri-cycle	- Private Bus	Bus03
MV. 7 Fixed Route Taxi (Subaru)		Small Rural Bus	sBus04
MV. 8 Motor tri-cycle Taxi (Tuk Tuk)		Truck	
MV. 6 Urban Taxi	PC04 taxi	- Non Fixed Route Truck	Truck01
MV. 5 Interprovincial Taxi	PC05 Commercial rent car	- Private Truck	Truck02
MV. 9 Hotel Taxi			
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			

For specific functional form for each vehicle type, three general vehicle population models were used as follows.

1. **Exponential function [23]**
2. **Logistic Regression function [11, 24, 25, 26]**
3. **Combined function of the two above**

4.2.1 Exponential Vehicle Population Models

The most general form to predict the vehicle population is in the exponential function. The vehicle population record can be fitted with necessary parameters such as the level of economic situation, per capita, time or even other country-specific variables. In this work, the Gross Domestic Products (GDP) will be used as the level of economic situation and other considered parameter include per capita and time. Thus, the exponential population model can be written as follows.

$$NV = a \cdot GDP^{b} \cdot Pop^{c} \cdot (yr - \tau)^{t}$$

where	NV	=	Number of considered vehicle [number of vehicle]
	GDP	=	Gross Domestic Product at constant price [Baht]
	Pop	=	Population [person]
	yr	=	Year, which is the parameter of time
	τ	=	Reference year
	a, b, c, t	=	Constant coefficients, which are fitted in the model

In general, the number of vehicle is linearly depended on the population (c = 1 for linear dependency) so the vehicle population model can be written as

$$VO = a \cdot GDP^{b} \cdot (yr - \tau)^{t}$$

where VO = a ratio of number of vehicle to the population.

4.2.2 Logistic Regression Function

Although the exponential vehicle population model can be well fitted with historic record, the predicted result may be unreliable in long-term estimation. The logistic regression function is an improved mathematic form, which is specific for modeling the vehicle population. The general form is written as follows with the graphical representation shown in Fig. 13.

$$ln\left(\frac{VO}{S-VO}\right) = a + b_1 \ln X_1 + b_2 \ln X_2 + ... + b_n \ln X_n$$

where	X_1, X_2 …	=	set of socio-economic influences, e.g. GDP per capita
	a, b_1, b_2 …	=	Constant coefficients, which are fitted in the model
	S	=	Saturated level of vehicle population [vehicles per persons]

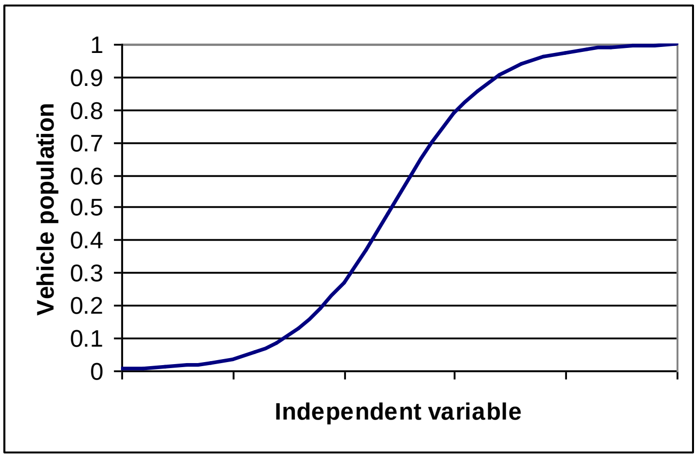


Fig. 13 Logistic regression function

It is shown here that the number of vehicle described by this function is controlled by the independent variable range. Three regions can be identified from a "S" curve in Fig. 13 as an initial low level of dependency, an intermediate medium rapidly increased region and the final saturation region. In this work, the saturated levels (S) are equal to 0.8, 0.5 and 0.6 for the "Passenger car" (PC01) [25], "Van & Pickup" (PC02) [11] and Motorcycle (PC06) [26], respectively.

4.2.3 Combined function

In fact, the record of registered vehicle shows that there are some relationships between some vehicle types in Bangkok region. For instances, "Non fixed route bus" (Bus02) and "Private bus" (Bus03) as well as "Non fixed route truck" (Truck01) and "Private truck" (Truck02). It shows that when one vehicle type increases, the other will decrease. Furthermore, the summation of both vehicle types can be fitted with the exponential vehicle population or the Logistic regression function. The fraction between these two vehicle groups can be fitted as an exponential function of time, as shown below and in Fig. 14.

$$
\begin{aligned}
NV_A &= X_A \cdot f(GDP, T, POP) \\
NV_B &= X_B \cdot f(GDP, T, POP) \\
&= (1 - X_A) \cdot f(GDP, T, POP) \\
X_A &= g \cdot e^{-h \cdot (yr - \tau)}
\end{aligned}
$$

where X_A, X_B = Fraction of vehicle type A and B, ($X_B = 1 - X_A$)

g, h = Constant coefficients, which are fitted in the model

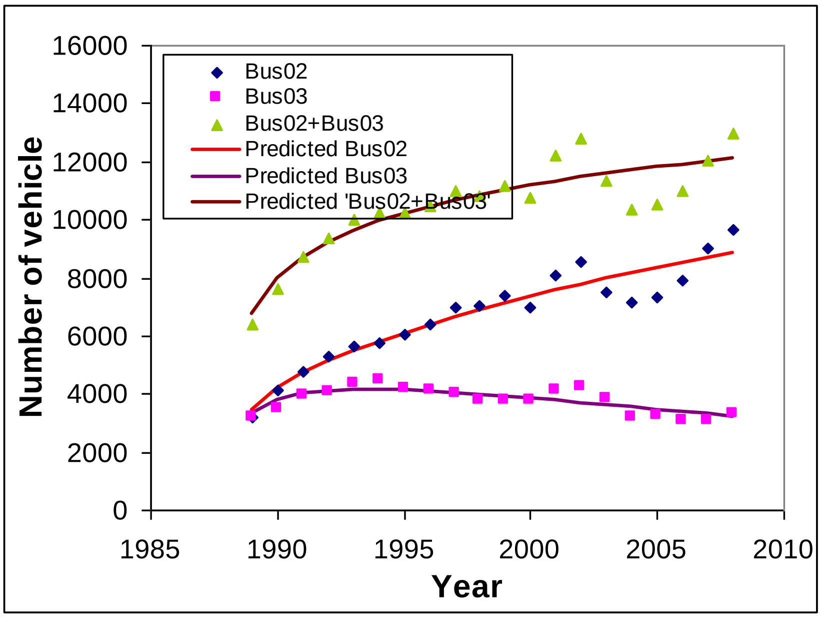


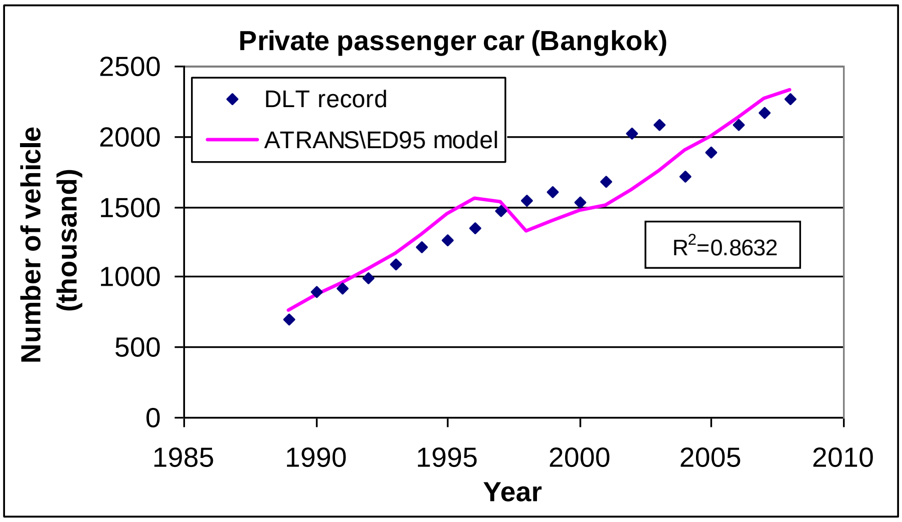
Fig. 14 Combined function for regression in bus ownership model

4.2.4 Vehicle population model

The vehicle population models for all vehicle types are concluded in this section. The models for Bangkok vehicle are shown in the Table 14, followed by the plot of their predicted results against historic record for each vehicle type in Fig. 15. On the other thand, the vehicle models for Provincial region are shown in Table 15, followed by the plot of their predicted results against historic record for each vehicle type in Fig. 16. It is shown that the predicted results are well-fitted with their historic record except for the vehicle population of the "Motor tri-cycle" (PC03) of provincial region, as shown in Fig. 16(c). This unusual behavior is difficult to be modeled with any independent parameter. With economic crisis in Thailand during 199701998, those data sets may be omitted from regression to better enhance the R^2 value.

Table 14: Vehicle population models for all vehicle types in Bangkok

	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	$NV=\left(1-0.5071\cdot e^{-0.0323*(yr-\tau)}\right)\cdot\left(1786.9\,ln(yr-\tau)+6724.6\right)$ $\tau=1988$	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



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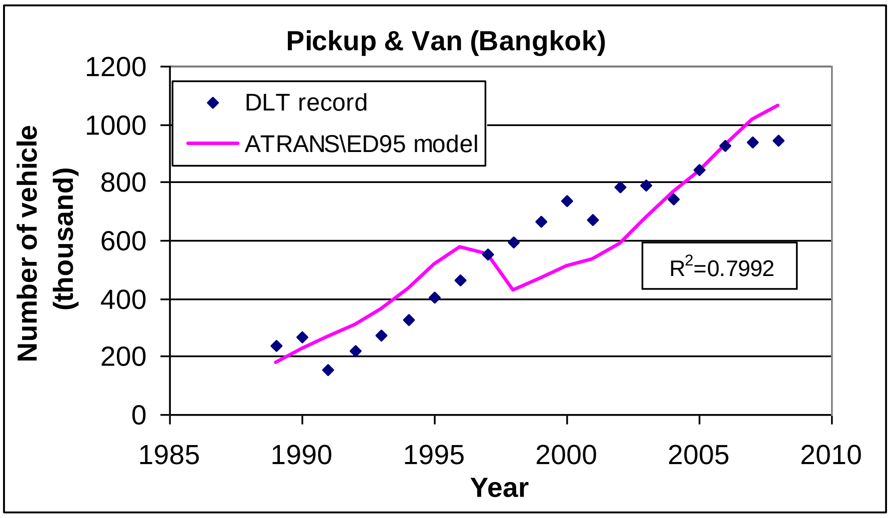

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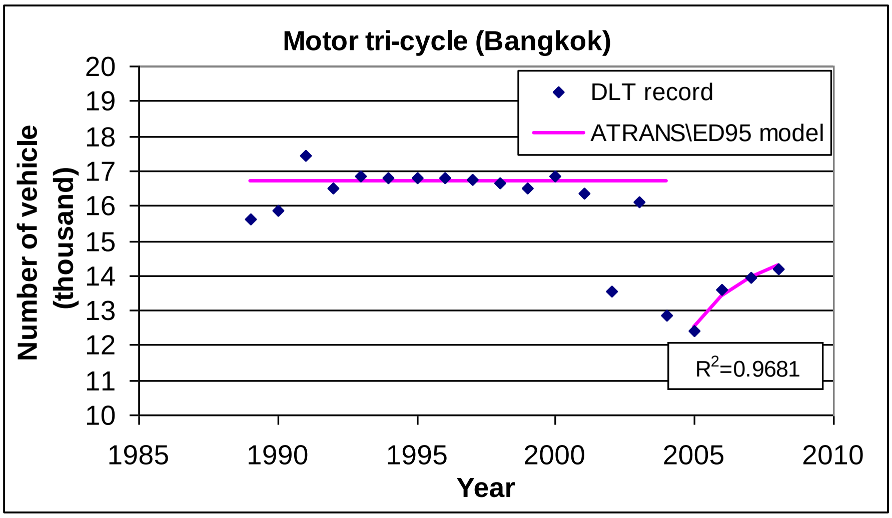
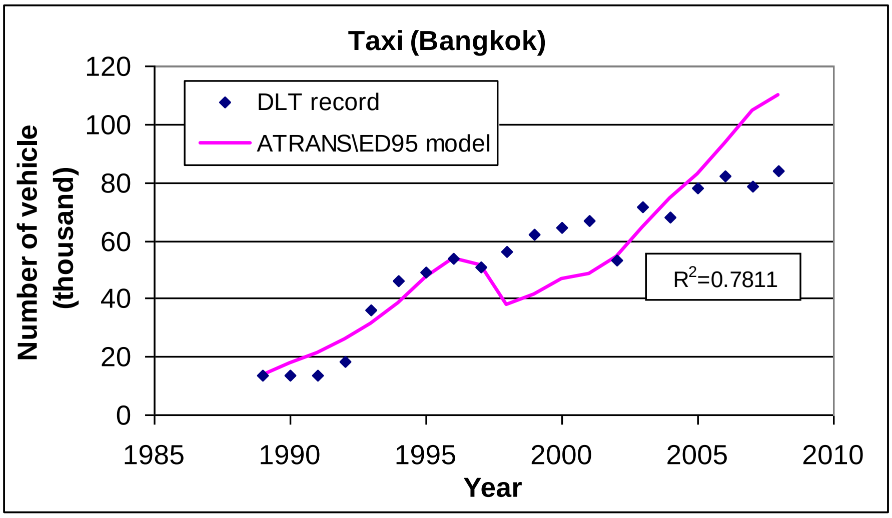


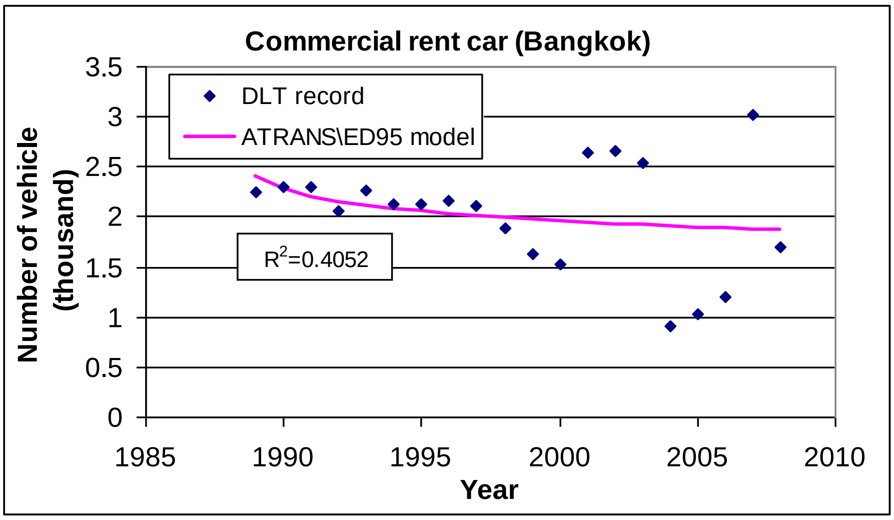
(c)

(a) PC01, (b) PC02 and (c) PC03

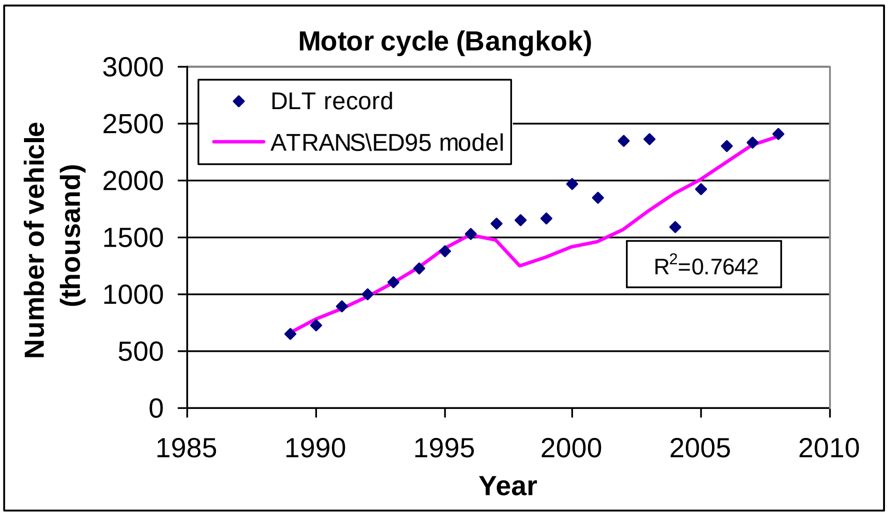
Fig. 15 Vehicle population model (Bangkok)



(d)



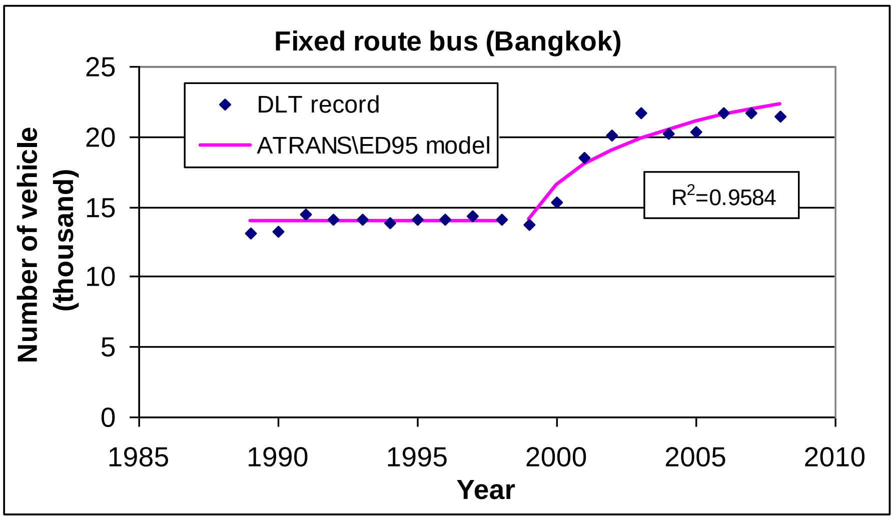
(e)



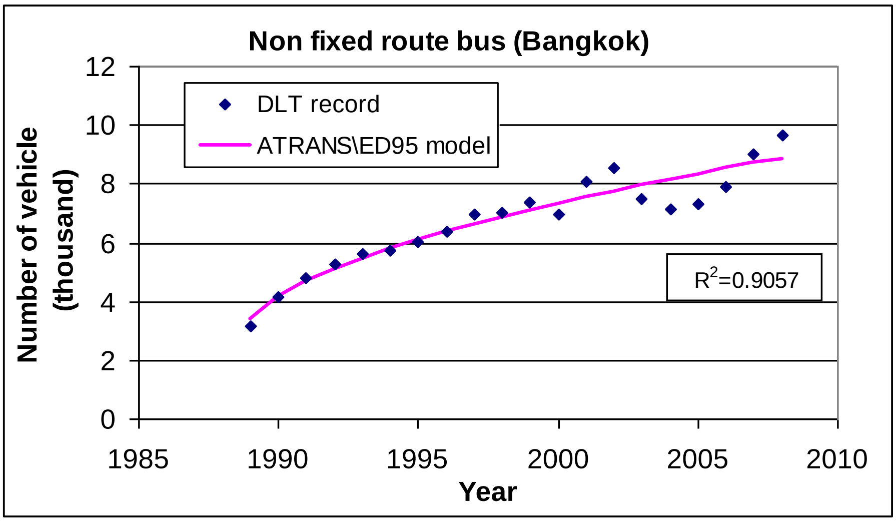
(f)

(d) PC04, (e) PC05 and (f) PC06

Fig. 15 Vehicle population model (Bangkok), (cont.)



(g)



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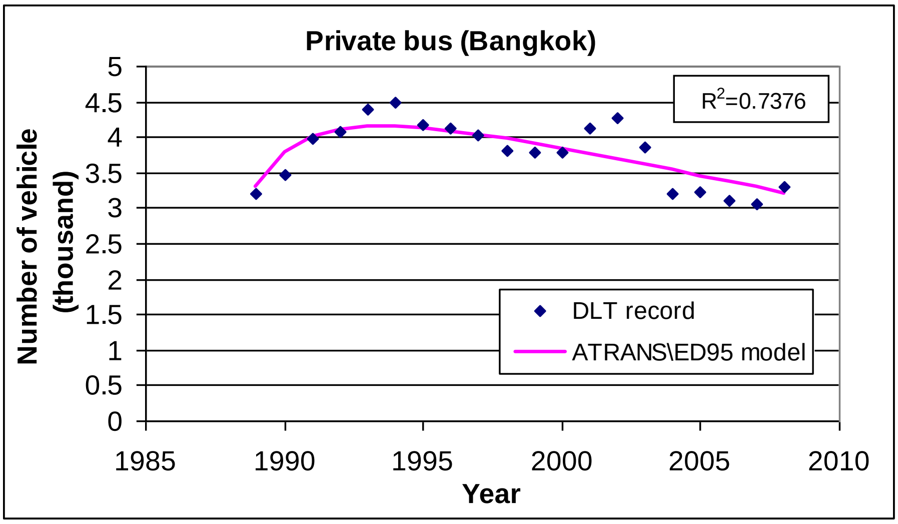
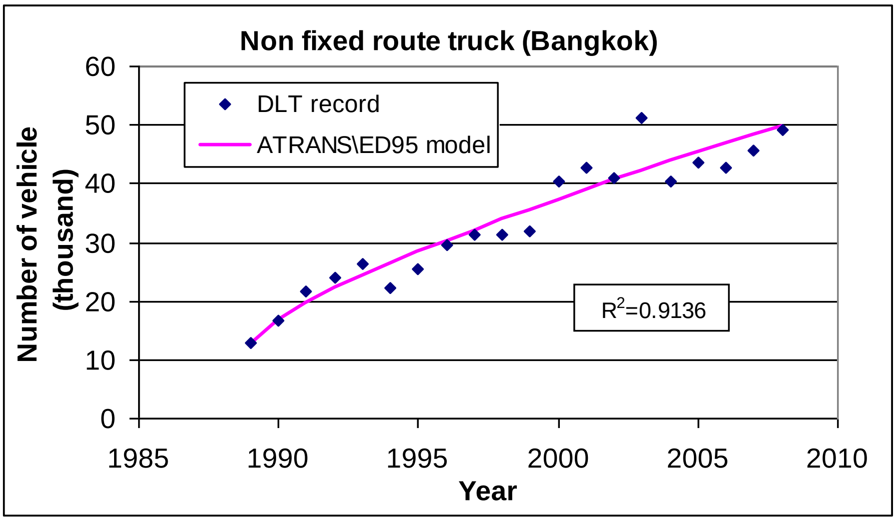


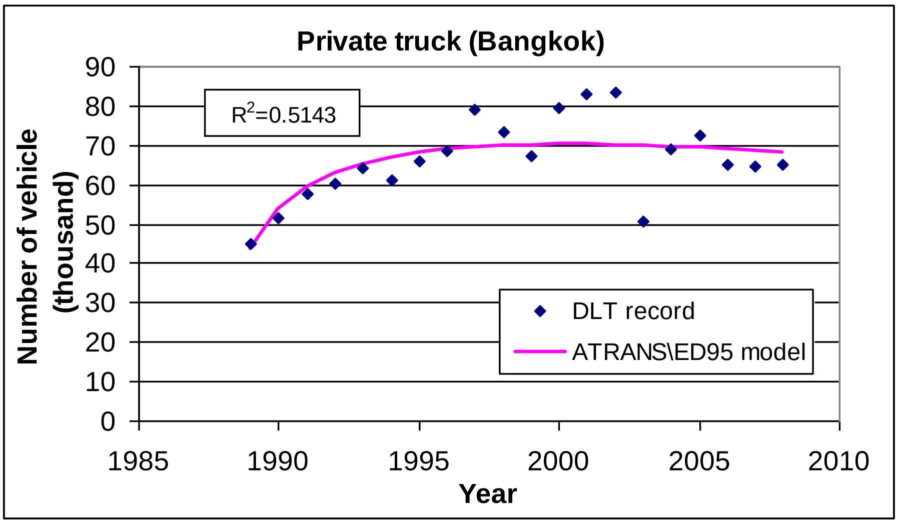
(i)

(g) BUS01, (h) BUS02 and (i) BUS03

Fig. 15 Vehicle population model (Bangkok), (cont.)



(j)



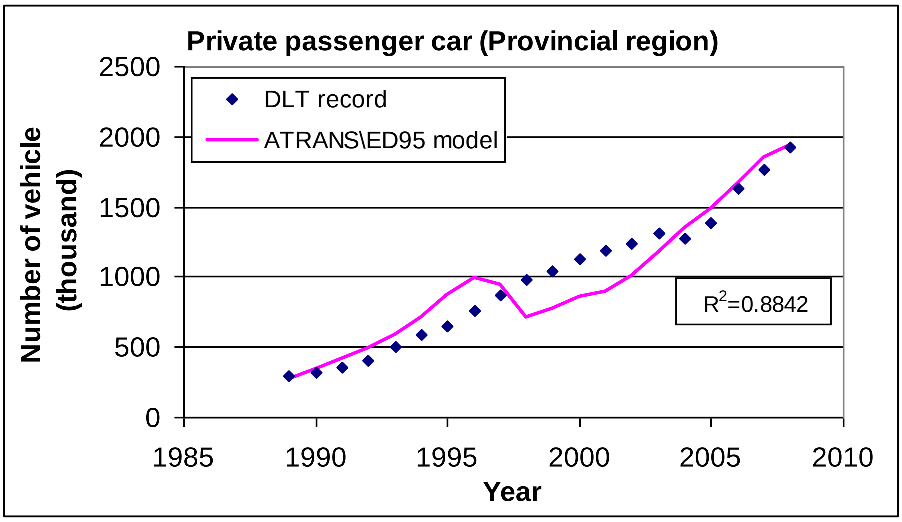
(k)

(j) Truck01 and (k) Truck02

Fig. 15 Vehicle population model (Bangkok), (cont.)

Table 15: Vehicle population models for all vehicle types in Provincial regions

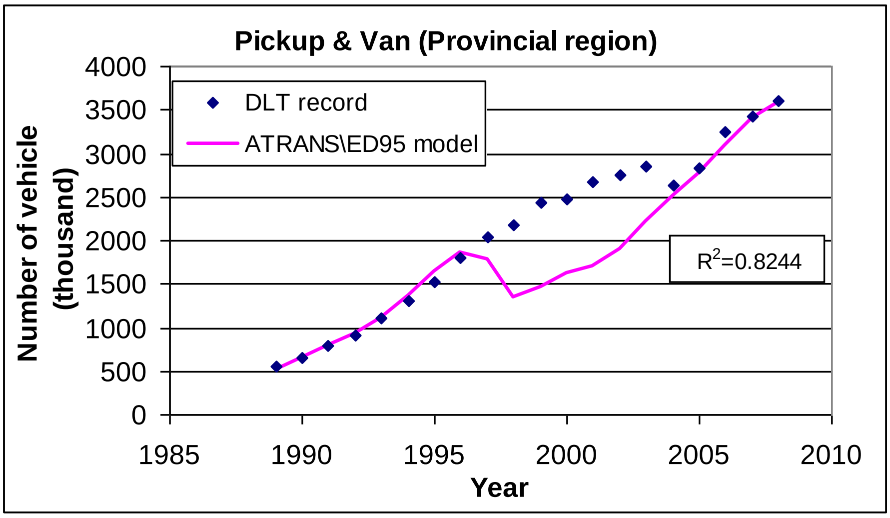
	N_vehicle Provincial (GDPpCap)	R^2
PC01 private passenger car	$\ln\left(\frac{VO}{0.812-VO}\right)=2.5007\ln GDPpCap-31.025$	0.8842
PC02 pickup	$\ln\left(\frac{VO}{0.5-VO}\right)=2.5491\ln GDPpCap-30.388$	0.8244
PC03 motor tri-cycle	$VO=0.0005188$	0.0041
PC04 taxi	$\ln(VO)=-2.2974\ln GDPpCap+14.4340$	0.5965
PC05 commercial rent car	$\ln(VO)=1.8111\ln GDPpCap-31.1840$	0.6464
PC06 motor cycle	$\ln\left(\frac{VO}{0.6-VO}\right)=2.3609\ln GDPpCap-26.678$	0.7021
Bus01 fixed route bus	$\ln(VO)=0.2530\ln GDPpCap-9.7824$	0.8181
Bus02 non fixed route bus	$\ln(VO)=1.6778\ln GDPpCap-26.689$	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



(a)

(a) PC01

Fig. 16 Vehicle population model (Provincial regions)



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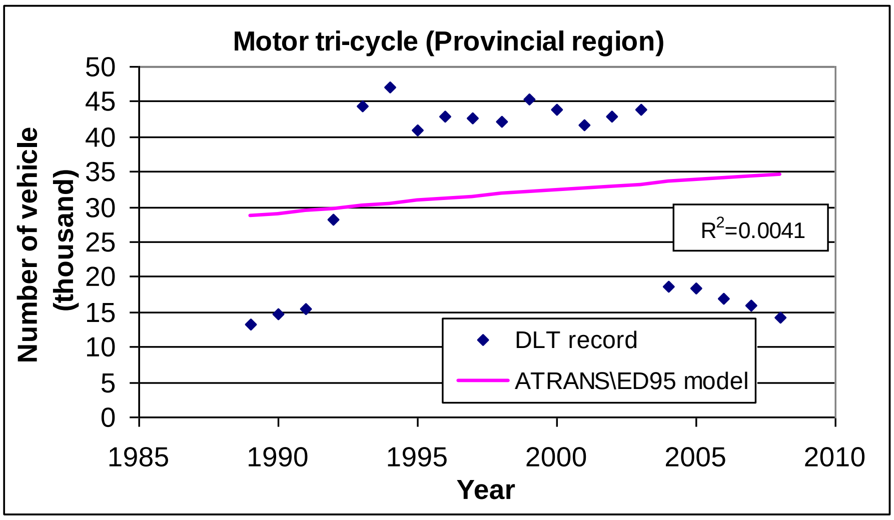
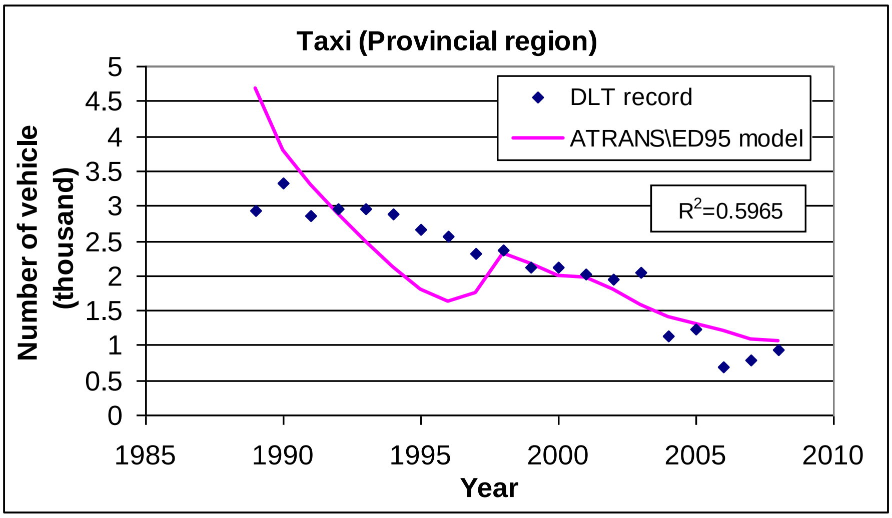


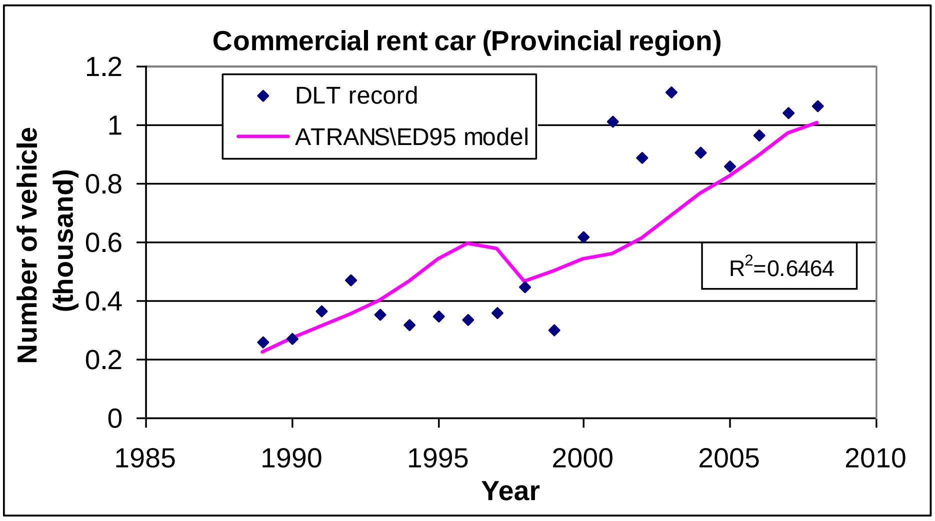
(c)



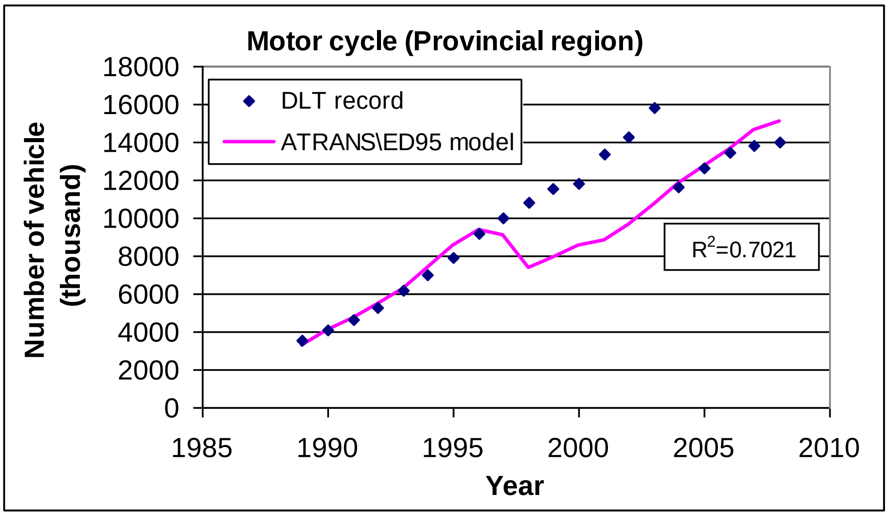
(d)

(b) PC02, (c) PC03 and (d) PC04

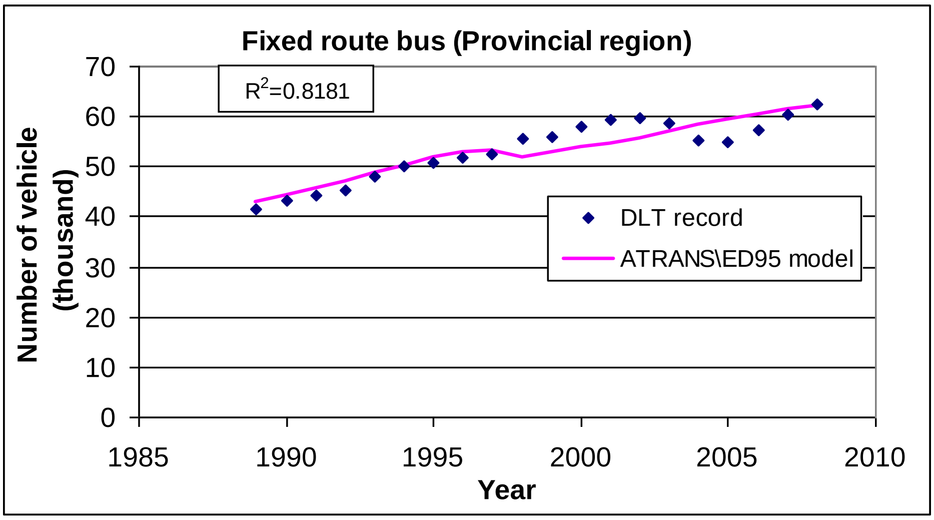
Fig. 16 Vehicle population model (Provincial regions), (cont.)



(e)



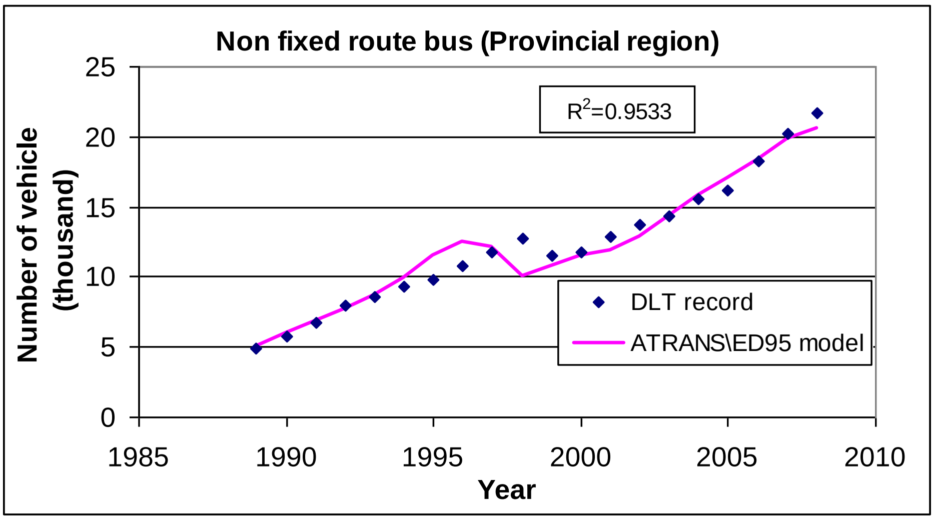
(f)



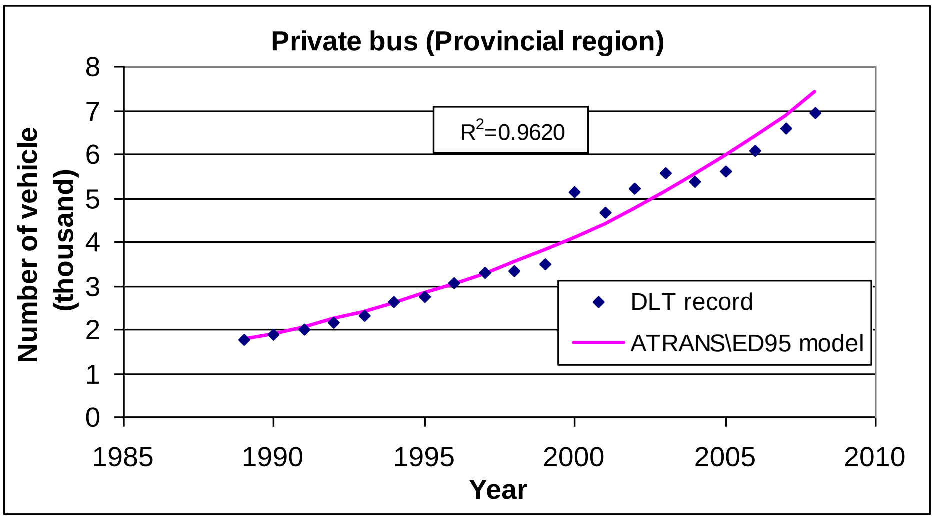
(g)

(e) PC05, (f) PC06 and (g) BUS01

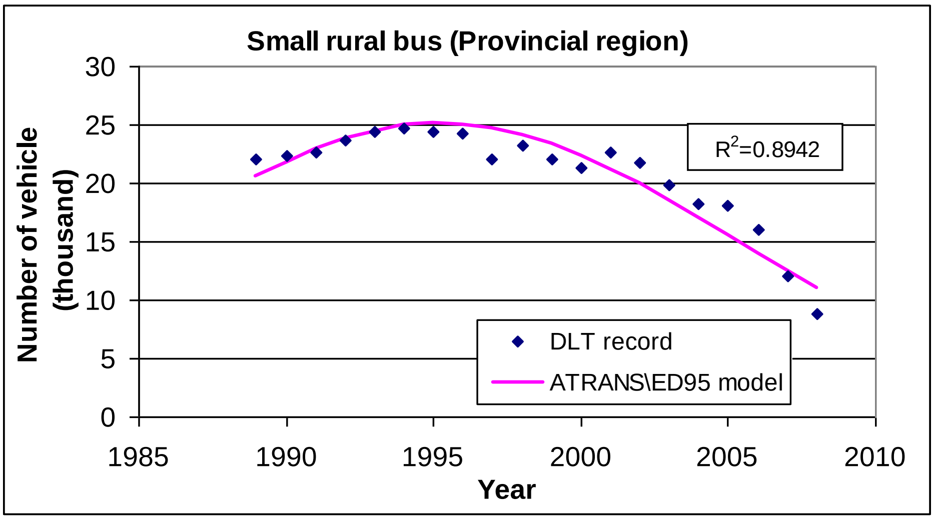
Fig. 16 Vehicle population model (Provincial regions), (cont.)



(h)



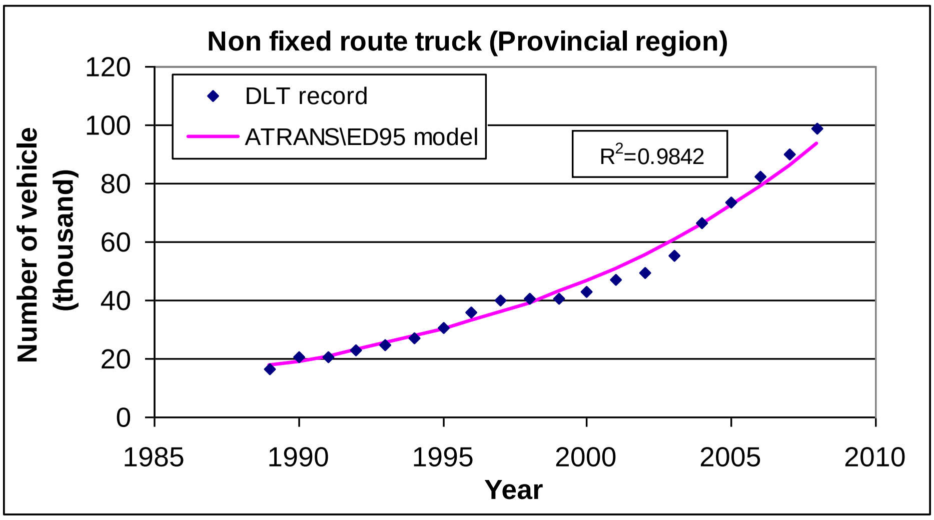
(i)



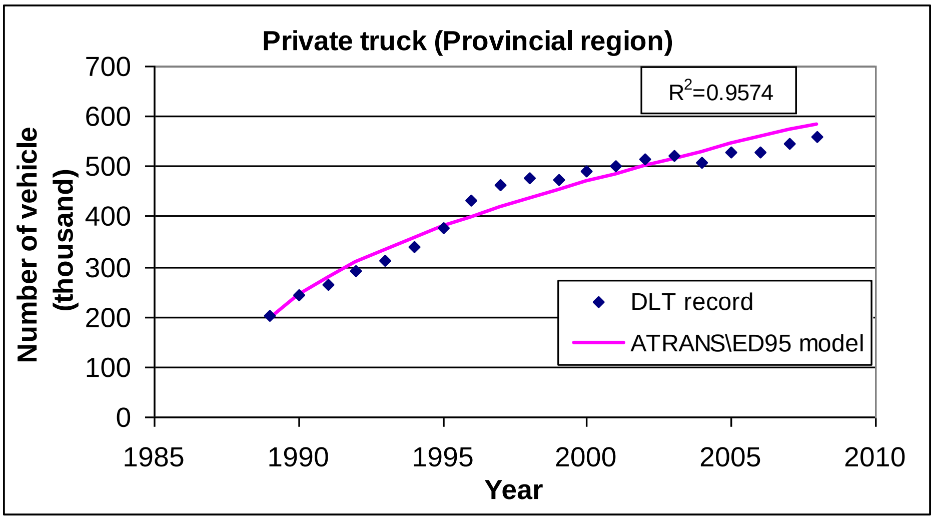
(j)

(h) BUS02, (i) BUS03 and (j) sBUS04

Fig. 16 Vehicle population model (Provincial regions), (cont.)



(k)



(l)

(k) Truck01 and (l) Truck02

Fig. 16 Vehicle population model (Provincial regions), (cont.)

4.3 Vehicle Kilometer of Travel (VKT) Model

The vehicle kilometer of travel (VKT) is defined as the average vehicle mileage in a year, which reflects 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. There are only two survey researches available, which are both funded by EPPO [15, 20]. In those works, the VKT data was collected on the basis of different vehicle categories than DLT in Table 13 so certain assumption for grouping must be made with the results shown I Fig. 17.

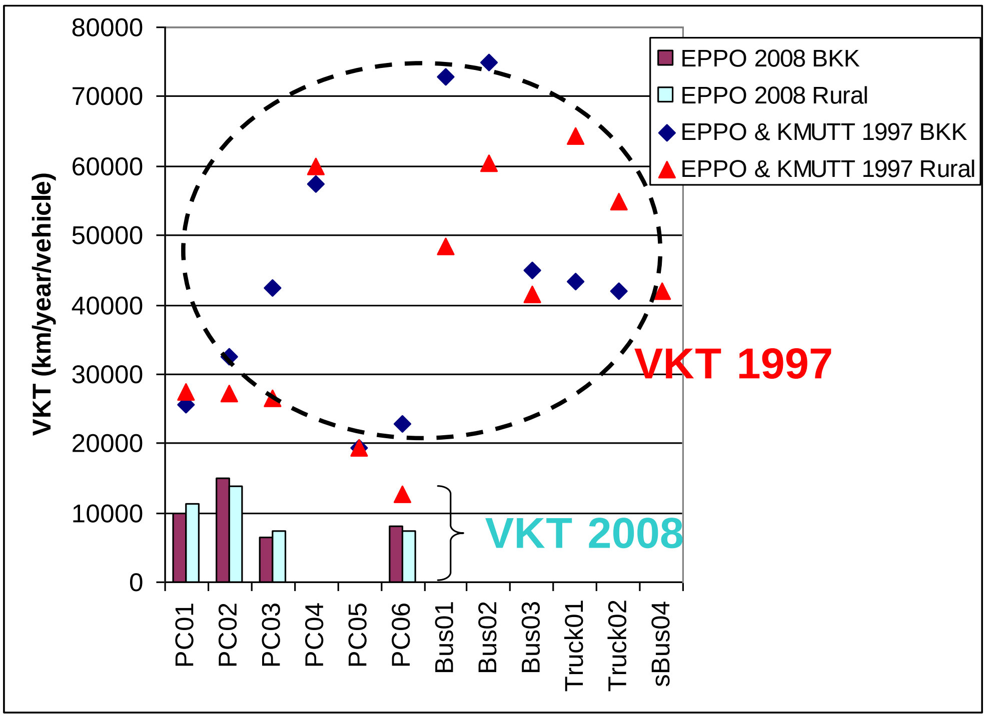


Fig. 17 Available data for VKT in Thailand

As clearly shown in Fig. 17, the most recent survey data collected in 2008 [15] 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, it is clear that VKT has decreased with time, as expected. In order to get complete data for recent year, the following assumptions are made.

- 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, within the interested vehicle type, VKT from time "2" can be extrapolated from time "1" via the following simple equation.

$$\frac{RD_2}{RD_1} = \frac{VKT_2}{VKT_1} \cdot \frac{\sum NV_2}{\sum NV_1}$$

where NV = Number of considered vehicle [number of vehicle]

RD = Road distance [km]

1, 2 = point in time (year) of interest

For instance, if the road distance is constant but the number of vehicle increases, the VKT will likely decrease due to traffic congestion. On the other hand, if the road distance increases without number of vehicle increasing, the VKT will likely increase.

Further assumption is required to treat Bangkok and Provincial region, separately. According to Department of Highways (DoH), Ministry of Transport, the increase in road distance is dominated by the provincial region. For the simplicity of the current model, the RD in Bangkok region is assumed constant as follows.

$$\frac{RD_2}{RD_1}(\approx 1) = \frac{VKT_2}{VKT_1} \cdot \frac{\sum NV_2}{\sum NV_1}$$

$$\text{thus,} \quad \frac{VKT_2}{VKT_1} = \frac{\sum NV_1}{\sum NV_2}$$

where 1, 2 = year 1997 and 2008, respectively

On the other hand, the RD in provincial region is increased by the statistics from DoH, as shown in Table 16 and Fig. 18.

Table 16: The rural road distance and total number of vehicles

Year	Rural road distance (km)	Total number of vehicles	
		Bangkok	Provincial area
1997	55,321	3,872,327	13,793,913
1998	57,233	4,016,594	14,843,918
1999	59,306	4,162,846	15,933,690
2000	60,788	4,496,618	16,339,066
2001	62,195	4,464,158	18,125,027
2002	64,095	5,399,153	19,118,097
2003	63,983	5,481,160	20,897,702
2004	63,287	4,288,468	16,336,251
2005	63,062	4,899,969	17,671,093
2006	63,773	5,557,111	19,250,186
2007	64,745	5,715,078	19,903,369
2008	66,266	5,911,696	20,505,657

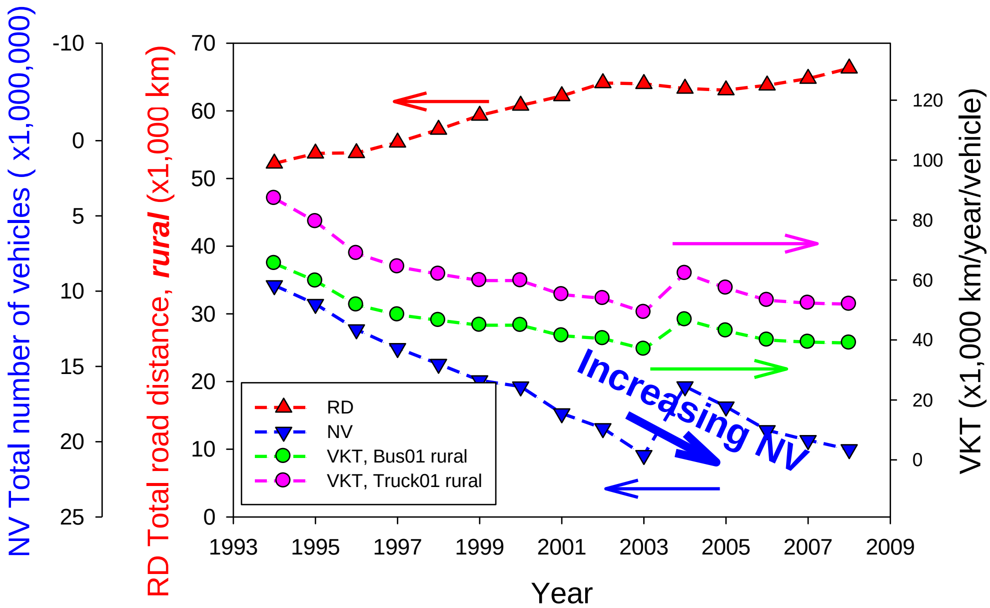


Fig. 18 Assumption of VKT variation with time in Provincial region (only Bus01 and Truck01 are shown)

The complete VKT values for each vehicle type in both Bangkok and Provincial region can now be calculated as shown in the Table 17. If the survey data in 2008 [15] is available, it is directly reported in Table 17. On the other hand, if the survey data in 2008 [15] is not available, the survey data in 1997 [20] is extrapolated and reported in Table 17.

Table 17: Vehicle kilometer of travel (VKT) in year 2008 (used in the model)

	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	37,651**	48,347**
PC05 Commercial rent car	12,626**	15,531**
PC06 Motor cycle	8,097*	7,414*
Bus01 Fixed route bus	47,787**	38,993**
Bus02 Non fixed route bus	49,127**	48,692**
Bus03 Private bus	29,476**	33,422**
sBus04 Small rural bus	-	33,831**
Truck01 Non fixed route truck	28,450**	51,920**
Truck02 Private truck	27,430**	44,138**

*** Reference from the VKT data in year 2008 [15]**

**** Calculated in this work from VKT data in 1997 [20]**

4.4 Fuel Economy (FE) Model

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) engine and compression ignition (CI, diesel) engine. The distributed fuel types can also be categorized into gasoline, gasohol E10, gasohol E20, Diesel B2, Diesel B5, liquid petroleum gas (LPG) and compressed natural gas (CNG). Clearly, many parameters can affect FE, and certain assumption must be made prior to being used in the energy demand model.

The current work is focused on

- **Vehicle/engine size, e.g. larger engine size typically consumes more fuel per km**
- **Vehicle/engine type, e.g. gasoline (SI) vs. diesel (CI) engines**
- **Vehicle/engine efficiency, which is improved with time v**
- **For two-fuel vehicle/engine, FE is calculated from each fuel used under certain assumption to be discussed below.**

From the DLT registered database, vehicle technology can simply be categorized as

- **Liquid-fueled vehicle, e.g. gasoline, gasohol (E10, E20) and diesel (B2, B5)**
- **Gas-fueled vehicle, e.g. dedicated LPG, CNG**
- **Liquid/Gas-fueled vehicle, e.g. bi-fuel and dual fuel**

The proportions of each fuel used can be specified for each vehicle technology with available record from recent survey research [15, 20]. Similar to VKT, some assumptions are necessary to extrapolate 1997 data [20] to 2008 data [15]. The detailed descriptions and necessary assumptions for each vehicle technology are explained in the following Sections 4.4.1 to 4.4.3. A new parameter, the Device Share (DS), is 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 (diesel and CNG).

4.4.1 Liquid-Fueled Engine

The liquid-fueled engine can be separated by the combustion technology as follows.

- **SI engine, which can be fueled with gasoline and gasohol**
- **CI engine, which can be fueled with diesel and biodiesel blended B5**

The populations of SI and CI vehicles are recorded from registered database of DLT. Although there are currently two diesel fuels in the market (Diesel B2 and B5), it will be considered as the single diesel fuel for simplicity in this work. The alcohol fuel (ethanol) has been distributed for spark ignition vehicles since 2001 as the gasohol E10 but its market share was not evident until 2004 [1]. Then, the gasohol E20 and E85 were followed to the market just in the last few years so their current market share is still much less significant than E10, especially E85 where only a few gas stations carry. Therefore, the considered gasohol fuels in this work are limited to E10 and E20.

In fact, the vehicle owner's decision to fuel his/her vehicle is dynamic, depending on many parameters such as fuel price, availability of gas station, vehicle constrain etc. Indeed, it is difficult to model this dynamic variation. A better way is to use the fraction of each fuel, recorded from statistical survey work, into the FE model as the Device Share (DS). For example, DS for gasohol E10 fuel uses the ratio of gasoline to ethanol = 90:10 by volume. Of course, the heating value is a function of weight basis so the density must be taken into account.

4.4.2 Gas-Fueled Engine

There are two types of gas fuel sold in Thailand, Liquid Petroleum Gas (LPG) and Compressed Natural Gas (CNG). The gas-fueled vehicles are specifically regulated by DLT for safety thus the gas-fueled vehicle is frequently called the dedicated gas vehicle. The FE of these gas-fueled engines are less efficient than the liquid-fueled engine because of lower volumetric efficiency.

4.4.3 Liquid/Gas-Fueled Engine

As previously mentioned for gas-fueled vehicle, DLT regulation also governs the Liquid/Gas-Fueled vehicle as well, which beneficially help record the populations of all LPG-fueled, CNG-fueled and Liquid/Gas-Fueled in DLT database. The Liquid/Gas-Fueled engine is applicable to both SI and CI engines. The SI liquid/gas-fueled vehicle is usually called the Bi-fuel vehicle, which uses either gasoline or CNG at a given time, not both simultaneously. The ratio between gas to liquid fuel is assumed to be 80 to 20 according to [27], which is used as Device Share (DS) parameter in the present model. Since the liquid and gas fuels are singly supplied to Bi-fuel engine at a given time, the final FE is calculated from FE of liquid-fueled engine and FE of gas-fueled engine, as follows.

$$\overline{FE} = FE_{liquid} \cdot DS_{liquid} + FE_{gas} \cdot DS_{gas}$$

For CI engine, the diesel liquid/gas-fueled engine is often called Diesel Dual Fuel (DDF), which is different from Bi-fuel engine in term of both diesel and CNG are simultaneously consumed at a given time. The gas fuel is supplied as the main energy source by mixing with air during the intake or compression stroke. On the other hand, the diesel fuel is injected to initiate the combustion at the appropriate period. Therefore, the DDF engine uses both liquid and gas fuels at an instance with the ratio (or Device share, DS) between diesel and CNG varying according to engine load, which of course changes FE of DDF engine as well. The FE and DS values at various engine load can be referred to [28] for the CNG-fueled DDF engine. However, these FE and DS parameters are fixed in this work to decrease complicated degree of calculation. The FE and DS for the LPG-fueled DDF engine are assumed from CNG DDF engine on the basis of energy fraction. The calculation algorithm to determine the fuel economy in the present model may be described as follows.

$$\overline{FE} = FE_{DDF.} \cdot \left(DS_{liquid} + DS_{gas} \right)$$

where FE_{DDF} is calculated from [28] to be 1.287 time of FE_{Diesel}.

DS_{liquid}, DS_{gas} are defined to determine the liquid and gas fuel requirement in the model, e.g. $DS_{gas,\ CNG}$ and $DS_{gas,\ LPG}$ = 61.1% and 63.33% of energy unit, respectively.

In summary, the percent shares of fuel use for each vehicle type are calculated as shown in Table 18. For simplicity of the modeling, those small percent shares are approximated as zero with others adjusted accordingly, as shown in Table 19. The percent shares for SI vehicle, CI vehicle, Bi-fuel vehicle (LPG and CNG), Diesel Dual fuel vehicle (LPG and CNG) and dedicated gas vehicle (LPG and CNG) are referred to DLT record [2]. With limited data availability, the percent shares of the SI vehicles (gasoline, gasohol E10 and gasohol E20) are referred to [15] for

- **passenger car (PC01), pickup & van (PC02), motor tri-cycle (PC03) and motor cycle (PC06),**
- **taxi (PC04) and commercial rent car (PC05) are assumed to use passenger car (PC01).**
- **bus and truck (Bus01, Bus02, Bus03, sBus04, Truck01 and Truck02) are assumed to use 100 percent of gasoline engine.**

Table 18: Actual percent share for fuel used by each vehicle type in (a) Bangkok and (b) provincial region

Bangkok Actual	Liquid fueled engine				Liquid/gas fueled engine				Dedicated gas	
	SI Engine*			Diesel*	Bi-fuel SI LPG*	Bi-fuel SI CNG*	DDF LPG*	DDF CNG*	LPG dedic.*	CNG dedic.*
	Gasoline**	E10**	E20**							
PC01	78.16%			20.38%	1.21%	0.22%	0.00%	0.00%	0.03%	0.00%
	42.86%	56.57%	0.57%							
PC02	5.08%			94.75%	0.11%	0.02%	0.01%	0.01%	0.02%	0.00%
	67.95%	32.05%	0.00%							
PC03	42.26%			0.21%	17.84%	0.07%	0.00%	0.00%	37.48%	2.16%
	79.58%	20.42%	0.00%							
PC04	13.63%			0.38%	77.00%	7.30%	0.01%	0.00%	1.37%	0.32%
	42.86%	56.57%	0.57%							
PC05	69.73%			26.92%	3.09%	0.00%	0.00%	0.00%	0.25%	0.00%
	42.86%	56.57%	0.57%							
PC06	100.00%			0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	65.57%	34.43%	0.00%							
Bus07	1.24%			94.77%	1.95%	0.38%	0.04%	0.45%	0.40%	0.78%
	100.00%	0.00%	0.00%							
Bus08	0.25%			99.61%	0.09%	0.03%	0.00%	0.01%	0.00%	0.01%
	100.00%	0.00%	0.00%							
Bus09	0.61%			99.19%	0.06%	0.06%	0.00%	0.03%	0.00%	0.03%
	100.00%	0.00%	0.00%							
sBus04										
Truck10	0.05%			99.25%	0.00%	0.01%	0.21%	0.47%	0.01%	0.00%
	100.00%	0.00%	0.00%							
Truck11	0.24%			99.61%	0.01%	0.00%	0.02%	0.11%	0.01%	0.01%
	100.00%	0.00%	0.00%							

Province Actual	Liquid fueled engine				Liquid/gas fuel engine				Dedicated gas	
	SI Engine*			Diesel*	Bi-fuel SI LPG*	Bi-fuel SI CNG*	DDF LPG*	DDF CNG*	LPG dedic.*	CNG dedic.*
	Gasoline*	E10*	E20*							
PC01	68.83%			30.31%	0.74%	0.07%	0.01%	0.00%	0.03%	0.00%

Model	SI Engine (total)	Gasoline	E10	E20	Diesel	Bi-fuel SI LPG	Bi-fuel SI CNG	DDF LPG	DDF CNG	LPG dedic.	CNG dedic.
		49.83%	50.17%	0.00%							
PC02	7.06%	67.95%	32.05%	0.00%	92.83%	0.08%	0.00%	0.01%	0.00%	0.02%	0.00%
PC03	46.09%	79.58%	20.42%	0.00%	1.51%	2.88%	0.01%	0.01%	0.00%	49.50%	0.00%
PC04	68.61%	49.83%	50.17%	0.00%	19.13%	11.66%	0.00%	0.00%	0.00%	0.60%	0.00%
PC05	84.01%	49.83%	50.17%	0.00%	10.18%	5.71%	0.00%	0.00%	0.00%	0.10%	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	3.28%	100.00%	0.00%	0.00%	96.29%	0.28%	0.04%	0.01%	0.01%	0.09%	0.01%
Bus08	22.61 %	100.00%	0.00%	0.00%	75.85%	0.19%	0.03%	0.01%	0.01%	1.30%	0.00%
Bus09	0.46%	100.00%	0.00%	0.00%	99.46%	0.00%	0.02%	0.02%	0.02%	0.03%	0.00%
sBus04	13.08%	100.00%	0.00%	0.00%	86.68%	0.10%	0.04%	0.02%	0.00%	0.09%	0.00%
Truck10	0.03%	100.00%	0.00%	0.00%	99.79%	0.03%	0.01%	0.04%	0.07%	0.02%	0.01%
Truck11	0.08%	100.00%	0.00%	0.00%	99.85%	0.01%	0.00%	0.01%	0.02%	0.01%	0.00%

Table 19: Modeling percent share for fuel used by each vehicle type in (a) Bangkok and (b) provincial region

Bangkok Model	Liquid fueled engine					Liquid/gas fueled engine				Dedicated gas	
	SI Engine*				Diesel*	Bi-fuel SI LPG*	Bi-fuel SI CNG*	DDF LPG*	DDF CNG*	LPG dedic.*	CNG dedic.*
	(total)	Gasoline**	E10**	E20**							
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%

*** Registered record from DLT [2]**

**** EPPO report 2009 [15]**

Province Model	Liquid fueled engine					Liquid/gas fuel engine				Dedicated gas	
	SI Engine*				Diesel*	Bi-fuel SI LPG*	Bi-fuel SI CNG*	DDF LPG*	DDF CNG*	LPG dedic.*	CNG dedic.*
	(total)	Gasoline**	E10**	E20**							
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%				19.13%	12.26%	0.00%	0.00%	0.00%	0.00%	0.00%

	49.83%	50.17%	0.00%							
PC05	84.01%			10.18%	5.81%	0.00%	0.00%	0.00%	0.00%	0.00%
	49.83%	50.17%	0.00%							
PC06	100.00%			0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	74.56%	25.44%	0.00%							
Bus07	3.71%			96.29%	0.00%	0.00%	0.00%	0.00%	0.00%	0.01%
	100.00%	0.00%	0.00%							
Bus08	24.15 %			75.85%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	100.00%	0.00%	0.00%							
Bus09	0.00%			100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	100.00%	0.00%	0.00%							
sBus04	13.32%			86.68%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	100.00%	0.00%	0.00%							
Truck10	0.00%			100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	100.00%	0.00%	0.00%							
Truck11	0.00%			100.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.00%
	100.00%	0.00%	0.00%							

***Registered record from DLT [2]**

****EPPO report 2009 [15]**

All fuel economy values for all vehicle/fuel types are shown in the Table 20 and Table 21 for Bangkok and Provincial regions, respectively. The items for Bi-fuel and DDF vehicle are not shown here because their FE values are calculated from the equation previously given. The FE of Bi-fuel vehicle is calculated from the FE of SI vehicle and dedicated gas vehicle while the FE of DDF vehicle is 1.287 times of FE_{Diesel} but consumes both liquid and gas fuels at their respective device shares.

Note that the values in Table 20 and Table 21 are referred to [15] and calculated from [20] under the following assumptions.

- **Within the same year, FE ratio of different vehicle categories according to DLT (Table 13) only depends on the engine size and type (SI vs. CI)**
- **Within the same vehicle type, engine technology (both SI and CI) has become more efficient over year so FE ratio of SI to CI is assumed to be constant in year 1997 in order to fill out required data in year 2008.**

Table 20: Fuel economy for fuel used in each vehicle type for Bangkok region

km/litre and km/kg for CNG	Single fuel engine				Dedicative gas engine	
	Spark ignition engine			Diesel engine	LPG	CNG
	Gasoline	E10	E20			
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**

***Referred from EPPO report [15]**

****Calculated from previous EPPO report [20]**

Table 21: Fuel economy for fuel used in each vehicle type for Provincial region

km/litre and km/kg for CNG	Single fuel engine				Dedicative gas engine	
	Spark ignition engine			Diesel engine	LPG	CNG
	Gasoline	E10	E20			
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*	15.00**	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**

***Referred from EPPO report [15]**

****Calculated from previous EPPO report [20]**

4.5 Validation of Energy Demand Model

From all factors above mentioned, energy demand model can be used to predict energy consumption in transportation sector. However, early validation results show the effects of specific habit of Thai vehicle owners on the model accuracy. In Thai transportation sector, when global economic crisis occurred and reflected on increase of fuel price, many vehicle owners decided to modify their vehicles to use gas fuel (LPG or CNG) due to its lower price in comparison to liquid fuel (gasoline and diesel) under governmental control. Unfortunately, the stock vehicles in the LEAP model cannot be directly changed from user input. Rather, LEAP model can adjust stock vehicles over time by addition of new vehicles, which can be specified as gas fuel vehicles. The shift in predicted fuel sharing results from the model is then slower than the real situation. Therefore, a correction factor approach has to be applied on the model to take into account of this behavior.

4.5.1 Correction Factor Approach

In fact, there are many influencing parameters in real situation that is related to owner's decision for fuel consumption. For simplicity, all of these factors would reflect on a single

parameter, which is the distributed fuel price. During validation years (2006-2008), fuel price increased rapidly, and Thai vehicle owners modified their vehicles to use gas fuel. Therefore, liquid fuel proportions (gasoline and diesel) have decreased from the increasing gas fuel proportions (LPG and CNG). Moreover, prediction results are greater than historical record for total fuel consumption during this period. It is reasonable to postulate that when fuel price increase, the Thai vehicle owners optimize their driving habits. Therefore, vehicle kilometer of travel (VKT) would decrease proportionally, and total fuel consumption is lower.

To include this fuel price impact into the LEAP model, the correction factor is defined as the ratio between historical record and predicted results. Gasoline and LPG consumptions are assumed to relate to gasoline fuel price while diesel and CNG consumptions are assumed to relate to diesel fuel price. Since the distributed fuel pricing depends on uncertain political tax support so the correction factor is fitted with ex-refinery price. The average ex-refinery price of gasoline and diesel are shown in Fig. 19.

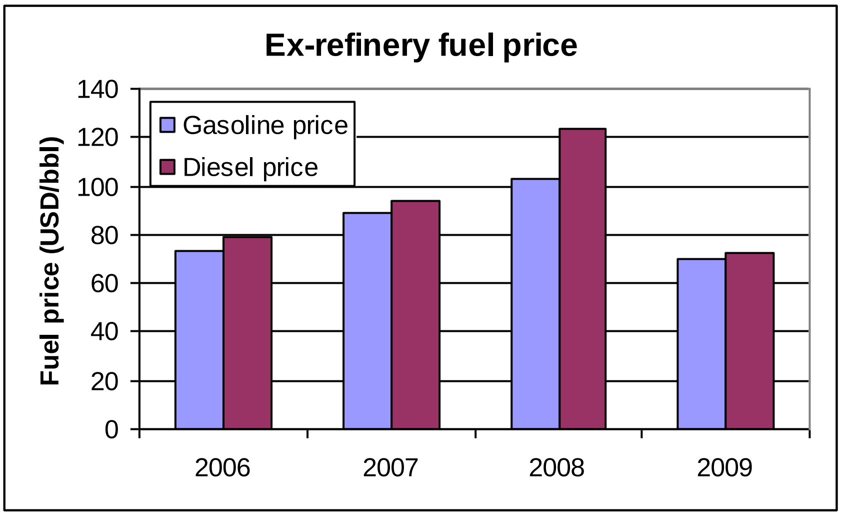


Fig. 19 Ex-refinery fuel price in year 2006-2009

It is shown that the fuel price increases unnaturally from 2006 to 2008, and decreases back in 2009. Hence, the correction factor is fitted during 2006-2008 to capture the impact of fuel price increase on the fuel consumption behaviors. The correction factors are specified as the mileage correction factor in the constructed model. Other externalities that may affect the accuracy of the energy demand model include

- financial economic crisis in 1997-1998 period, which may affect a parameter like GDP used in vehicle ownership model (see Fig. 20),
- certain regulations that may affect vehicle ownership models and/or vehicle type registration, e.g. PC03, PC05, BUS01 in Bangkok; PC03 in provincial region,
- certain measure and support to introduce new fuels like E10 and E20 so that their demands have abruptly increased, among many others

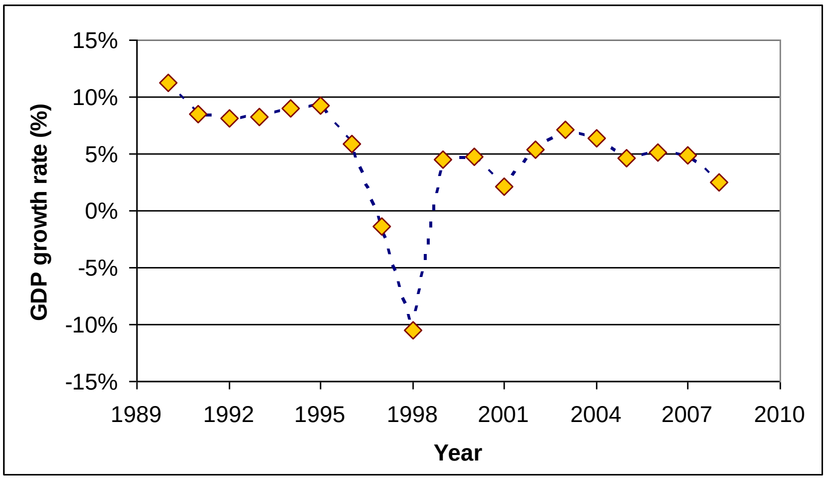
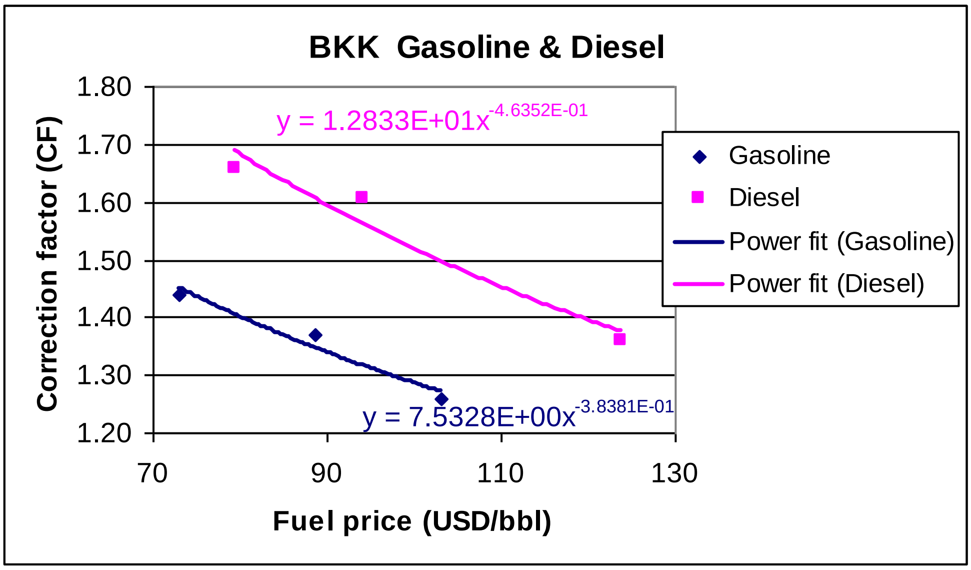
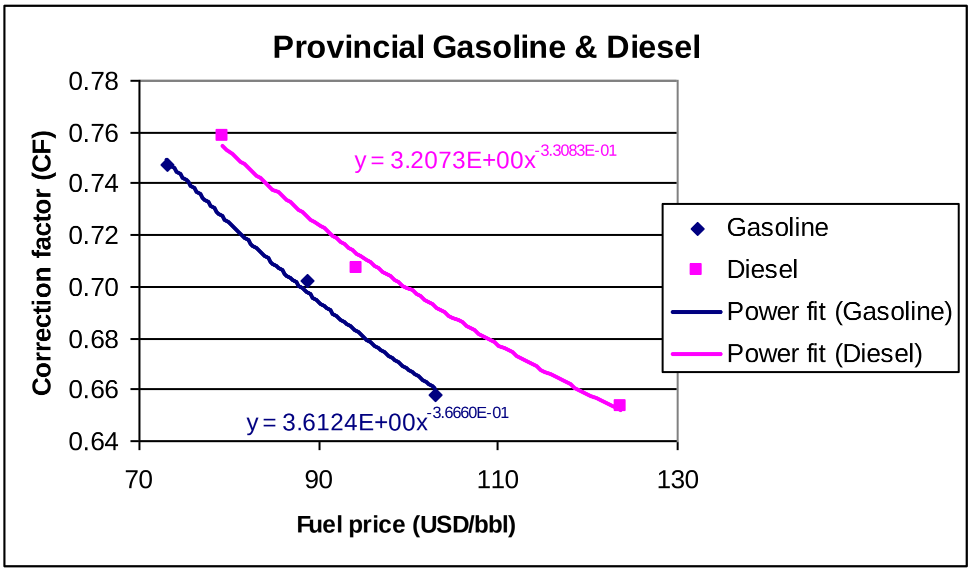


Fig. 20 Evolution of GDP growth rate

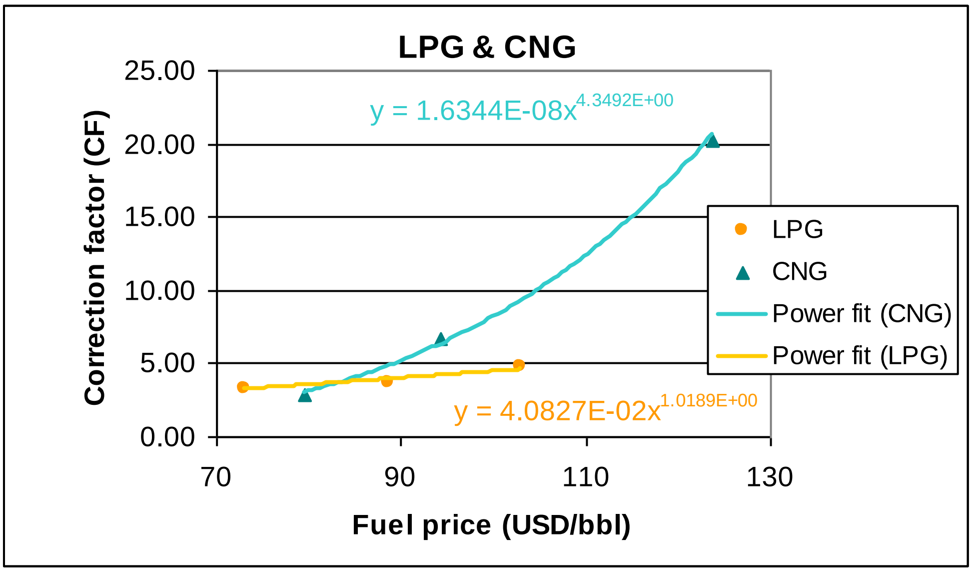
Fig. 20 shows the evolution of the GDP growth rate over time. In the present study, the GDP parameter is estimated using a linear function of time with a constant growth rate equal to 4.98% and the base year GDP from historic record. The growth rate is averaged from the value after the economic crisis in 1998. It is showed here that the predicted GDP may over predict due to the systematic prediction error during the validated years. Additional factors may also affect estimated NV, VKT and FE from their actual values. The relationship between developed correction factors and fuel price is shown in Fig. 21, which can be fitted as the power function summarized in Table 22. However, it must be emphasized that the correction factor approach is not applied to the vehicle types of which driven habits are not affected by fuel prices such as the fixed route bus, taxi etc.



(a)



(b)



(c)

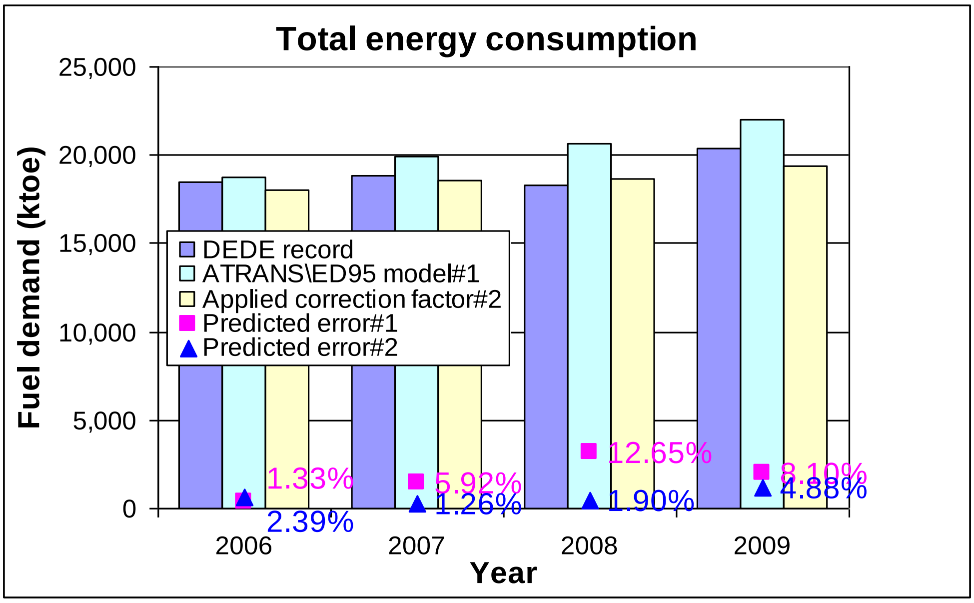
Fig. 21 Relationship between correction factor and distributed fuel price of (a) gasoline and diesel in Bangkok region, (b) gasoline and diesel in provincial region and (c) LPG and CNG

Table 22: Summary of power function fits between correction factor and fuel price

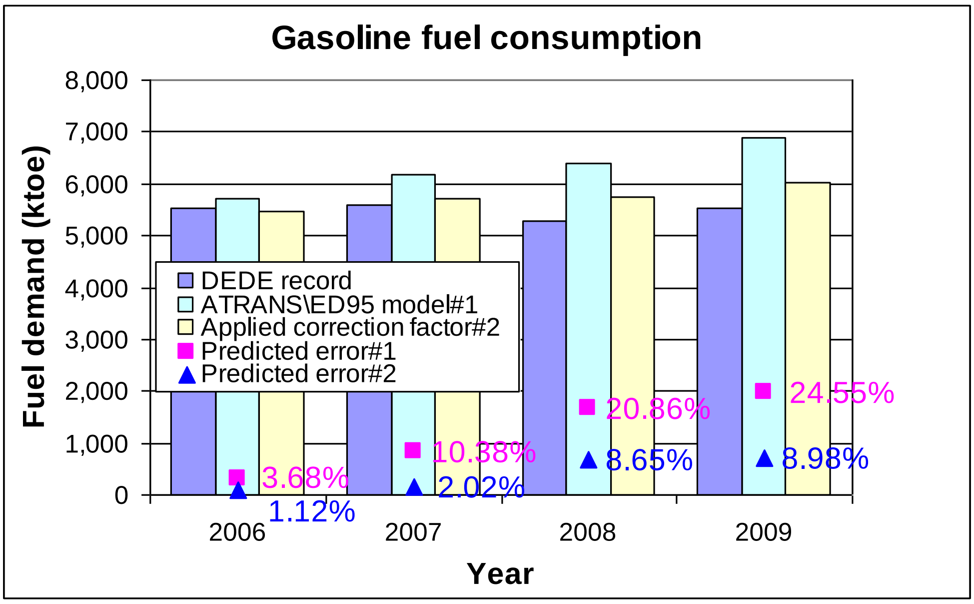
	Bangkok region	Provincial region
Gasoline	$7.5328 \cdot 10^{0} \, Price_{gasoline}^{-3.8381 \cdot 10^{-1}}$	$3.6124 \cdot 10^{0} \, Price_{gasoline}^{-3.6660 \cdot 10^{-1}}$
Diesel	$1.2833 \cdot 10^{1} \, Price_{diesel}^{-4.6352 \cdot 10^{-1}}$	$3.2073 \cdot 10^{0} \, Price_{diesel}^{-3.3083 \cdot 10^{-1}}$
LPG	$4.0827 \cdot 10^{-2} \, Price_{gasoline}^{1.0189 \cdot 10^{0}}$	
CNG	$1.6344 \cdot 10^{-8} \, Price_{diesel}^{4.3492 \cdot 10^{0}}$	

4.5.2 Validation Results

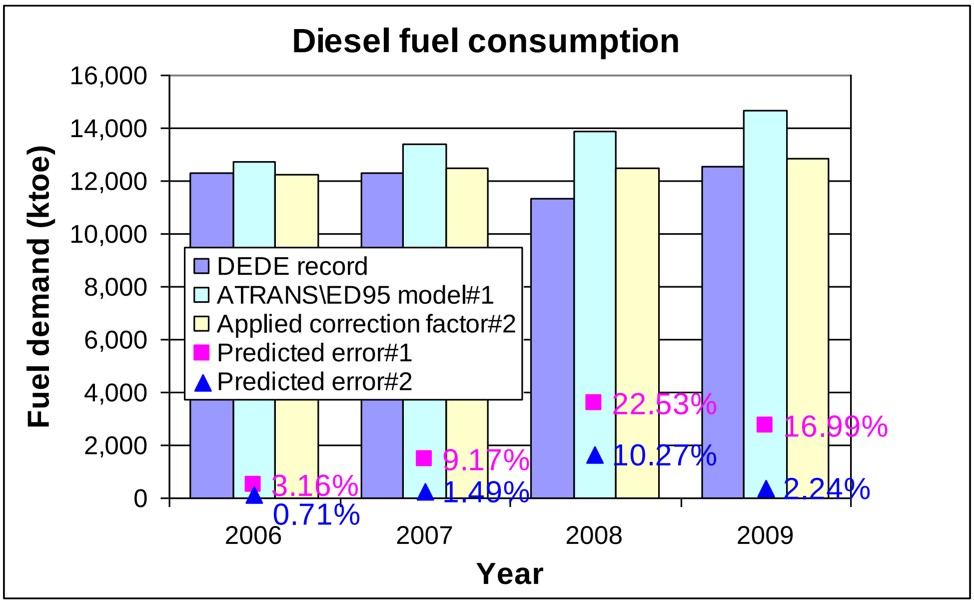
The model results are validated against the fuel sale record, as shown in Fig. 22. Historical record from DEDE [1], raw results without correction approach and the results with applying developed correction factors are respectively shown for base year and other years.



(a)



(b)

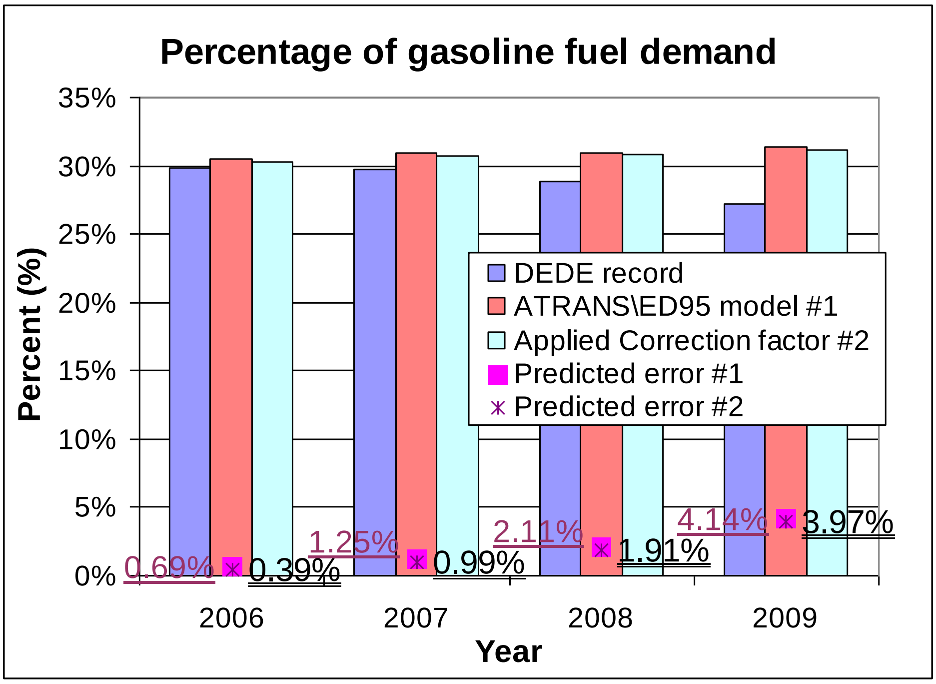


(c)

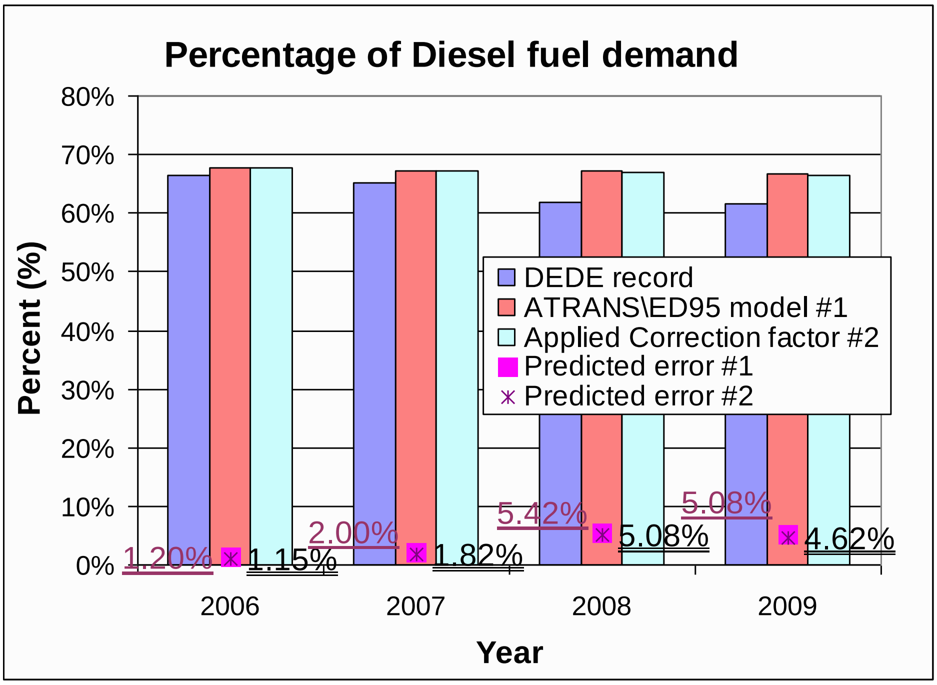
Fig. 22 Validation of energy demand model after correction factor with fuel consumption in year 2006-2009 for (a) all, (b) gasoline and (c) diesel fuels

Without applying correction factor, the predicted energy demand deviates from historical record during 2006-2008 where fuel prices increases unnaturally. Until 2009, fuel price decreases and prediction error is close to a value in a year before (2008). When correction approach is on, the prediction error is almost around 2% while highest prediction error of about 10% occurs in year 2008, where fuel prices are greatest in the validation period. Furthermore, validation of energy demand model was shown as percentage by fuel and year in Fig. 23 and Fig. 24, respectively.

When the validation is done on the basis of fuel fractions of gasoline and diesel in Fig. 23, the predicted results are much improved (~1-2%) even at the year 2008 (<6%), then decrease at one year later (2009). The correction factor impact can be seen as a few improvements of gasoline and diesel fractions.

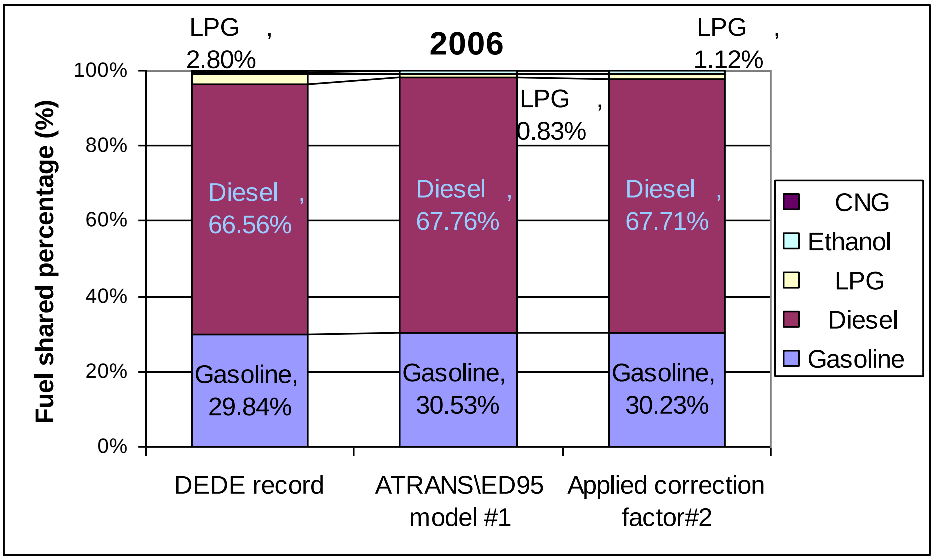


(a)

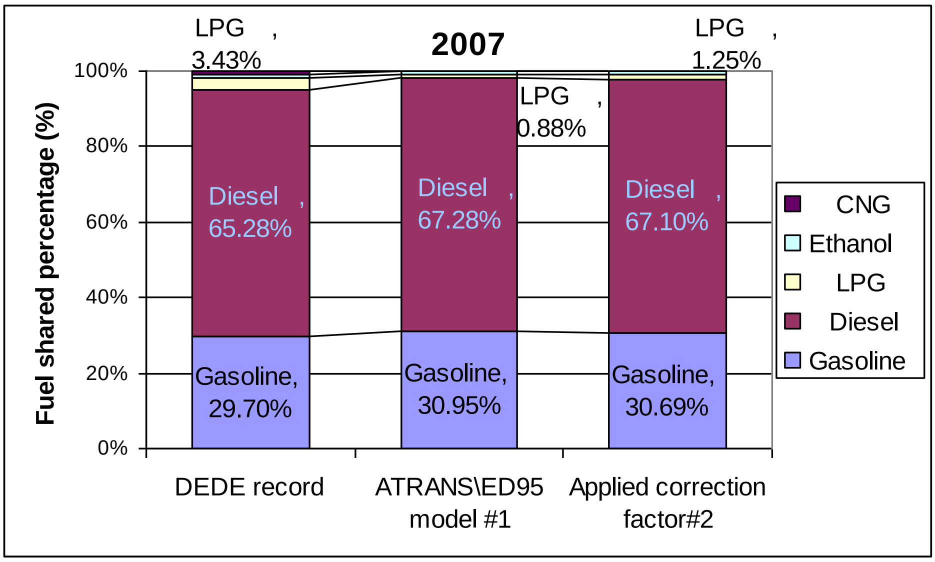


(b)

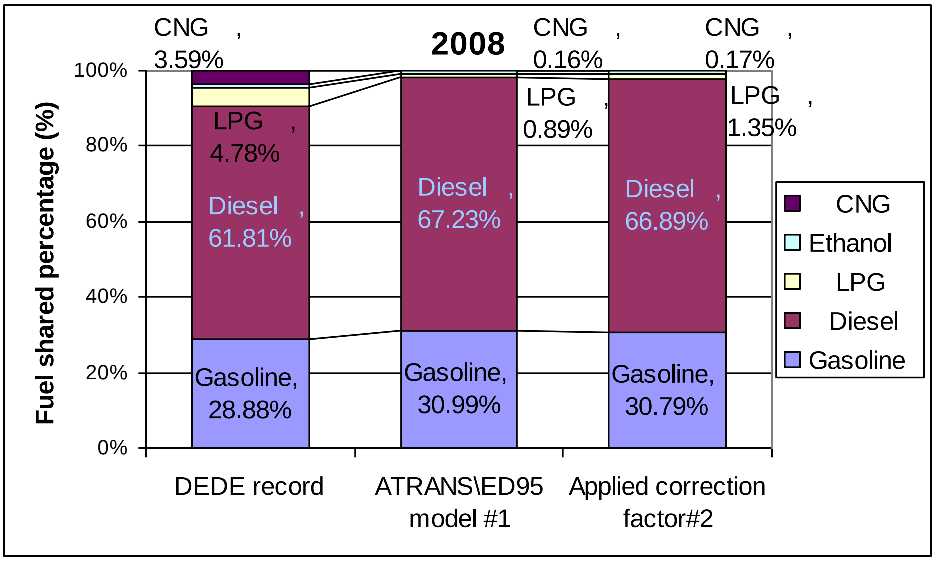
Fig. 23 Validation of energy demand model with %fuel consumption in year 2006-2009 for (a) gasoline and (b) diesel


2006
Fuel shared percentage (%)
100%
80%
60%
40%
20%
0%
LPG , 2.80%
LPG , 1.12%
LPG , 0.83%
Diesel , 66.56%
Diesel , 67.76%
Diesel , 67.71%
Gasoline, 29.84%
Gasoline, 30.53%
Gasoline, 30.23%
DEDE record
ATRANS\ED95 model #1
Applied correction factor#2
CNG
Ethanol
LPG
Diesel
Gasoline

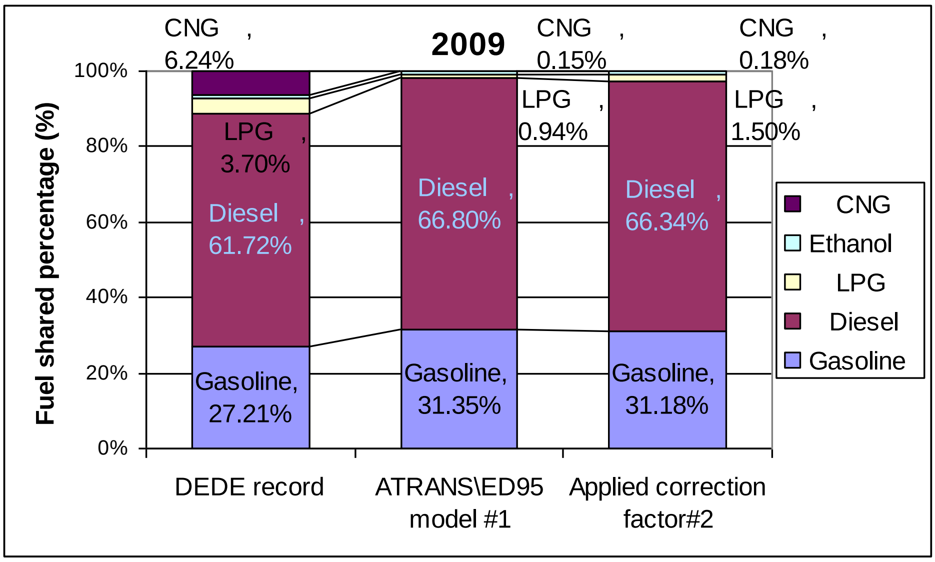
(a)


2007
Fuel shared percentage (%)
100%
80%
60%
40%
20%
0%
LPG , 3.43%
LPG , 1.25%
LPG , 0.88%
Diesel , 65.28%
Diesel , 67.28%
Diesel , 67.10%
Gasoline, 29.70%
Gasoline, 30.95%
Gasoline, 30.69%
DEDE record
ATRANS\ED95 model #1
Applied correction factor#2
CNG
Ethanol
LPG
Diesel
Gasoline

(b)


2008
Fuel shared percentage (%)
100%
80%
60%
40%
20%
0%
CNG , 3.59%
CNG , 0.16%
CNG , 0.17%
LPG , 4.78%
LPG , 0.89%
LPG , 1.35%
Diesel , 61.81%
Diesel , 67.23%
Diesel , 66.89%
Gasoline, 28.88%
Gasoline, 30.99%
Gasoline, 30.79%
DEDE record
ATRANS\ED95 model #1
Applied correction factor#2
CNG
Ethanol
LPG
Diesel
Gasoline

(c)



(d)

Fig. 24 Validation of energy demand model with %fuel consumption in year (a) 2006 (b) 2007 (c) 2008 and (d) 2009

Further examination into all fuels in Fig. 24 shows that the deviations of predicted results mainly come from the gas fractions (LPG and CNG). The DEDE record shows that the proportions of fuel shares are not constant over time as above discussion, which is difficult to describe in the energy demand model. The proportions of fuel shares depend on the vehicle owner's decision but the proportions of fuel shares in the present model are referred from the survey report [15], which gives a constant value. The correction factor approach, which is applied as mileage correction factor, targets to significantly increase gas fuel fraction in the validation years, but still slower than the historical data due to model capability. Overall, the constructed model can predict energy demand with good accuracy while the predicted fuel sharing can be acceptable.

CHAPTER 5 RESULTS & DISCUSSION FOR VARIOUS SCENARIOS

5.1 Scenarios Set Up

As previously discussed, ethanol diesel technology has been developed for heavy duty vehicle such as bus and truck. Ethanol fuel ED95 for this engine is specific, which is a mixture between ethanol 95%vol and ignition improver additive 5%vol. The specially-designed vehicle should be driven in a fixed route where the ED95 station is available to minimize capital investment for supporting infrastructure. Thus, the fixed route bus is chosen as basis for scenario construction in the present work. Reasonable assumptions along with government policy are assumed in the BAU scenario starting from year 2010 as follows.

- ✓ **New SI vehicle will switch to E20 (20% ethanol blended in gasoline) within 10 years [7]**
- ✓ **New SI motorcycle will switch to E10 (10% ethanol blended in gasoline) within 10 years [7]**
- ✓ **New fixed route bus (Bus01) will switch to NGV within 10 years [7]**
- ✓ **All assumptions above follow technology penetration behavior of S-curve, as shown in Fig. 25 [29].**

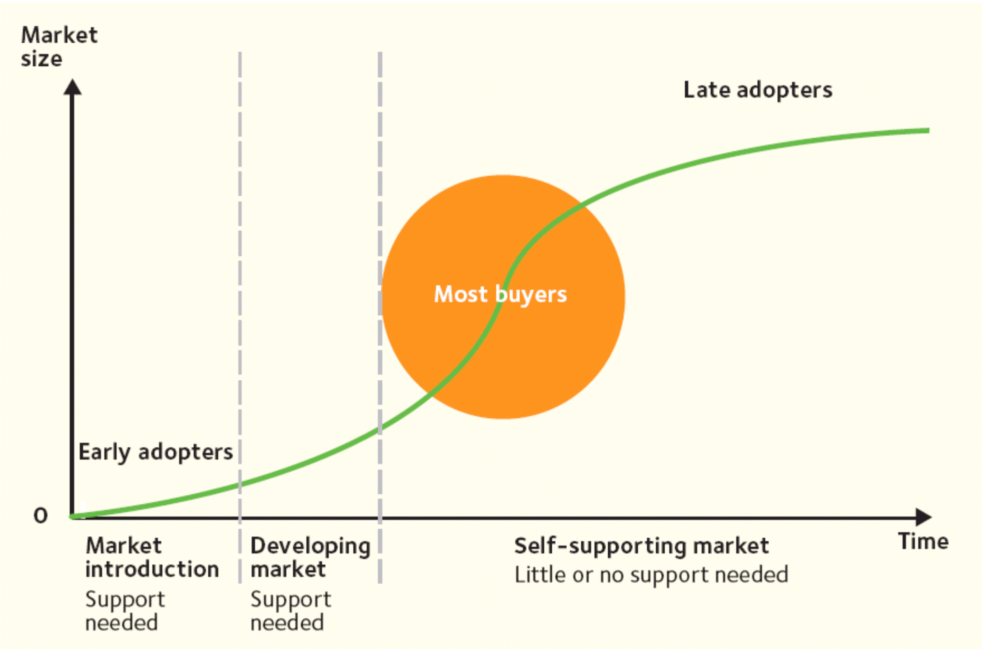


Fig. 25 S-curve of technology penetration [29]

Scenario analyses are classified into three categories as described in Section 2.1.2, which are

1. **Apply existing ED95 technology on the fixed route bus (Bus01)**
   - **A.1** **Applying ED95 to Bus01 in Bangkok region instead of CNG bus at year 2020 with technology penetration within 10 years**
   - **A.2.1 (a)** **Applying ED95 to Bus01 in Bangkok region instead of CNG bus at year 2010 with technology penetration within 10 years**
   - **(b)** **Applying ED95 to Bus01 in Bangkok region instead of CNG bus at year 2010 with technology penetration within 5 years**
   - **A.2.2 (a)** **From the scenario A.2.1(a), extending ED95 to Bus01 in Provincial region instead of CNG bus at year 2020 with technology penetration within 10 years**
   - **(b)** **From the scenario A.2.1(b), extending ED95 to Bus01 in Provincial region instead of CNG bus at year 2015 with technology penetration within 10 years**
2. **Assume the technology penetrating from scenario A.2.2(a) to non-fixed route bus/truck in Bangkok region at year 2020 with technology penetration within 10 years**
   - **B.1** **From the scenario A.2.2(a), extending ED95 to non-fixed route bus (Bus02)**
   - **B.2** **From the scenario A.2.2(a), extending ED95 to private bus (Bus03)**
   - **B.3** **From the scenario A.2.2(a), extending ED95 to non-fixed route truck (Truck01)**
   - **B.4** **From the scenario A.2.2(a), extending ED95 to private truck (Truck02)**
3. **Assume the new technology developed for small ethanol diesel engine that capable for using in small vehicle in Bangkok region at year 2020 with technology penetration within 10 years**
   - **C.1** **From the scenario A.2.2(a), extending ED95 to private passenger car (PC01)**
   - **C.2** **From the scenario A.2.2(a), extending applying ED95 to pickup truck (PC02)**

Note that all the technology penetration behavior still assumes S-curve, as shown in Fig. 25. All scenarios analyses are summarized in Table 23 and Fig. 26.

Table 23: Summary of various assumptions on BAU and scenario analyses

<table>
<tr><th>Cases</th><th>Based assumption applied at 2010 within 10 years</th><th>NGV substituted by ED95 in fixed route bus</th><th>Diesel substituted by ED95 @2020 within 10 years</th></tr>
<tr><td>BAU</td><td rowspan="3">✓ New SI vehicle will switch to E20 within 10 years
✓ New SI motorcycle will switch to E10 within 10 years</td><td>-</td><td>-</td></tr>
<tr><td>A.1</td><td>BKK @2020 within 10 years</td><td>-</td></tr>
<tr><td>A.2.1(a)</td><td>BKK @2010 within 10 years</td><td>-</td></tr>
</table>

A.2.1(b)	✓ New fixed route bus will switch to NGV within 10 years	BKK @2010 within 5 years	
A.2.2(a)		BKK @2010 & Provincial @2020 within 10 years	
A.2.2(b)		BKK @2010 within 5 years & Provincial @2015 within 10 years	
B.1		BKK @2010 & Provincial @2020 within 10 years	Non fixed route bus BKK
B.2			Private bus BKK
B.3			Non fixed route truck BKK
B.4			Private truck BKK
C.5			Passenger car BKK
C.6			Pick up truck BKK

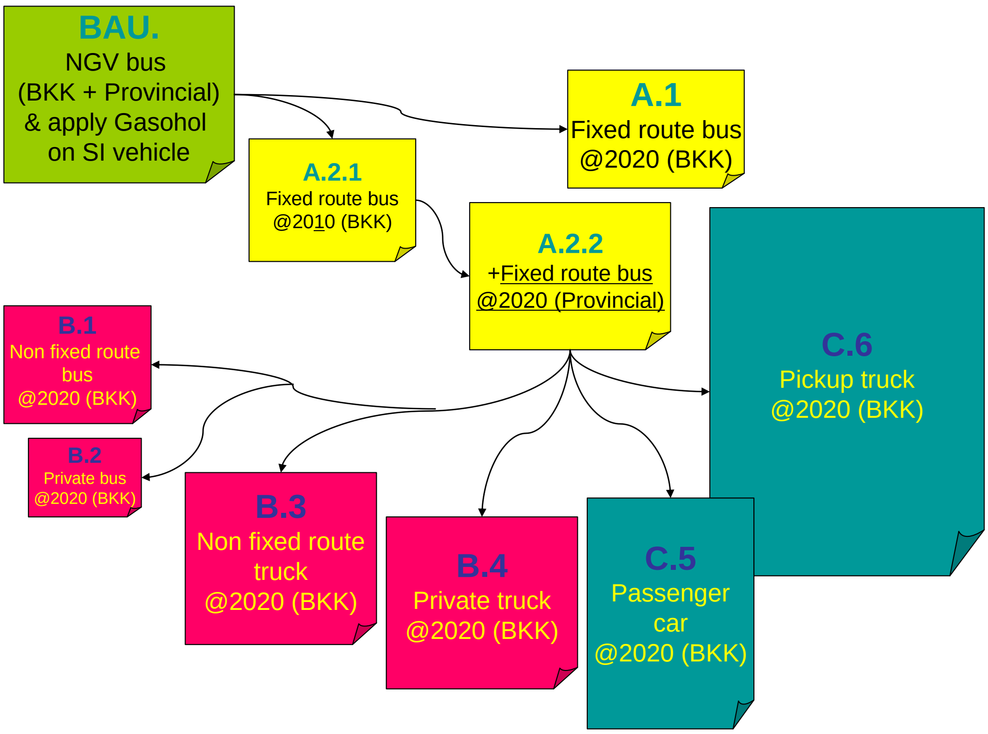
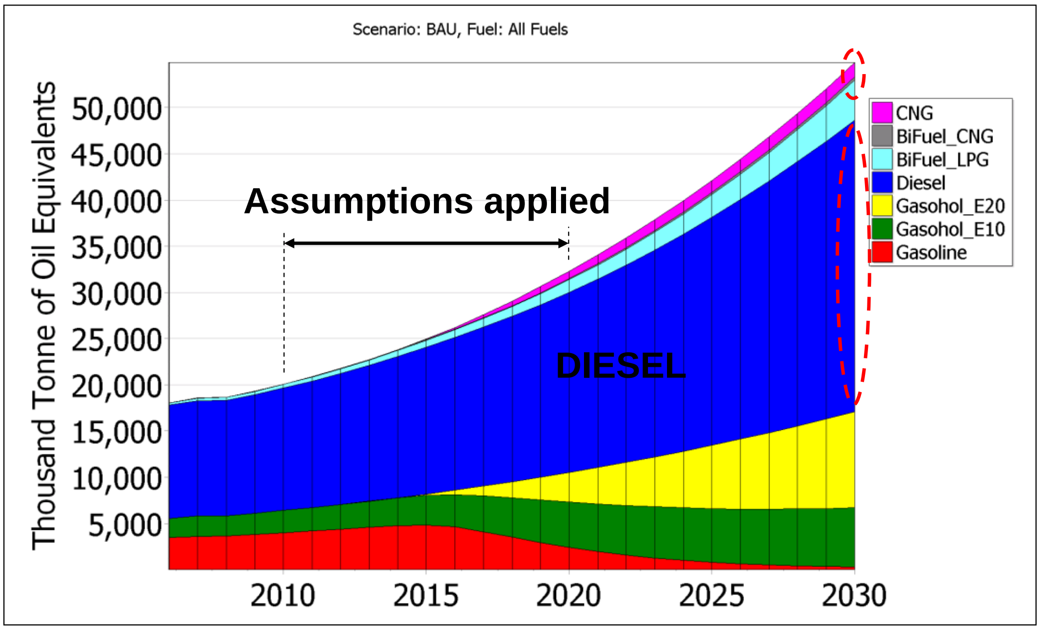


Fig. 26 Schematic diagram for various scenarios

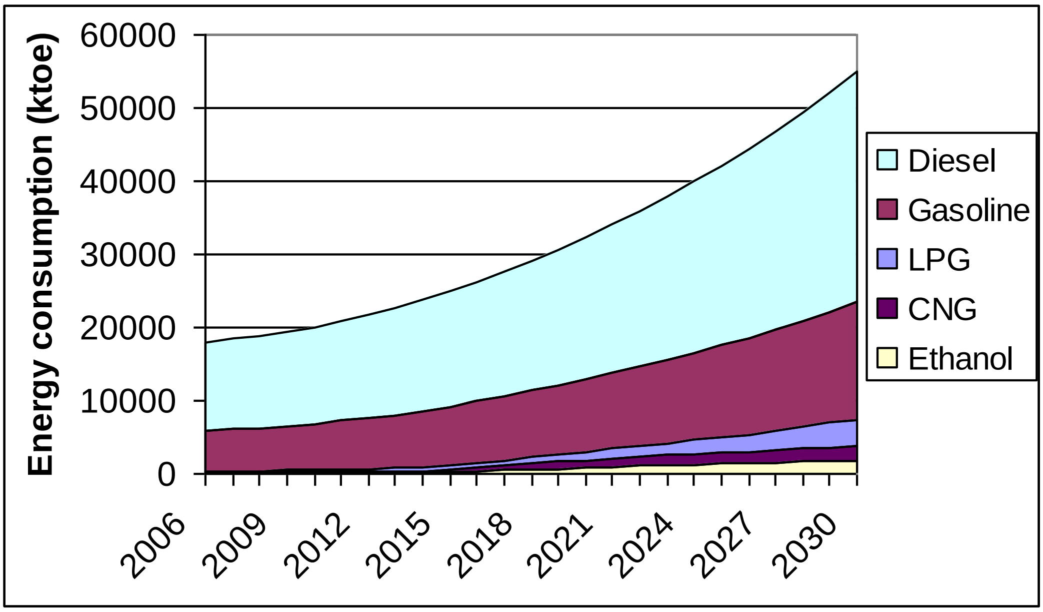
For BAU analysis, Fig. 27(a) shows predicted BAU demand of various finished fuels in Thai transportation sector during 2010-2030. Clearly, the BAU assumptions in Table 23 applied during 2010-2020 have resulted in

- ✓ a switch from gasoline to E10 (new motorcycle),
- ✓ a switch from E10 to E20 (new passenger car), and
- ✓ an increase of CNG from new NGV fixed route bus.

When the BAU result is displayed in terms of based fuel (diesel, gasoline, LPG, CNG and ethanol) as in Fig. 27(b), diesel is still a dominating fuel till 2030, followed by gasoline, LPG, CNG and ethanol, respectively.



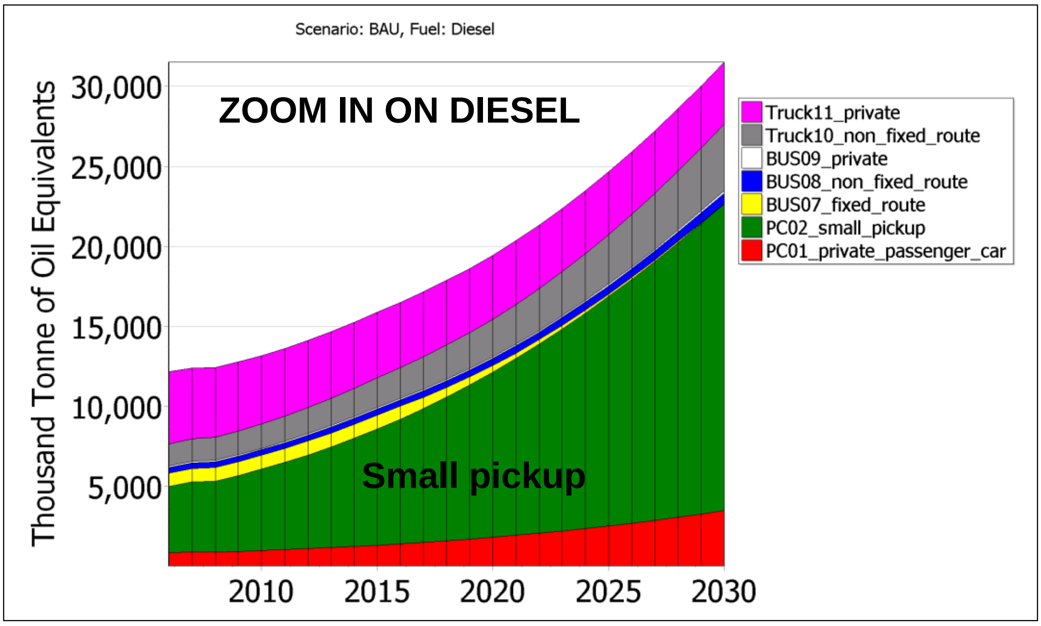
(a)



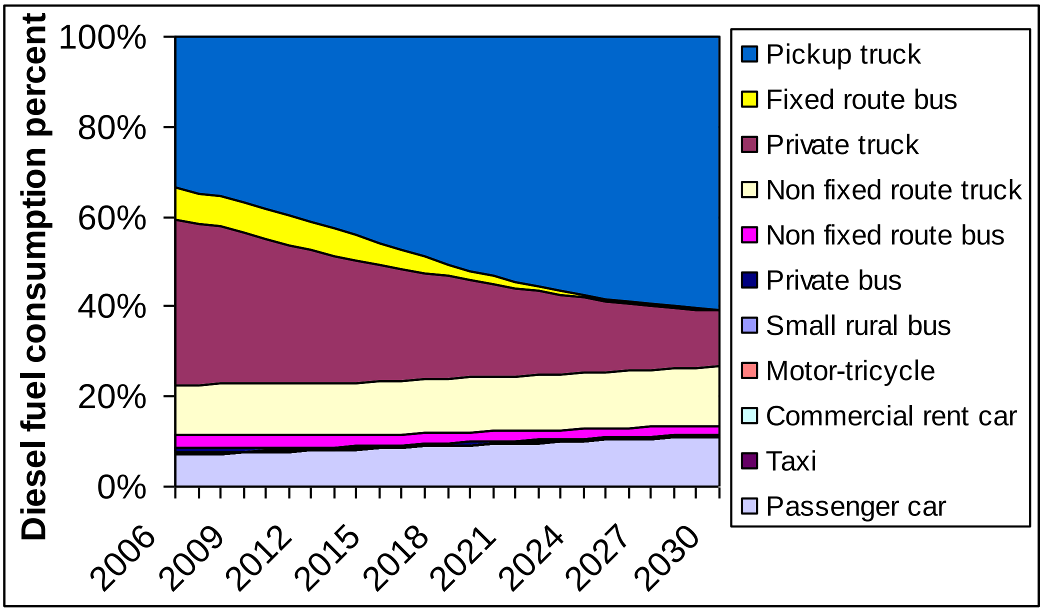
(b)

Fig. 27 Energy demand prediction (BAU) during 2010-2030 by (a) finished fuel type and (b) based fuel type

With a zoom in on diesel prediction in Fig. 27, Fig. 28(a) shows that small pick-up truck is still a dominating sector for diesel consumption while diesel consumption in fixed route bus decreases due to BAU assumption of new NGV bus. Even though BAU assumption requires all new fixed route bus to be of CNG bus after 2020, a fraction of diesel fuel consumption by fixed route bus still exists due to the old fixed route bus in stock. However, this fraction is decreasing over time from the vehicle retirement behavior. As shown by the percentage prediction in Fig. 28(b), the faster growth of small pick-up truck predicted by vehicle ownership model has made pick-up truck a major sector in diesel consumption, greater than 50% after 2020. This provides rationale for ED95 technology introduction in this sector, which will be discussed in Section 5.4.



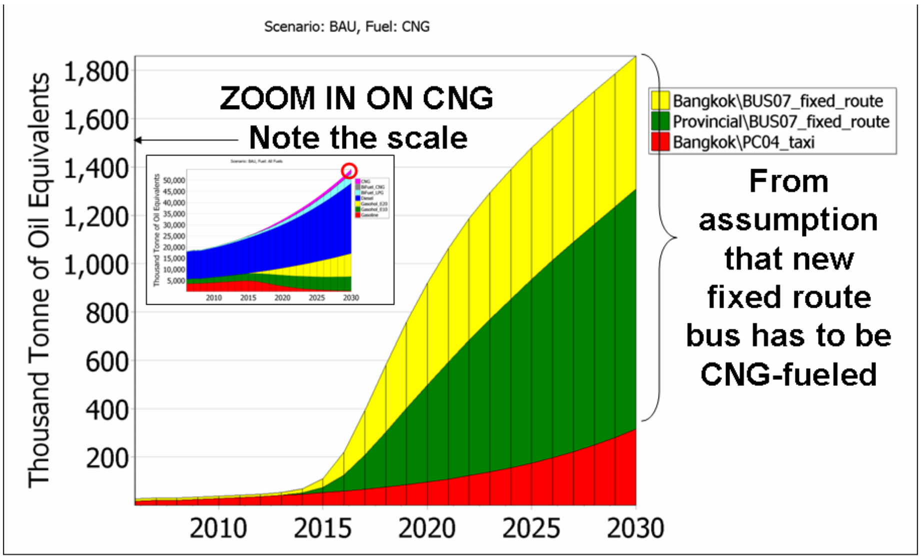
(a)



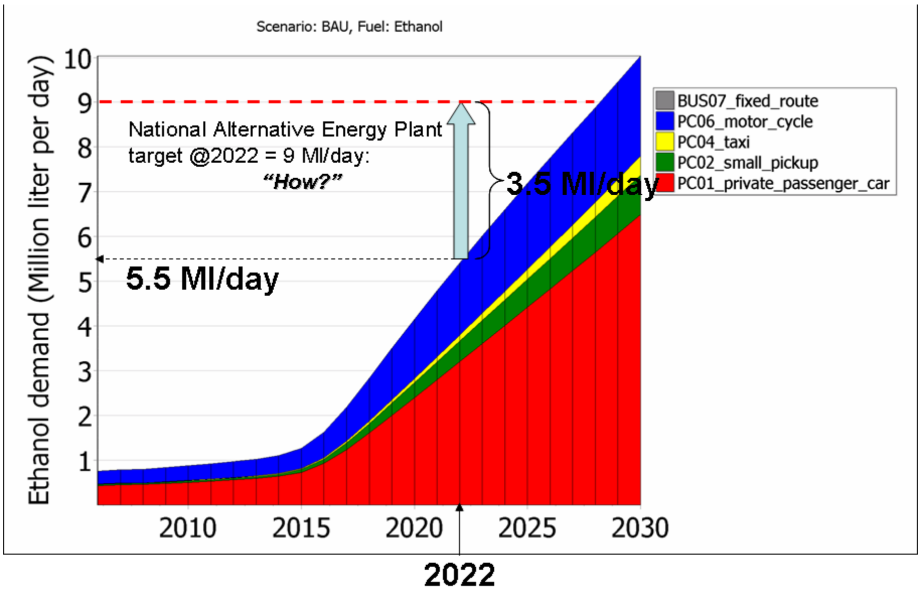
(b)

Fig. 28 Energy demand prediction (BAU) during 2010-2030 for diesel in (a) ktoe and (b) percentage

With a zoom in on CNG in Fig. 27, Fig. 29 (a) shows a sharp increase in a fixed route bus sector, from both BKK and provincial regions due to the BAU assumption of new CNG bus requirement. Although the number of fixed route bus is smaller than taxi, its fuel consumption is higher, and the majority of CNG will be consumed within fixed route bus sector, especially with new CNG bus assumption. As for ethanol demand, Fig. 29(b) shows that private passenger car is a dominating sector, especially after 2015 with assumption of new E20 vehicle. The BAU assumption of new E10 motorcycle also helps increase the ethanol demand. However, without additional strong ethanol promotion policy, ethanol demand by 2022 will only reach 5.5 ML/day, still short by 3.5 ML/day for the 9 ML/day target in Thailand Alternative Energy Strategic Plan shown in Fig. 3(a). This is where ED95 technology can offer additional ethanol demand to meet the 9 ML/day target.



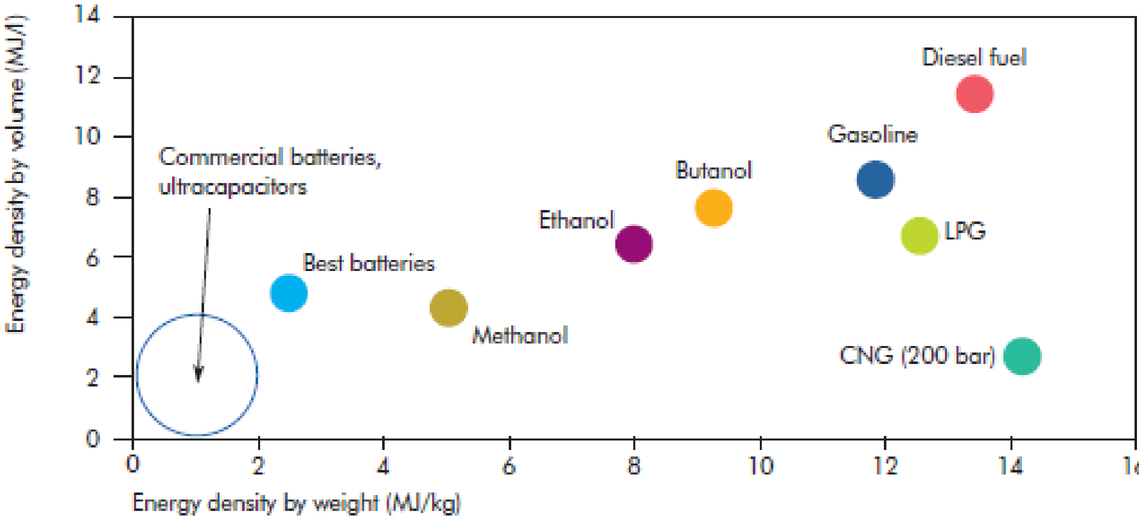
(a)



(b)

Fig. 29 Energy demand prediction (BAU) during 2010-2030 for (a) CNG and (b) ethanol

Another remark worth discussing is the rationale for substituting CNG-fueled vehicle by diesel-fueled vehicle. Despite the current promotion of CNG in both taxi and bus sectors, CNG as a transportation fuel still suffers a rather low volumetric energy density, as shown in Fig. 30 [30]. In addition, CNG has a high octane number so it is most suitable for spark ignition vehicle. For taxi, CNG can be fed into intake manifold to reduce the injection of gasoline. On the other hand, dedicated CNG bus would need engine modification by converting compression-ignition (CI) diesel engine into spark-ignition (SI) CNG engine. From the combustion principle, SI engine has lower thermal efficiency than CI engine. Hence, the BAU assumption of new CNG fixed route bus would have the drawback of lower efficiency engine, despite the merit of cleaner combustion emission than diesel. For illustration purpose, energy demand in fixed route bus is analyzed for the switching from diesel to CNG fuel. Given the vehicle ownership model, fuel economy and VKT of fixed route bus, Fig. 31 and Table 24 show how much more energy is needed for CNG fuel bus to satisfy the same travel demand for diesel fuel bus.



Source: Various, including IEA data on the relationship between volumetric and mass density of batteries and IEA assumptions on the efficiencies of engines (25% to 30% for internal combustion engines) and electric motors (90% to 95%).

Fig. 30 Relationship of energy density by volume and by weight for various transportation fuel

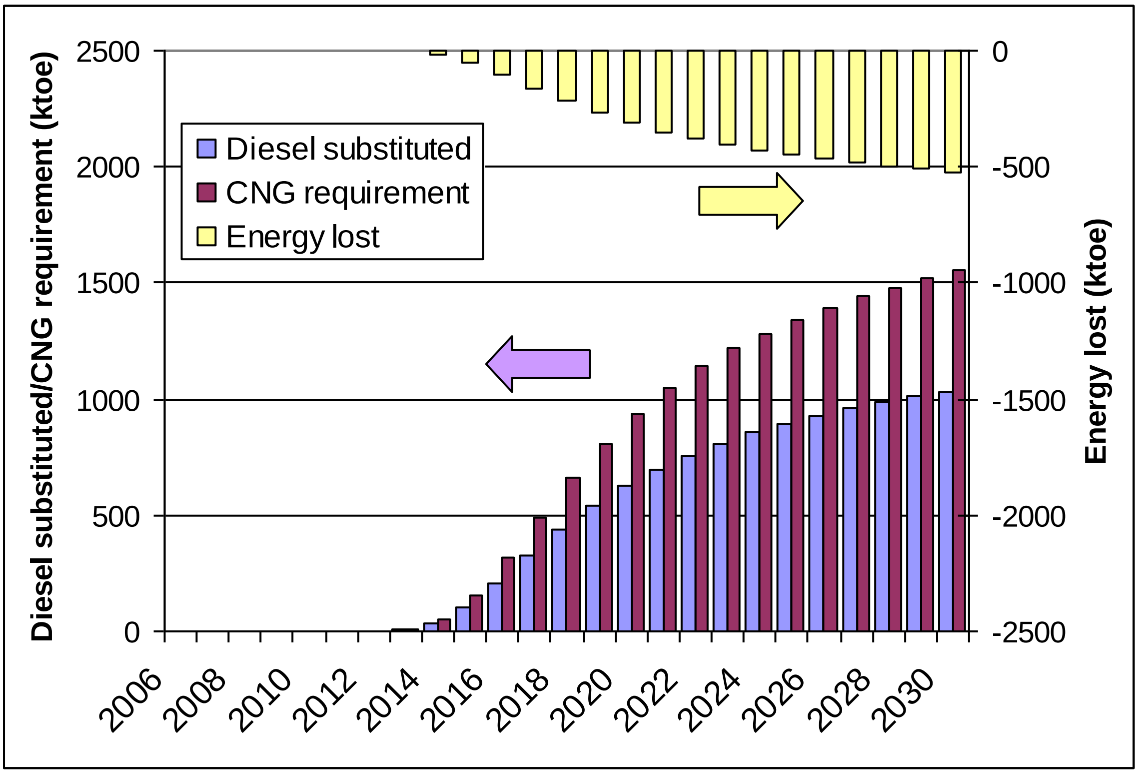


Fig. 31 Diesel substitution by CNG in CNG-SI bus for BAU scenario

Table 24: Diesel substitution by CNG in CNG-SI bus for BAU scenario

	Diesel-substituted		CNG-requirement		Energy lost
	ML/year	ktoe	kTon/year	ktoe	ktoe
2006	0.00	0.00	0.00	0.00	0.00

2009	0.00	0.02	0.03	0.03	-0.01
2012	1.83	1.76	2.56	2.63	-0.87
2015	112.13	100.73	146.50	150.50	-49.77
2018	490.53	441.26	642.46	660.02	-218.76
2021	776.52	698.41	1,018.70	1,046.54	-348.13
2024	950.38	855.30	1,249.71	1,283.87	-428.57
2027	1,065.07	958.29	1,401.99	1,440.31	-482.02
2030	1,146.52	1,031.78	1,510.77	1,552.07	-520.29

To illustrate the merit of ED95 for CNG substitution, scenario A.2.1(a) was analyzed to compare the CNG and ethanol fuel needed for the same travel demand. Since ED95 engine is compression-ignition (CI), the fuel conversion efficiency is higher than the CNG-SI engine in the CNG bus, as shown by the amount of energy saved in Fig. 32 and Table 25.

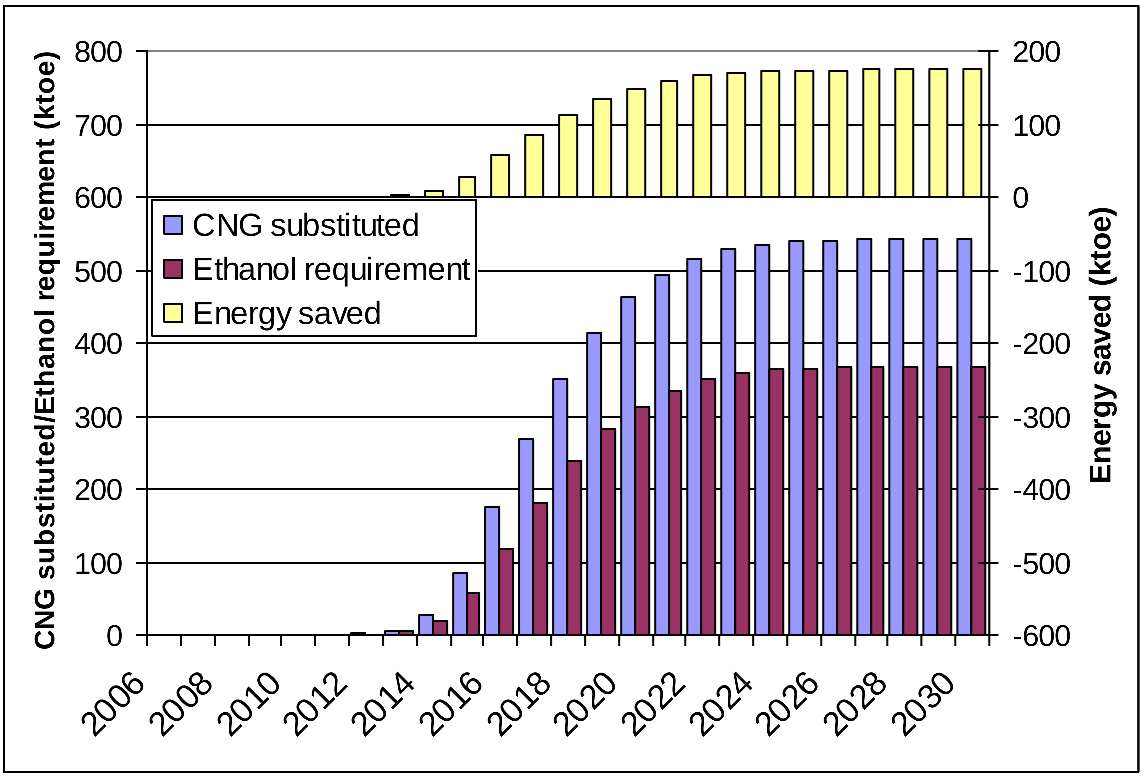


Fig. 32 CNG substitution by ethanol in ED95-CI bus for scenario A.2.1(a)

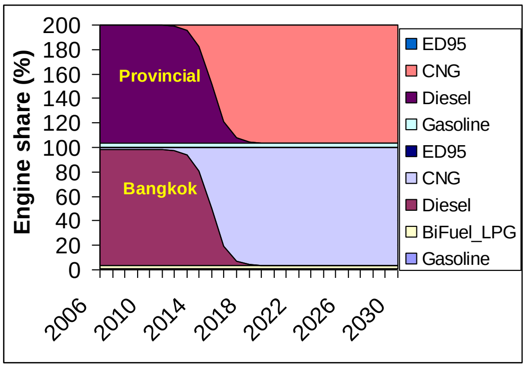
Table 25: CNG substitution by ethanol in ED95-CI bus for scenario A.2.1(a)

	CNG-substituted		Ethanol-requirement		Energy saved
	kTon/year	ktoe	ML/year	ktoe	ktoe
2006	0.00	0.00	0.00	0.00	0.00
2009	0.02	0.02	0.00	0.01	0.01
2012	1.48	1.52	2.19	1.03	0.49
2015	82.81	85.08	113.96	57.72	27.36
2018	340.31	349.62	469.35	237.18	112.44
2021	481.26	494.41	663.66	335.41	159.01
2024	520.91	535.15	718.08	363.04	172.11

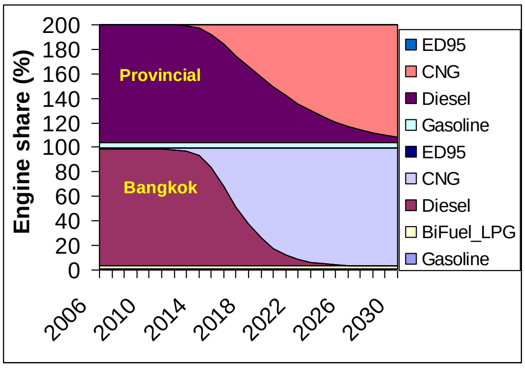
2027	527.15	541.56	726.85	367.39	174.17
2030	527.71	542.13	727.58	367.78	174.36

5.2 Applying Existing ED95 Technology on the Fixed Route Bus

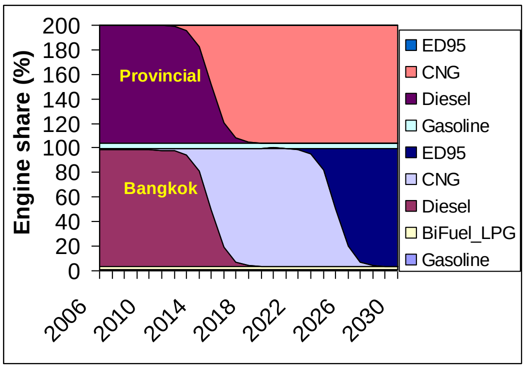
With commercially available ED95 technology for city bus, it is most reasonable to assume ED95 technology penetration into fixed route bus (Bus01). Five cases were studied with various assumptions on regions (Bangkok vs. Provincial), year of implementation (2010 vs. 2020) and duration of ED95 bus introduction (10 vs. 5 years). Fig. 33 shows fraction of fixed route bus engine share for various fuels. Various scenarios clearly show how fast ED95 bus can penetrate vehicle stock from ED95 bus introduction in both Bangkok and provincial regions. Note that S-curve assumption of technology penetration is well reflected here.



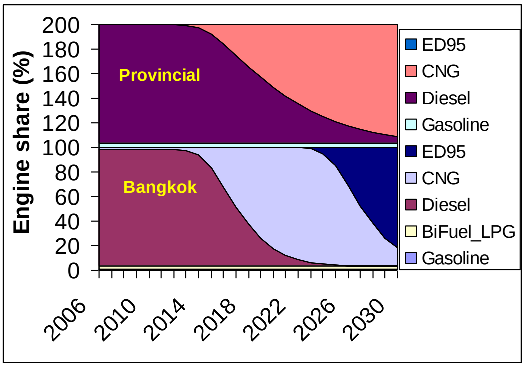
(a) vehicle sold, BAU



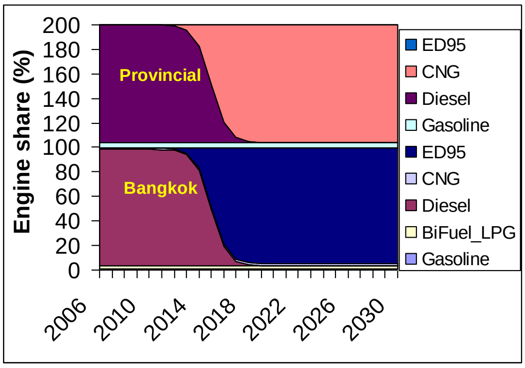
(aa) vehicle stock, BAU



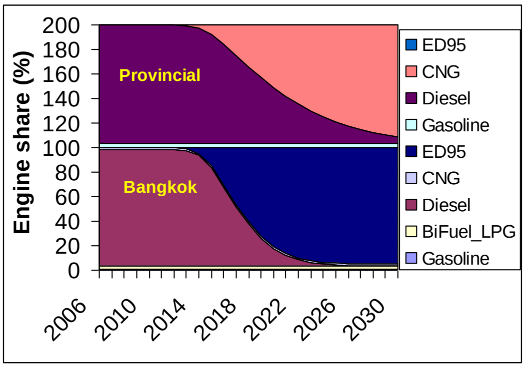
(b) vehicle sold, A.1



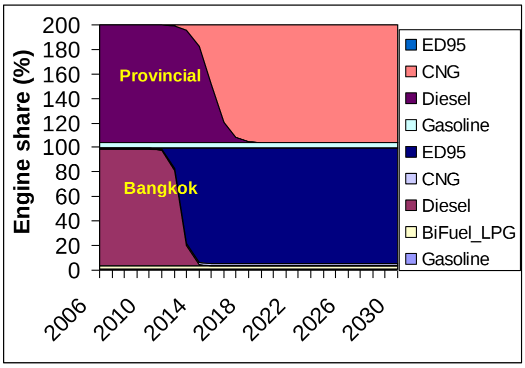
(bb) vehicle stock, A.1



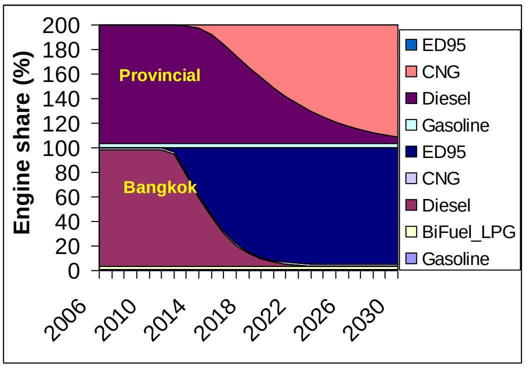
(c) vehicle sold, A.2.1(a)



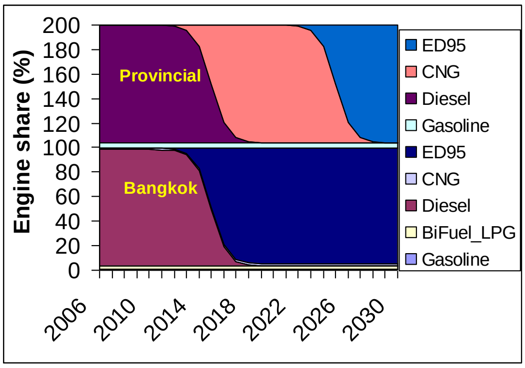
(cc) vehicle stock, A.2.1(a)



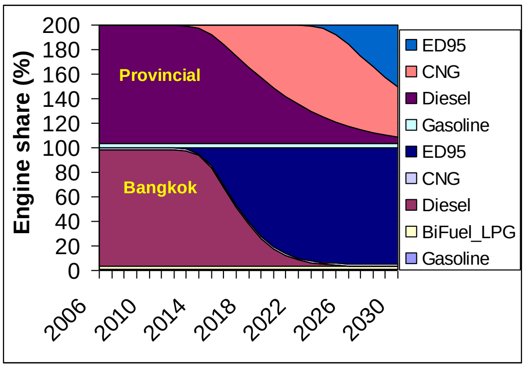
(d) vehicle sold, A.2.1(b)



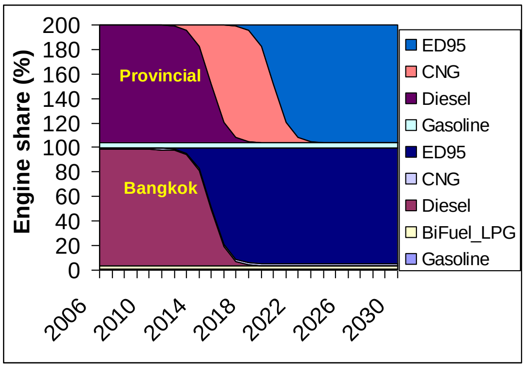
(dd) vehicle stock, A.2.1(b)



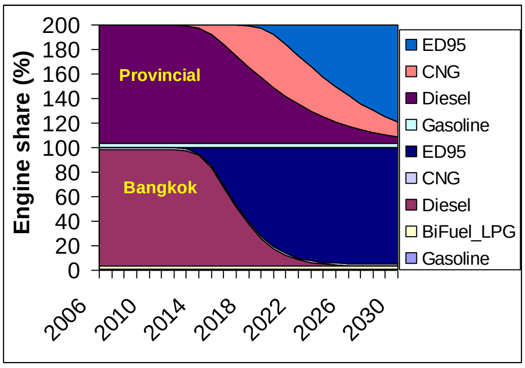
(e) vehicle sold, A.2.2(a)



(ee) vehicle stock, A.2.2(a)



(f) vehicle sold, A.2.2(b)



(ff) vehicle stock, A.2.2(b)

Fig. 33 Evolution of engine percentage for fixed route bus in various scenarios (a, aa) BAU, (b, bb) A.1, (c, cc) A.2.1(a), (d, dd) A.2.1(b), (e, ee) A.2.2(a), (f, ff) A.2.2(b)

With focus on ethanol demand target in Fig. 3, ethanol demand from ED95 technology penetration in various scenarios is shown in Fig. 34 and Table 26. Clearly, even with strongest push for ED95 technology in fixed route bus, the 9 ML/day target of ethanol demand cannot be reached.

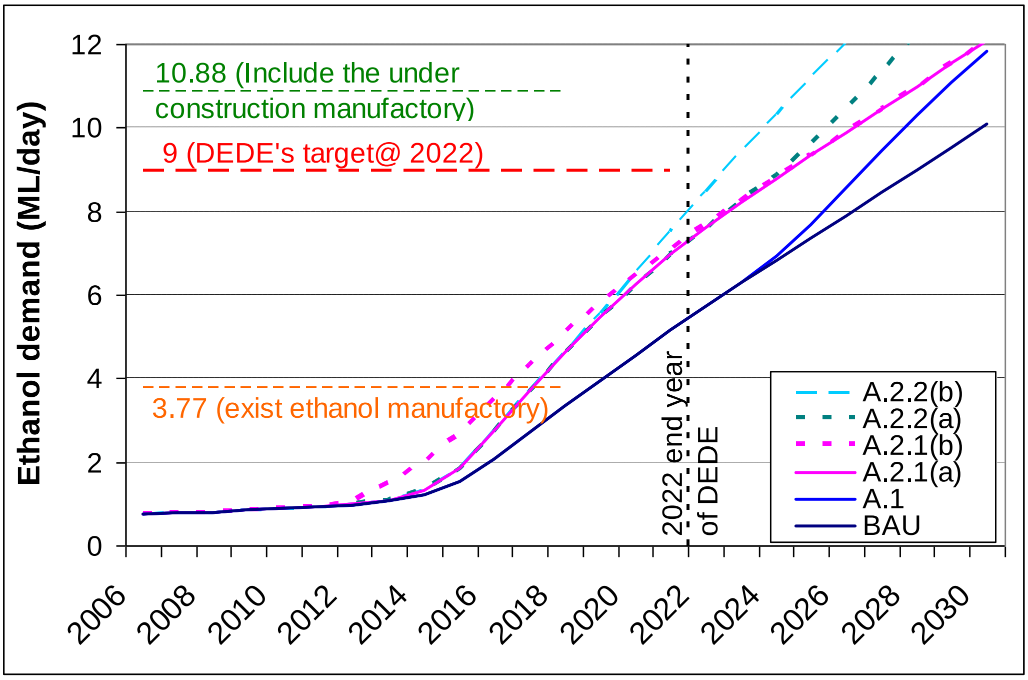


Fig. 34 Ethanol demand for applying existing technology on the fixed route bus

Table 26: Ethanol demand for applying existing technology on the fixed route bus

	Ethanol demand (ML/day)					
	BAU.	A.1	A.2.1(a)	A.2.1(b)	A.2.2(a)	A.2.2(b)
2006	0.758	0.758	0.758	0.758	0.758	0.758
2009	0.836	0.836	0.836	0.836	0.836	0.836
2012	0.976	0.976	0.982	1.057	0.982	0.982
2015	1.541	1.541	1.853	2.699	1.853	1.854
2018	3.325	3.325	4.610	5.108	4.610	4.629
2021	5.139	5.140	6.956	7.101	6.957	7.491
2022	5.710	5.716	7.604	7.688	7.608	8.465
2024	6.818	6.921	8.784	8.807	8.870	10.300
2027	8.434	9.435	10.424	10.426	11.357	12.821
2030	10.094	11.819	12.086	12.086	14.072	15.189

In addition, ED95 technology offer environmental benefit since combustion of renewable ethanol fuel results in less GHG emission than combustion of fossil diesel and CNG, as discussed in Section 2.4. Table 27 shows amount of diesel and CNG substituted by ED95. Note that only scenario A.2.1(b) with 5 year introduction of ED95 bus, some of the diesel bus will be converted to ED95 directly. Fig. 35 and Table 28 show amount of GHG emissions reduction from BAU. It is clear that the stronger is the push for ED95 bus, the faster GHG emission reduction can be realized.

Table 27: CNG and Diesel substitution with referring to BAU scenario

	Fuel substitution (CNG: kTon/year, Diesel: ML/year)									
	A.1		A.2.1(a)		A.2.1(b)		A.2.2(a)		A.2.2(b)	
	CNG	Diesel	CNG	Diesel	CNG	Diesel	CNG	Diesel	CNG	Diesel

2006	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00
2012	0.00	0.00	1.48	0.00	1.48	15.34	1.48	0.00	1.48	0.00
2015	0.00	0.00	82.81	0.00	82.81	173.49	82.81	0.00	82.84	0.00
2018	0.00	0.00	340.31	0.00	340.31	102.27	340.32	0.00	345.49	0.00
2021	0.33	0.00	481.26	0.00	481.26	29.59	481.53	0.00	627.48	0.00
2024	27.43	0.00	520.91	0.00	520.91	4.75	544.53	0.00	935.18	0.00
2027	265.13	0.00	527.15	0.00	527.15	0.37	782.20	0.00	1,182.33	0.00
2030	456.90	0.00	527.71	0.00	527.71	0.37	1,070.61	0.00	1,375.76	0.00

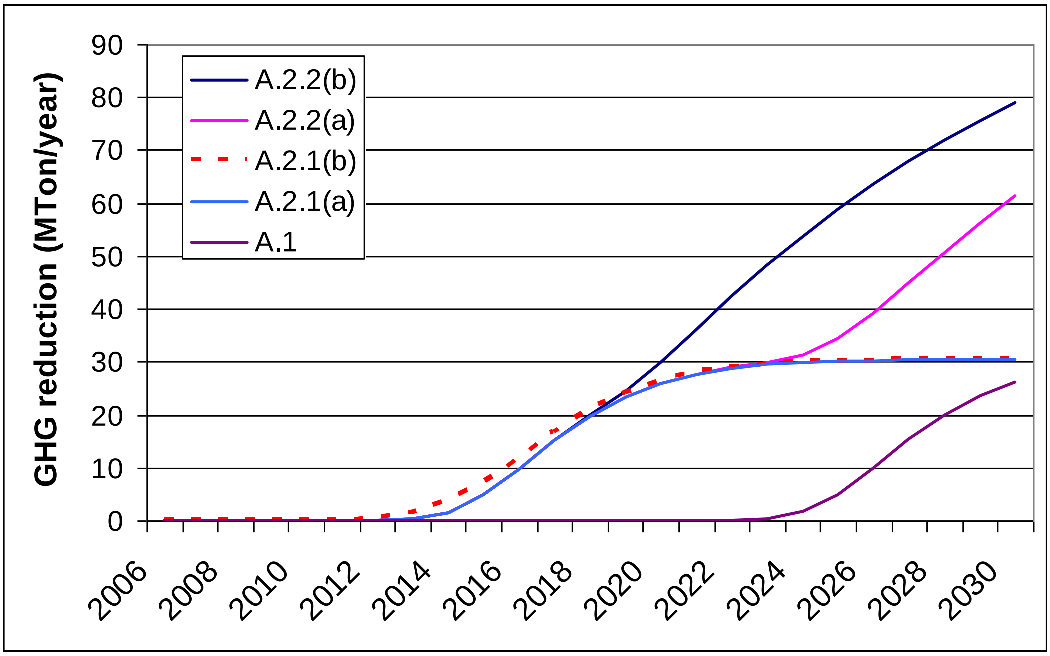


Fig. 35 GHG emission reduction (MTon of $CO_{2,eq}$) by applying ED95 on fixed route bus, with referring to BAU scenario

Table 28: GHG emission reduction (MTon of $CO_{2,eq}$) by applying ED95 on fixed route bus, with referring to BAU scenario

	A.1	A.2.1(a)	A.2.1(b)	A.2.2(a)	A.2.2(b)
2006	0.00	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00	0.00
2012	0.00	0.08	0.30	0.08	0.08
2015	0.00	4.75	7.18	4.75	4.75
2018	0.00	19.53	20.97	19.53	19.83
2021	0.02	27.62	28.04	27.64	36.01
2024	1.57	29.90	29.97	31.25	53.68
2027	15.22	30.26	30.26	44.90	67.86
2030	26.22	30.29	30.29	61.45	78.96

5.3 Technology Penetration of Fixed Route Bus (A.2.2(a)) to Non-Fixed Route Bus/Truck in Bangkok region

These scenarios assume that the ED95 technology has expanded to other non-fixed route bus/truck after successful introduction in fixed route bus. Due to the ED95 fueling infrastructure requirement, these scenarios on non-fixed route bus/truck are confined within Bangkok with the starting time of implementation in 2020 for 10 years. The target vehicles are the non-fixed route heavy duty vehicles that ED95 technology can be applied without much research effort on new technology. These vehicles are non-fixed route bus (Bus02), private bus (Bus03), non-fixed route truck (Truck01) and private truck (Truck02). These vehicles are mostly diesel vehicle so the development of vehicle sold is similar, as shown in Fig. 36. On the other hand, the evolution of vehicle stocks is dependent on their life time and growth rate of vehicle number, as shown in Fig. 37.

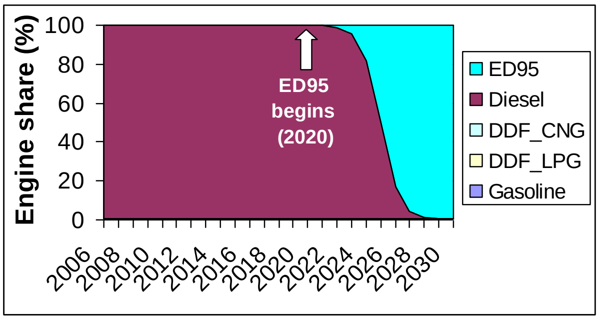
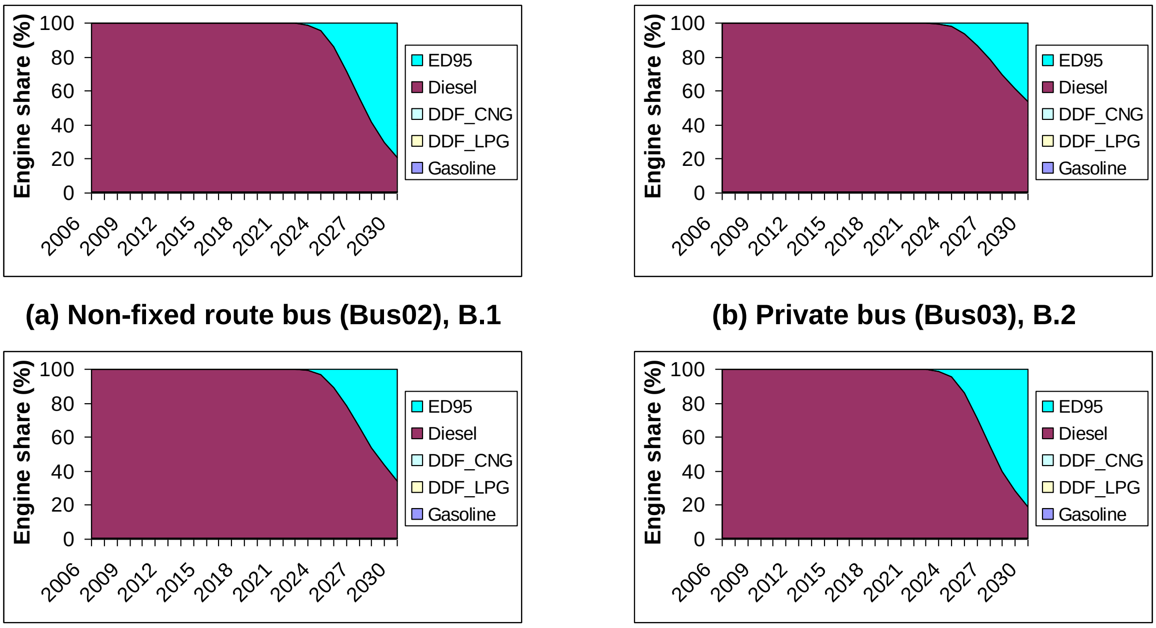


Fig. 36 Evolution of engine percent for vehicle sold when applying ED95 technology to the non-fixed route heavy duty vehicle: scenario B



(a) Non-fixed route bus (Bus02), B.1

(b) Private bus (Bus03), B.2

(c) Non-fixed route truck (Truck01), B.3

(d) Private truck (Truck02), B.4

Fig. 37 Evolution of engine percent for vehicle stock when applying ED95 technology to the non-fixed route heavy duty vehicle: scenario B

The ethanol demands for these scenarios are depicted in Fig. 38 and Table 29 in comparison with the results of scenario A.2.2(a). Since scenarios B introduced ED95 technology to other non-fixed route bus and truck after 2020, the ethanol demand starts to increase from the based scenario A.2.2(a) after 2024, where 9 ML/d target is reached (2 years after the targeted year of 2022).

The effectiveness of increasing ethanol demand depends on the number of ED95 in vehicle stock that is related to the growth of ED95 fraction (in Fig. 37) and number of vehicle (in section 4.2.4). Clearly from Fig. 14, the potential of private bus (Bus03) is the lowest because of lowest growth of ED95 fraction and vehicle number. Hence, B.2 curve is not so different from A.2.2(a) curve in Fig. 38. Furthermore, since the predicted number of vehicles for non-fixed route truck (Truck01) and private truck (Truck02) are similar and both higher than non-fixed route bus (Bus02), the ethanol demand prediction in Fig. 38 shows similar B3 and B4 curves, both higher than B1..

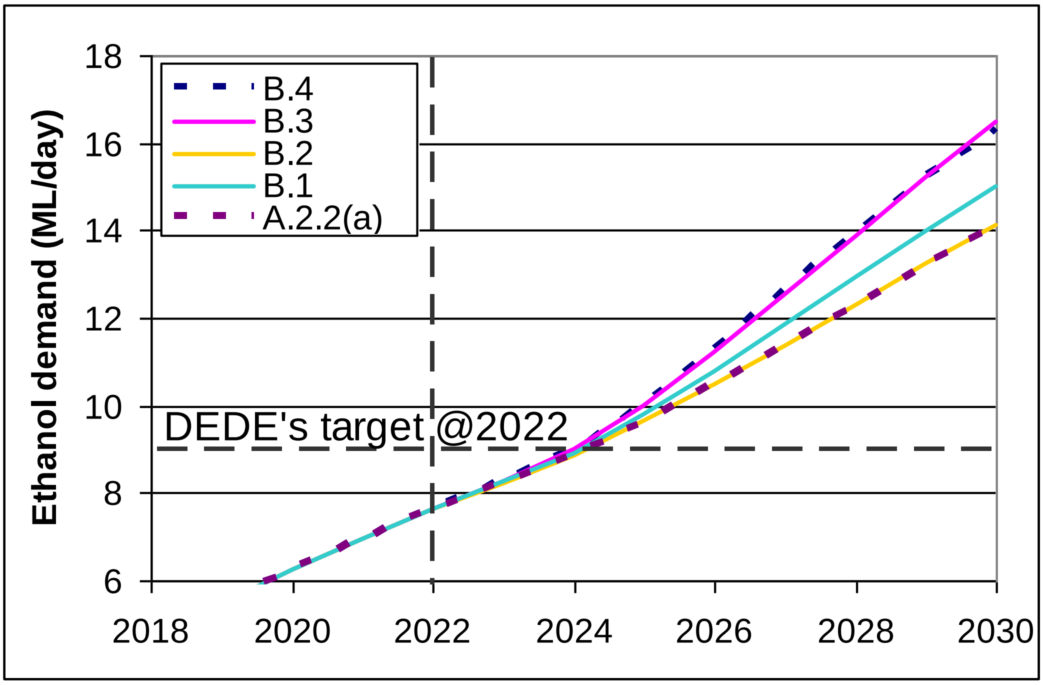


Fig. 38 Ethanol demand (ML/day) for applying existing technology on the non-fixed route heavy duty vehicle

Table 29: Ethanol demand (ML/day) for applying existing technology on the non-fixed route heavy duty vehicle

	A.2.2(a)	B.1	B.2	B.3	B.4
2006	0.758	0.758	0.758	0.758	0.758
2009	0.836	0.836	0.836	0.836	0.836
2012	0.982	0.982	0.982	0.982	0.982
2015	1.853	1.853	1.853	1.853	1.853
2018	4.610	4.610	4.610	4.610	4.610
2021	6.957	6.957	6.957	6.958	6.958
2024	8.870	8.919	8.872	8.982	9.008
2027	11.357	11.853	11.379	12.544	12.665
2030	14.072	14.986	14.114	16.471	16.326

Since these scenarios introduce ED95 technology to those vehicles running on diesel, diesel fuel demand can be reduced, as shown in Fig. 39 and Table 30 in comparison to scenario A.2.2(a). Moreover, Fig. 40 **and** Table 31 **show additional GHG emission reduction to the result from scenario A.2.2(a).**

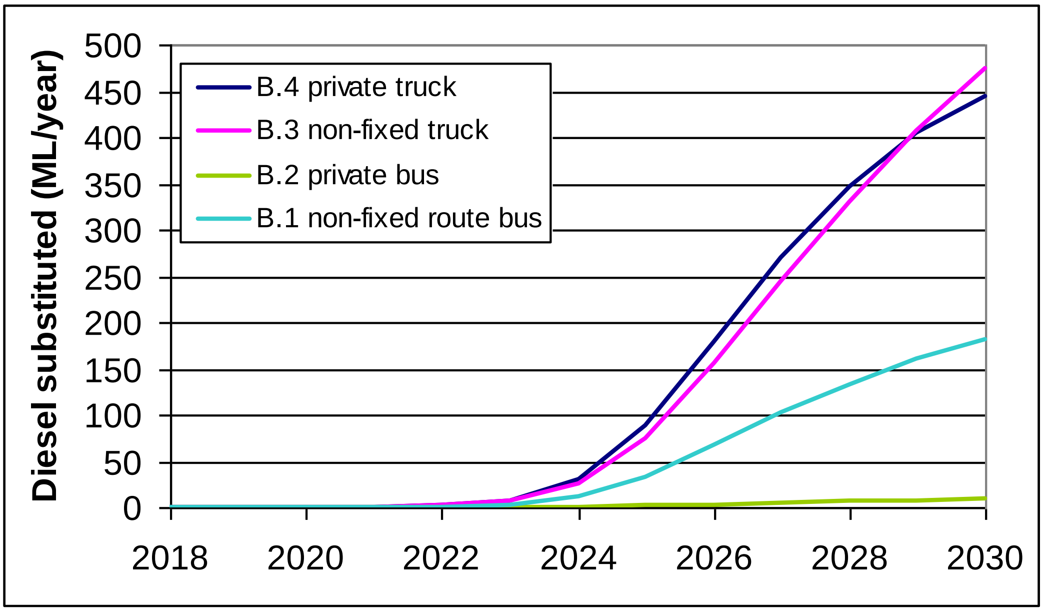


Fig. 39 Diesel substituted (ML/year) by applying ED95 technology to non-fixed route heavy duty vehicle: scenario B

Table 30: Diesel substituted (ML/year) by applying ED95 technology to non-fixed route heavy duty vehicle: scenario B

	B.1	B.2	B.3	B.4
2006	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00
2012	0.00	0.00	0.00	0.00
2015	0.00	0.00	0.00	0.00
2018	0.00	0.00	0.00	0.00
2021	0.00	0.00	0.00	0.37
2024	10.59	0.73	24.47	29.95
2027	101.90	4.75	244.35	269.19
2030	180.43	8.40	473.36	444.87

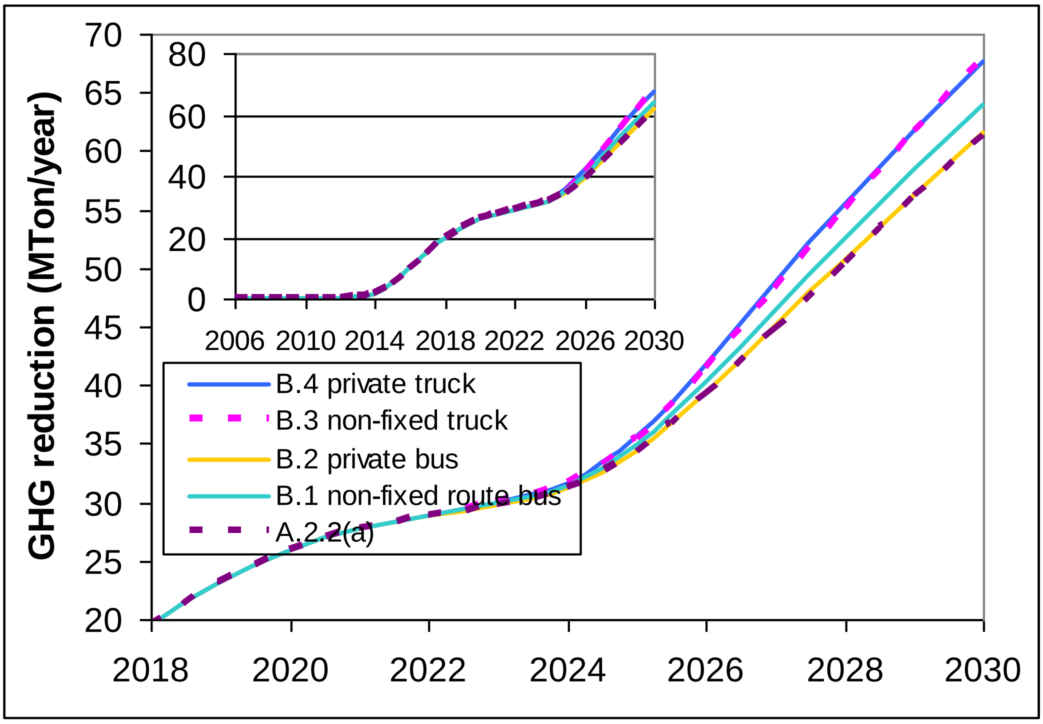


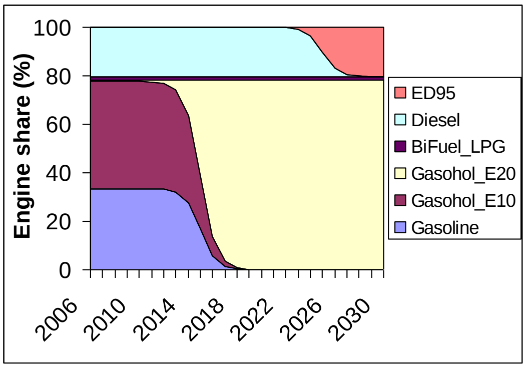
Fig. 40 GHG reduction (MTon of $CO_{2,eq}$) by applying ED95 technology to non-fixed route heavy duty vehicle: scenario B

Table 31: GHG reduction (MTon of $CO_{2,eq}$) by applying ED95 technology to non-fixed route heavy duty vehicle: scenario B

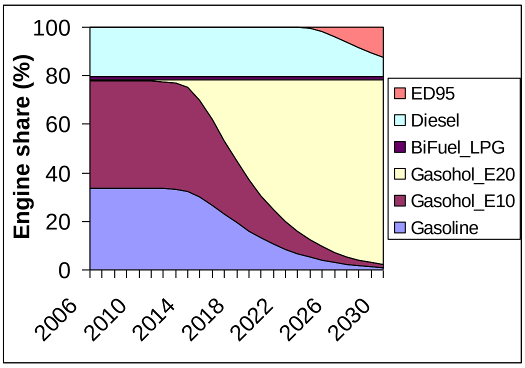
	A.2.2(a)	B.1	B.2	B.3	B.4
2006	0.00	0.00	0.00	0.00	0.00
2009	0.00	0.00	0.00	0.00	0.00
2012	0.08	0.08	0.08	0.08	0.08
2015	4.75	4.75	4.75	4.75	4.75
2018	19.53	19.53	19.53	19.53	19.53
2021	27.64	27.64	27.64	27.64	27.64
2024	31.25	31.40	31.26	31.59	31.67
2027	44.90	46.32	44.96	48.32	48.67
2030	61.45	63.97	61.57	68.07	67.67

5.4 New ED95 Technology Development for Small Engine (Passenger Car and Pick-up Truck) in Bangkok region

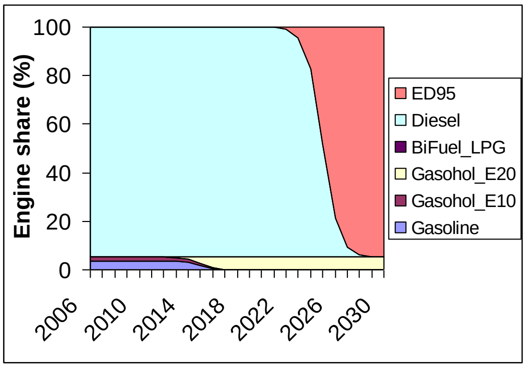
The strongest push for ED95 technology is reflected in this scenario analysis, where indigenous ED95 technology is developed for passenger car (PC01) and pick-up truck (PC02). Similar to previous section, the assumption is confined to Bangkok region with the starting year of 2020 for a period of 10 years. The engine shared percent of vehicle sold and stock for PC01 and PC02 in these scenarios are shown in Fig. 41 with comparison to BAU result.



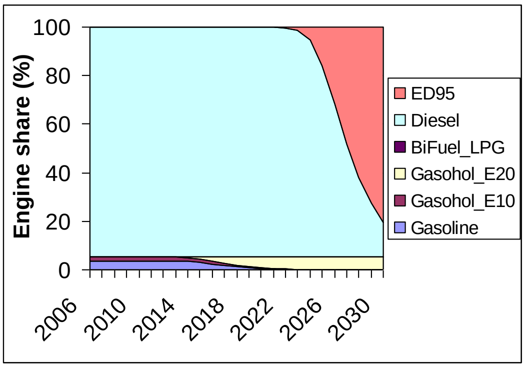
(a) Vehicle sold, C.1



(aa) Vehicle stock, C.1



(b) Vehicle sold, C.2



(bb) Vehicle stock, C.2

Fig. 41 Evolution of engine percent when applying ethanol diesel technology on small vehicle (a, aa) passenger car (PC01, scenario C.1), (b, bb) pickup truck (PC02, scenario C.2)

The ethanol demand from both scenarios are shown in Fig. 42 and Table 32, with comparison to scenario A.2.2(a). It is expected that ED95 technology introduction to pick-up truck sector would yield the most effective way to increase ethanol demand, up to 55.7 ML/day by 2030. However, the ethanol target of 9 ML/day is not reached till 2023, 1 year after the targeted year. The amount of diesel being substituted by ED95 fuel referenced to A.2.2(a) is shown in Fig. 43 and Table 33, with the GHG emission reductions shown in Fig. 44 and Table 34.

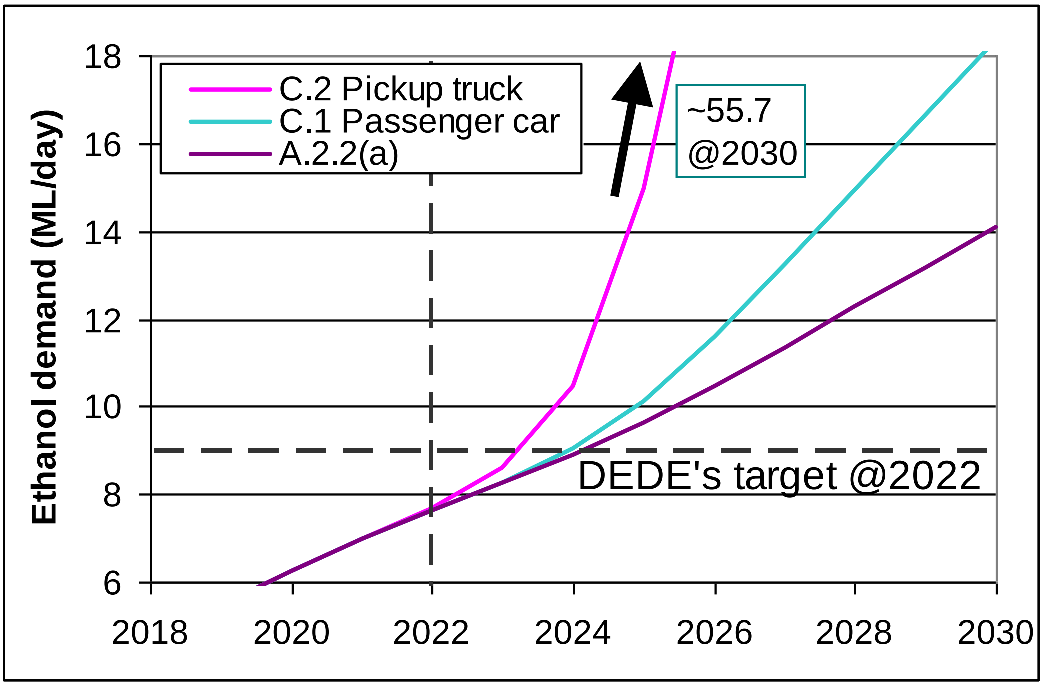


Fig. 42 Ethanol demand (ML/day) when applying ethanol diesel technology on small vehicle: scenario C

Table 32: Ethanol demand (ML/day) when applying ethanol diesel technology on small vehicle: scenario C

	A.2.2(a)	C.1	C.2
2006	0.758	0.758	0.758
2009	0.836	0.836	0.836
2012	0.982	0.982	0.982
2015	1.853	1.853	1.853
2018	4.610	4.610	4.610
2021	6.957	6.958	6.972
2024	8.870	9.029	10.479
2027	11.357	13.230	30.787
2030	14.072	18.330	55.712

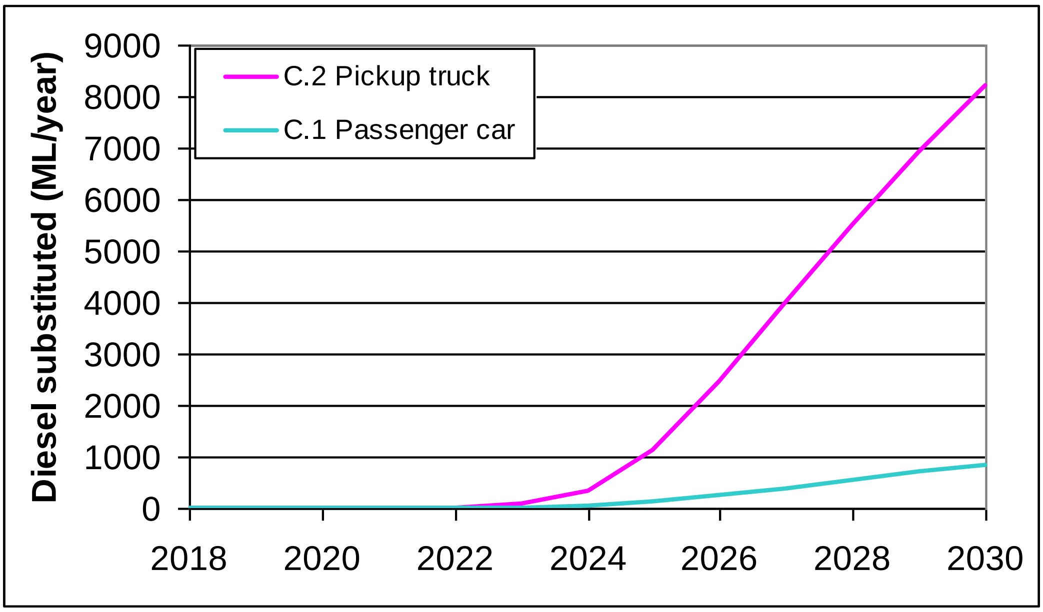


Fig. 43 Diesel substituted (ML/year) by applying ethanol diesel technology on small vehicle: scenario C

Table 33: Diesel substituted (ML/year) by applying ethanol diesel technology on small vehicle: scenario C

	C.1	C.2
2006	0.00	0.00
2009	0.00	0.00
2012	0.00	0.00
2015	0.00	0.00
2018	0.00	0.00
2021	0.37	3.29
2024	34.33	346.99
2027	385.34	3,999.12
2030	840.08	8,212.65

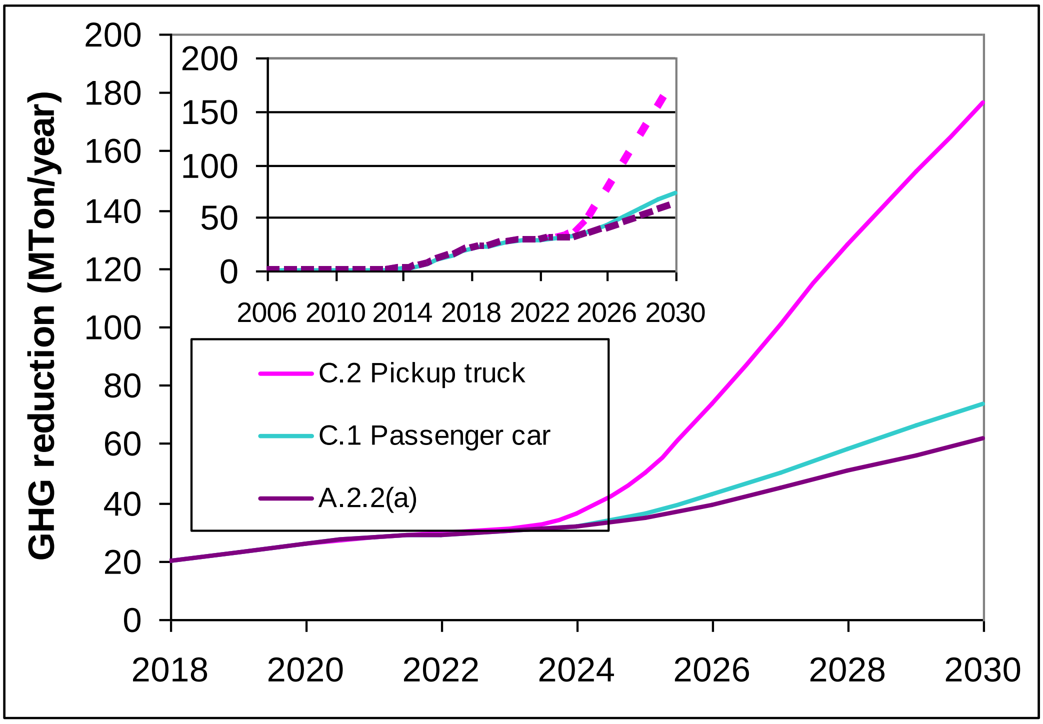


Fig. 44 GHG reduction (MTon of $CO_{2,eq}$) by applying ethanol diesel technology on small vehicle: scenario C

Table 34: GHG reduction (MTon of $CO_{2,eq}$) by applying ethanol diesel technology on small vehicle: scenario C

	A.2.2(a)	C.1	C.2
2006	0.00	0.00	0.00
2009	0.00	0.00	0.00
2012	0.08	0.08	0.08
2015	4.75	4.75	4.75
2018	19.53	19.53	19.53
2021	27.64	27.64	27.69
2024	31.25	31.73	36.11
2027	44.90	50.29	100.89
2030	61.45	73.21	176.45

CHAPTER 6 CONCLUSION

The present study has followed the bottom-up approach in developing an energy demand model, by recourse to LEAP program, in Thai transportation sector. Numerous statistical and technical data were collected and modeled, such as number and type of vehicles, representative fuel economy, fuel sharing and vehicle kilometer of travel (VKT). However, it was sometimes necessary to make some reasonable extrapolation for any unavailable but necessary data. With various externalities influencing on the energy demand, such as sudden fuel price and consumer behaviors, correction factor approach was necessary in order to calibrate the developed mathematical model. The calibrated model showed acceptable accuracy, which was then used to predict energy demand trend with comparative capability to assess the impact of any policy push or new technology penetration

Within the scope of the present study, ethanol bus (ED95) technology, where ethanol of 95% with 5% additive can be used as a fuel for specially-modified compression-ignition engine, was analyzed. The target of 9 ML/day ethanol consumption in 2022 from Thailand Alternative Energy Strategic Plan (2008-2022) was set as a goal for scenario analyses. With already commercially available ED95 bus, the scenario investigated could be categorized into 3 levels in an increasing order of difficulty.

- ✓ **Applying existing ED95 technology on the fixed route bus**
- ✓ **Extending ED95 technology to non-fixed route bus/truck**
- ✓ **Developing new ED95 technology for small compression-ignition engine**

For each scenario, additional assumptions on vehicle type, applied region, starting year and a period of ED95 technology introduction were applied to predict energy demand from 2010 to 2030. Ethanol demand at 2022 was checked against 9 ML/day target. Additional benefits from using ED95 technology, including CNG/diesel substitution and GHG reduction, were quantified. The following results were found.

- ✓ **ED95 technology offers another mechanism to increase ethanol demand as projected by Thailand Alternative Energy Strategic Plan (9 ML/day target in 2022).**
    - **For all scenarios studied, none could reach 9 ML/day target in 2022**
    - **With Bangkok fixed route bus converted to ED95 bus (start from 2010 for 5-10 years), 9 ML/day target will be reached by 2027**
    - **With Bangkok fixed route bus converted to ED95 bus (start from 2010 for 5 years) and Provincial fixed route bus converted to ED95 bus (start from 2015 for 10 years), 9 ML/day target will be reached by 2024 (case A.2.2)**
    - **Additional conversion of other than fixed route bus to ED95 bus after 2020 would reach 9 ML/day target by 2024**
    - **With additional pick-up truck converted to ED95 engine (start from 2020 for 10 years) on top of case A.2.2, 9 ML/day target will be reached by 2023**

- **Tentative policy recommendation**
    - **ED95 bus should be introduced into Bangkok fixed route bus (from 2010 for 5 years) and later in provincial region (from 2015 for 10 years) for most probable and effective promotion of ethanol utilization (case A.2.2).**
    - **Research on converting pick-up truck engine to ED95 engine should be supported for long term increase of ethanol demand.**
- **ED95 can be employed to decrease fossil fuel consumption and increase nation energy security from domestic renewable energy resource such as ethanol. Furthermore, greenhouse gas emission could be reduced by switching from CNG or diesel to ethanol with ED95 technology.**

However, further studies on financial aspect, as well as infrastructure investment, should be considered for final assessment of the policy recommendation.

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