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Development of Harmonized Energy Demand Model for Road Transportation with GHG Prediction for Thailand

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DEVELOPMENT OF HARMONIZED ENERGY DEMAND MODEL FOR ROAD TRANSPORTATION WITH GHG PREDICTION FOR THAILAND

ATRANS
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List of Abbreviations and Acronyms

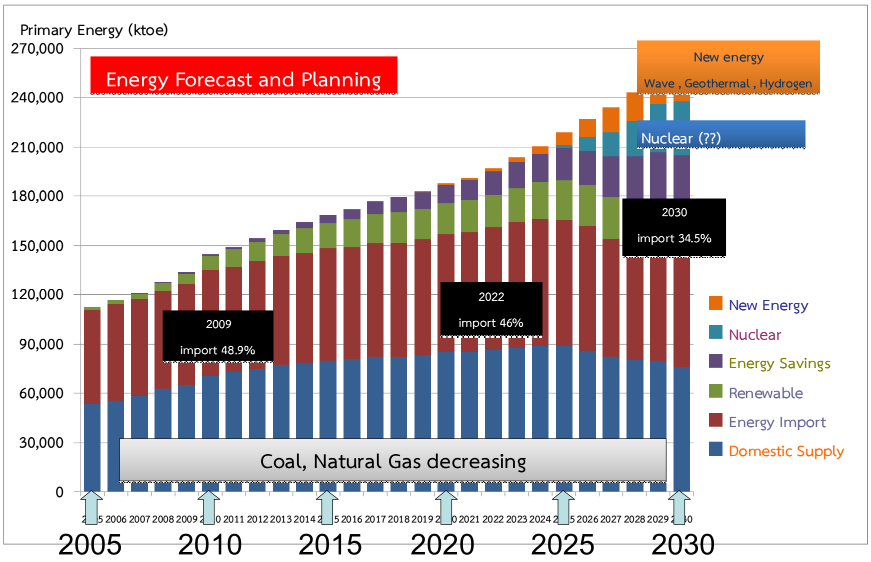
ASIF	Activity (A), Mode Share (S), Fuel Intensity (I) and Fuel Choice (F)
BAU	Business-As-Usual
CI	compression-ignition
DEDE	Department of Alternative Energy Development and Efficiency, Ministry of Energy (Thailand)
EPPO	Energy Policy and Planning Office
FE	Fuel economy
GDP	Gross domestic product
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
ktoe	Kilotonne of oil equivalent
LPD	Liter per day
LPG	Liquefied Petroleum Gas
MW	Megawatts
NEPC	National Energy Policy Council
NGV	Natural gas for vehicle
R&D	Research and development
SEI	Stockholm Environment Institute
SI	spark-ignition
THB	Thai Baht
TRF	Thailand Research Fund
VKT	Vehicle Kilometer Traveled
yrs	Years

CHAPTER I INTRODUCTION

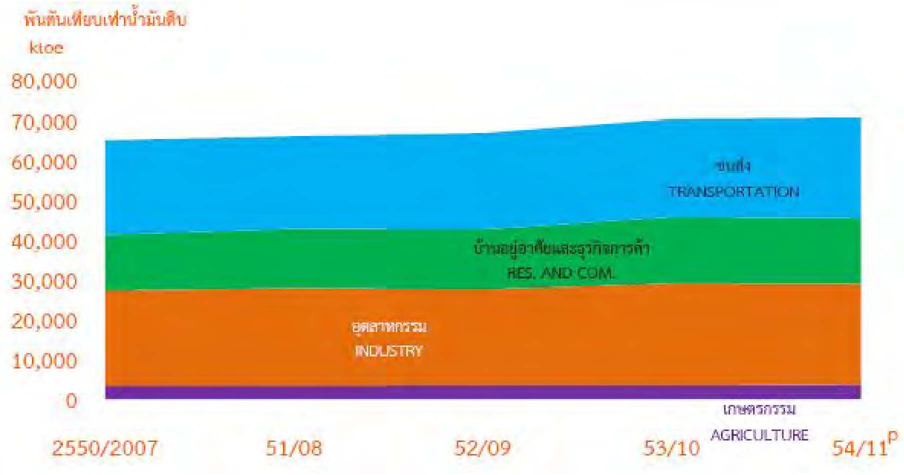
1.1 Rationale

As a net energy importer, Thailand has strived to secure energy supply for domestic demand. As shown in Fig. 1(a), Thailand Ministry of Energy has forecasted and planned the energy demand till 2030, based on currently available statistics on population and economic growths. To enhance national energy security, Thailand has two energy master plans. The first is 20-year Energy Efficiency Development Plan (EEDP: 2011-2030), which is labeled as "Energy Savings" in Fig. 1(a). On the other hand, the second is 10-year Alternative Energy Development Plan (AEDP: 2012-2021), which is labeled as "Renewable" in Fig. 1(a). From the past 5 years (2007-2011), Fig. 1(b) [1] shows that industry and transportation sectors are dominating with approximately 35-37% each. Hence, it is critical for policy makers to understand how energy demands from these two sectors behave with certain capability to be able to speculate and predict the trend in the future. In accordance with ATRANS interest, the present investigation will focus on road transportation sector, which dominates other sectors, as shown in Fig. 1(c).

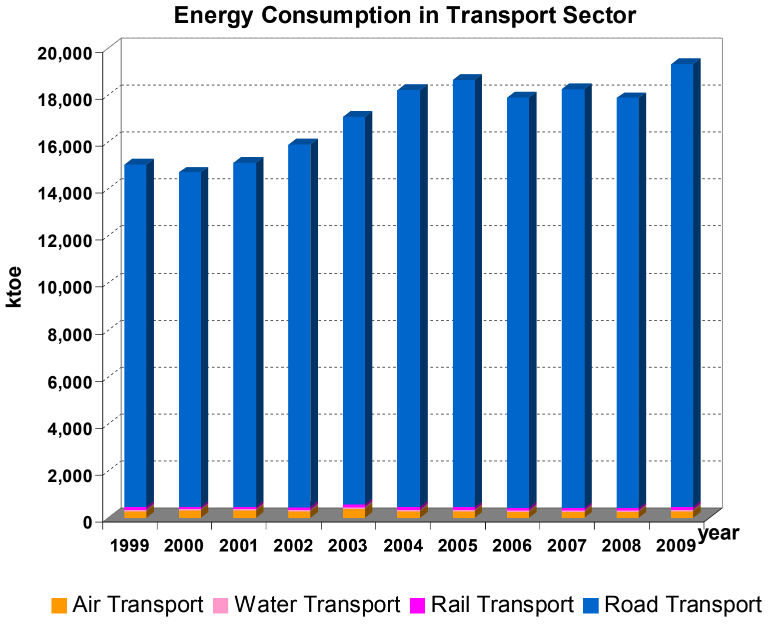
Road transportation sector in Thailand is dominated by diesel and gasoline, which are used to transport people and goods for economic prosperity, as shown in Fig. 1(d). Table 1 shows breakdown of vehicles in Thailand (as of 31 March 2013) by fuel types ranging from gasoline (with and without ethanol blend), diesel (with biodiesel blend mandate), LPG, CNG to even electricity. [2]. Various policies have been initiated and implemented in order to reduce fossil consumption. With a bless from mother nature, Thailand has competitive advantage on biofuel, which has been included in Alternative Energy Development Plan (AEDP), as shown in Fig. 2(a). Two forms of biofuels, ethanol and biodiesel, have been commercially used throughout Thailand, not only to strengthen national energy security but also to reduce GHG (greenhouse gas) emission. Furthermore, higher efficiency vehicle, such as many types of electric vehicles (EVs), is included as one of the measure for transportation sector within Energy Efficiency Development Plan (EEDP), as shown in Fig. 2(b).


Primary Energy (ktoe)
270,000
240,000
210,000
180,000
150,000
120,000
90,000
60,000
30,000
0
Energy Forecast and Planning
New energy
Wave , Geothermal , Hydrogen
Nuclear (??)
2030
import 34.5%
2022
import 46%
2009
import 48.9%
Coal, Natural Gas decreasing
New Energy
Nuclear
Energy Savings
Renewable
Energy Import
Domestic Supply
2006 2007 2008 2009 2011 2012 2013 2014 2016 2017 2018 2019 2021 2022 2023 2024 2026 2027 2028 2029
2005
2010
2015
2020
2025
2030

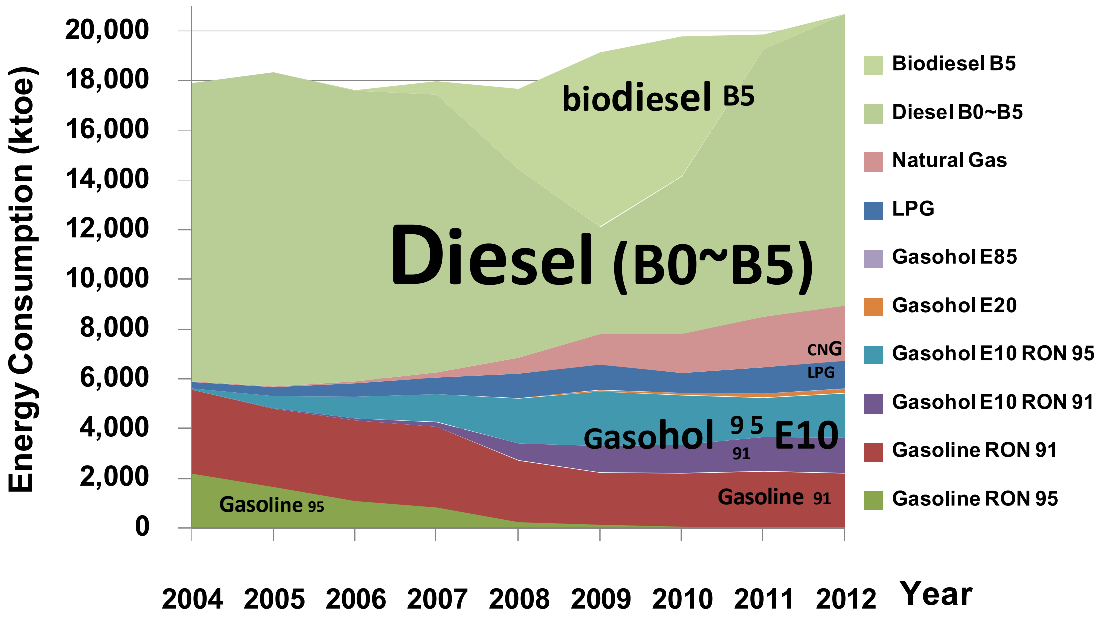
(a)


พันตันเทียบเท่าน้ำมันดิบ
ktoe
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
ขนส่ง
TRANSPORTATION
บ้านอยู่อาศัยและธุรกิจการค้า
RES. AND COM.
อุตสาหกรรม
INDUSTRY
เกษตรกรรม
AGRICULTURE
2550/2007
51/08
52/09
53/10
54/11P

(b)


Energy Consumption in Transport Sector
ktoe
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
year
Air Transport
Water Transport
Rail Transport
Road Transport

(c)

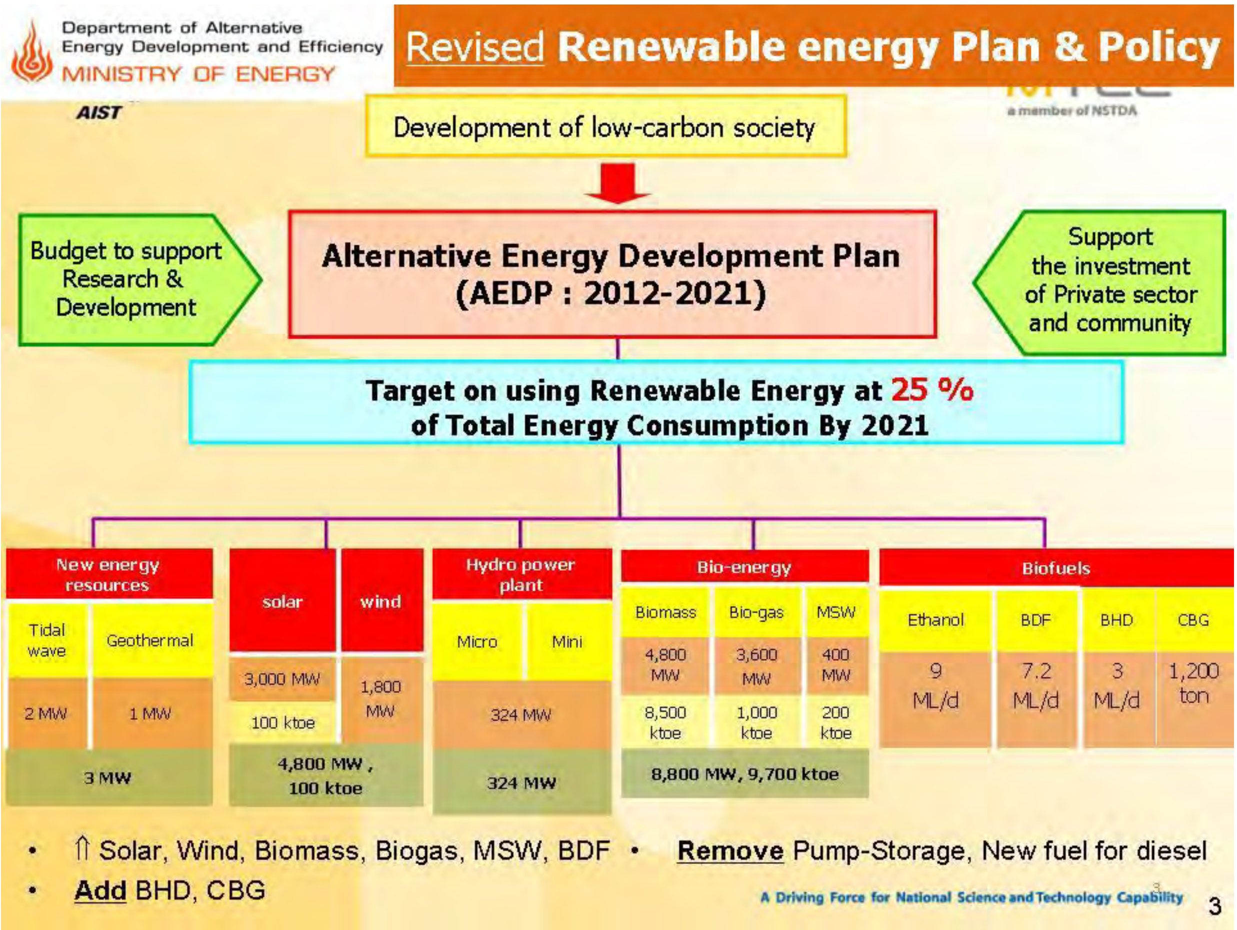


(d)

Fig. 1 (a) Thailand energy demand (with forecasting), (b) Thailand energy consumption by economic sectors, (c) Thailand energy consumption in transport sector by mean and (d) Thailand transport energy consumption by type

Table 1: List of vehicles in Thailand by fuel type

Type	Total	Gasoline	Diesel	All LPG	All CNG	Hybrid	Electric	Non fuel	Other
Passenger Cars	6,575,208	3,705,852	1,804,518	851,579	154,525	43,676	21	-	15,037
Pick-up Truck	5,527,731	203,503	5,125,407	128,236	49,218	2	6	-	21,359
Motorcycle	19,291,407	19,286,984	-	-	-	72	4,351	-	-
Public Motorcycle	120,149	120,149	-	-	-	-	-	-	-
Tuk Tuk	22,205	3,934	71	16,487	1,676	-	3	-	34
Taxi	117,810	4,368	1,145	40,478	71,729	75	2	-	13
Truck	912,370	678	710,047	1,852	38,102	1	17	151,101	10,572
Bus	139,265	5,606	101,763	4,463	27,220	26	32	-	155
Tractor & Farm Vehicle	447,604	-	447,604	-	-	-	-	-	-
Other	13,790	-	10,955	-	-	-	-	2,835	-
All	**33,167,625**	**23,331,104**	**8,201,542**	**1,043,099**	**342,490**	**43,826**	**4,426**	**153,968**	**47,170**



Department of Alternative Energy Development and Efficiency
MINISTRY OF ENERGY

AIST

Revised Renewable energy Plan & Policy

a member of NSTDA

Development of low-carbon society

Budget to support Research & Development

Alternative Energy Development Plan (AEDP : 2012-2021)

Support the investment of Private sector and community

Target on using Renewable Energy at 25 % of Total Energy Consumption By 2021

New energy resources
- Tidal wave: 2 MW
- Geothermal: 1 MW
- 3 MW

solar: 3,000 MW, 100 ktoe
wind: 1,800 MW
- 4,800 MW , 100 ktoe

Hydro power plant
- Micro, Mini: 324 MW
- 324 MW

Bio-energy
- Biomass: 4,800 MW, 8,500 ktoe
- Bio-gas: 3,600 MW, 1,000 ktoe
- MSW: 400 MW, 200 ktoe
- 8,800 MW, 9,700 ktoe

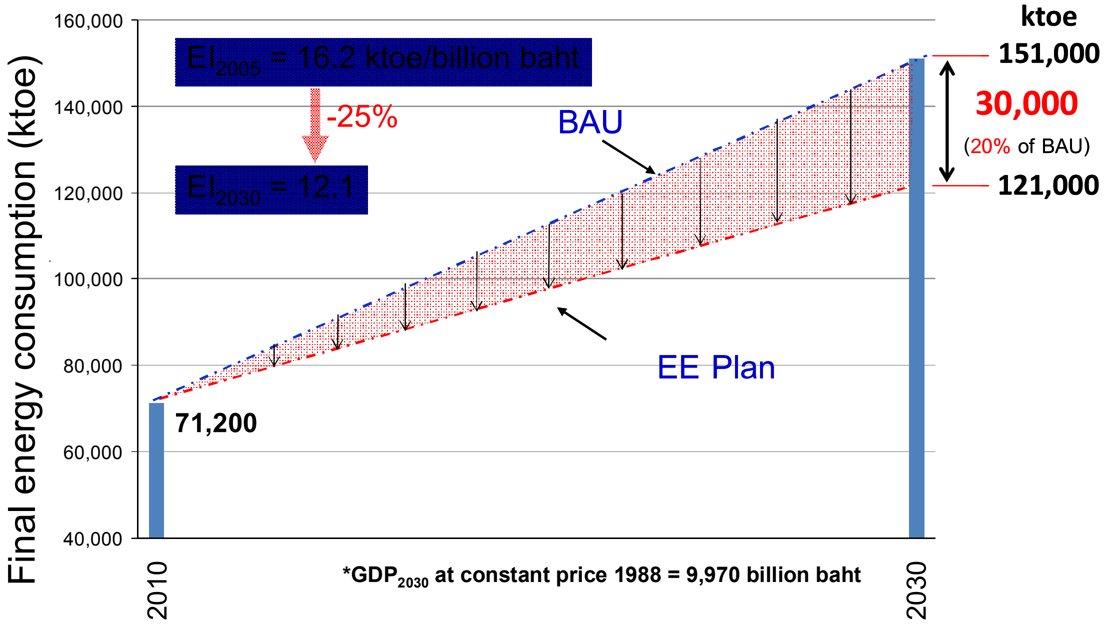
Biofuels
- Ethanol: 9 ML/d
- BDF: 7.2 ML/d
- BHD: 3 ML/d
- CBG: 1,200 ton

- ⇑ Solar, Wind, Biomass, Biogas, MSW, BDF
- **Remove** Pump-Storage, New fuel for diesel
- **Add** BHD, CBG

A Driving Force for National Science and Technology Capability

3

(a)



*GDP_{2030} at constant price 1988 = 9,970 billion baht

(b)

Fig. 2 (a) Thailand Alternative Energy Development Plan (AEDP) and (b) Thailand Energy Efficiency Development Plan (EEDP)

1.2 Objectives

To be able to understand the energy demand behavior with capability to predict future demand with potential benefit from GHG reduction by a use of renewable biofuel and/or higher efficiency electric vehicle, energy demand modeling is needed. A bottom-up engineering approach, e.g. LEAP (Long-range Energy Alternatives Planning) model [3], has been proved suitable for this kind of problem worldwide. However, only a few groups of Thai researchers [4, 5], including previous ATRANS project [6], have been actively investigating different aspects. Hence, the objectives of the proposed investigation are

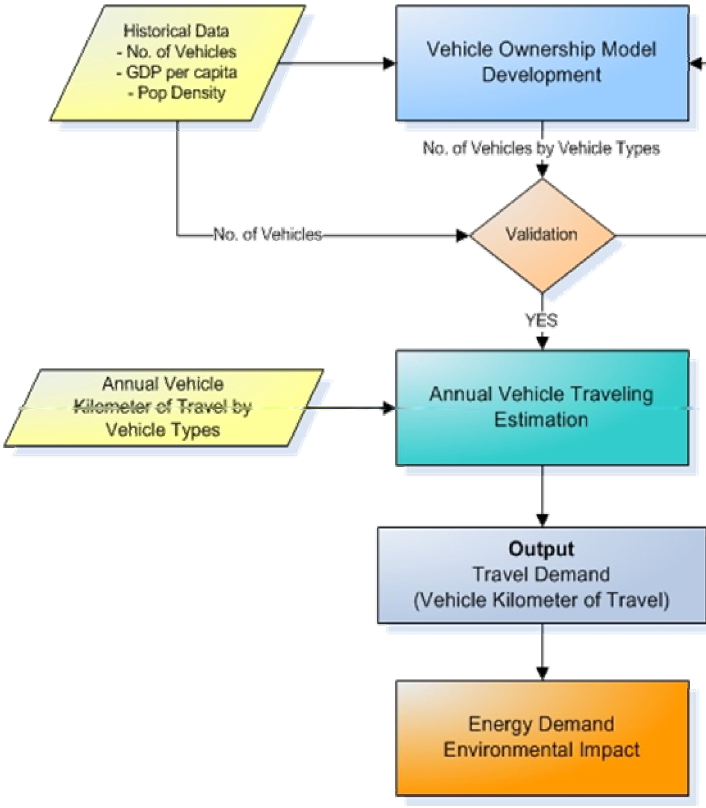
1. To review and compare various energy demand modeling in Thailand with LEAP program.
2. To construct a harmonized version that best fit the current situation with most versatile capability.
3. To analyze and forecast energy demand with GHG benefit from biofuel.

1.3 Methodology

In order to analyze energy use pattern in transportation sector with capability to predict energy demand with resulting emission, 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 2 [7]. 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. 3 [3]. Among many others, Long-range Energy Alternatives Planning (LEAP) system [3] will be utilized to construct the energy demand model in this study.

Table 2: Differences between top-down and bottom-up approach in energy model

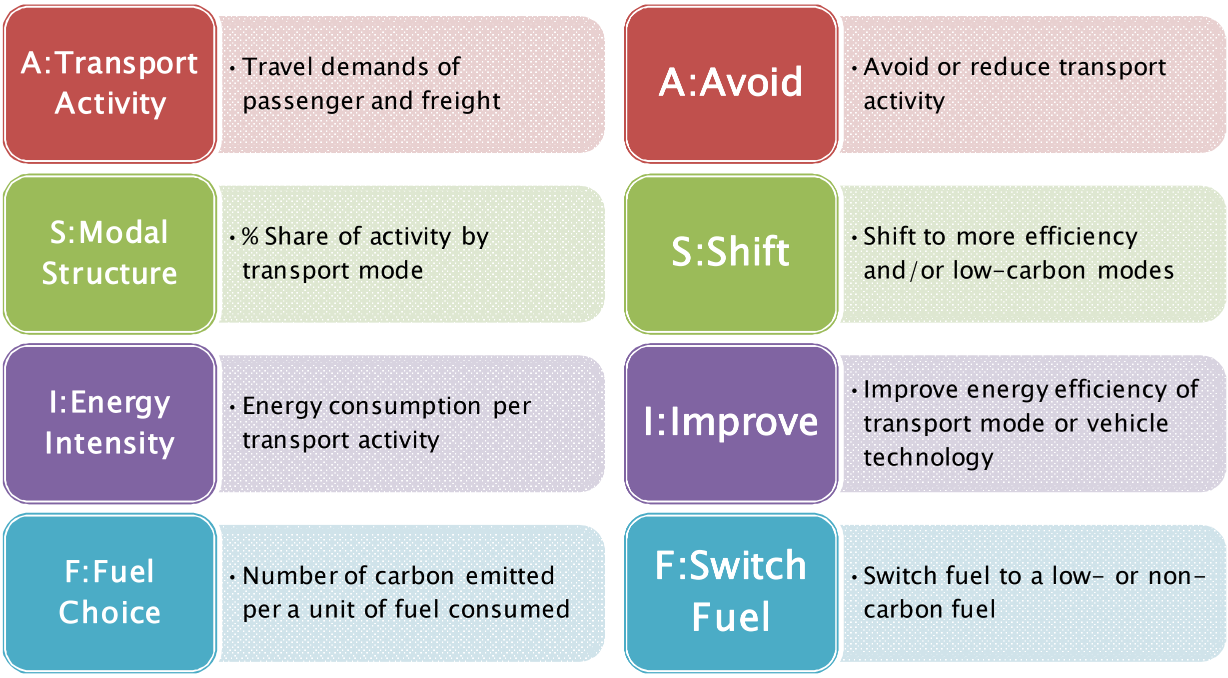
Top-down	Bottom-up
Use aggregated economic data	Use detailed data on fuels, technologies and policies
Assess costs/benefits through impact on output, income, GDP	Assess costs/benefits of individual technologies and policies
Implicitly capture administrative, implementation and other costs.	Can explicitly 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.	



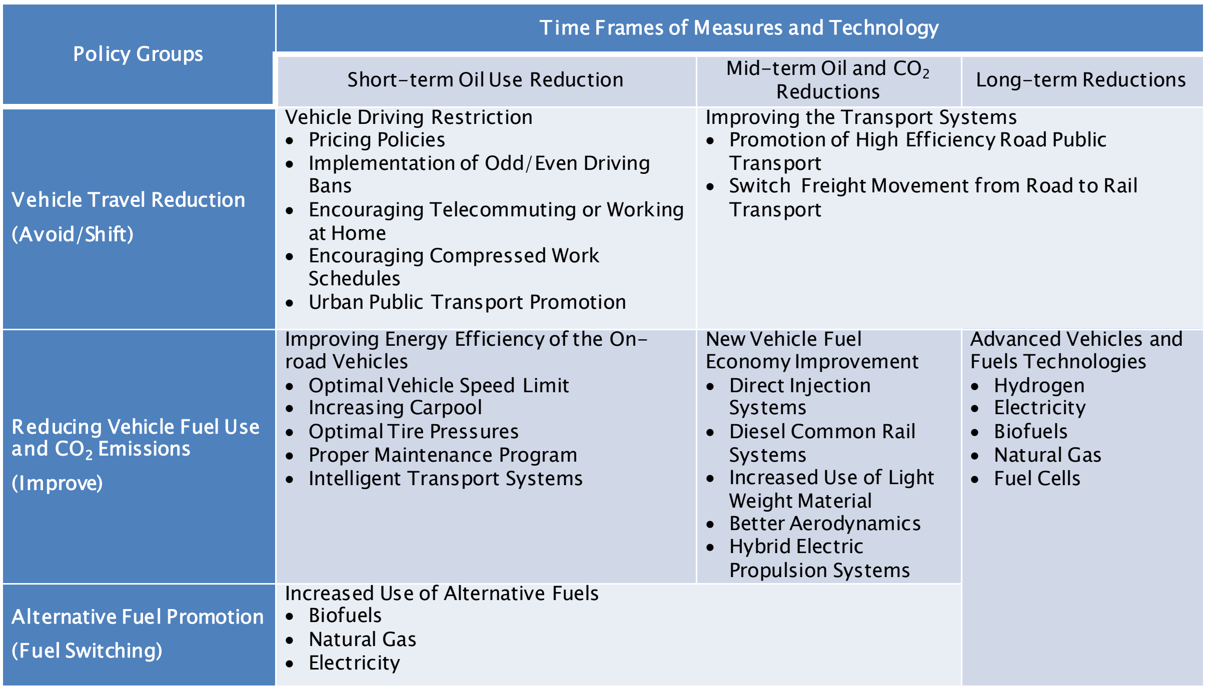
				Energy demand module			
Sector	Sub-sector	End-use	Device	Energy intensity			Energy demand
Transport sector (vehicle)	Transport mode (per cent)	Modal split (per cent)	Vehicle kilometer of travel (kilometer)	Type of fuel used (per cent)	Fuel economy of vehicle (GJ per veh-km)	⇨	Scenario analysis (GJ or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

Fig. 3 Flow of bottom-up energy demand model

From previous study [8], 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) [9, 10, 11], as shown in Fig. 4(a). This ASIF concept can be applied for emission reduction in transportation sector as shown in Fig. 4(b), which include both renewable biofuel and higher efficiency electric vehicle.



(a)



Policy Groups	Time Frames of Measures and Technology		
	Short-term Oil Use Reduction	Mid-term Oil and CO_2 Reductions	Long-term Reductions
Vehicle Travel Reduction (Avoid/Shift)	Vehicle Driving Restriction • Pricing Policies • Implementation of Odd/Even Driving Bans • Encouraging Telecommuting or Working at Home • Encouraging Compressed Work Schedules • Urban Public Transport Promotion	Improving the Transport Systems • Promotion of High Efficiency Road Public Transport • Switch Freight Movement from Road to Rail Transport	
Reducing Vehicle Fuel Use and CO_2 Emissions (Improve)	Improving Energy Efficiency of the On-road Vehicles • Optimal Vehicle Speed Limit • Increasing Carpool • Optimal Tire Pressures • Proper Maintenance Program • Intelligent Transport Systems	New Vehicle Fuel Economy Improvement • Direct Injection Systems • Diesel Common Rail Systems • Increased Use of Light Weight Material • Better Aerodynamics • Hybrid Electric Propulsion Systems	Advanced Vehicles and Fuels Technologies • Hydrogen • Electricity • Biofuels • Natural Gas • Fuel Cells
Alternative Fuel Promotion (Fuel Switching)	Increased Use of Alternative Fuels • Biofuels • Natural Gas • Electricity		

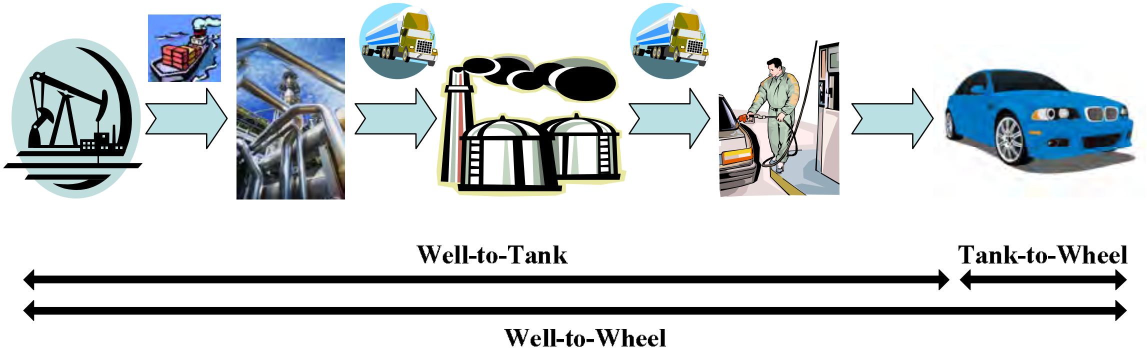
(b)

Fig. 4 (a) "ASIF" Concept: Activity (A), Mode Share (S), Fuel Intensity (I) and Fuel Choice (F) with its implication on (b) emission reduction

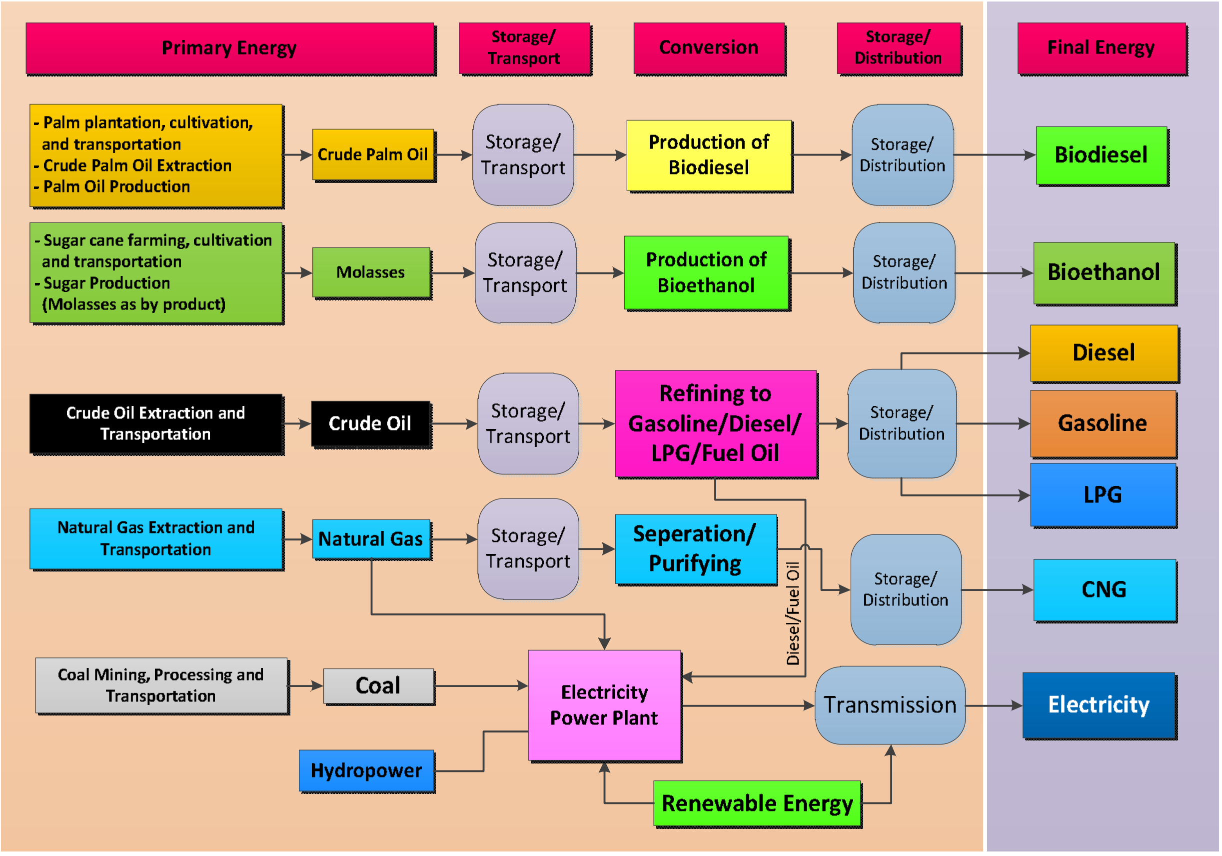
A bottom-up engineering energy demand model is composed of main variables such as

1. **number of vehicles**
2. **fuel economy, and**
3. **vehicle kilometer of travel (VKT),**

Various LEAP models in Thailand will be compared and discussed based on these three factors to arrive at harmonized database. Issues, such as functional forms of vehicle ownership models, fuel economy variation and trend, fuel sharing and difficulty to obtain VKT, will be addressed with some sensitivity studies. Once the harmonized version is developed, it will be benchmarked against historic data of energy consumption. For GHG module, Well-To-Wheel analysis of both fossil, biofuel and electricity generation will be reviewed with emphasis on gathering secondary data on biofuel (both ethanol and biodiesel), as well as national inventory data on electricity generation, as shown in Fig. 5 [4]. With careful calibration on both energy consumption and GHG emission, the final model with database will be utilized to investigate various effects from both EEDP and AEDP. Finally, complete model and database will be available for academically sharing among researchers and policy makers under ATRANS policy.



(a)



(b)

Fig. 5 (a) Schematic concept of “Well-to-Tank”, “Tank-to-Wheel” and “Well-to-Wheel” life cycle with (b) detailed example on various transportation fuel

CHAPTER 2 METHODOLOGY

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 [3]. LEAP modeling capabilities are highlighted as follows, with the calculation flows shown in Fig. 6.

- 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.

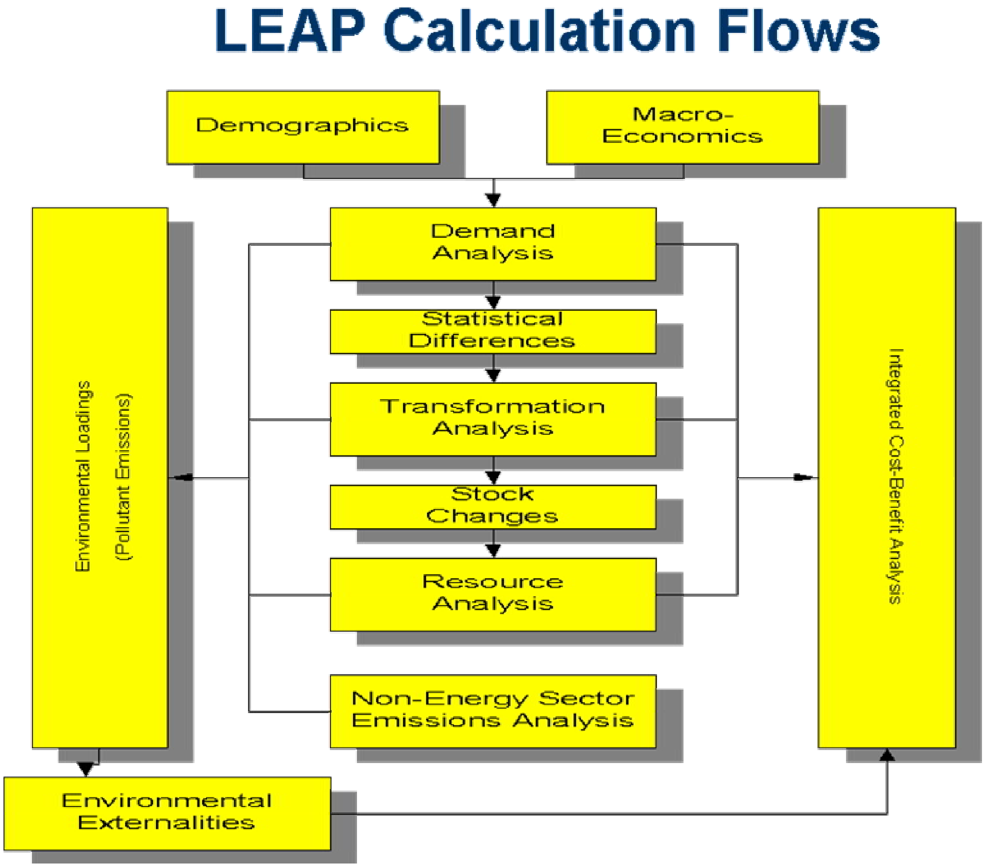
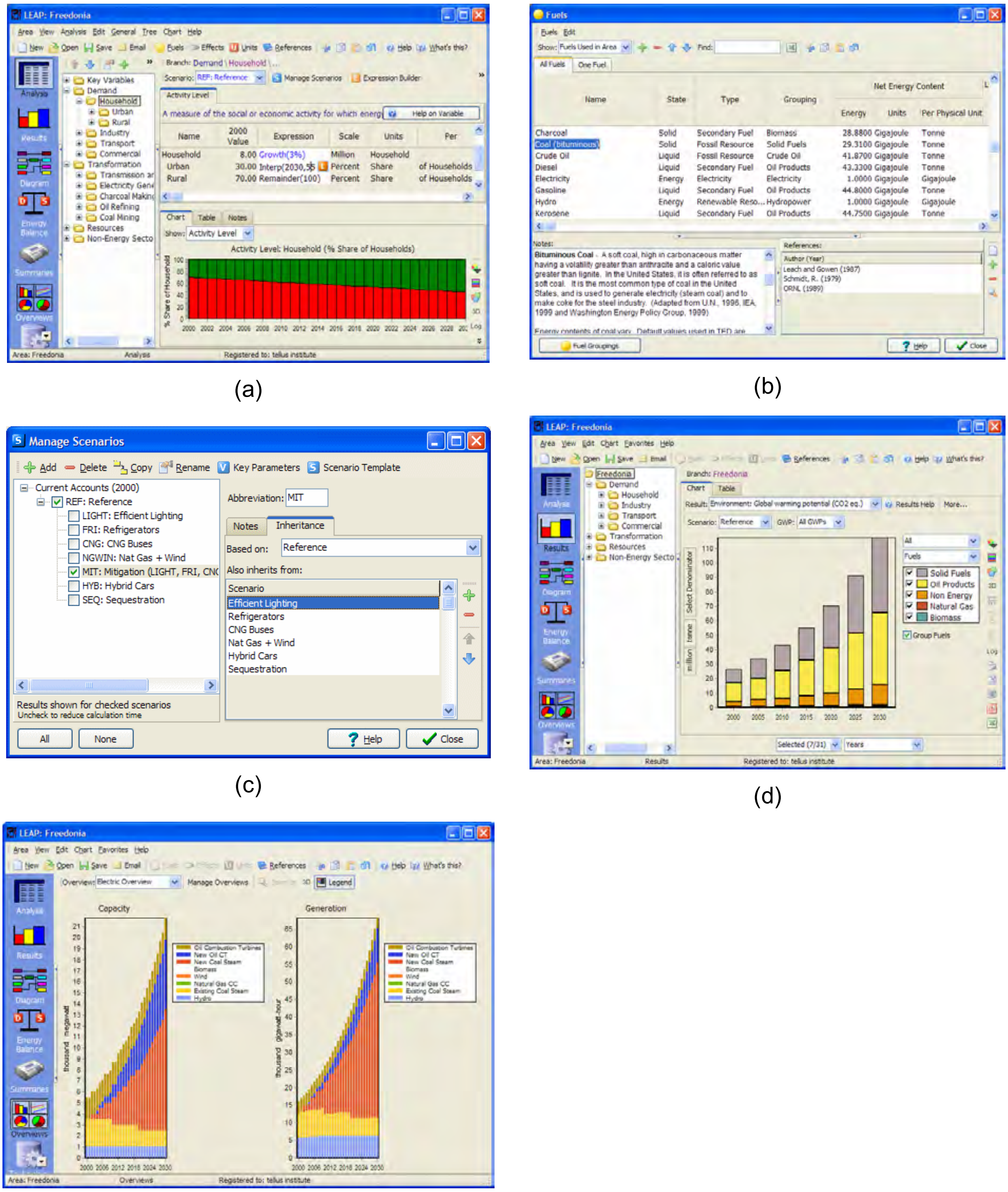


Fig. 6 LEAP calculation flows

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. 7.

- **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. 7(a)-(c).**
- **The *Results View* allows user to examine the outcomes of input scenarios as charts and tables shown in Fig. 7(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. 7(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.**



(a)

Branch: Demand \ Household \ ...

Scenario: REF: Reference

Activity Level

A measure of the social or economic activity for which energy

Name	2000 Value	Expression	Scale	Units	Per
Household	8.00	Growth(3%)	Million	Household	
Urban	30.00	Interp(2030,55	Percent	Share	of Households
Rural	70.00	Remainder(100)	Percent	Share	of Households

Show: Activity Level

Activity Level: Household (% Share of Households)

(b)

Show: Fuels Used in Area

Name	State	Type	Grouping	Net Energy Content		
				Energy	Units	Per Physical Unit
Charcoal	Solid	Secondary Fuel	Biomass	28.8800	Gigajoule	Tonne
Coal (bituminous)	Solid	Fossil Resource	Solid Fuels	29.3100	Gigajoule	Tonne
Crude Oil	Liquid	Fossil Resource	Crude Oil	41.8700	Gigajoule	Tonne
Diesel	Liquid	Secondary Fuel	Oil Products	43.3300	Gigajoule	Tonne
Electricity	Energy	Electricity	Electricity	1.0000	Gigajoule	Gigajoule
Gasoline	Liquid	Secondary Fuel	Oil Products	44.8000	Gigajoule	Tonne
Hydro	Energy	Renewable Reso...	Hydropower	1.0000	Gigajoule	Gigajoule
Kerosene	Liquid	Secondary Fuel	Oil Products	44.7500	Gigajoule	Tonne

Notes:

Bituminous Coal - A soft coal, high in carbonaceous matter having a volatility greater than anthracite and a caloric value greater than lignite. In the United States, it is often referred to as soft coal. It is the most common type of coal in the United States, and is used to generate electricity (steam coal) and to make coke for the steel industry. (Adapted from U.N., 1996, IEA, 1999 and Washington Energy Policy Group, 1999)

Energy contents of coal vary. Default values used in TED are

References:

Author (Year)
Leach and Gowen (1987)
Schmidt, R. (1979)
ORNL (1989)

(c)

Manage Scenarios

- Current Accounts (2000)
  - ☑ REF: Reference
    - ☐ LIGHT: Efficient Lighting
    - ☐ FRI: Refrigerators
    - ☐ CNG: CNG Buses
    - ☐ NGWIN: Nat Gas + Wind
    - ☑ MIT: Mitigation (LIGHT, FRI, CNG
    - ☐ HYB: Hybrid Cars
    - ☐ SEQ: Sequestration

Results shown for checked scenarios
Uncheck to reduce calculation time

Abbreviation: MIT

Based on: Reference

Also inherits from:

Scenario
Efficient Lighting
Refrigerators
CNG Buses
Nat Gas + Wind
Hybrid Cars
Sequestration

(d)

Branch: Freedonia

Result: Environment: Global warming potential (CO2 eq.)

Scenario: Reference GWP: All GWPs

(e)

Overview: Electric Overview

Fig. 7 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 mentioned earlier, important assumptions or variables for energy demand model are

1. estimate the number of vehicles (NV),
2. estimate the distances traveled by each vehicle (VKT),
3. estimate the fuel economy of each vehicle (FE)

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. Of course, various previous works [4, 5, 6] may have specific functional forms, which would be combined for best accuracy for up-to-date data. An example of such function is [12]

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

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 Vehicle Kilometer Traveled (or VKT) of each vehicle type will govern how much fuel or energy is consumed for each vehicle type within a unit distance. Unfortunately, Thailand does have this database regularly updated so previous works [4, 6] have relied on project-based survey [13, 14]

Last, the fuel economy of each vehicle type (or FE), together with VKT, will directly give total fuel or energy needed. Similarly, this variable is not regularly updated so certain assumptions must be made from the engineering aspects, such as type of engine (spark-ignition vs compression-ignition), engine age, fuel ratio used (liquid with biofuel blended or gas)

Hence, total energy demand can be estimated via the following simple relation.

$$ED_{ij} = NV_{ij} \times VKT_{j} \times FE_{ij}$$

where ED_{ij} = energy demand of fuel type “i” from vehicle type “j” (liter)
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)
FE_{ij} = fuel economy of registered vehicle type “j” that uses fuel type “i” (liter/km)

Lastly, total energy or fuel demand predicted from the model will be calibrated with the statistical data of various fuel sold in order to improve the accuracy. Once the model is calibrated, it can be used to answer the “What if” questions of interest, such as effect of biofuel and electric vehicle.

2.2 Energy and environmental assessment

As previously mentioned, the direct output from LEAP model is the total energy demand calculated from the number of vehicle at various vehicular fuel economy over distanced traveled. The energy and environment impact will be assessed on the reduction of fossil fuel demand and reduction of GHGs emission from various degrees of national policy implementation, AEDP for biofuel and EEDP for EVs.

As for reduction of fossil fuel, it is calculated based on the assumption of biofuel introduction in the case of AEDP and EVs introduction in the case of EEDP, based on the same economic activities in terms of vehicle growth, VKT and FE projection. As for reduction of GHGs emission, the whole WTW (well-to-wheel) value is calculated from WTT (well-to-tank) and TTW (tank-to-wheel) components. For fossil fuel (gasoline and diesel), the WTT component can be obtained based on Thai refinery database or standard estimate from TTW values [1, 15, 16]; whereas, the TTW component can be obtained from IPCC default value [17], as shown in Fig. 8(a). On the other hand, WTW GHGs emission from biofuel (bioethanol and biodiesel) is strongly dependent on the WTT component; thus, the WTW GHGs emission factor used will be referenced from the prior analyses conducted in the case of bioethanol and biodiesel production in Thailand [18, 19, 20], as shown in Fig. 8(b). For GHGs emission reduction from EVs introduction, it is a bit more complicated as the net reduction will be the difference of WTW GHGs emission from fossil fuel reduction and WTW GHGs emission from additional electricity generation for EVs. The WTW GHGs emission from additional electricity generation will use emission factor of Thailand electricity energy mix from National Power Development Plan [21], as shown in Fig. 8(c). Hence, each scenario will be analyzed for GHGs emission reduction based on various assumption of biofuel (AEDP) and EVs (EEDP) introduction.

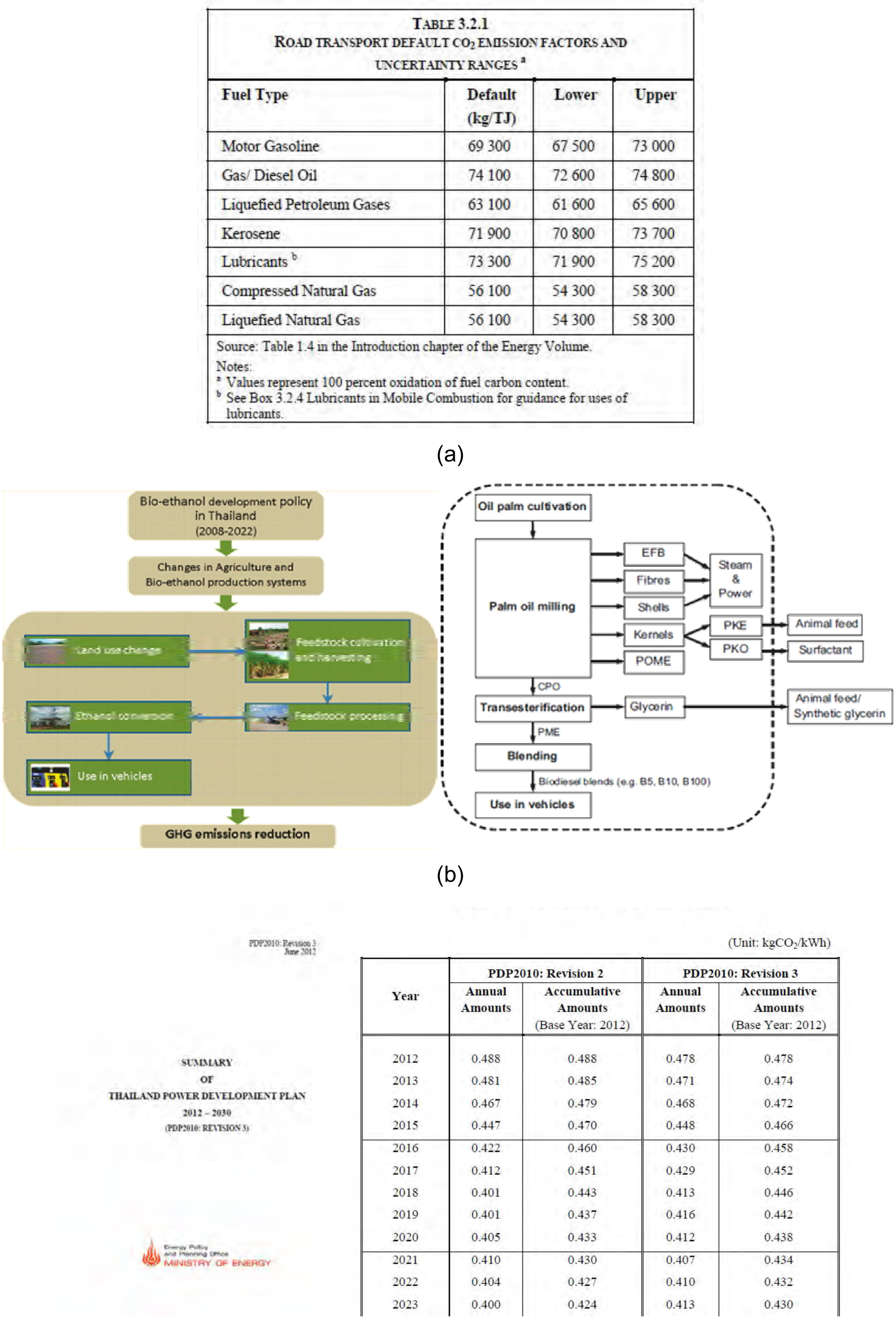


TABLE 3.2.1
ROAD TRANSPORT DEFAULT CO_2 EMISSION FACTORS AND UNCERTAINTY RANGES [a]

Fuel Type	Default (kg/TJ)	Lower	Upper
Motor Gasoline	69 300	67 500	73 000
Gas/ Diesel Oil	74 100	72 600	74 800
Liquefied Petroleum Gases	63 100	61 600	65 600
Kerosene	71 900	70 800	73 700
Lubricants [b]	73 300	71 900	75 200
Compressed Natural Gas	56 100	54 300	58 300
Liquefied Natural Gas	56 100	54 300	58 300

Source: Table 1.4 in the Introduction chapter of the Energy Volume.

Notes:

[a] Values represent 100 percent oxidation of fuel carbon content.

[b] See Box 3.2.4 Lubricants in Mobile Combustion for guidance for uses of lubricants.

(a)

(b)

PDP2010: Revision 3
June 2012

SUMMARY
OF
THAILAND POWER DEVELOPMENT PLAN
2012 – 2030
(PDP2010: REVISION 3)

Energy Policy
and Planning Office
MINISTRY OF ENERGY

(Unit: $kgCO_2/kWh$)

Year	PDP2010: Revision 2		PDP2010: Revision 3	
	Annual Amounts	Accumulative Amounts (Base Year: 2012)	Annual Amounts	Accumulative Amounts (Base Year: 2012)
2012	0.488	0.488	0.478	0.478
2013	0.481	0.485	0.471	0.474
2014	0.467	0.479	0.468	0.472
2015	0.447	0.470	0.448	0.466
2016	0.422	0.460	0.430	0.458
2017	0.412	0.451	0.429	0.452
2018	0.401	0.443	0.413	0.446
2019	0.401	0.437	0.416	0.442
2020	0.405	0.433	0.412	0.438
2021	0.410	0.430	0.407	0.434
2022	0.404	0.427	0.410	0.432
2023	0.400	0.424	0.413	0.430

(c)

Fig. 8 Example of GHGs emission calculation from (a) IPCC default value of TTW GHGs emission from fossil fuel, (b) Thailand bioethanol (left) and biodiesel (right) schemes and (c) additional electricity demand for EVs

2.3 Case studies

As previously mentioned, the present study focuses on the policy impact from both AEDP (biofuel) and EEDP (EVs) 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 Business-As-Usual reference case assumes there is no additional measure or policy to push. For the scenarios analyses in case studies of interest, three cases pursued are defined as follows, which could be adjusted later on.

1. AEDP target for biofuel
    - Assume biofuel target of 9 ML/d ethanol and 5.97 ML/d biodiesel is achieved in year 2021
    - Assume 50% of biofuel target is achieved
    - Evaluate effects on fossil fuel reduction, biofuel consumption and GHG emission
2. EEDP target for EVs
    - Assume electric motorcycles (eMCs) target of 75% of new motorcycle is achieved in 2030
    - Assume electric light duty vehicles (eLDVs) target from IEA roadmap
    - Assume a combination of both eMCs and eLDVs target with some variations
    - Evaluate effects on fossil fuel reduction, electricity consumption and GHG emission
3. Combined AEDP and EEDP targets for both biofuel and EVs, respectively
    - Assume a combination of both AEDP and EEDP targets with some variation
    - Evaluate effects on fossil fuel reduction, biofuel/electricity consumption and GHG emission

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

CHAPTER 3 RESEARCH PLAN

3.1 Project Schedule

Table 3 shows the project planning schedule. All project members are scheduled to meet once a month to discuss the technical results performed by project research assistant, and directions of the project. Occasionally, the progress report will be presented to the advisors to further seek guidelines and comments of the results and future direction.

Table 3: Project planning schedule

Activity	2012									2013		
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Review current LEAP models for pro & con in details	🟨	🟨										
Compare and discuss various assumptions and database to achieve harmonized version with versatile scope		🟨	🟨	🟨	🟨							
Model calibration with historical energy consumption					🟨	🟨	🟨					
Review Well-to-Wheel analysis of fossil and biofuel in Thailand							🟨	🟨				
Analyze for most suitable emission factor for use in LEAP program								🟨	🟨			
Model calibration with historical GHG emission									🟨	🟨		
Utilize final model to investigate various aspects of EEDP and AEDP										🟨	🟨	🟨
Inception report submission	30-Apr											
Progress report presentation			24-Jun									
Interim report presentation						04-Sep						
Interim report submission						30-Sep						
Roundtable discussion/workshop										🟦		
Final report presentation										10/12/14 Dec		
Final report submission												31-Mar

3.2 Project Expenditure

Table 4 shows the breakdown of the project expenditure.

Table 4: Project expenditure

No.	Item	Unit cost	Number of units	Sub total
1	Project leader	3,000	12	36,000
2	Advisors participation in project meeting (1,000 THB/day x 2 persons x 4 days)	1,000	8	8,000
3	Members participation in monthly project meeting (1,000 THB/day x 4 persons x 12 days)	1,000	48	48,000
4	Research assistant (full time for 12 months, with master degree)	18,000	12	216,000
5	Misc. expenses for monthly project meeting	3,000	12	36,000
6	Interview expenses with related researchers for secondary data analysis	3,000	6	18,000
7	Project meetings	3,000	12	36,000
8	Office & computer supply	3,500	12	42,000
9	Secretariat's participation portion	10,000	1	10,000
10	Publishing proportion of the report book	50,000	1	50,000
				500,000

CHAPTER 4 ENERGY DEMAND MODEL SETUP

This section will follow similar methodology from previous ATRANS 2009-10 project [6] with update from additional database recently available and other works [4, 5]. Detailed methodology should be referred to [6].

4.1 Database Framework

From Section 2.1, the energy demand function can be modeled as follows.

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

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 construct each component. Firstly, the functional form of number of registered vehicle (NV) is updated from previous works [6] with additional recent historical record from Transport Statistics Sub-Division, Department of Land Transport (DLT) and consideration from [4]. Secondly, Vehicle Kilometer of Travel (VKT) still needs to adapt those in [6] as there is no additional update data since 2010. Thirdly, Fuel Economy (FE) will mostly follow [6] with minor update especially on the FE of EVs. Finally, the predicted energy demand will be calibrated with additional data since [6] for improved accuracy.

4.2 Vehicle Population Model

Following [6], the vehicle types are still re-categorized from DLT classification for the purpose of LEAP calculation, as shown in the Table 5. Please note that the agriculture vehicle, utility vehicle and automobile trailer are not considered in this work because they consume small fraction of energy.

Table 5: 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

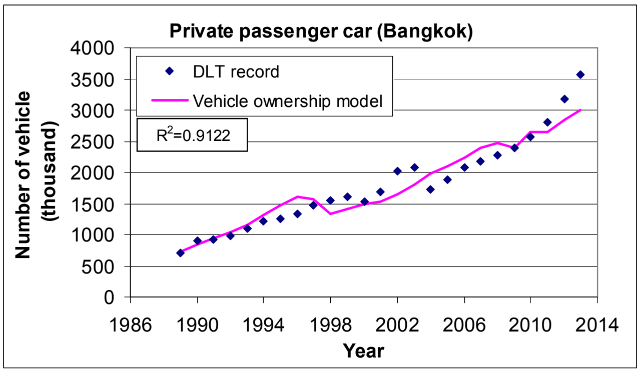
MV. 4 Motor tri-cycle	**PC03** **motor tri-cycle**	**- Private Bus**	**Bus03**
MV. 7 Fixed Route Taxi (Subaru)		**Small Rural Bus**	**sBus04**
MV. 8 Motor tri-cycle Taxi (Tuk Tuk)		**Truck**	
MV. 6 Urban Taxi	**PC04 taxi**	**- Non Fixed Route Truck**	**Truck01**
MV. 5 Interprovincial Taxi	**PC05** **Commercial 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			

From [6], specific functional form for each vehicle type is still retained with consideration of [4] but fitted with more data update from DLT. The models for Bangkok vehicle are shown in the Table 6, followed by the plot of their predicted results against historic record for each vehicle type in Fig. 9. On the other hand, the vehicle models for Provincial region are shown in Table 7, followed by the plot of their predicted results against historic record for each vehicle type in Fig. 10. 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. 10(c). This unusual behavior is difficult to be modeled with any independent parameter. With economic crisis in Thailand during 1997-1998, those data sets may be omitted from regression to better enhance the R^2 value.

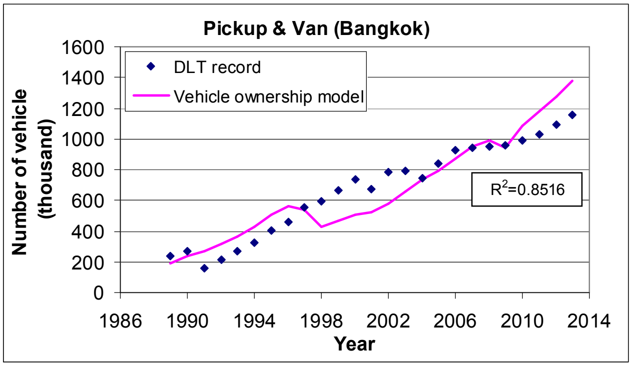
Table 6: Vehicle population models for all vehicle types in Bangkok

	N_vehicle Bangkok (GDPpCap)	R^2
PC01 private passenger car	$\ln\left(\frac{VO}{0.812-VO}\right)=1.4843\ln GDPpCap-19.4997$	0.9122
PC02 pickup	$\ln\left(\frac{VO}{0.5-VO}\right)=2.0434\ln GDPpCap-26.1439$	0.8295
PC03 motor tri-cycle	$NV=16{,}686.9 \qquad yr\le 2003$ $NV=-62.8521\ln(yr-\tau)+13{,}239.2345 \;;\; \tau=2003$ $yr\ge 2004$	0.7981 (2004-2013)
PC04 taxi	$\ln VO=2.3484\ln GDPpCap-32.5572$	0.8768
PC05 commercial rent car	$NV=-215.3791\ln(yr-\tau)+2453.9905; \;;\; \tau=1988$	0.4617 (1989-2000)
PC06 motor cycle	$\ln\left(\frac{VO}{0.6-VO}\right)=1.5579\ln GDPpCap-19.9935$	0.8074

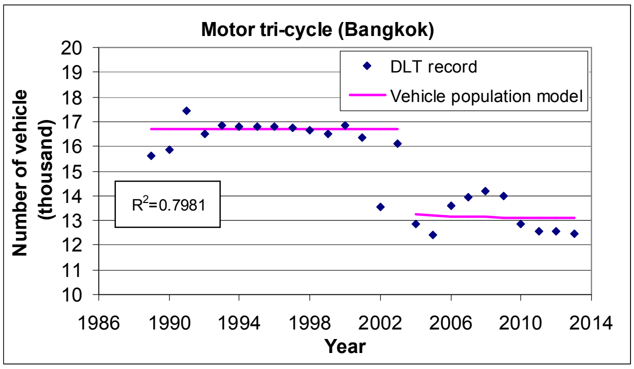
Bus01 fixed route bus	$NV = 13970 \qquad yr \le 1998$ $NV = 3780.5450\,ln(yr-\tau)+13839.6365 \quad ; \quad \tau = 1998$ $yr \ge 1999$	0.9701
Bus02 non fixed route bus	$NV = \left(1\text{-}0.5146 \cdot e^{-0.0341*(yr-\tau)}\right)\cdot\left(2162.9755\,ln(yr-\tau)+6149.6650\right)$ $\tau = 1988$	0.8928
Bus03 private bus	$NV = \left(0.5146 \cdot e^{-0.0341*(yr-\tau)}\right)\cdot\left(2162.9755\,ln(yr-\tau)+6149.6650\right)$ $\tau = 1988$	0.7644
sBus04 small rural bus	-	-
Truck01 non fixed route truck	$NV = \left(1-0.8019 \cdot e^{-0.0179*(yr-\tau)}\right)\cdot\left(20500.6162\,ln(yr-\tau)+56359.1341\right)$ $\tau = 1988$	0.9372
Truck02 private truck	$NV = \left(0.8019 \cdot e^{-0.0179*(yr-\tau)}\right)\cdot\left(20500.6162\,ln(yr-\tau)+56359.1341\right)$ $\tau = 1988$	0.5169



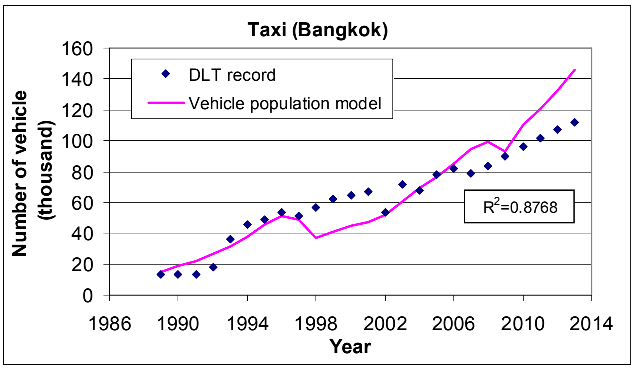
(a)



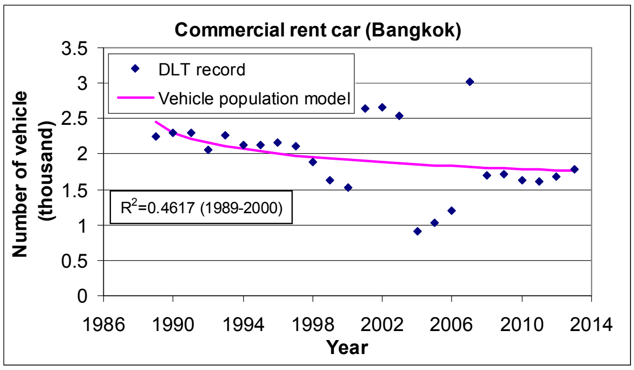
(b)



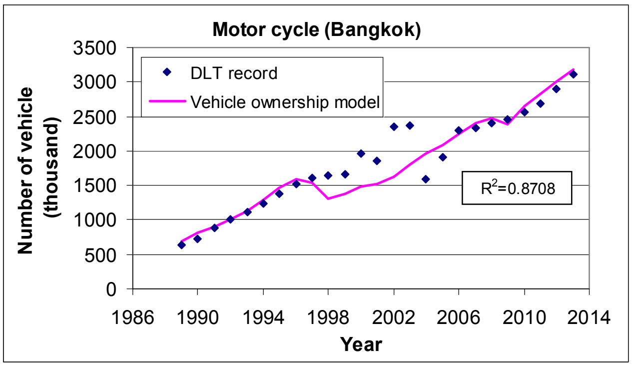
(c)


Taxi (Bangkok)
DLT record
Vehicle population model
R^2=0.8768
Number of vehicle (thousand)
0
20
40
60
80
100
120
140
160
1986
1990
1994
1998
2002
2006
2010
2014
Year

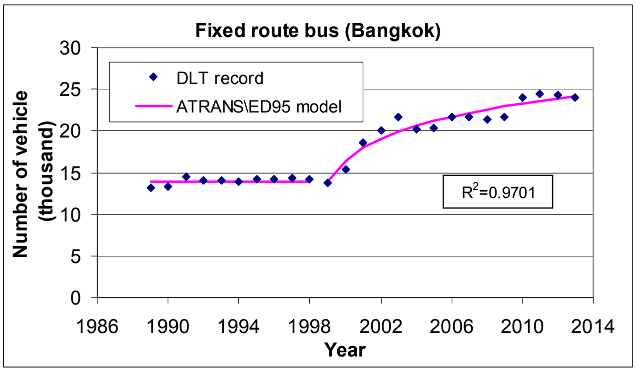
(d)


Commercial rent car (Bangkok)
DLT record
Vehicle population model
R^2=0.4617 (1989-2000)
Number of vehicle (thousand)
0
0.5
1
1.5
2
2.5
3
3.5
1986
1990
1994
1998
2002
2006
2010
2014
Year

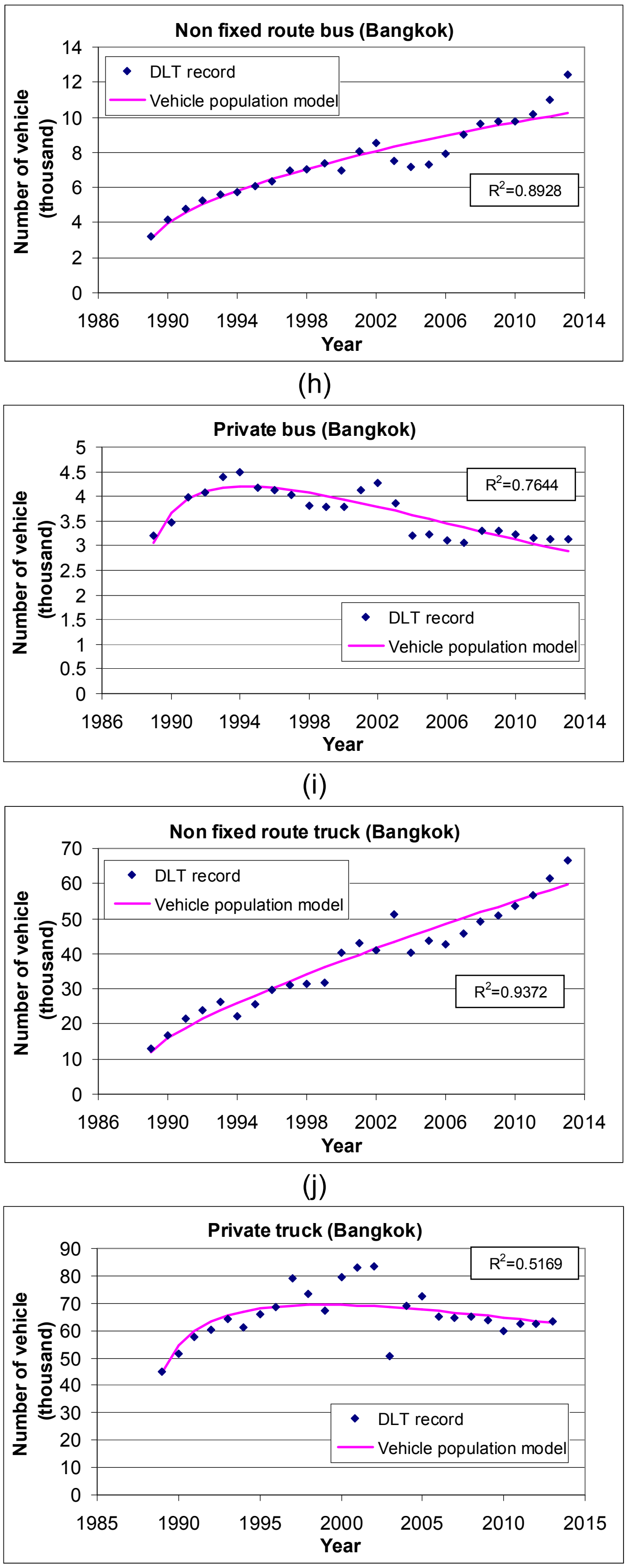
(e)


Motor cycle (Bangkok)
DLT record
Vehicle ownership model
R^2=0.8708
Number of vehicle (thousand)
0
500
1000
1500
2000
2500
3000
3500
1986
1990
1994
1998
2002
2006
2010
2014
Year

(f)


Fixed route bus (Bangkok)
DLT record
ATRANS\ED95 model
R^2=0.9701
Number of vehicle (thousand)
0
5
10
15
20
25
30
1986
1990
1994
1998
2002
2006
2010
2014
Year

(g)



(h)

(i)

(j)

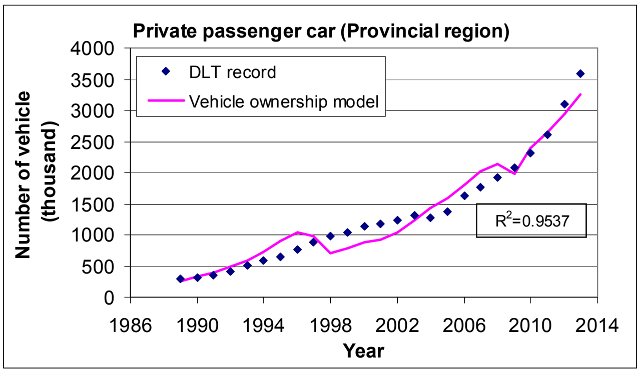
(k)

Fig. 9 Vehicle population model (Bangkok) for (a) PC01, (b) PC02, (c) PC03, (d) PC04, (e) PC05, (f) PC06, (g) BUS01, (h) BUS02, (i) BUS03, (j) Truck01 and (k) Truck02

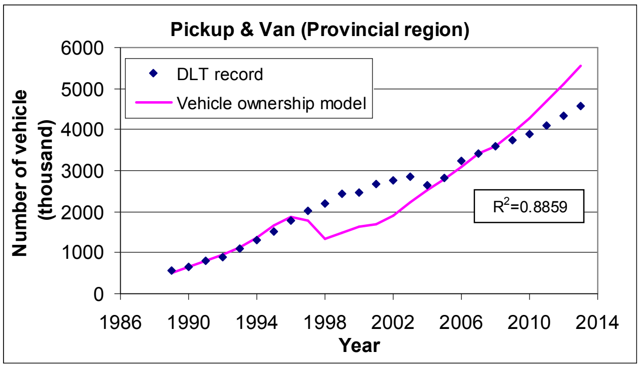
Table 7: Vehicle population models for all vehicle types in Provincial regions

	N_vehicle Provincial (GDPpCap)	R^2

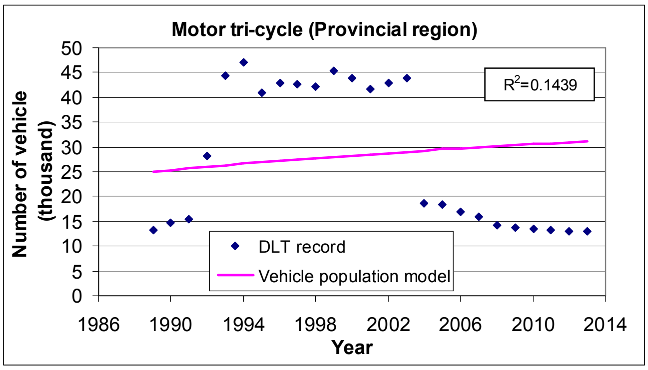
PC01 private passenger car	$\ln\left(\frac{VO}{0.812-VO}\right)=2.7376\ln GDPpCap-33.5569$	0.9537
PC02 pickup	$\ln\left(\frac{VO}{0.5-VO}\right)=2.5503\ln GDPpCap-30.3984$	0.8859
PC03 motor tri-cycle	$VO=0.0004537$	0.1439
PC04 taxi	$\ln(VO)=-1.6975\ln GDPpCap+8.0152$	0.4831
PC05 commercial rent car	$\ln(VO)=2.0946\ln GDPpCap-34.2175$	0.7073
PC06 motor cycle	$\ln\left(\frac{VO}{0.6-VO}\right)=2.1849\ln GDPpCap-24.8218$	0.7270
Bus01 fixed route bus	$\ln(VO)=0.2305\ln GDPpCap-9.5408$	0.8825
Bus02 non fixed route bus	$\ln(VO)=1.7795\ln GDPpCap-27.7744$	0.9770
Bus03 private bus	$\ln(VO)=0.0589(yr-\tau)-10.3657$ $\tau=1988$	0.9659
sBus04 small rural bus	$\ln(VO)=-0.0104\,(yr-\tau)^2+0.1671\,(yr-\tau)-8.2912$ $\tau=1988$	0.8739
Truck01 non fixed route truck	$\ln(VO)=0.0812(yr-\tau)-8.1633$ $\tau=1988$	0.9935
Truck02 private truck	$\ln(VO)=0.3038\ln(yr-\tau)-5.6547$ $\tau=1988$	0.9684



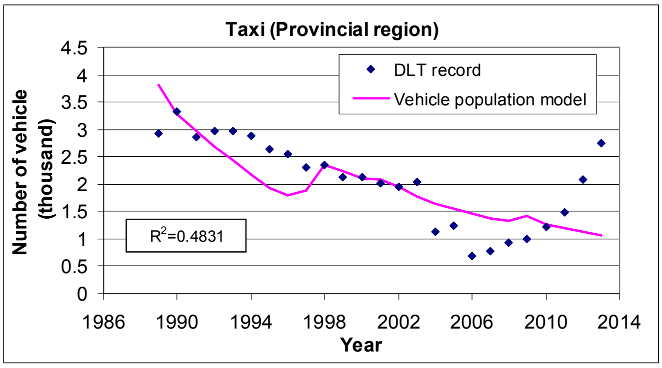
(a)



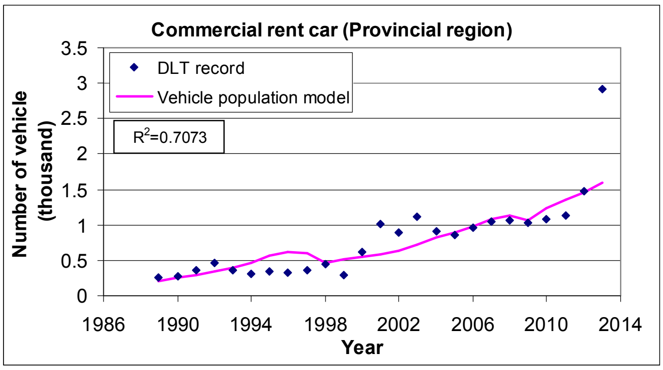
(b)


Motor tri-cycle (Provincial region)
Number of vehicle (thousand)
50
45
40
35
30
25
20
15
10
5
0
1986
1990
1994
1998
2002
2006
2010
2014
Year
R^2=0.1439
DLT record
Vehicle population model

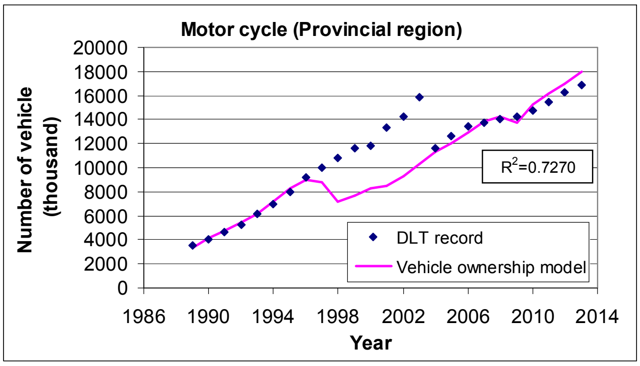
(c)


Taxi (Provincial region)
Number of vehicle (thousand)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1986
1990
1994
1998
2002
2006
2010
2014
Year
DLT record
Vehicle population model
R^2=0.4831

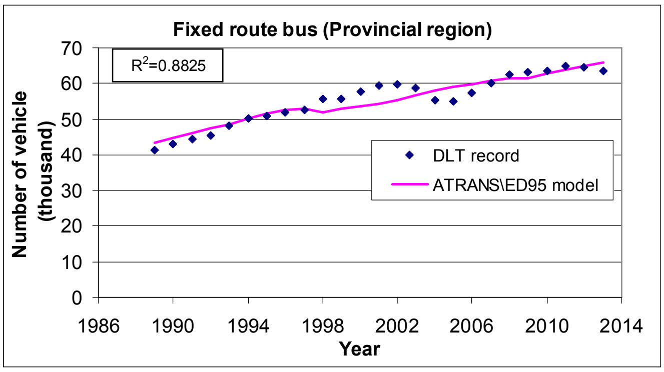
(d)


Commercial rent car (Provincial region)
Number of vehicle (thousand)
3.5
3
2.5
2
1.5
1
0.5
0
1986
1990
1994
1998
2002
2006
2010
2014
Year
DLT record
Vehicle population model
R^2=0.7073

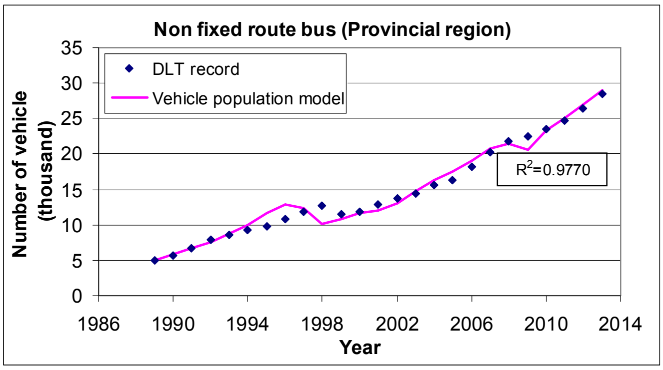
(e)


Motor cycle (Provincial region)
Number of vehicle (thousand)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1986
1990
1994
1998
2002
2006
2010
2014
Year
R^2=0.7270
DLT record
Vehicle ownership model

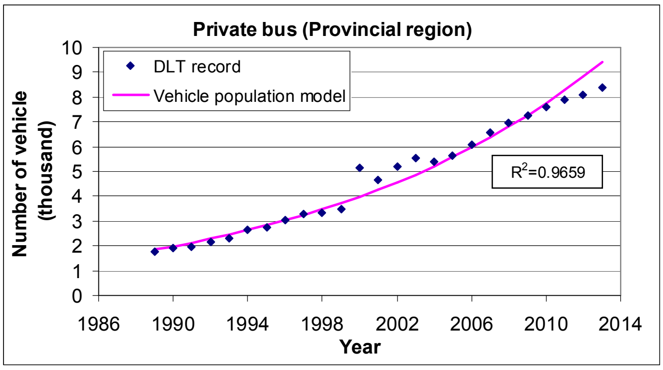
(f)


Fixed route bus (Provincial region)
R^2=0.8825
DLT record
ATRANS\ED95 model
Number of vehicle (thousand)
0
10
20
30
40
50
60
70
1986
1990
1994
1998
2002
2006
2010
2014
Year

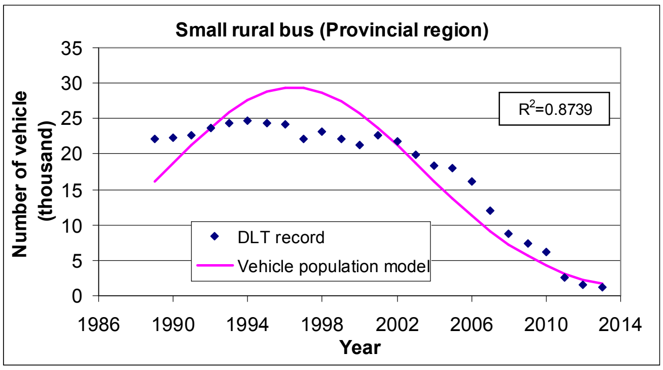
(g)


Non fixed route bus (Provincial region)
DLT record
Vehicle population model
R^2=0.9770
Number of vehicle (thousand)
0
5
10
15
20
25
30
35
1986
1990
1994
1998
2002
2006
2010
2014
Year

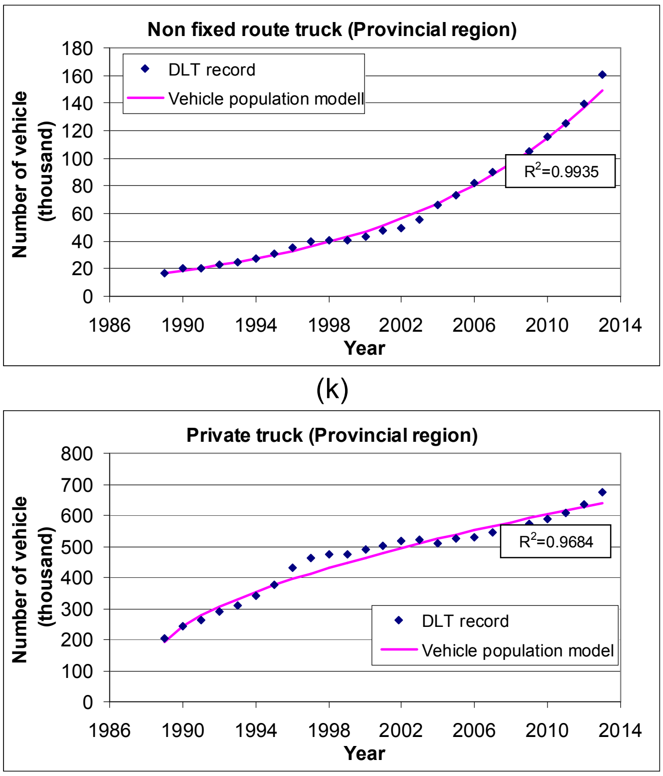
(h)


Private bus (Provincial region)
DLT record
Vehicle population model
R^2=0.9659
Number of vehicle (thousand)
0
1
2
3
4
5
6
7
8
9
10
1986
1990
1994
1998
2002
2006
2010
2014
Year

(i)


Small rural bus (Provincial region)
R^2=0.8739
DLT record
Vehicle population model
Number of vehicle (thousand)
0
5
10
15
20
25
30
35
1986
1990
1994
1998
2002
2006
2010
2014
Year

(j)



(k)

(l)

Fig. 10 Vehicle population model (Provincial regions) for (a) PC01, (b) PC02, (c) PC03, (d) PC04, (e) PC05, (f) PC06, (g) BUS01, (h) BUS02, (i) BUS03, (j) sBUS04 (k) Truck01 and (l) Truck02

4.3 Vehicle Kilometer of Travel (VKT) Model

Without repeating VKT model development in [6], the complete VKT values for each vehicle type in both Bangkok and Provincial regions are shown in the Table 8. In brief, if the survey data in 2008 [14] is available, it is directly reported in Table 8. On the other hand, if the survey data in 2008 [14] is not available, the survey data in 1997 [13] is extrapolated and reported in Table 8.

Table 8: 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 [14]**

**** Calculated in this work from VKT data in 1997 [13]**

4.4 Fuel Economy (FE) Model

Without repeating FE model development in [6], the percent shares of fuel use for each vehicle type are shown in Table 9 and Table 10 for Bangkok and provincial region, respectively; whereas, the fuel economy is shown in Table 11 and Table 12 for Bangkok and provincial region, respectively.

Table 9: Modeling percent share for fuel used by each vehicle type in Bangkok

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.*
	Gasoline**	E10**	E20**							
PC01	78.16%			20.38%	1.46%	0.00%	0.00%	0.00%	0.00%	0.00%
	42.86%	56.57%	0.57%							
PC02	5.25%			94.75%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	67.95%	32.05%	0.00%							
PC03	42.46%			0.00%	17.84%	0.00%	0.00%	0.00%	37.48%	2.22%
	79.58%	20.42%	0.00%							
PC04	14.01%			0.00%	77.00%	7.62%	0.00%	0.00%	1.37%	0.00%
	42.86%	56.57%	0.57%							
PC05	69.73%			26.92%	3.35%	0.00%	0.00%	0.00%	0.00%	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%	2.39%	0.00%	0.00%	0.00%	0.00%	1.60%
	100.00%	0.00%	0.00%							
Bus08	0.39%			99.61%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	100.00%	0.00%	0.00%							
Bus09	0.80%			99.20%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	100.00%	0.00%	0.00%							
sBus04	▨			▨	▨	▨	▨	▨	▨	▨
	▨	▨	▨							
Truck10	0.00%			99.30%	0.00%	0.00%	0.22%	0.48%	0.00%	0.00%
	100.00%	0.00%	0.00%							
Truck11	0.39%			99.61%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	100.00%	0.00%	0.00%							

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

**** EPPO report 2008 [14]**

Table 10: Modeling percent share for fuel used by each vehicle type in provincial region

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.*
	Gasoline**	E10**	E20**							
PC01	68.83%			30.31%	0.86%	0.00%	0.00%	0.00%	0.00%	0.00%
	49.83%	50.17%	0.00%							
PC02	7.17%			92.83%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	67.95%	32.05%	0.00%							
PC03	47.60%			0.00%	0.00%	0.00%	0.00%	0.00%	52.40%	0.00%
	79.58%	20.42%	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 2008 [14]**

Table 11: 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 [14]**

****Calculated from previous EPPO report [13]**

Table 12: 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 [14]**

****Calculated from previous EPPO report [13]**

However, the data of fuel economy for electric vehicles were not available in Thailand. In this work, only the commercialized electric vehicles, e.g. electric passenger car (PcEV) and electric motorcycle (eMC) are considered. As the previous work [22], the fuel economy of eMC is referred from the results of a eMC demonstration project, done in King Mongkut's Institute of Technology Ladkrabang (KMITL) [23]; while the US-EPA report entitled 'Fuel Economy Guide' [24] was referred for the PcEV. The fuel economy of both eMC and PcEV was considered as gasoline-referred value. The eMC is battery electric arrangement (dedicated electrification) but the PcEV is composed of 4 electrification-internal combustion engine hybrids. The PcEV can be separated to four categorizes, e.g., Hybrid Electric Vehicle (HEV, generally an electric-conventional engine hybrid), Plug-in Hybrid Electric Vehicle (PHEV, a HEV which can be charge with external electric source), Battery Electric Vehicle (BEV). Fuel economies of PcEV and eMC are shown in Table 13 and Table 14, respectively.

Table 13: Fuel economy of Passenger Car Electric Vehicle (PcEV) in the gasoline-reference value

Light duty vehicle	**SI-fuel economy relative improvement (%)**	**Estimated FE***		**FE unit**
		Bangkok	**Outside Bangkok**	
HEV	**29.74**	**15.11**	**17.48**	**km/liter**
PHEV	**52.27**	**22.25**	**25.73**	**km/literGE****
BEV	**71.51**	**37.27**	**43.11**	**km/literGE**
		(23.68)	**(20.47)**	**(kW-hr/100 km)**
Gasoline	**-**	**10.62**	**12.28**	**km/liter**

*Calculate by referring to fuel economy of private passenger car in Thailand

**LiterGE is the energy unit in a same quantity of 1 liter of gasoline

Table 14: Fuel economy of Electric Motorcycle (eMC) in the gasoline-reference value

Motorcycle	**SI-fuel economy relative improvement (%)**	**Estimated FE***		**FE unit**
		Bangkok	**Outside Bangkok**	
Electric MC	**86.34**	**239.86**	**188.48**	**km/literGE****
		(3.70)	**(4.68)**	**(kW-hr/100 km)**
Motorcycle	**-**	**32.77**	**25.75**	**km/liter**

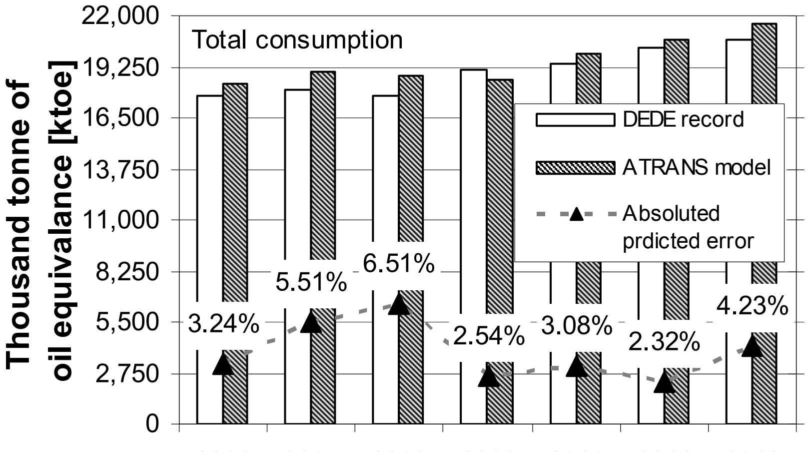
*Calculate by comparing to fuel economy of motorcycle in Thailand

**LiterGE is the energy unit in a same quantity of 1 liter of gasoline

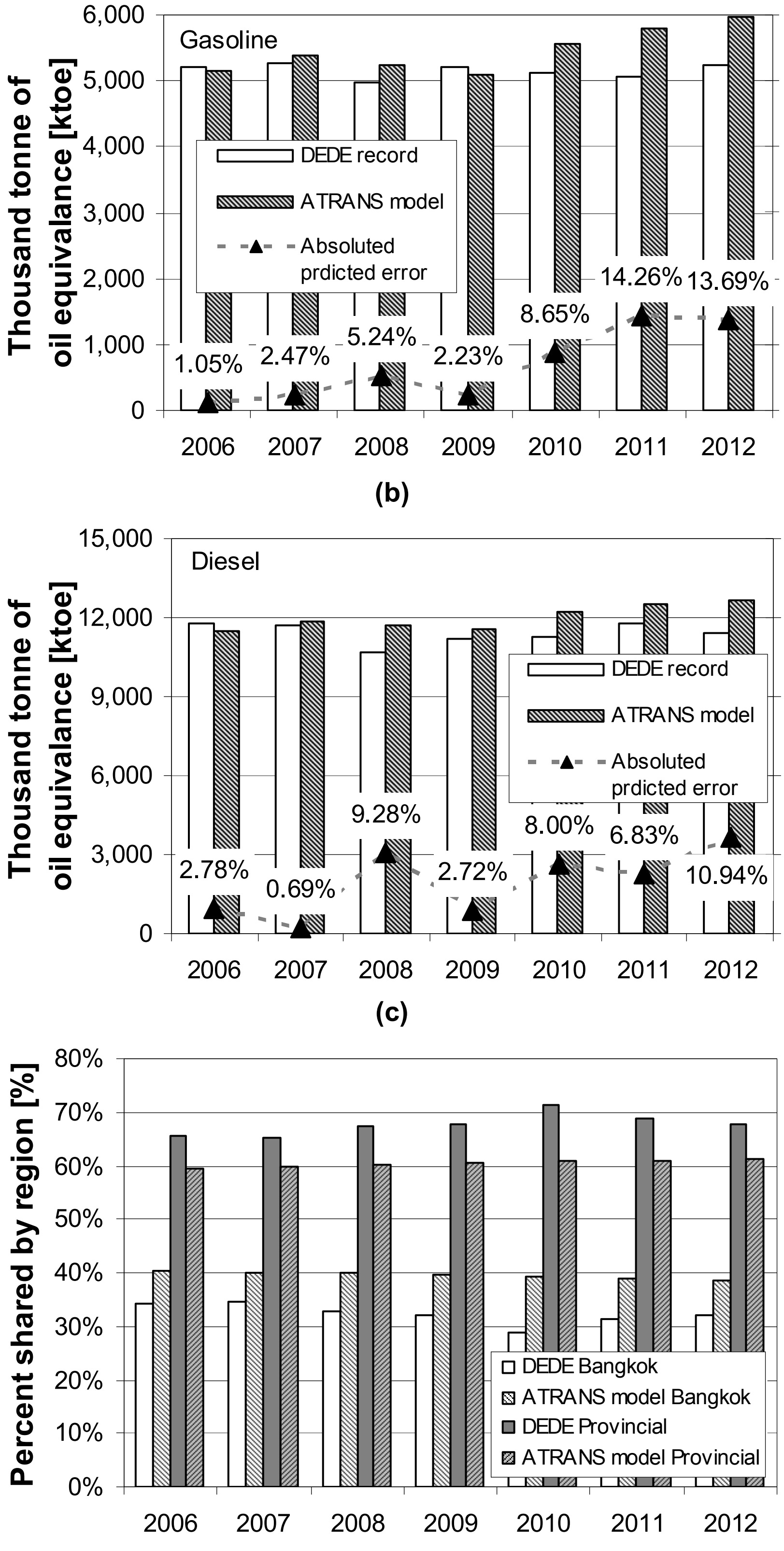
While the conventional vehicle requires fossil fuel or bio-fuel for the internal combustion engine; the EV (in the cases of PHEV, BEV and eMC) requires electricity, which is stored in the battery and transformed to mechanical power via the electric motor. In the view point of electric supplier, the use of EV will increase annual electric consumption (in the unit of GW-hr) and top-up the daily load demand (in the unit of MW). The GW-hr can be calculated from the energy demand model as fuel economy shown in Table 13 and Table 14 but the effect of EV on the daily load demand depends on how many EV are instantaneously plugged-in to the grid and which charging standard is used for EV charging (how fast the EV is charged). In this study, the worst case charging scenario, referred from [25], was considered. EV is assumed to be uncontrollably plugged into the electric grid as the 'Charge wherever they park' profile, which increases additional demand between the peak period of 7.30pm and 9.30pm. The impacts of PcEV (PHEV and BEV) and eMC are accounted for 164.43 and 44.41 kW/100 vehicles, respectively.

4.5 Validation of Energy Demand Model

Following [6], energy demand model can be constructed from all factors mentioned above, and then calibrated with actual energy consumption in transportation sector, as shown in Fig. 11.



(a)



(b)

(c)

(d)

Fig. 11 Validation of energy demand model with fuel consumption in year 2006-2012 for (a) all, (b) gasoline and (c) diesel fuels; with (d) percentage by region

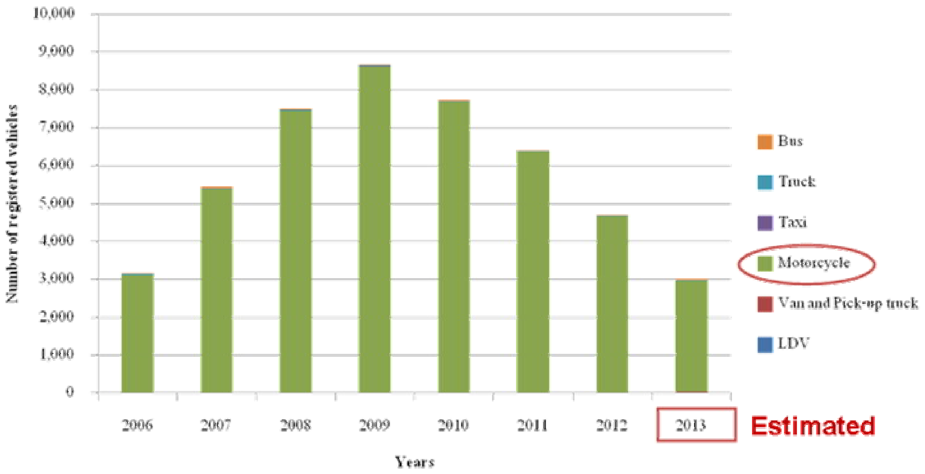
CHAPTER 5 RESULTS & DISCUSSION FOR VARIOUS SCENARIOS

5.1 Scenarios Set Up and Business as Usual (BAU)

As previously discussed, energy demand model can be used to evaluate the long-term impact of specific policy implementation via scenario analyses. In the present study, biofuel from AEDP (including ethanol and biodiesel) and electric vehicle technology from EEDP policy will be focused with the following details. First, BAU assumptions are shown in Table 15 and Fig. 12. Then, the results of BAU scenario are shown in Fig. 13 for fuel/electricity consumption and Fig. 14 for GHG emission. Fig. 13 shows the results until the AEDP target year (2021); whereas, Fig. 14 shows the results until the calculation end (2030).

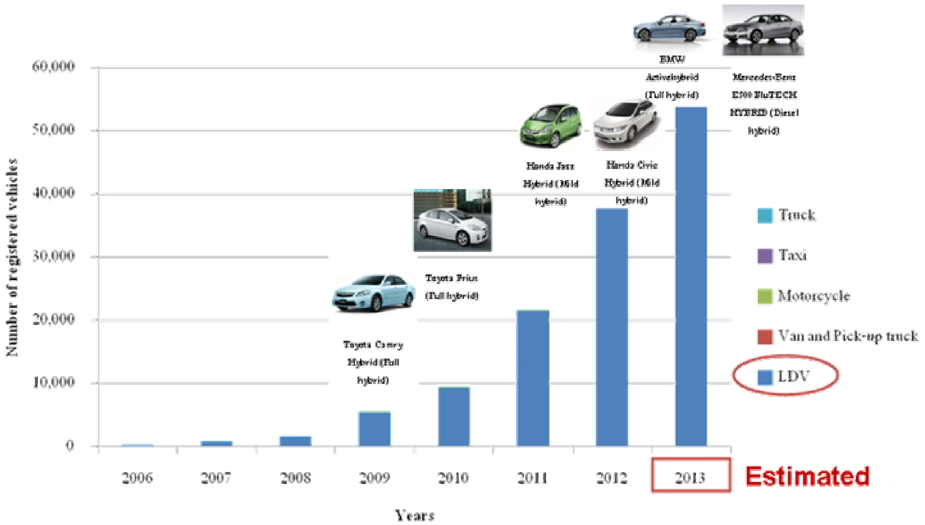
Table 15: BAU assumptions

BAU			
Biofuel		Electric vehicle (see Fig. 12)	
Gasoline segment	Diesel segment	Electric motorcycle (eMC)	Electric light duty vehicle (e-LDV)
-For light duty vehicle (PC01) : Gasoline and Gasohol_E10 will be changed to Gasohol_E20 within 5 years between 2010 to 2015 -For motorcycle (PC06) : Gasoline will be changed to Gasohol_E10 within 5 years between 2010 to 2015	-Current diesel fuel is diesel B5 (diesel fuel + 5% of FAME biodiesel), which will be increased to 7% in 2014	-Currently (2011) small fraction of electric (battery) motorcycle (eMC) of 0.04% (6,431 unit from ~18 million motorcycle) → will keep this ratio constant	-Currently (2011) only hybrid electric vehicle (HEV) in the light duty vehicle segment of 0.2% (20,878 unit from ~10 million LDV consisting of ~4.9 million passenger car and ~5.1 million pickup truck) → will keep this ratio constant -Plug-in hybrid electric vehicle (PHEV) and Battery electric vehicle (BEV) are not yet sold in Thailand's at LDV market.



Number of BEVs in Thailand

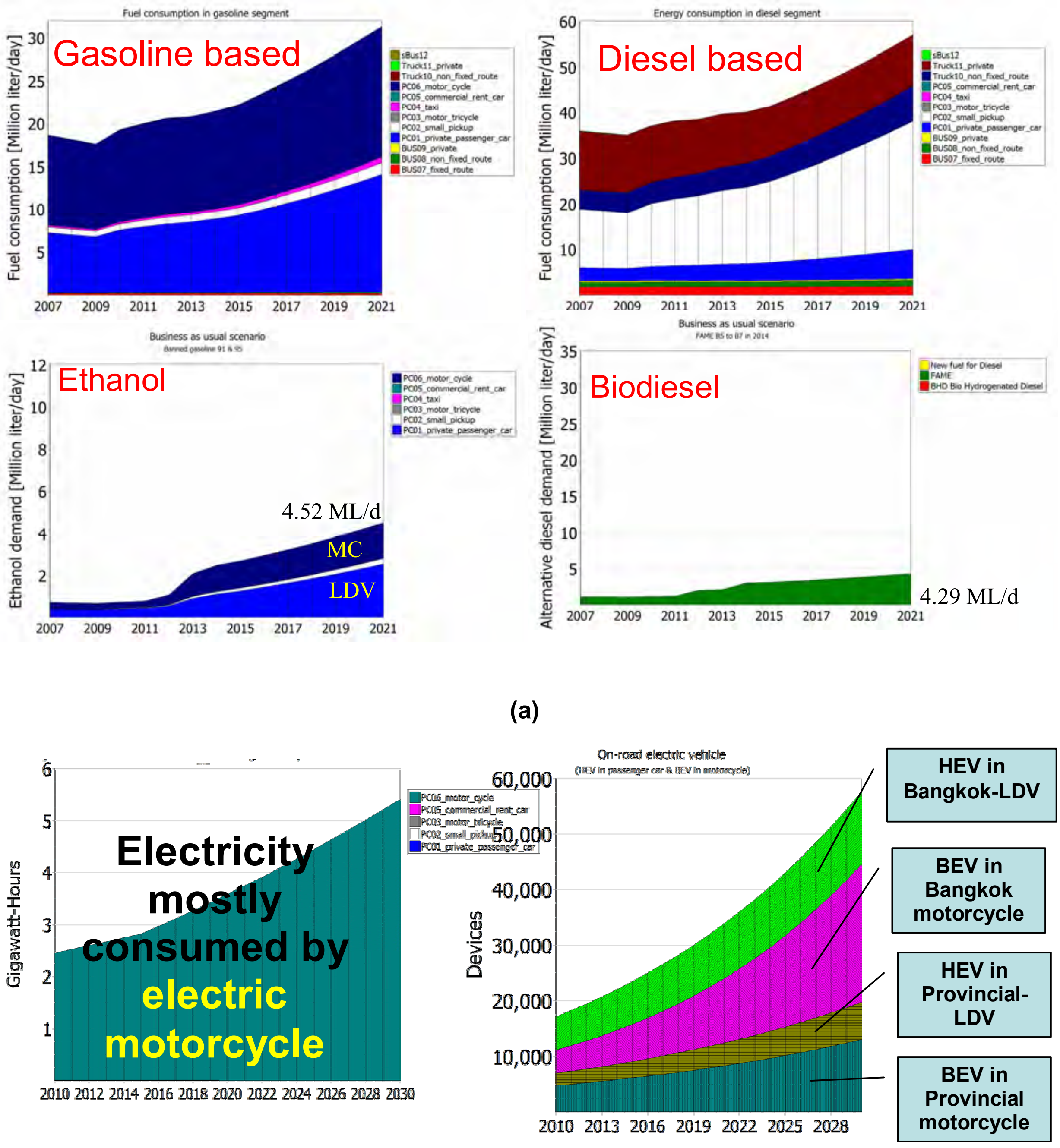
(a)



Number of HEVs in Thailand

(b)

Fig. 12 Current number of EVs in Thailand: (a) BEVs and (b) HEVs



(a)

(b)

Fig. 13 BAU results for (a) gasoline and diesel segments showing blends of bioethanol and biodiesel, and (b) EVs

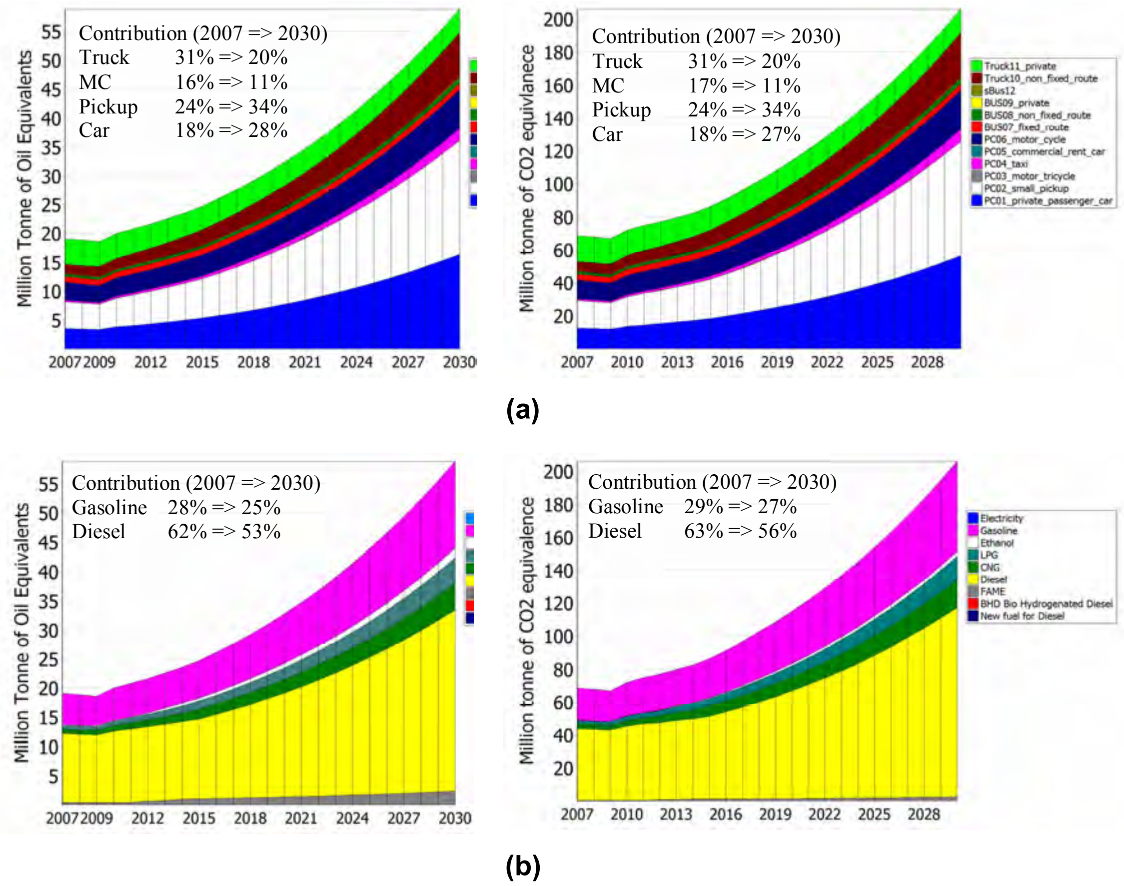


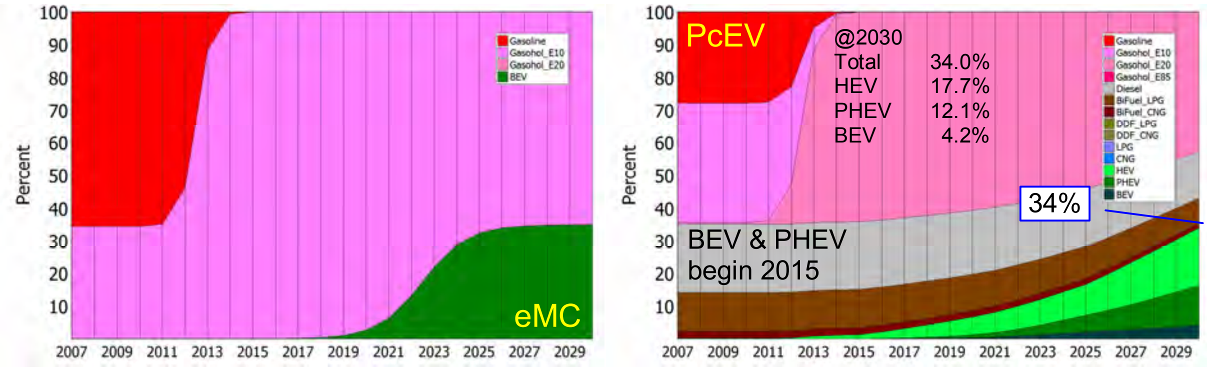
Fig. 14 Fuel consumption and Well-to-wheel GHG emission in BAU case (a) by various vehicles (b) by various secondary fuels

With current trends of transport energy policy and technology status, the scenario of biofuel from AEDP and EV for EEDP can be classified into 3 scenarios, namely bioethanol, biodiesel and EV, as shown in Table 16. The results for each scenario are discussed in the following sections. The trends of EV technology penetration are shown in Fig. 15 and Fig. 16 for new and on-road vehicles, respectively.

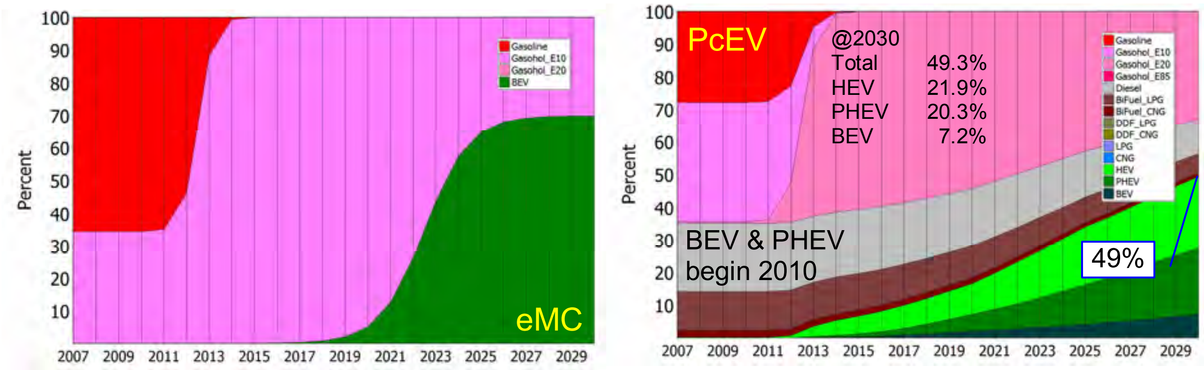
Table 16: Scenarios assumptions

Model		**Biofuel**					**EV**	
		Gasoline				**Diesel**	**eMC**	**e-LDV**
BAU		**See Table 15**						
Ethanol		**LDV**		**MC**				
		New	**On-road**	**New**	**On-road**			
	BAU	**E20**	**E0 → E10**	**E10**	**No change**			
	E20-LDV	**E20**	**All → E20**	**E10**	**All → E10**			
	E20extreme (LDV&MC)	**E20**	**All → E20**	**E20**	**All → E20**			
	E85-new LDV	**E85**	**E0 → E20**	**E10**	**No change**			

Diesel			**2014, B10 from FAME 2017, B10 + BHD 3 ML/d 2015-2020, apply NFD**		
EVs	**BAU**	**See Table 15**			
	50%EEDP-IEA5y			**From 2015, meet half EEDP target (35%) in 2030**	**From 2015, follow IEA EV roadmap with 5 years delay till 2030**
	EEDP-IEA			**From 2015, meet EEDP target (70%) in 2030**	**From 2015, follow IEA EV roadmap till 2030**



(a)



(b)

Fig. 15 Projections of new EV sale shares for eMC and PcEV in (a) 50%EEDP-IEA5y scenario and (b) EEDP-IEA scenario

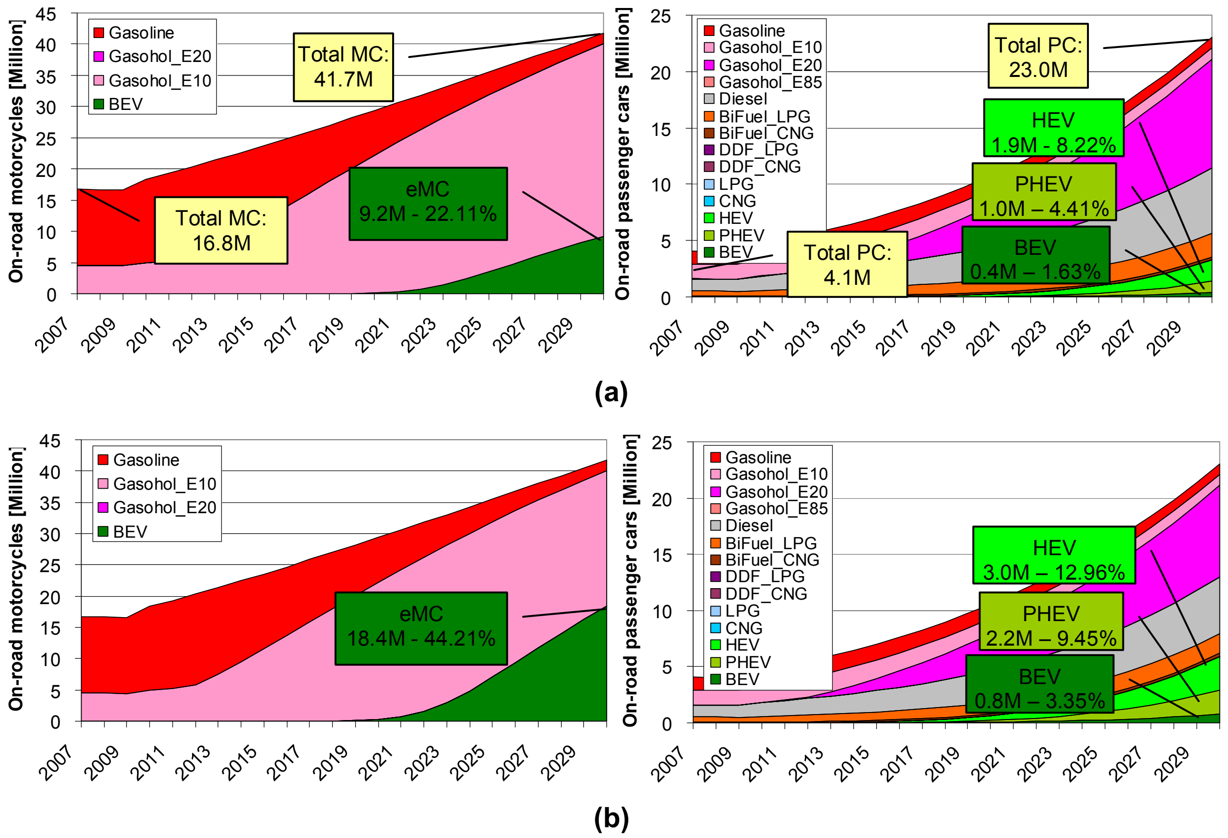


Fig. 16 Projections of on-road EV for eMC and PcEV in (a) 50%EEDP-IEA5y scenario and (b) EEDP-IEA scenario

5.2 Gasohol scenario

By blending ethanol with gasoline, the gasohol can be used in different blending fraction, depends on the acceptable level from the engine. There are three retailed gasohol fuels commercially available in Thailand, e.g. gasohol E10, E20 and E85. At present, the new spark ignition vehicle in Thailand is gasohol E20 acceptable. There are some portions of vintage passenger cars and motorcycles, which are not compatible with gasohol fuel, still present among on-road vehicles because Thai vehicle has long survival age. Hence, the gasohol conversion kit is necessary for this vehicle group. Even though the E85 conversion kit could be used, the E85 retailed station is still not widespread throughout Thailand. Therefore, conversion kit is considered only for the gasohol E20 in this work; by two implement levels for LDV and for both LDV and motorcycle. The new E85 is only considered for some portion in the new car segment. The results of ethanol scenarios are shown from Fig. 17 to Fig. 19.

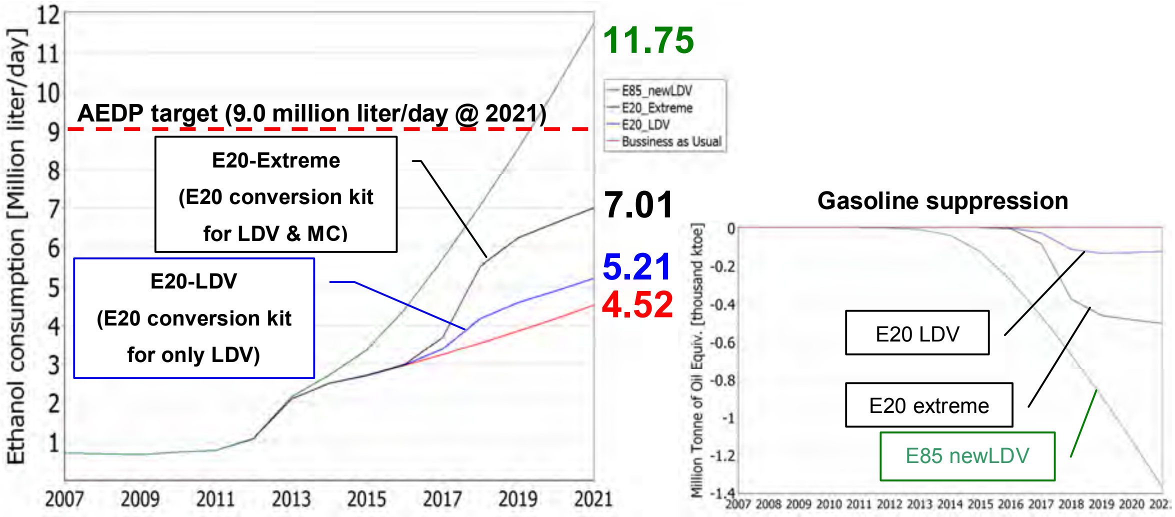


Fig. 17 Total ethanol consumption and gasoline suppression from various scenarios

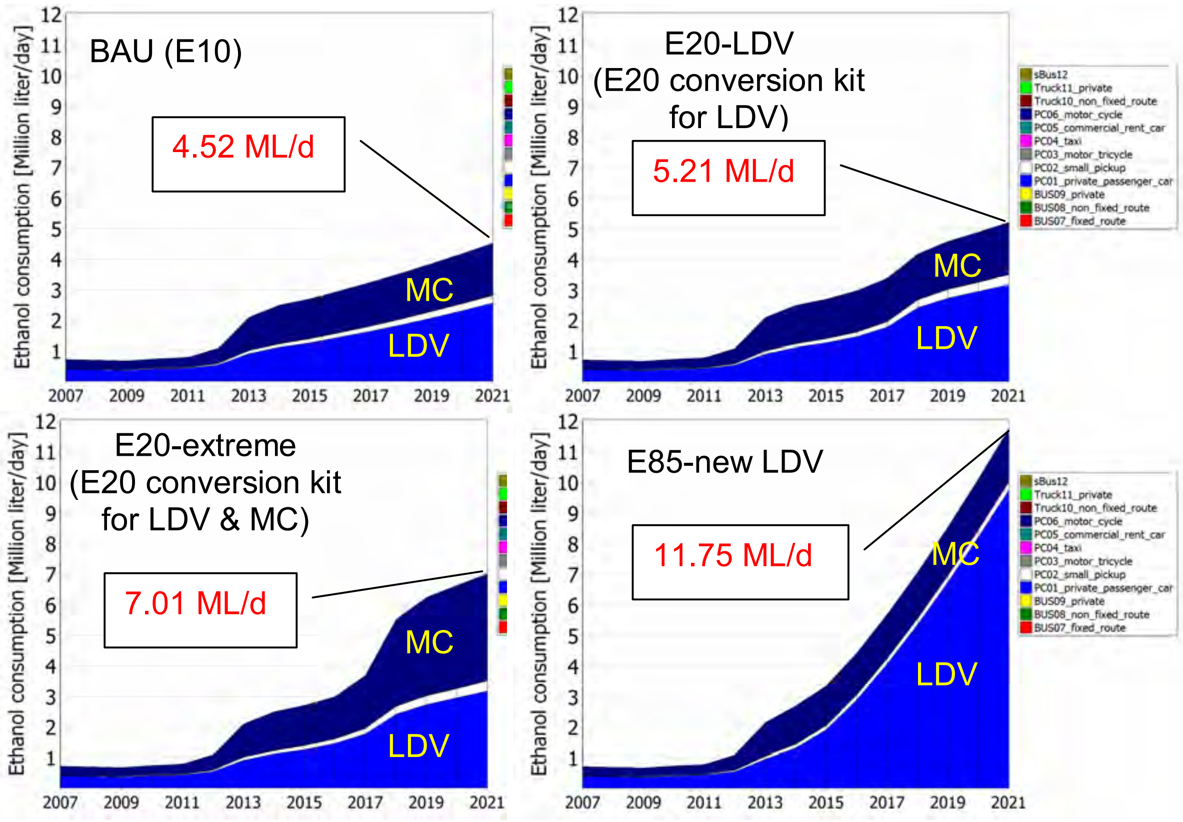


Fig. 18 Contributions of ethanol consumption from related vehicles in various scenarios

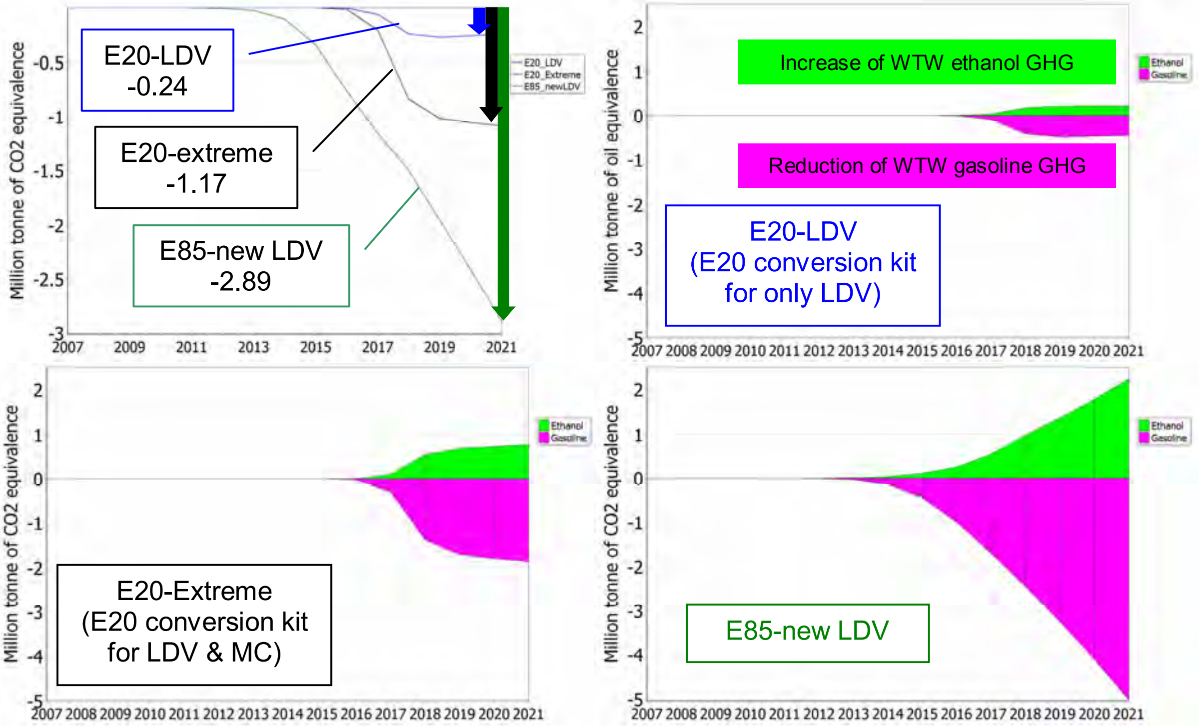
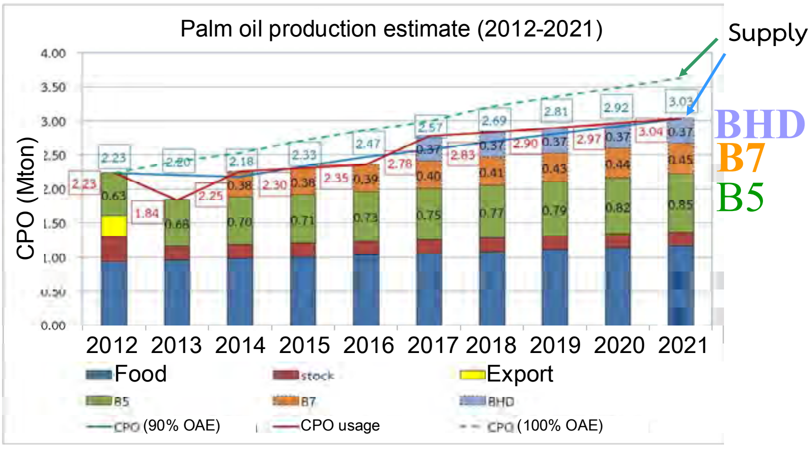


Fig. 19 Well-to-wheel GHG reduction by various gasohol scenarios (a) annual GHG reduction @ 2021, (b) evolution of WTW Greenhouse Gas

Consider the AEDP target of 9ML/d ethanol, the results show that E85-new LDV case will consume more ethanol than the target in 2021. E20-LDV and E20-extreme will consume less ethanol in 2021 but the consumption will grow due to vehicle population growth rate. It is found that ethanol consumption for these two E20 cases will achieve 9 ML/d in 2026 (E20-extreme) and 2030 (E20-LDV), respectively. In addition, the results of WTW-GHG emission show gasohol can help decrease road transport GHG emission because of lower WTT Greenhouse Gas production.

5.3 Biodiesel scenario

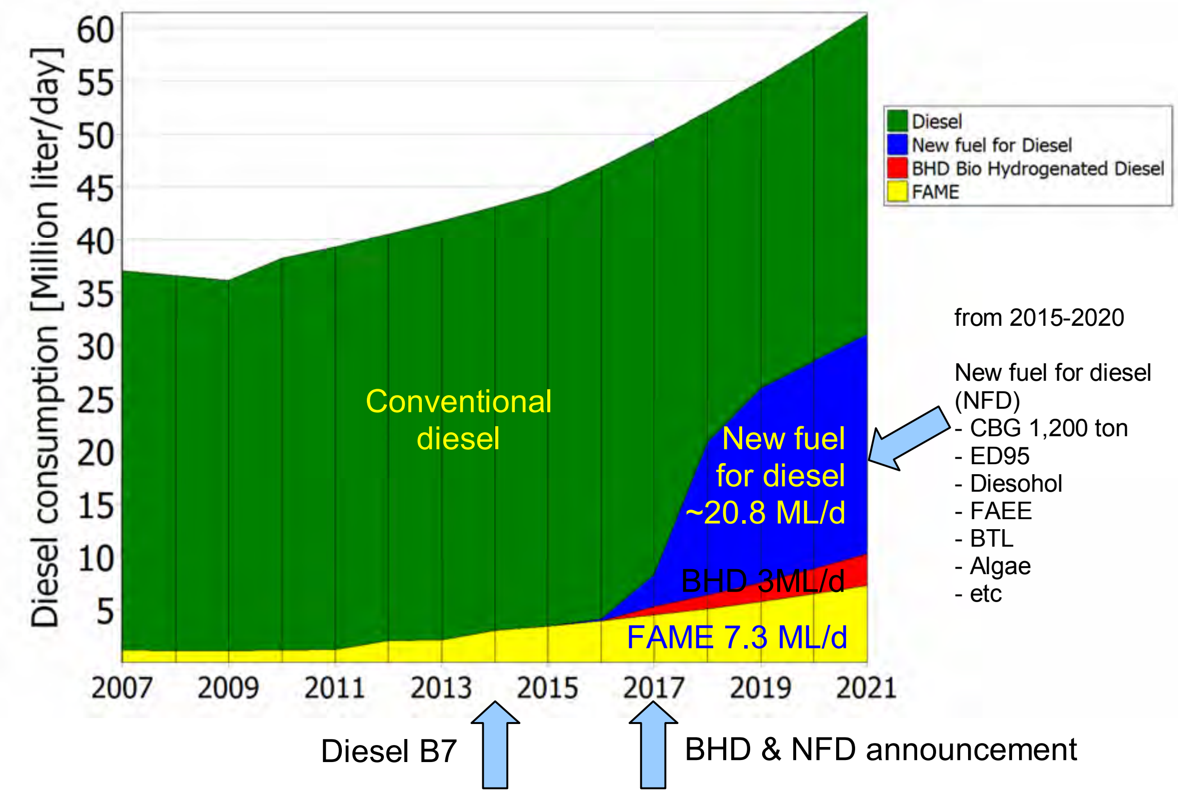
Similar to gasoline demand, which is suppressed by ethanol blended in gasohol fuels, the consumption of diesel fuel is reduced with increasing blending fraction of diesel alternatives, e.g. fatty acid methyl ester (FAME), bio-hydrotreated diesel (BHD), and biofuel-to-liquid (BTL). In addition, the new fuel for diesel (NFD), which is targeted in AEDP, is specified as another choice for alternative diesel fuel in the future. Compared to the definition of BAU in Table 15, biodiesel scenario is categorized into 3 different cases. First, the B10 or 10% biodiesel is targeted at 2021. Second, ~2% of BHD or 3 ML/d is added from 2017. Third, the target of NFD to suppress 30 million liter/day of fossil diesel fuel was considered. The projection of supplied palm oil for increasing biodiesel consumption is shown in Fig. 20. The results of biodiesel scenario are shown from Fig. 21 to Fig. 23.



Source: Palm productivity from OAE (Office of Agricultural Economics), 7 Feb 2013

Diesel consumption increases from 54.4 ML/d in 2012 to 71.5 ML/d in 2021 (EPPO)

Fig. 20 Projection of supplied palm oil for increasing of biodiesel consumption



from 2015-2020

New fuel for diesel (NFD)
- CBG 1,200 ton
- ED95
- Diesohol
- FAEE
- BTL
- Algae
- etc

Fig. 21 AEDP targets of diesel alternatives

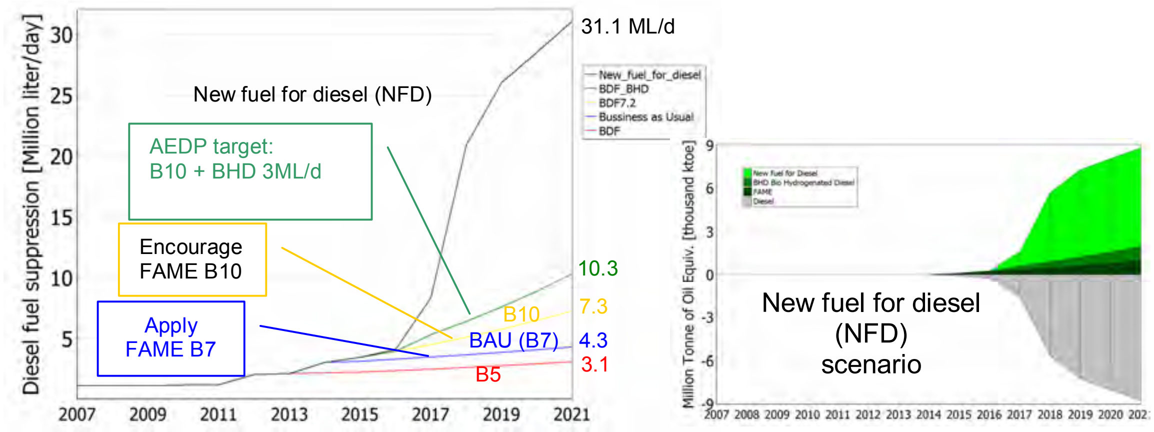


Fig. 22 Biodiesel fraction to meet AEDP target in 2021 and diesel suppression

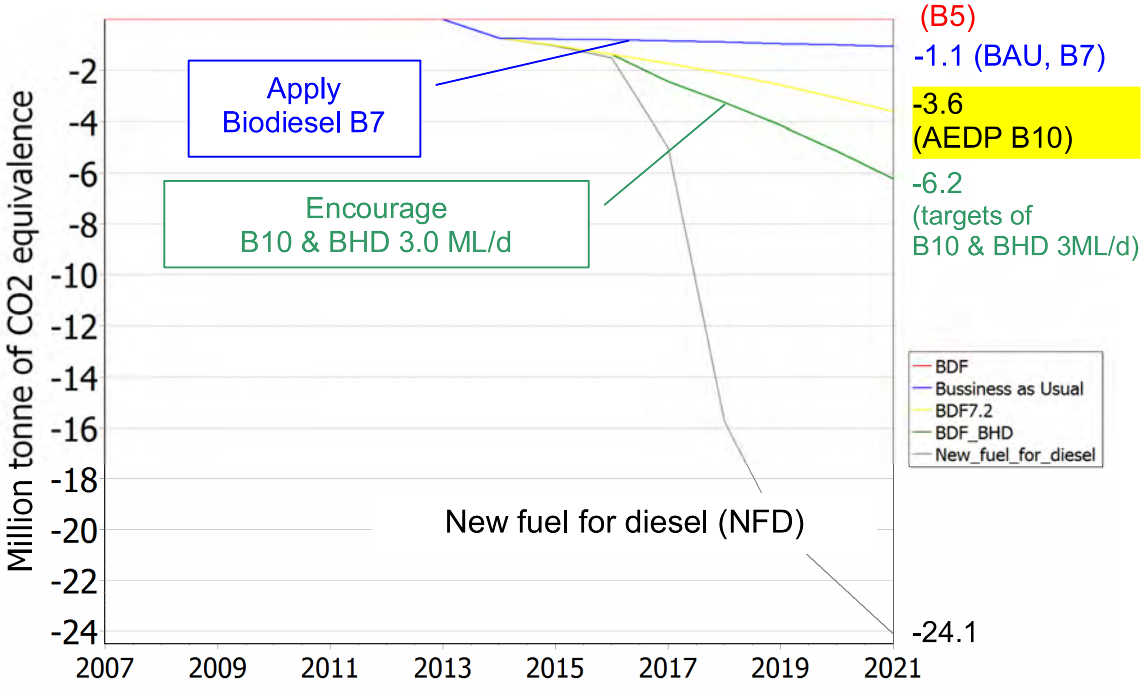


Fig. 23 Well-to-wheel GHG reduction for various biodiesel scenarios (compare to current B5). Note that BDF7.2 is a target of B10 ~ 7.2 ML/d BDF

Consider AEDP target of biodiesel consumption, the biodiesel blended fraction in diesel fuel can be calculated. Some issues regarding the conversion of blending percentage and physical amount (ML/d) arise from the heating value of non-commercial fuels such as BHD and BTL. Hence, the present model assume that BDF, BHD and BTL have similar heating value for the ease of calculation and conversion

5.4 Electric vehicle from EEDP and global green target

As shown in section 5.1, the penetration of electric vehicle (EV) technology is referred from the global trend of IEA technology perspective and Thailand EEDP for passenger car electric vehicle (PcEV) and electric motorcycle (eMC), respectively. The

requirement of additional electric demand, increasing peak daily load and the effects on reduction of fossil fuel and well-to-wheel greenhouse gas emission are shown from Fig. 24 to Fig. 27. The effects of EV technology penetration are shown for various scenarios with detailed contribution of each sub-sector (or region). The maximum potentials of EV technology are identified as the results of EEDP-IEA (extreme case).

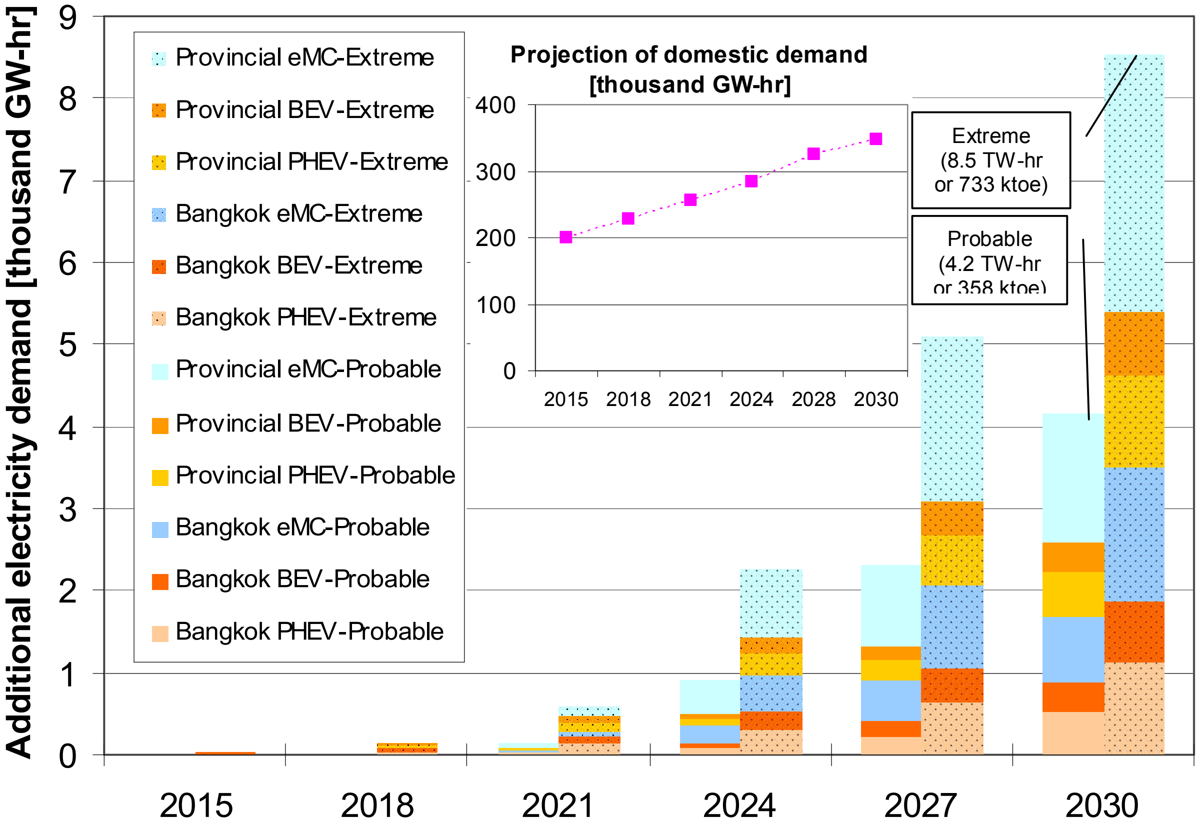


Fig. 24 Additional electricity demand for charging EV

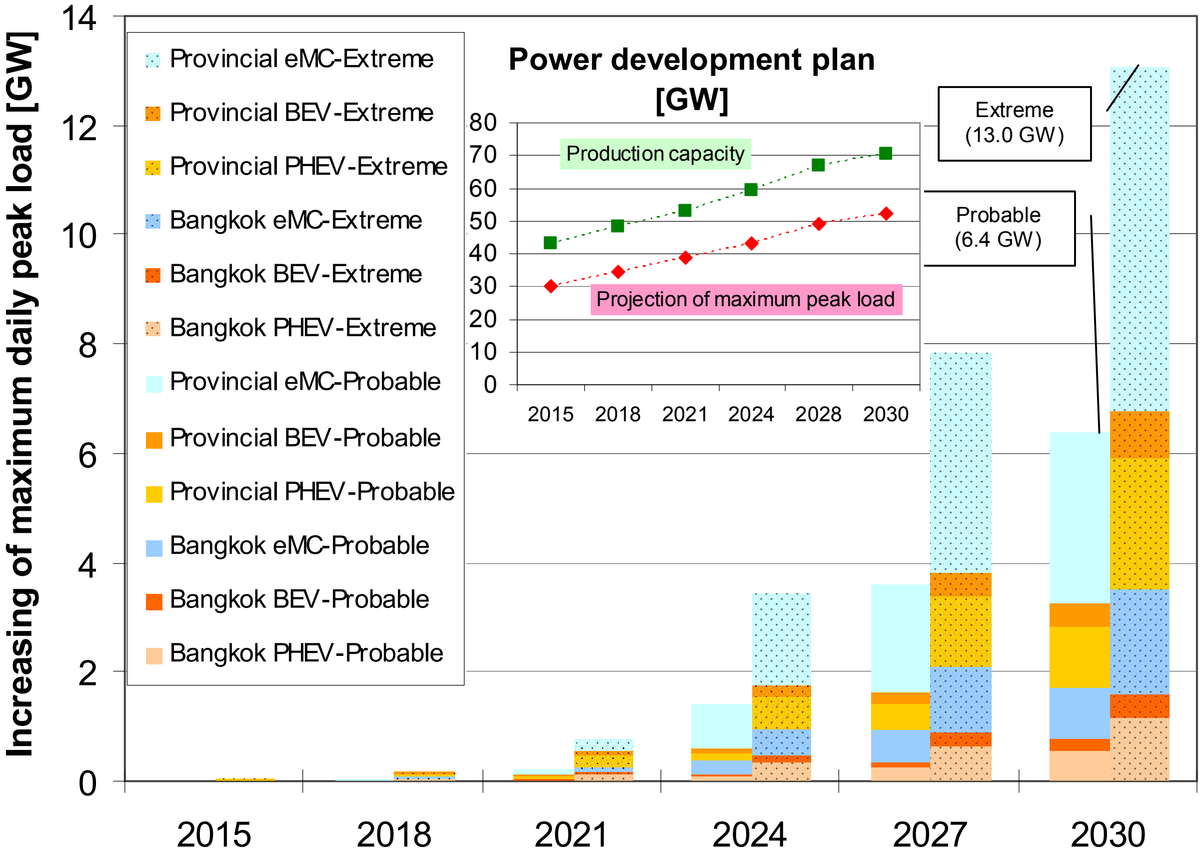


Fig. 25 Increasing of maximum daily peak load

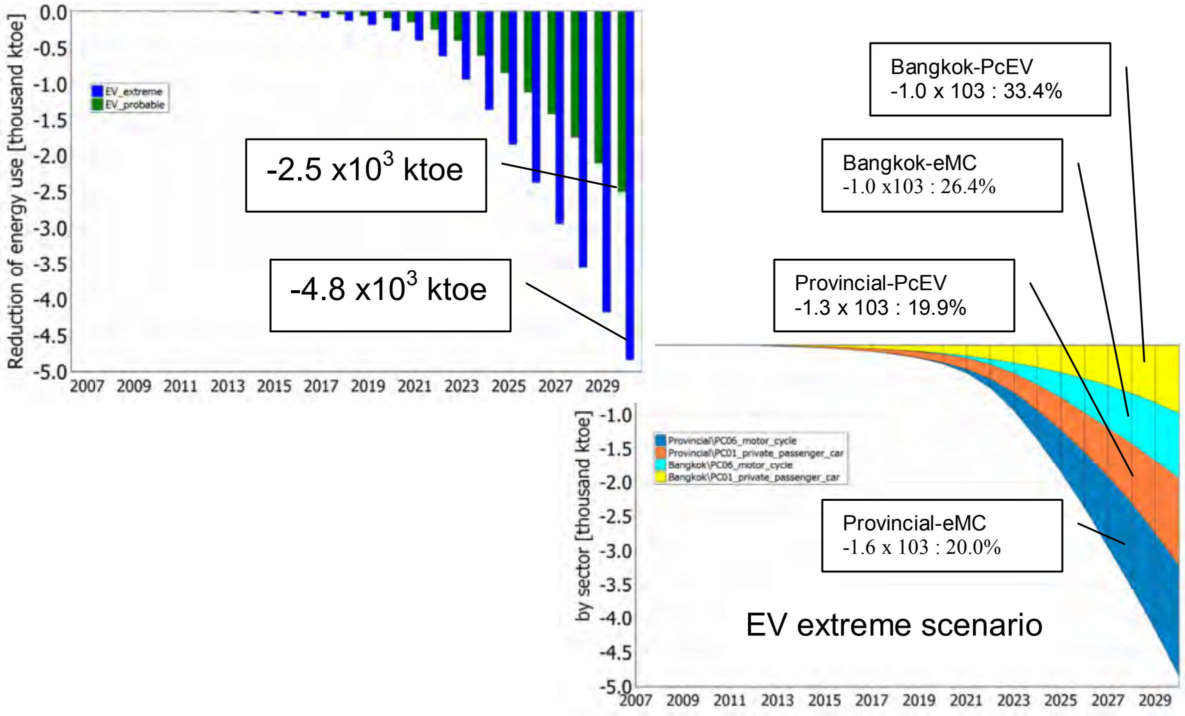


Fig. 26 Fossil fuel reduction for various scenarios and by sector

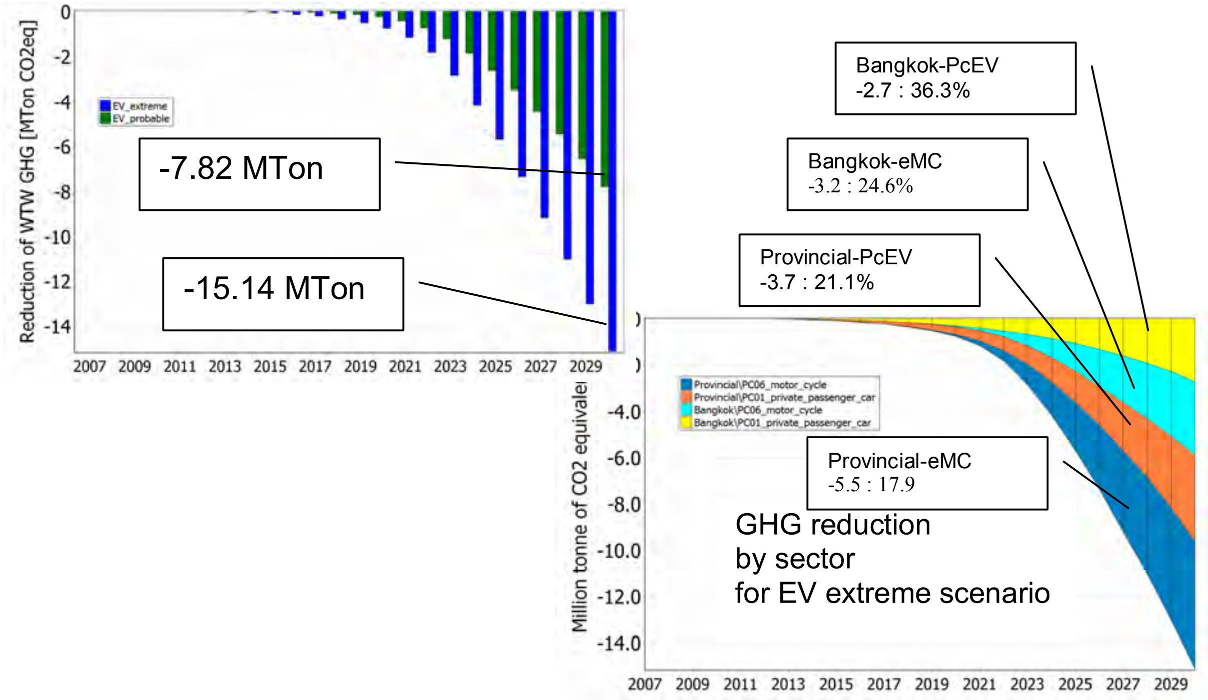


Fig. 27 Reduction of well-to-wheel GHG emissions

Since current EV technology is mostly focused on passenger vehicle, EV result is compared to gasohol scenario. The potential on reduction of gasoline fuel (shown in Fig. 18 for gasohol scenario) and WTW GHG emission (shown in Fig. 19 for gasohol scenario) are quite similar between gasohol and EV scenarios. The results show that the EV technology requires additional electricity demand (Fig. 24) by a number of electric motorcycles and higher electric consumption of PcEV. In addition, Fig. 25 shows that a large number of motorcycles have higher potentials on increasing peak electric load. Nontheless, the EV technology has the potentials on reducing overall energy consumption and WTW GHG emission up to 403 ktoe and 1.17 MTon of $CO_{2,\ equivalence}$, respectively in 2021, and up to 4,846 ktoe and 15.14 MTon of $CO_{2,\ equivalence}$, respectively in 2030.

5.5 Comparison between energy policies and a probable case of combined scenario

The maximum potentials of selected energy policies are compared in Fig. 28 and Fig. 29. According to maximum energy efficiency, the EV scenario has highest potentials on decreasing energy demand, up to 4,846 ktoe in 2030. The biodiesel has higher potential on reducing WTW GHG emission because Thai road transportation is more relied on diesel sector. The NFD scenario is account for reduction of 23.0 MTon of $CO_{2,equivalence}$ in 2021 and 38.3 MTon of $CO_{2,equivalence}$ in 2030 (reference to BAU, B7).

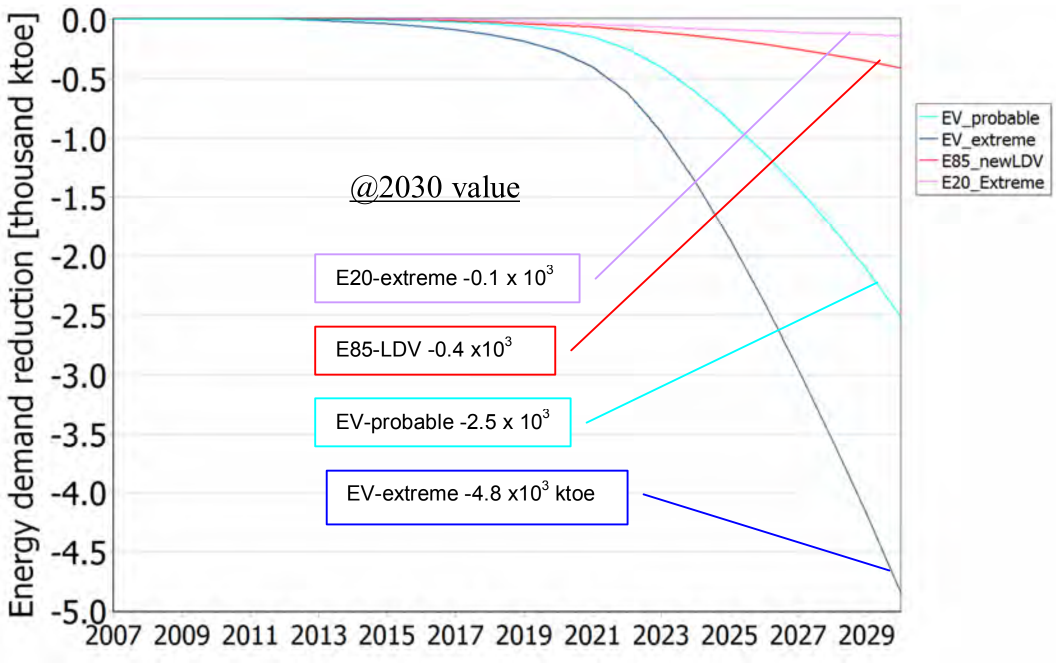


Fig. 28 Energy demand reduction (compare to BAU scenario)

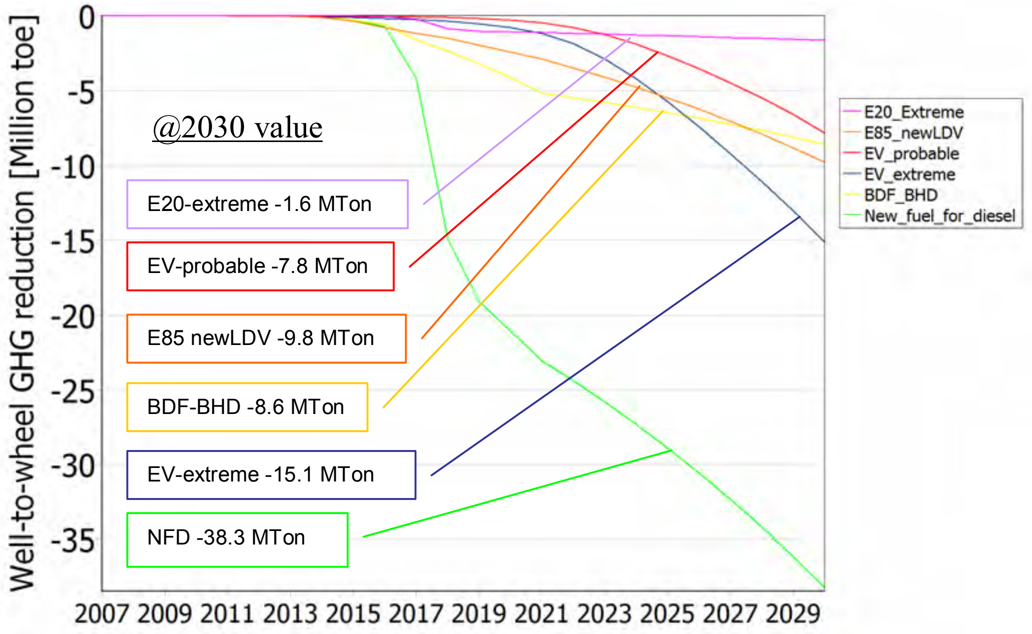


Fig. 29 Well-to-wheel GHG reduction

To realize the effects of energy policy implementation, the combination of all scenarios is constructed from the probable case in each scenario. The definition of combined scenario is shown in Table 17. The results of combination scenario are compared to other scenario in Fig. 30 and Fig. 31. The results show that the ATRANS model is capable of analyzing combined implementation of various energy policies.

Table 17: Definition of the combined probable case

		BAU	Combined scenario
Passenger car gasoline	New car	E20 (5 yr*)	E20 (5 yr)
	On road	E10 (5 yr)	E10 (5 yr) and E20 (5 yr 2015)
Motorcycle	New MC	E10 (5 yr)	E10 (5yr) and E20 (5yr 2015)
	On road	E10 (5 yr)	E10 (5yr) and E20 (5yr 2015)
Biodiesel fraction	For all diesel vehicle	B7	FAME 7.2 ML/d & BHD 3 ML/d
Electric vehicle	Passenger car	EV share for new car do not change	IEA bluemap + 5yr (2015)
	Motorcycle	Electric MC do not change	IEA bluemap

*If the begin years is not shown. It means that penetration begins at 2010.

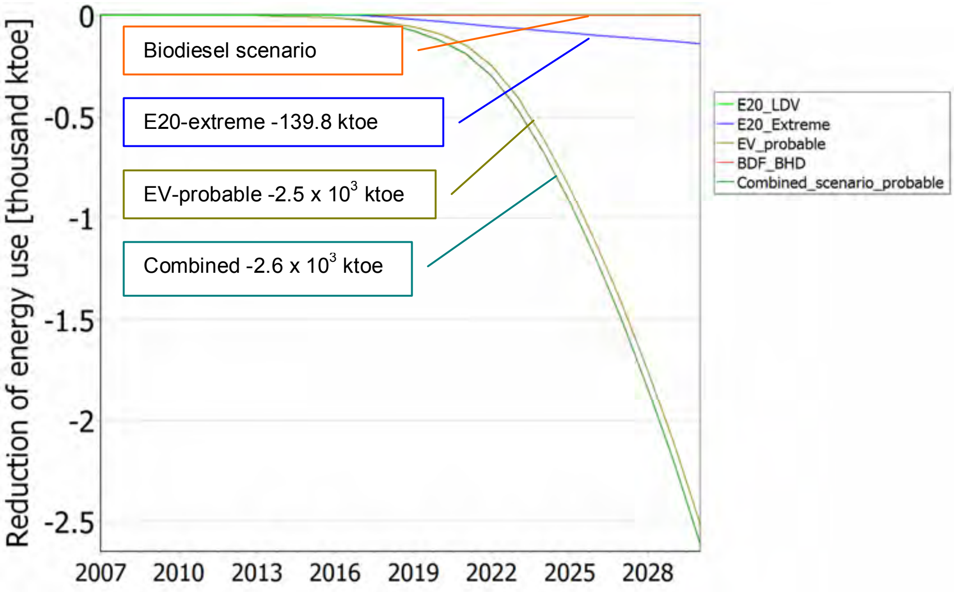


Fig. 30 Reduction of energy consumption for combined scenario and selected probable case

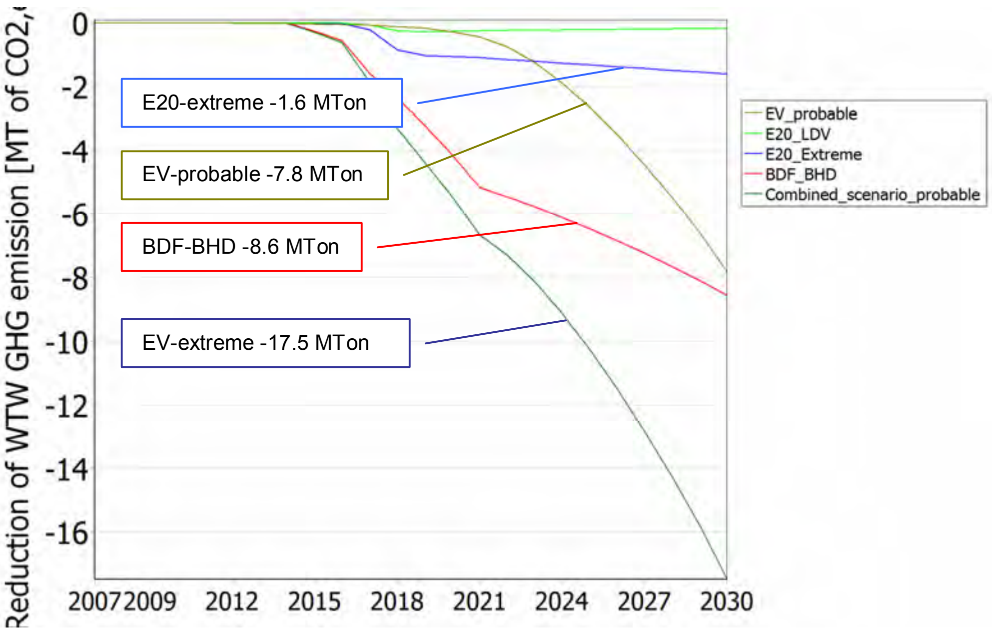


Fig. 31 Reduction of WTW GHG emission for combined scenario and selected probable case

CHAPTER 6 CONCLUSION

Clearly shown as a powerful tool to analyze the impacts of road transport energy policy, the bottom-up energy demand model was improved in this work. The number of vehicle has been validated with the updated historical record at the present time (2013). The vehicle ownership model has been revised to avoid over-prediction or negative number projection. Well-to-wheel emission factor for Thai road transportation were reviewed from available academic references, and incorporated into the database of Long-range Energy Alternatives Planning (LEAP) program. Hence, the powerful bottom-up energy demand model has been updated and harmonized with Greenhouse Gas calculation for Thai road transportation.

In addition, three energy policies have been investigated as case studies, e.g. bioethanol (or gasohol), biodiesel/diesel-substitute and electric vehicle technology. The results show the difference between each implement policy, and the potentials of each policy has been quantified.

References

1. DEDE (2012), "Thailand Energy Statistics 2012 (Preliminary)", http://www.dede.go.th/dede/images/stories/stat_dede/statistics_2012_5mar56/thailand%20energy%20statistics%202012%20na%205%20march%202013_1.pdf
2. http://apps.dlt.go.th/statistics_web/quarter/stat_q2_56.pdf
3. LEAP, http://www.energycommunity.org/
4. Pongthanaisawan, J. (2012), "Energy demand of road transport sector and fuel/vehicle technology alternatives for greenhouse gas emissions mitigation in Thailand", Ph.D. thesis, JGSEE
5. Santisirisomboon, J (2001), "Environmental Emission Abatement Strategies in the Energy Sector: The Integrated Economic, Environment and Energy Approach", Ph.D. thesis, SIIT
6. ATRANS 2009-2010 Research Project, "Possibility of Ethanol Usage as Diesel Substitutes in Thai Transportation Sector," http://www.atransociety.com/2013/pdf/pdfResearch2010/ATRANS_FY09_ED95_ReportDrNuwong.pdf
7. UNFCC (2005), "UNFCC Mitigation Assessments", http://unfccc.int/resource/cd_roms/na1/mitigation/Module_5/Module_5_1/a_Mitigation_assessment_tools_energy/Module5_1.ppt
8. Laoonual, Y., Chindaprasert, N. and Pongthanaisawan, J. (2008), "Development of Necessary Database for Planning and Assessment of Energy Conservation in Transportation Sector", Final report submitted to TRF
9. Schipper, L., et al. (2000) "Flexing the Link between Transport and Greenhouse Gas Emissions: A Path of the World Bank," Internationl Energy Agency, Paris
10. Schipper, L., et al. (2009) "Transport and Carbon Dioxide Emissions: Forecasts, Options Analysis, and Evaluation," ADB Sustainable Development Working Paper Series Asian Development Bank
11. Dalkmann, H. and Brannigan, C. (2007) "Transport and Climate Change," German Technical Cooperation (GTZ), Eschborn, Germany
12. Laoonual, Y., Chindaprasert, N., Pongthanaisawan, J. and Trinuruk, P. (2008), "Assessment of E85 Promotion Policy in Transportation Energy Sector", Final report submitted to TRF
13. Energy Policy and Planning Office: EPPO (1997). Investigation of Energy Conservation in Automotive; Final report to Ministry of Energy: Bangkok, Thailand.
14. Energy Policy and Planning Office: EPPO (2008). Survey of Energy Consumption in Transportation Sector; Final report to Ministry of Energy: Bangkok,Thailand.
15. Thai National Life Cycle Inventory Database (2011)
16. IEA Energy Technology Perspective (2006)
17. IPCC (2006), "2006 IPCC Guidelines for National Greenhouse Gas Inventories", http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
18. Nguyen TLT, Gheewala SH, Garivait S. (2008), Applied Energy 2008;85(8):722-34.
19. Silalertruksa T, Gheewala SH. (2009), Energy 2009;34(11):1933-46.
20. Silalertruksa T, Bonnet S, Gheewala SH. (2012), Journal of Cleaner Production 2012;28(1):225-32
21. EPPO (2012), Thailand Power Development Plan (PDP2010rev3), 2012-2030, http://www.eppo.go.th/power/PDP2010-r3/PDP2010-Rev3-Cab19Jun2012.pdf
22. King Mongkut's University of Technology Thonburi (KMUTT) and National Metal and Materials Technology Center (MTEC) (2013), Assessment of Electric Vehicle Technology Development and Its Implication in Thailand. Research project funded by EGAT-NSTDA Research and Development Promotion Fund. (inThai)
23. King Mongkut's Institute of Technology Ladkrabang (2012), A Demonstration Test of Electric Motorcycle in Daily Mobility: A Comparison to Fossil Fuel Motorcycle. Research project funded by Energy Policy and Planning Office. (in Thai)
24. Environmental Protection Agency, United State of America (US-EPA) (2013), Fuel Economy Guide. U.S. Department of Energy, January 8, 2013, http://www.fueleconomy.gov/feg/download.shtml.

25. Parks, K, Denholm, P. and Markel, T., “Costs and Emissions Associated with Plug-in Hybrid Electric Vehicle Charging in the Xcel Energy Colorado Service Territory”, Technical report submitted to National Renewable Energy Laboratory (NREL), U.S. Department of Energy, Report no. NREL/TP-640-41410, May 2007.

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