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Modeling of tailpipe emission: Case study of biofuel in Thailand

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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
CO	Carbon monoxide
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
HC	Hydrocarbon
HDV	Heavy duty vehicle
IPCC	Intergovernmental Panel on Climate Change
ktoe	Kilotonne of oil equivalent
LDV	Light duty vehicle
LPD	Liter per day
LPG	Liquefied Petroleum Gas
MW	Megawatts
NEPC	National Energy Policy Council
NGV	Natural gas for vehicle
NOx	Nitrogen oxide
PM	Particulate matter
R&D	Research and development
SEI	Stockholm Environment Institute
SI	spark-ignition
THB	Thai Baht
TISI	Thai Industrial Standards Institute
TRF	Thailand Research Fund
VKT	Vehicle Kilometer Traveled
yrs	Years

CHAPTER I INTRODUCTION

1.1 Rationale

As a net energy importer, Thailand has developed national energy integrated plans under three crucial aspects: security, economy and ecology [1]. Firstly, security aspect focuses on securing supply of energy, which responds to growing energy demand according to the growths of economy and population as well as urbanization. Appropriate diversification of fuel mix is also highlighted. Secondly, economy aspect focuses on achieving fair energy prices that supports the development of economics and society in a long term by recourse to reforming the fuels price structure. Real cost with an appropriate taxing system will increase energy efficiency and public awareness of the efficient fuel usage. Thirdly, ecology aspect aims at increasing the portion of energy production from renewable energy sources and the use of high-efficiency technologies to produce energy in a pollution-reduction fashion. Hence, Thailand Integrated Energy Blueprint (TIEB) was established in 2015, which is composed of the following five national energy plans.

(1) Power Development Plan (PDP)

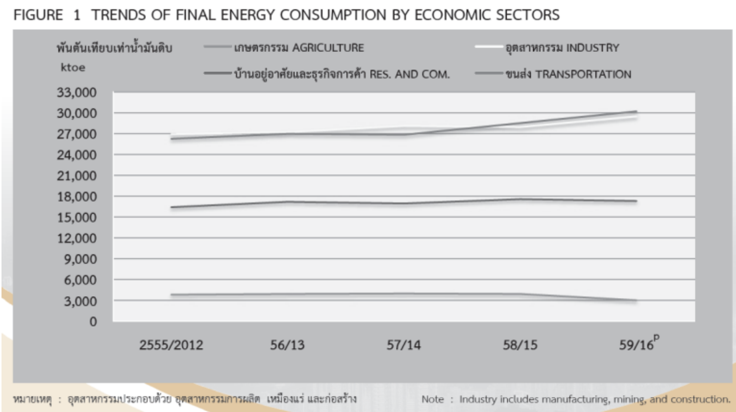
(2) Energy Efficiency Plan (EEP)

(3) Alternative Energy Development Plan (AEDP)

(4) Natural Gas Supplying Plan (Gas Plan)

(5) Oil Management Plan (Oil Plan)

As shown in Fig. 1(a) [2], final energy consumption in Thailand during 2012-2016 has increased with largest energy consumption in transportation and industry sectors, as high as 40% and 36% shown in Fig. 1(b) [3], respectively. With focus on transportation sector, approximately 20 million motorcycles and 16 million vehicles (three-wheelers, four-wheelers, buses and trucks) are registered in 2016, as shown in Fig. 2(a) [4], where pick-up truck (PU) and truck dominate fuel consumption mostly as diesel, and passenger car (PC) and motorcycle (MC) consume gasoline, as shown in Fig. 2(b) [5].



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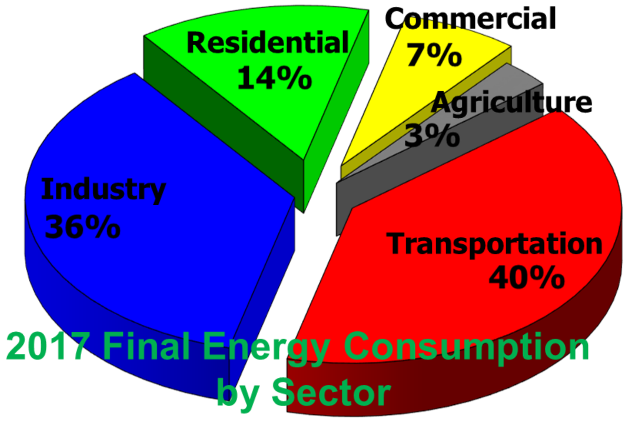
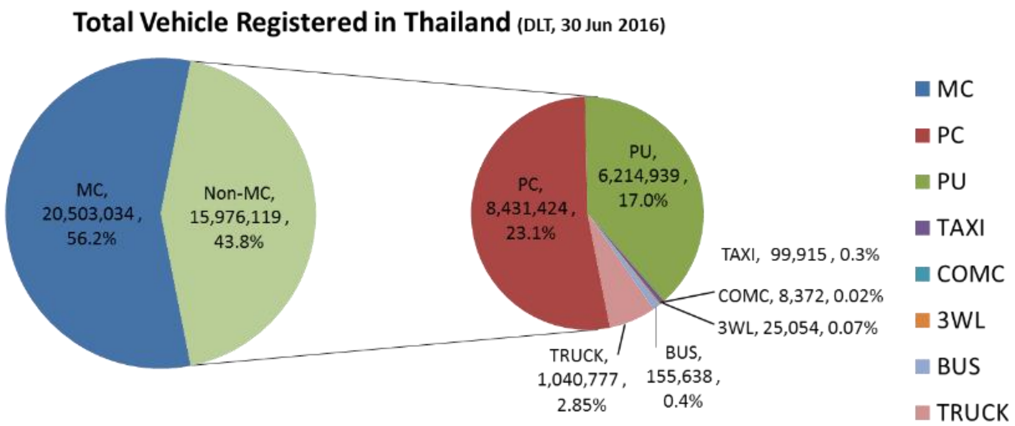


(b)

Fig. 1 (a) Thailand energy consumption by economic sectors (2012-2016) with 2017 snapshot



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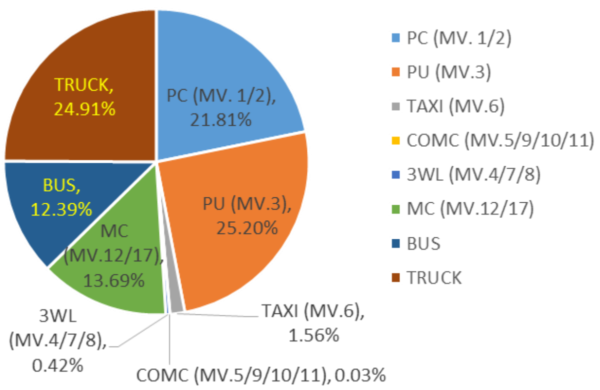
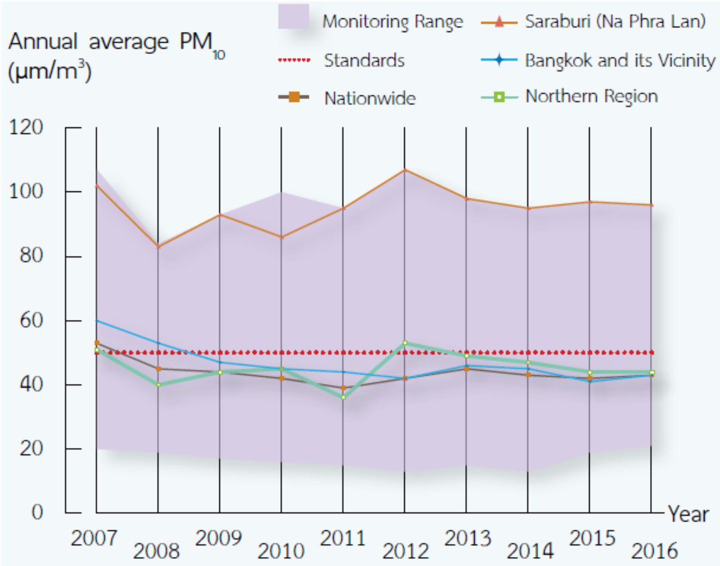


(b)

Fig. 2 (a) Vehicle registration by type in 2016 with (b) calculated fuel consumption in 2014 by vehicle type

Despite the tougher emission regulation implemented in Thailand with currently Euro4 for light duty vehicle and Euro3 for heavy duty vehicle, the regulation can only enforce

new vehicles, which account for approximately almost 1 million vehicles and almost 2 million motorcycles annually [4]. Moreover, about half of current 6 million pick-up truck is more than 10 years old. It is not surprising why particles of less than or equal to 10 microns (PM10) and 2.5 microns (PM2.5) have been identified as main problem of Thailand's air quality during 2007-2016, as shown in Fig. 3 [6].



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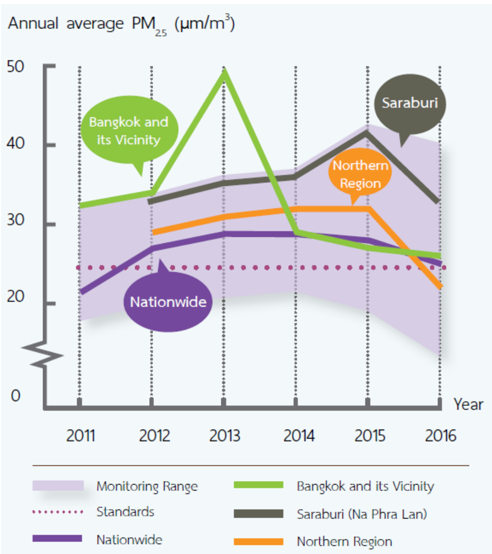


(b)

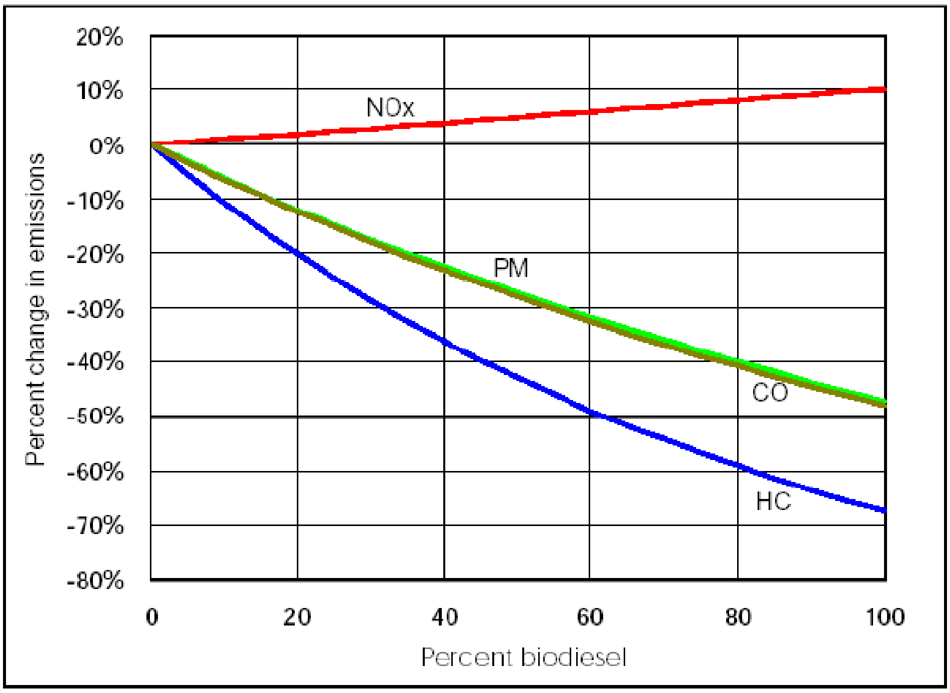
Fig. 3 Annual average concentration of (a) PM10 and (b) PM2.5

As biofuel, ethanol for gasoline [7] and biodiesel for diesel [8, 9], is known to help reduce tailpipe emission due to more complete combustion, as shown in Fig. 4 and Fig. 5, respectively. With current biofuel targets of 11.4 ML/d ethanol and 14 ML/d biodiesel in 2036 according to AEDP 2015-2036 [1] shown in Fig. 6, the effect of biofuel replacing fossil energy can be quantified to some extent by recourse to existing simulation tool as a case study for biofuel utilization in Thailand.

Emissions & FC	E20 over E10	E50 over E10	E85 over E10	E50 over E20	E85 over E20	E85 over E50
Test Vehicle : FFV1						
THC , g/km	-31.94(NS)	-6.94(NS)	-40.28	-40.12	-12.17(NS)	-54.23
NOx , g/km	-3.33(NS)	-15.83(NS)	-34.17	+8.33(NS)	+8.33(NS)	-1.11(NS)
CO , g/km	-2.85(NS)	-15.72	-51.71	-6.13(NS)	-29.82	-44.97
CO2 ,g/km	+3.85	-0.85(NS)	-3.58	+3.95	-0.39(NS)	-1.71
FC , l/100km	+7.77	+16.20	+34.74	+8.21	+17.12	+37.97
Formaldehyde , mg/km	+396.95 (NS)	-827.10 (NS)	-1496.77 (NS)	-207.27 (NS)	-1245.74 (NS)	-561.49 (NS)
Acetaldehyde, mg/km	+36.34 (NS)	+385.61	+1423.21	+24.64 (NS)	+241.32	+809.89
Test Vehicle : FFV2						
THC , g/km	-40.12	-12.17(NS)	-54.23	+46.67	-23.33	-47.62
NOx , g/km	+8.33(NS)	+8.33(NS)	-1.11(NS)	+0.00 (NS)	-7.78(NS)	- 7.78(NS)
CO , g/km	-6.13(NS)	-29.82	-44.97	-25.18	-41.16	-21.39
CO2 ,g/km	+3.95	-0.39(NS)	-1.71	-4.17	-5.43	- 1.31(NS)
FC , l/100km	+8.21	+17.12	+37.97	+8.24	+27.51	+17.81
Formaldehyde , mg/km	-207.27 (NS)	-1245.74 (NS)	-561.49 (NS)	+735.07	+452.78 (NS)	-34.23 (NS)
Acetaldehyde, mg/km	+24.64(NS)	+241.32	+809.89	+178.57	+644.38	+168.09

Note: *(NS) - Not Significant by statistical analysis*

Fig. 4 Effects of tailpipe emission with ethanol



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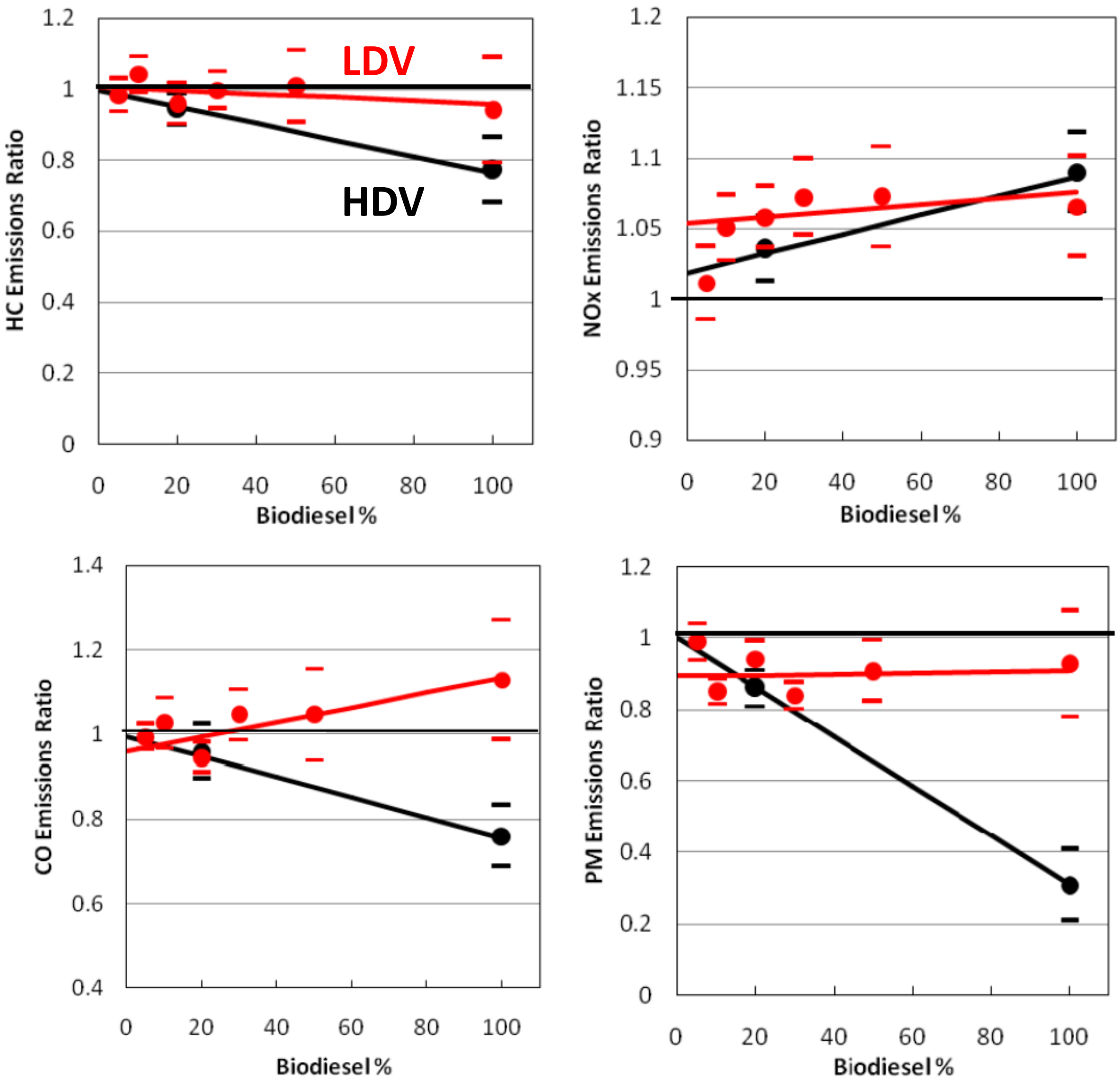
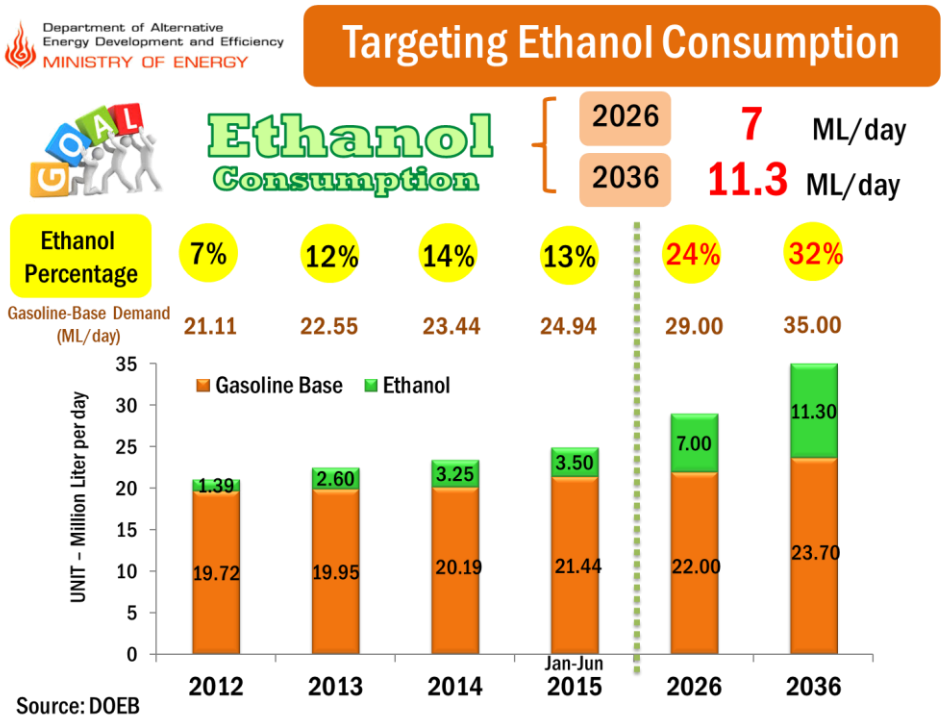


(b)

Fig. 5 Effects of tailpipe emission with biodiesel blending for (a) heavy and (b) light duty vehicles



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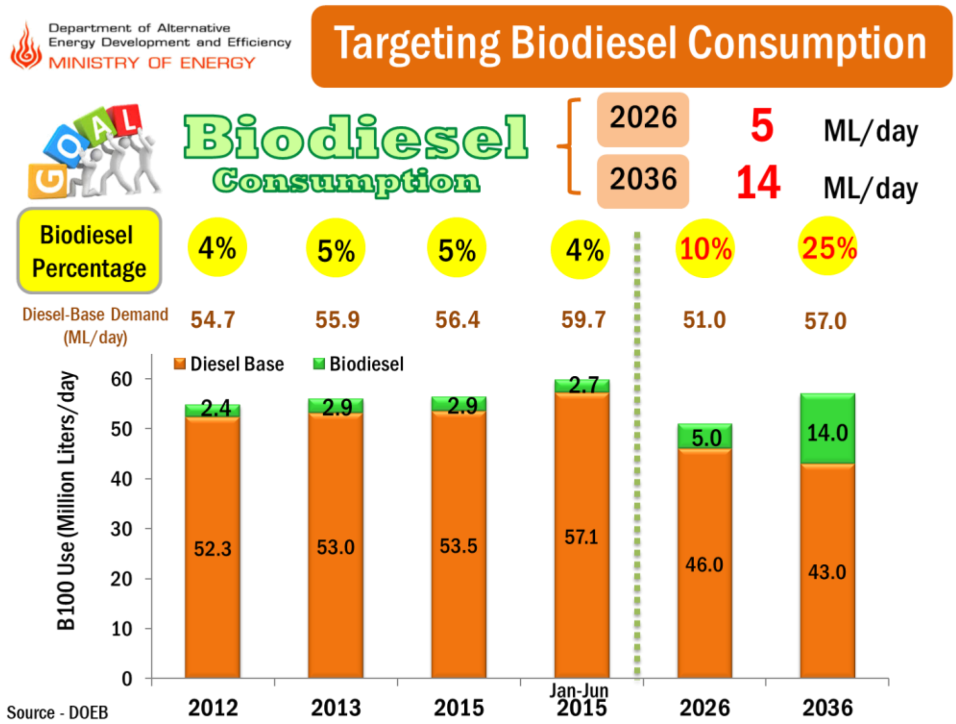


(b)

Fig. 6 Target of (a) ethanol and (b) biodiesel consumption according to AEDP

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 [10], has been utilized worldwide, including previous ATRANS project [11]. Hence, the objectives of the proposed investigation are

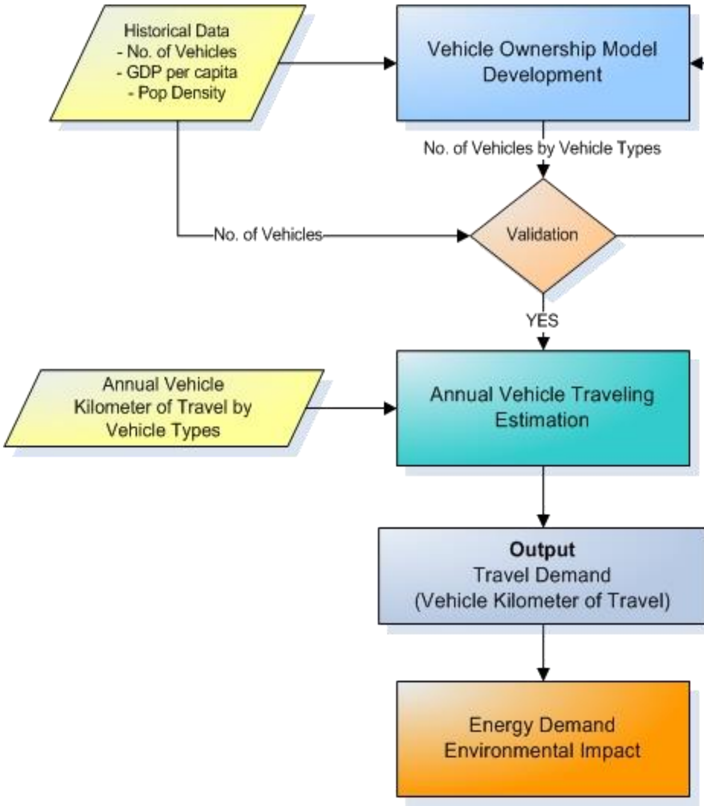
1. **To update LEAP database for Thailand energy demand modeling with calibration of current use of fossil and biofuel.**
2. **To quantify effects of biofuel usage in Thailand transportation sector onto tailpipe emission under difference scenarios according to AEDP.**

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 1 [12]. 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. 7 [10]. Among many others, Long-range Energy Alternatives Planning (LEAP) system [10] will be utilized to construct the energy demand model in this study.

Table 1: Differences between top-down and bottom-up approach in energy model

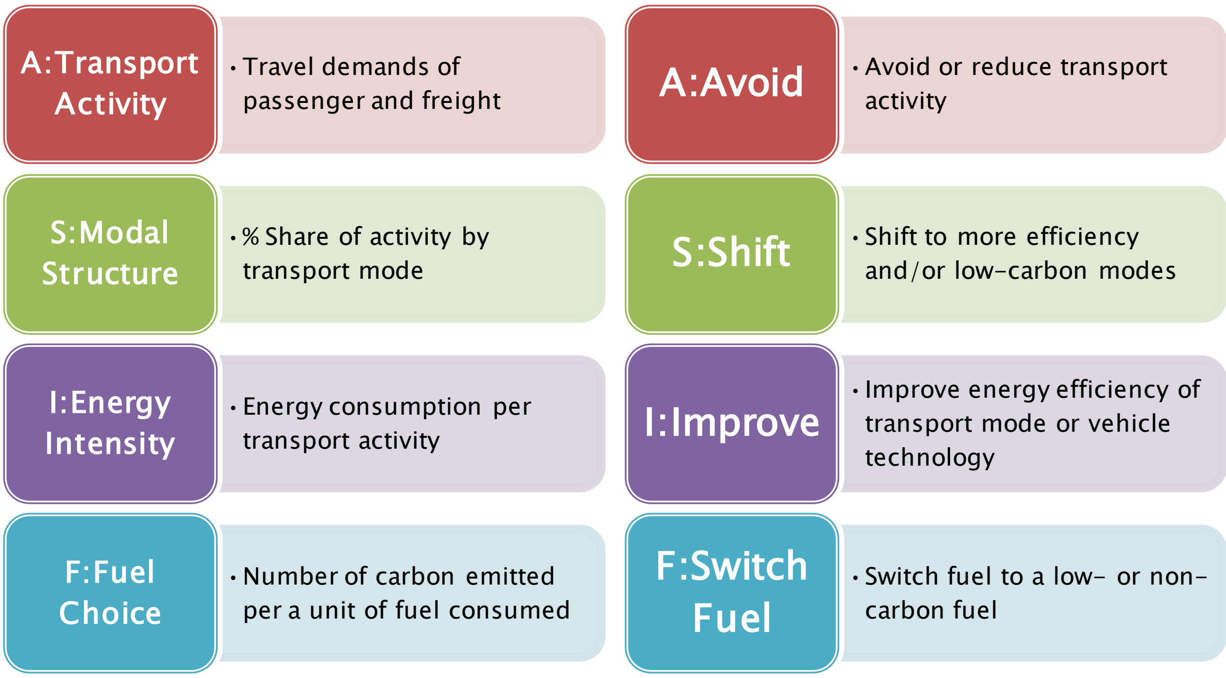
Top-down	Bottom-up
Use aggregated economic data	Use detailed data on fuels, technologies and policies
Assess costs/benefits through impact on output, income, GDP	Assess costs/benefits of individual technologies and policies
Implicitly capture administrative, implementation and other costs.	Can explicitly 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. 7 Flow of bottom-up energy demand model

From previous study [13], 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) [14, 15, 16], as shown in Fig. 8(a). This ASIF concept can be applied for emission reduction in transportation sector as shown in Fig. 8(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		

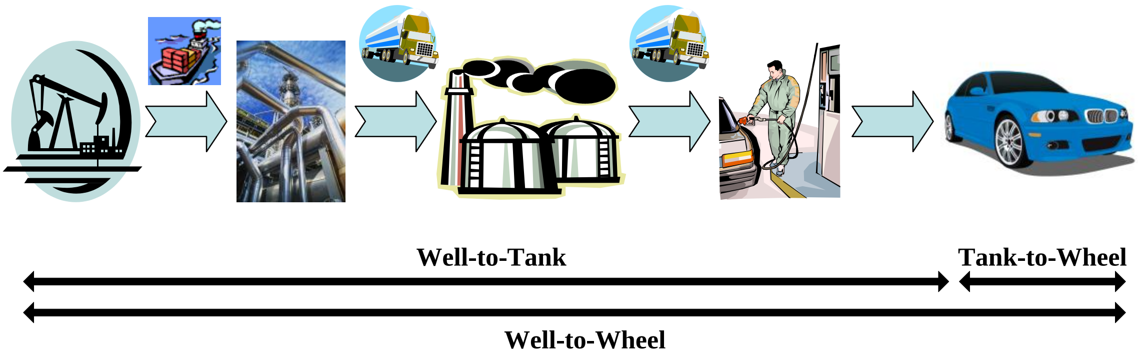
(b)

Fig. 8 (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),**

For model calibration, 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. 9 [17]. With careful calibration on both energy consumption and GHG emission, the final model with database will be utilized to investigate various effects from AEDP.



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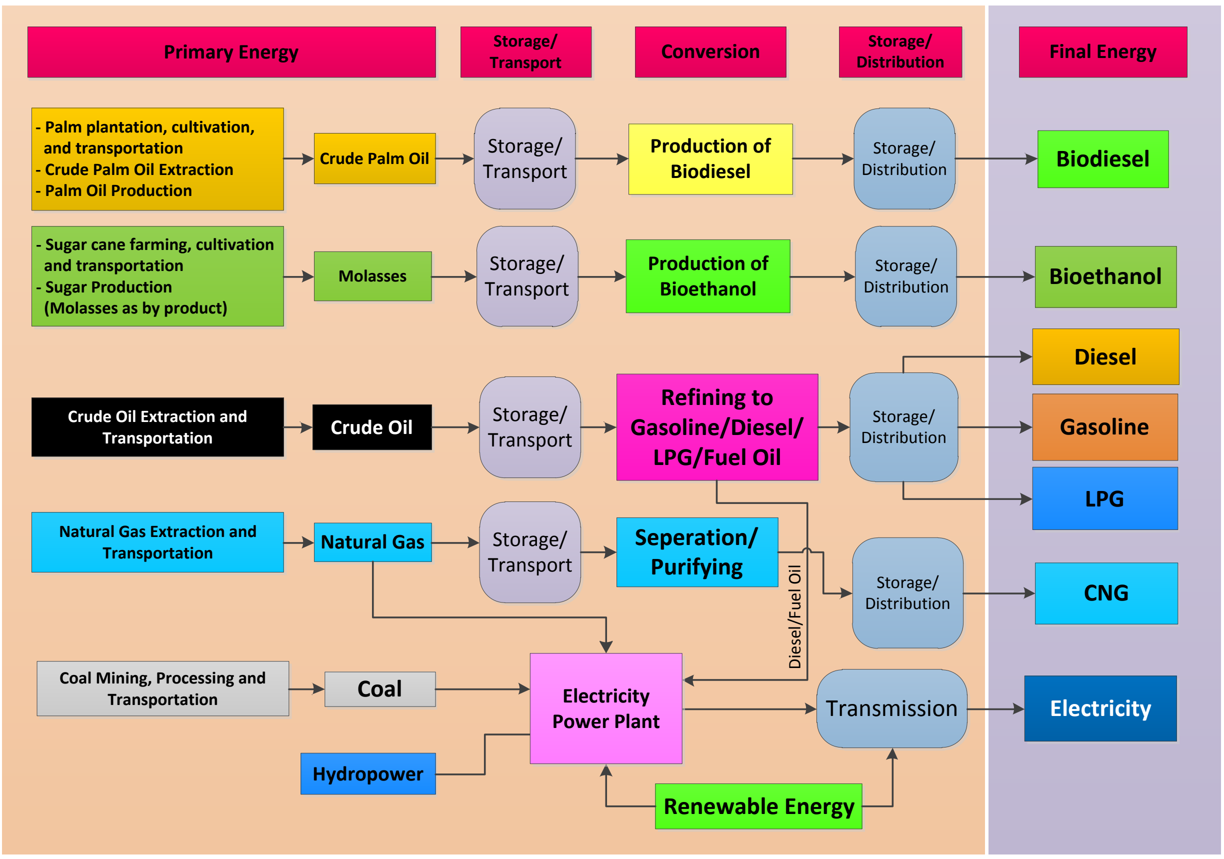


(b)

Fig. 9 (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 [10]. LEAP modeling capabilities are highlighted as follows, with the calculation flows shown in Fig. 10.

- **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.**

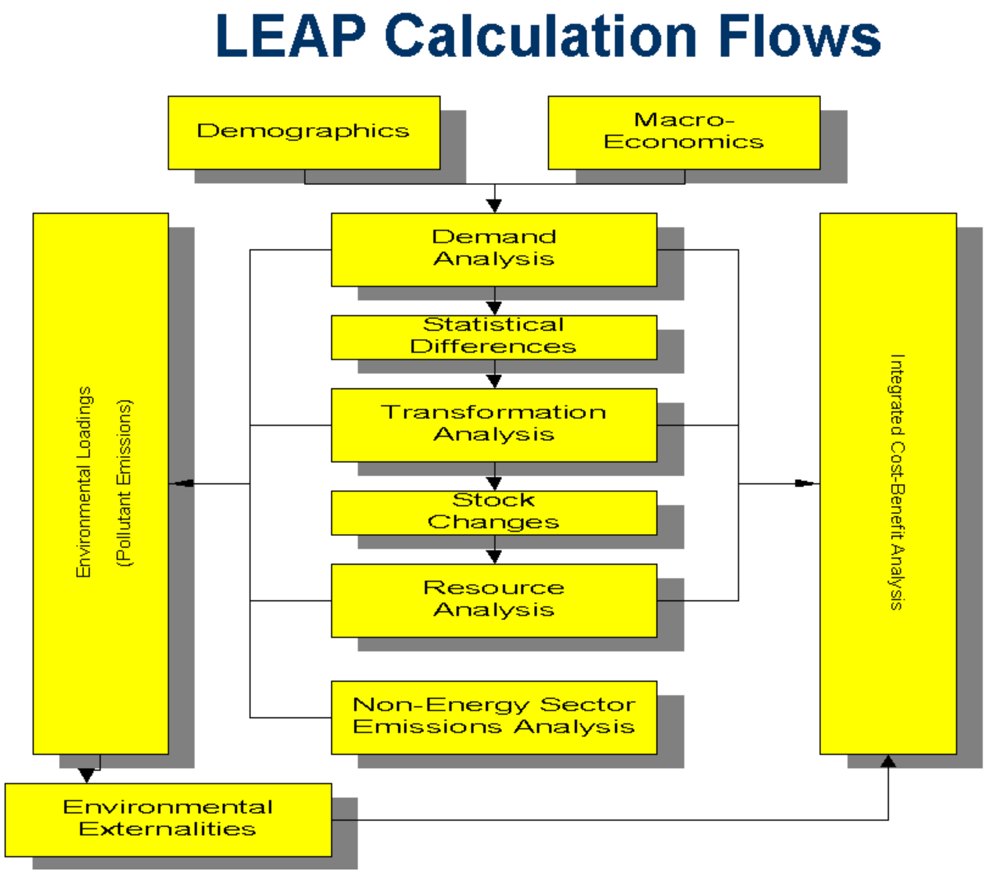


Fig. 10 LEAP calculation flows

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. 11.

- **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. 11(a)-(c).**
- **The *Results View* allows user to examine the outcomes of input scenarios as charts and tables shown in Fig. 11(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. 11(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.

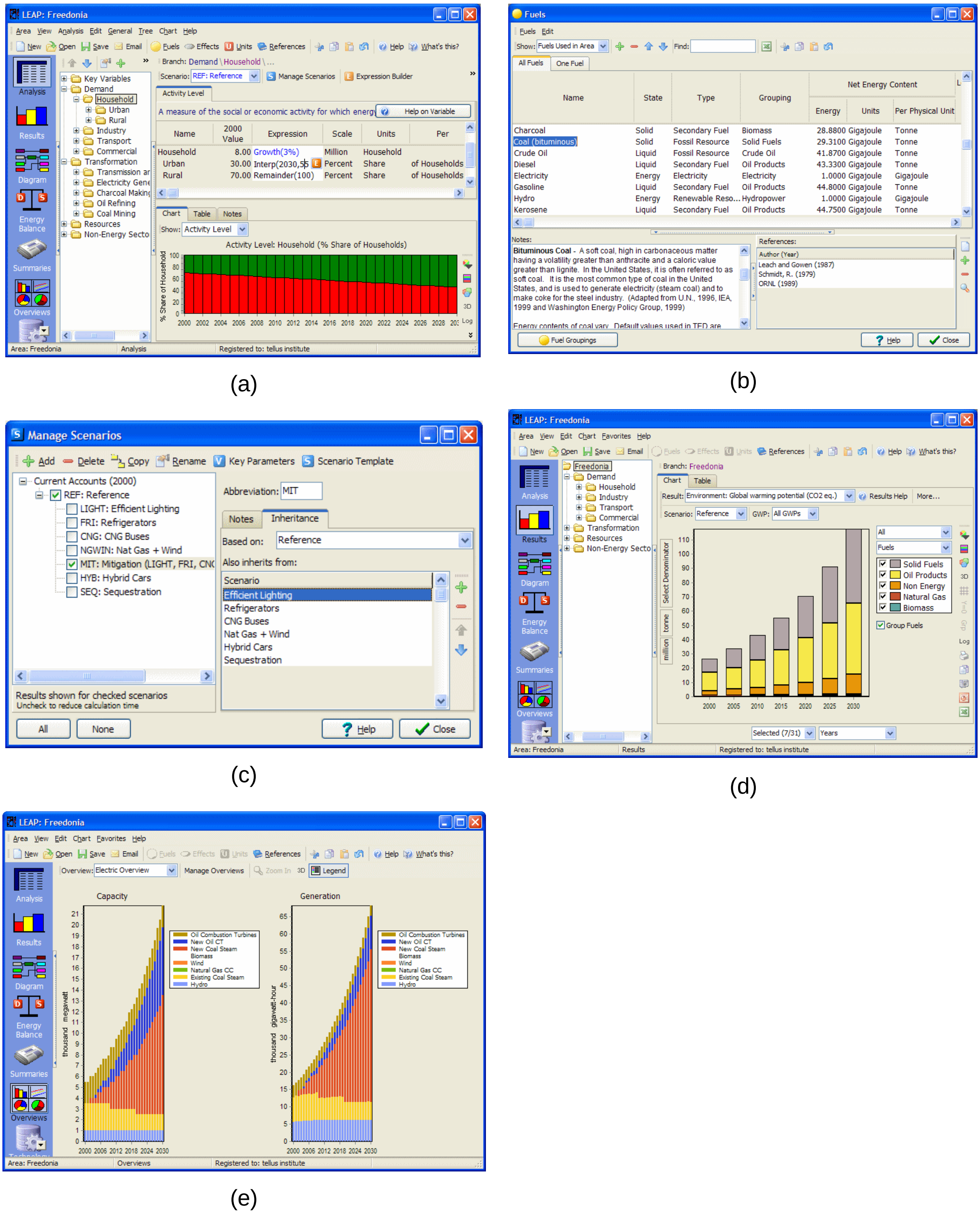


Fig. 11 Overview of LEAP system showing (a) Analysis View, (b) Fuel data customization, (c) Scenarios customization, (d) Result View and (e) Overview of interested results

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. An example of such function is [18]

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

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.

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.

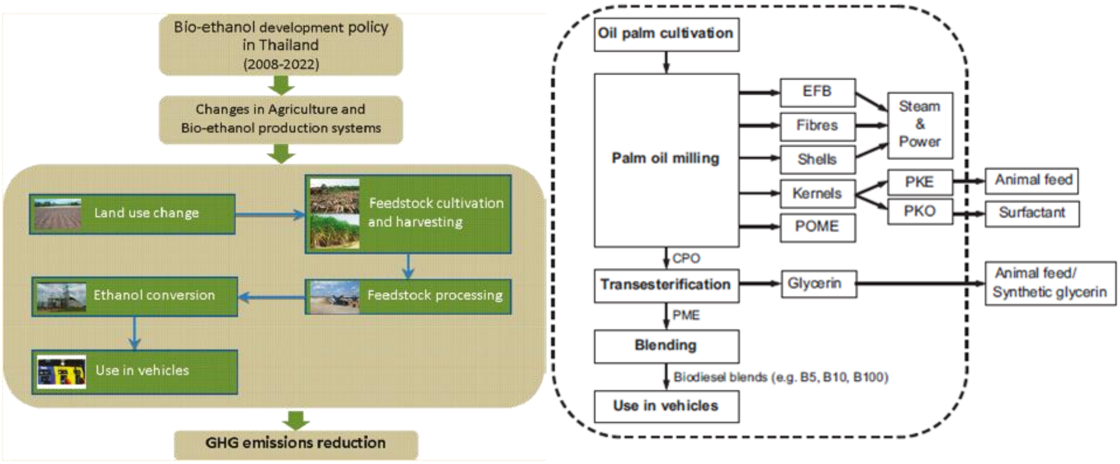
As for reduction of fossil fuel, it is calculated based on the assumption of biofuel introduction in the case of AEDP and EVs introduction in the case of EEDP, based on the same economic activities in terms of vehicle growth, VKT and FE projection. As for reduction of GHGs emission, the whole WTW (well-to-wheel) 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 [2, 19, 20]; whereas, the TTW component can be obtained from IPCC default value [21], as shown in Fig. 12(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 [22, 23, 24], as shown in Fig. 12(b). Hence, each scenario will be analyzed for GHGs emission reduction based on various assumption of biofuel (AEDP) 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)

Fig. 12 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

2.3 Case studies

As previously mentioned, the present study focuses on the policy impact from AEDP (bioethanol and biodiesel) 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.

CHAPTER 3 RESEARCH PLAN

3.1 Project Schedule

Table 2 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 2: Project planning schedule

Activity	2016									2017		
	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Literature review with database preparation												
Model design and calibration												
Running energy demand model												
Interpretation of simulation results												
Inception report submission	30 Apr											
Progress report presentation			29 Jun									
Interim report presentation						07 Sep						
Interim report submission						30-Sep						
Final report presentation									14 Dec			
ATRANS public forum										25 Jan		
Final report submission												31 Mar

3.2 Project Expenditure

Table 3 shows the breakdown of the project expenditure.

Table 3: Project expenditure

No.	Item	Unit cost	Number of units	Sub total
1	Project leader	3,000	12	36,000
2	2 Research assistants (200 THB/hr x 8 hrs/day x 6.25 days/month) for 12 months)	10,000	24	240,000
3	Expenses for project meeting	5,000	6	30,000
4	Travel expenses to collect database	2,000	6	12,000
5	Office & computer supply	3,000	6	18,000
6	Secretariat's participation portion	10,000	1	10,000
7	Publishing proportion of the report book	50,000	1	50,000
			Total	396,000

CHAPTER 4 ENERGY DEMAND MODEL SETUP

This section will follow similar methodology from previous ATRANS projects [11, 25] with updated data on both vehicle database and tailpipe emission modeling.

4.1 Vehicle 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 [25] with additional recent historical record from Transport Statistics Sub-Division, Department of Land Transport (DLT) [4]. Secondly, Vehicle Kilometer of Travel (VKT) use the recently updated value in [26]. Thirdly, Fuel Economy (FE) will mostly follow [25]. Finally, the predicted energy demand will be calibrated with additional data since [25] for improved accuracy.

Following [25], the vehicle types are still re-categorized from DLT classification for the purpose of LEAP calculation, as shown in the Table 4. 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 4: 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

A. Total vehicle under Motor Vehicle Act		B. Total vehicle under Land Transport Act	
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 [25], specific functional form for each vehicle type is still retained but fitted with more data update from DLT as follows.

$$ln\left(\frac{P}{S-P}\right) = a + b\,ln GDPpCap + \sum \delta_k c_k + t\,ln T$$

where P = vehicle population

S = saturated level of vehicle population

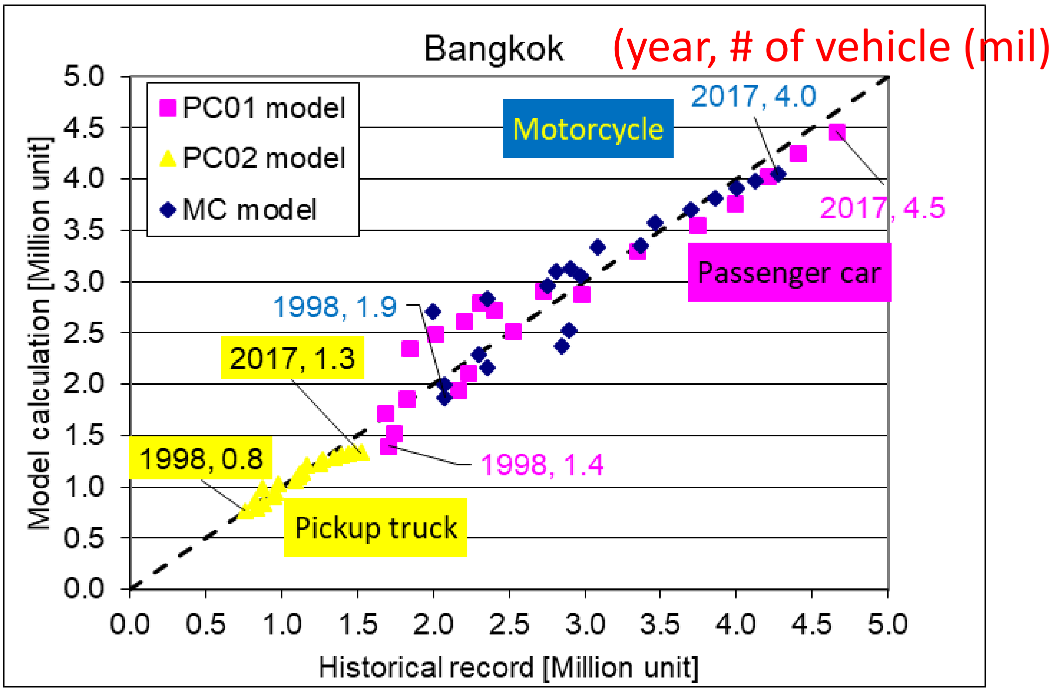
a, b, c_k, t = constant coefficients, which are fitted in the model

GDPpCap = GDP per capita

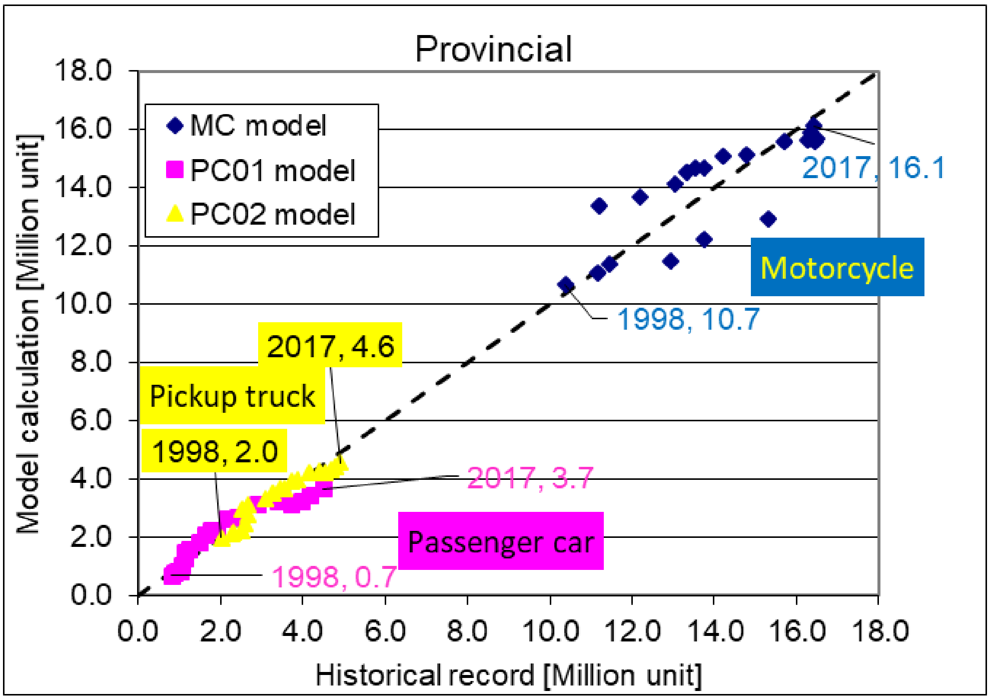
δ_k = various externalities

T = time period

Without repeating each vehicle ownership relationship, the validation is shown in Fig. 13.



(a)



(b)

Fig. 13 Validation of vehicle ownership model for (a) Bangkok and (b) Provincial

Without repeating VKT model development in [25], the complete VKT values for each vehicle type in both Bangkok and Provincial regions are shown in Table 5. Likewise, without repeating FE model development in [25], the percent shares of fuel use for each vehicle type are shown in Table 6 and Table 7 for Bangkok and provincial region, respectively; whereas, the fuel economy is shown in Table 8 and Table 9 for Bangkok and provincial region, respectively. By taking into account of average fuel economy improvement in Thailand [27],

the value of 0.86% improvement of fuel economy is taken into account as shown in Table 10 and Table 11 for Bangkok and provincial region, respectively..

Table 5: Vehicle kilometer of travel (VKT) used in the model

Vehicle type	Bangkok	Provincial region
PC01 Passenger car	20,230*	20,230*
PC02 Pickup	24,270*	24,270*
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 survey VKT from [26]**

† Reference from the VKT data in year 2008 [28]

‡ Calculated in this work from VKT data in 1997 [29]

Table 6: Modeling percent share for fuel used by each vehicle type in Bangkok

<table>
<tr><th rowspan="3">Bangkok Model</th><th colspan="6">Liquid fueled engine</th><th colspan="4">Liquid/gas fueled engine</th><th colspan="2">Dedicated gas</th></tr>
<tr><th colspan="4">SI Engine*</th><th rowspan="2">Hybrid Gasoline</th><th rowspan="2">Diesel*</th><th rowspan="2">Bi-fuel SI LPG*</th><th rowspan="2">Bi-fuel SI CNG*</th><th rowspan="2">DDF LPG*</th><th rowspan="2">DDF CNG*</th><th rowspan="2">LPG dedic.*</th><th rowspan="2">CNG dedic.*</th></tr>
<tr><th>Gasoline**</th><th>E10**</th><th>E20**</th><th>E85**</th></tr>
<tr><td rowspan="2">PC01</td><td colspan="4">58.35%</td><td rowspan="2">1.19%</td><td rowspan="2">22.29%</td><td rowspan="2">14.89%</td><td rowspan="2">3.19%</td><td rowspan="2">0.02%</td><td rowspan="2">0.02%</td><td rowspan="2">0.04%</td><td rowspan="2">0.01%</td></tr>
<tr><td>42.86%</td><td>56.57%</td><td>0.57%</td><td>0.00%</td></tr>
<tr><td rowspan="2">PC02</td><td colspan="4">3.16%</td><td rowspan="2">0.00%</td><td rowspan="2">89.24%</td><td rowspan="2">4.71%</td><td rowspan="2">2.10%</td><td rowspan="2">0.09%</td><td rowspan="2">0.07%</td><td rowspan="2">0.18%</td><td rowspan="2">0.45%</td></tr>
<tr><td>67.95%</td><td>32.05%</td><td>0.00%</td><td>0.00%</td></tr>
<tr><td rowspan="2">PC03</td><td colspan="4">12.36%</td><td rowspan="2">0.00%</td><td rowspan="2">0.12%</td><td rowspan="2">21.44%</td><td rowspan="2">0.08%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">55.50%</td><td rowspan="2">10.50%</td></tr>
<tr><td>79.58%</td><td>20.42%</td><td>0.00%</td><td>0.00%</td></tr>
<tr><td rowspan="2">PC04</td><td colspan="4">0.94%</td><td rowspan="2">0.00%</td><td rowspan="2">0.07%</td><td rowspan="2">30.92%</td><td rowspan="2">68.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.07%</td><td rowspan="2">0.00%</td></tr>
<tr><td>42.86%</td><td>56.57%</td><td>0.57%</td><td>0.00%</td></tr>
<tr><td rowspan="2">PC05</td><td colspan="4">20.12%</td><td rowspan="2">3.64%</td><td rowspan="2">23.09%</td><td rowspan="2">46.41%</td><td rowspan="2">6.73%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td></tr>
<tr><td>42.86%</td><td>56.57%</td><td>0.57%</td><td>0.00%</td></tr>
<tr><td rowspan="2">PC06</td><td colspan="4">100.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td></tr>
<tr><td>65.57%</td><td>34.43%</td><td>0.00%</td><td>0.00%</td></tr>
<tr><td rowspan="2">Bus07</td><td colspan="4">0.82%</td><td rowspan="2">0.00%</td><td rowspan="2">43.34%</td><td rowspan="2">2.39%</td><td rowspan="2">33.21%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">1.34%</td><td rowspan="2">18.90%</td></tr>
<tr><td>100.00%</td><td>0.00%</td><td>0.00%</td><td>0.00%</td></tr>
<tr><td rowspan="2">Bus08</td><td colspan="4">0.41%</td><td rowspan="2">0.00%</td><td rowspan="2">91.67%</td><td rowspan="2">1.21%</td><td rowspan="2">3.61%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">3.10%</td></tr>
<tr><td>100.00%</td><td>0.00%</td><td>0.00%</td><td>0.00%</td></tr>
<tr><td rowspan="2">Bus09</td><td colspan="4">1.77%</td><td rowspan="2">0.00%</td><td rowspan="2">98.23%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td></tr>
<tr><td>100.00%</td><td>0.00%</td><td>0.00%</td><td>0.00%</td></tr>
<tr><td rowspan="2">sBus04</td><td colspan="4"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Truck10</td><td colspan="4">0.03%</td><td rowspan="2">0.00%</td><td rowspan="2">90.07%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.20%</td><td rowspan="2">1.18%</td><td rowspan="2">0.00%</td><td rowspan="2">8.52%</td></tr>
<tr><td>100.00%</td><td>0.00%</td><td>0.00%</td><td>0.00%</td></tr>
<tr><td rowspan="2">Truck11</td><td colspan="4">0.19%</td><td rowspan="2">0.00%</td><td rowspan="2">97.42%</td><td rowspan="2">0.00%</td><td rowspan="2">0.00%</td><td rowspan="2">0.11%</td><td rowspan="2">0.73%</td><td rowspan="2">0.09%</td><td rowspan="2">1.46%</td></tr>
<tr><td>100.00%</td><td>0.00%</td><td>0.00%</td><td>0.00%</td></tr>
</table>

*** Registered record from DLT [4]**

**** EPPO report 2008 [28]**

Table 7: Modeling percent share for fuel used by each vehicle type in provincial region

Province Model	Liquid fueled engine: SI Engine* Gasoline**	E10**	E20**	E85**	Hybrid Gasoline**	Diesel*	Liquid/gas fuel engine: Bi-fuel SI LPG*	Bi-fuel SI CNG*	DDF LPG*	DDF CNG*	Dedicated gas: LPG dedic.*	CNG dedic.*
PC01	55.52%				0.20%	33.49%	9.70%	1.09%	0.00%	0.00%	0.00%	0.00%
	49.83%	50.17%	0.00%	0.00%								
PC02	4.65%				0.00%	94.10%	1.10%	0.15%	0.00%	0.00%	0.00%	0.00%
	67.95%	32.05%	0.00%	0.00%								
PC03	31.38%				0.00%	0.60%	9.47%	0.00%	0.00%	0.00%	58.55%	0.00%
	79.58%	20.42%	0.00%	0.00%								
PC04	34.84%				0.00%	14.00%	37.82%	13.34%	0.00%	0.00%	0.00%	0.00%
	49.83%	50.17%	0.00%	0.00%								
PC05	48.79%				0.00%	15.80%	34.67%	0.74%	0.00%	0.00%	0.00%	0.00%
	49.83%	50.17%	0.00%	0.00%								
PC06	100.00%				0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	74.56%	25.44%	0.00%	0.00%								
Bus07	2.82%				0.00%	84.77%	3.47%	4.43%	0.00%	0.51%	0.29%	3.71%
	100.00%	0.00%	0.00%	0.00%								
Bus08	16.13 %				0.00%	78.01%	2.88%	0.95%	0.00%	0.00%	0.69%	1.34%
	100.00%	0.00%	0.00%	0.00%								
Bus09	0.00%				0.00%	99.17%	0.00%	0.00%	0.00%	0.25%	0.17%	0.41%
	100.00%	0.00%	0.00%	0.00%								
sBus04	8.46%				0.00%	88.78%	2.21%	0.55%	0.00%	0.00%	0.00%	0.00%
	100.00%	0.00%	0.00%	0.00%								
Truck10	0.00%				0.00%	89.71%	0.00%	0.00%	0.19%	1.02%	0.13%	8.95%
	100.00%	0.00%	0.00%	0.00%								
Truck11	0.00%				0.00%	97.93%	0.00%	0.00%	0.15%	0.18%	0.20%	1.54%
	100.00%	0.00%	0.00%	0.00%								

***Registered record from DLT [4]**

****EPPO report 2008 [28]**

Table 8: Fuel economy for fuel used in each vehicle type for Bangkok region

km/litre and km/kg for CNG	Single fuel engine: Spark ignition engine Gasoline	E10	E20	E85	Hybrid Gasoline	Diesel engine	Dedicative gas engine: LPG	CNG
PC01	10.62*	11.30*	9.85†	7.36†	15.10‡	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†	7.33†	-	11.63†	9.83†	10.81†
PC05	11.83†	11.40†	10.97†	8.20†	-	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 [28]**

†Calculated from previous EPPO report [29]

‡Calculated from fueleconomy.gov database [30]

Table 9: 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				Hybrid gasoline	Diesel engine	LPG	CNG
	Gasoline	E10	E20	E85				
PC01	12.28*	12.43*	11.40†	8.51†	17.48‡	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†	8.38†	-	12.02†	11.03†	11.26†
PC05	10.82†	10.43†	10.04†	7.50†	-	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 [28]**

†Calculated from previous EPPO report [29]

‡Calculated from fueleconomy.gov database [30]

Table 10: Average fuel economy improvement in each vehicle type for Bangkok region

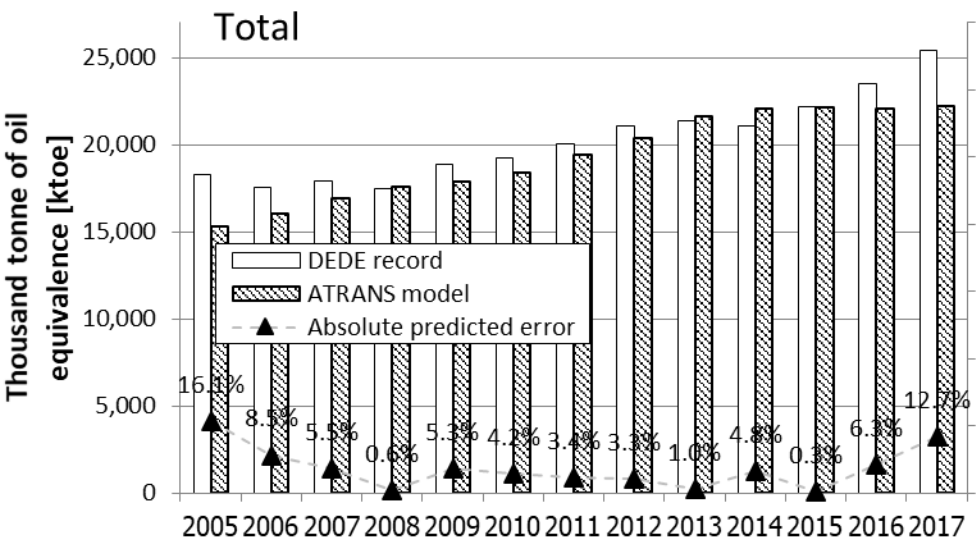
Fuel economy (km/litre)	2017	2020	2024	2028	2032	2036
	Gasoline vehicle					
PC01	10.80	11.09	11.48	11.88	12.30	12.73
PC02	10.17	10.44	10.81	11.19	11.58	11.99
PC03	11.11	11.40	11.80	12.22	12.65	13.09
PC04	10.77	11.05	11.44	11.84	12.26	12.69
PC05	12.03	12.35	12.78	13.23	13.70	14.18
PC06	33.34	34.22	35.42	36.66	37.95	39.29
	Diesel vehicle					
Bus01	2.44	2.51	2.59	2.69	2.78	2.88
Bus02	2.26	2.20	2.12	2.05	1.98	1.91
Bus03	2.27	2.21	2.13	2.06	1.99	1.92
sBus04	-	-	-	-	-	-
Truck01	2.87	2.95	3.05	3.16	3.27	3.39
Truck02	2.49	2.55	2.64	2.74	2.83	2.93

Table 11: Average fuel economy improvement in each vehicle type for Provincial region

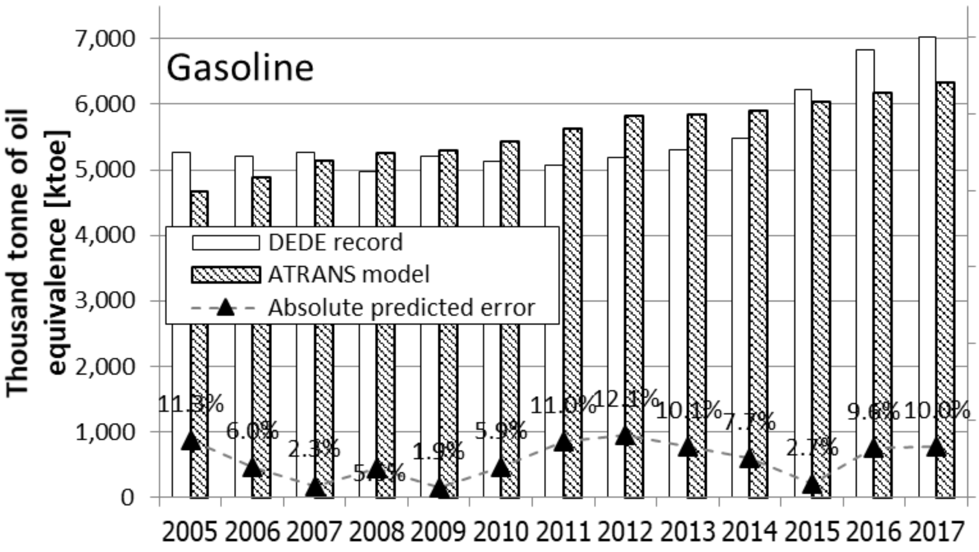
Fuel economy (km/litre)	2017	2020	2024	2028	2032	2036
	Gasoline vehicle					
PC01	12.50	12.83	13.28	13.74	14.23	14.73
PC02	12.08	12.40	12.84	13.29	13.76	14.24
PC03	16.44	16.87	17.46	18.08	18.71	19.37
PC04	12.30	12.63	13.07	13.53	14.01	14.50
PC05	11.01	11.30	11.69	12.10	12.53	12.97
PC06	26.20	26.89	27.83	28.81	29.82	30.87
	Diesel vehicle					
Bus01	4.23	4.34	4.49	4.65	4.81	4.98
Bus02	4.42	4.54	4.70	4.86	5.03	5.21
Bus03	4.40	4.51	4.67	4.84	5.01	5.18
sBus04	4.76	4.88	5.05	5.23	5.42	5.61
Truck01	4.09	4.20	4.35	4.50	4.66	4.82
Truck02	4.73	4.86	5.03	5.20	5.39	5.57

4.2 Validation of Energy Demand Model

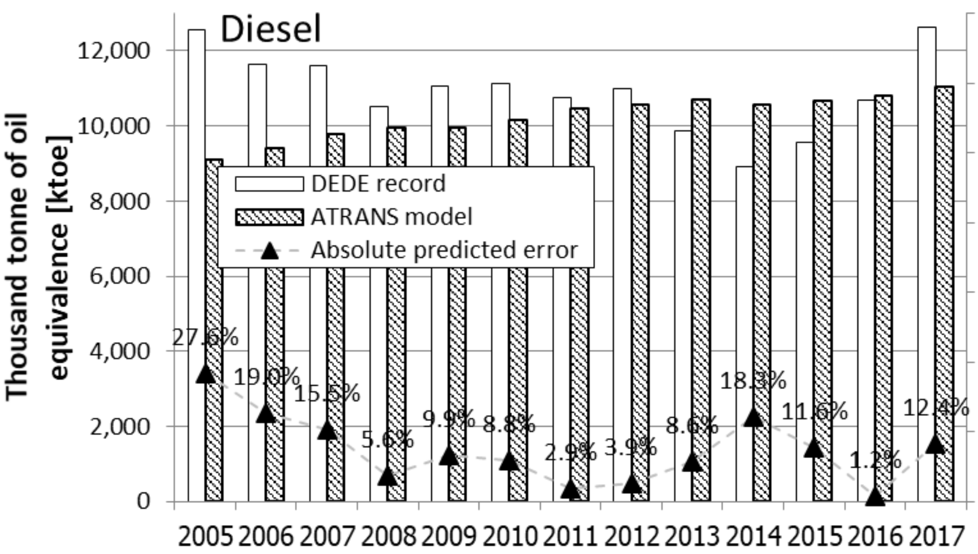
Following [25], energy demand model can be constructed from all factors mentioned above, and then calibrated with actual energy consumption in transportation sector, as shown in Fig. 14. The model shows fairly accurate results on both total, gasoline and diesel consumption during 2005-2017 period.



(a)



(b)



(c)

Fig. 14 Validation of energy demand model with fuel consumption in year 2005-2017 for (a) all, (b) gasoline and (c) diesel fuels

4.3 Emission Model

Following [25], emission model needs to be updated with newly constructed database for both regulated, namely carbon monoxide (CO), hydrocarbon (HC), nitrogen oxide (NOx) and particulate matter (PM), and unregulated, namely formaldehyde and acetaldehyde. In order to quantify emission improvement, baseline emission for each vehicle is needed with relative effect of emission from biofuel blending. For simple quantitative analysis, all vehicles are assumed to follow current Thai emission regulation throughout the study, namely Euro3 for heavy duty vehicle (diesel) [31] and Euro4 for light duty vehicle (diesel) [32] and passenger vehicle (gasoline) [33] even though the current vehicles may be of older emission regulation

and future vehicles may be of better emission regulation, as well as in-use vehicles may emit differently from emission regulation depending on vehicle ages, traffic condition and market fuel used. For non-regulated emission, namely acetaldehyde and formaldehyde, the baseline emission assumes literature measured for gasoline [7] and diesel [34] vehicles. Table 12 summaries baseline emission for analysis. Note that emission regulation for HDV is reported as gram per kilowatt-hour so gram per gigajoule is converted for further calculation with diesel fuel used by HDV.

Table 12: Baseline emission data for analysis

Emission	LDV		HDV (bus & truck)	
	Petrol [g/km]	Diesel [g/km]	Diesel [g/kWh]	Diesel [g/GJ]
Regulated	Euro4		Euro3	
CO	1	0.5	2.1	583.33
THC	0.1	0.05*	0.66	183.33
NOx	0.08	0.25	5	1,388.89
PM	0	0.025	0.13	36.11
HC+NOx		0.3		
Unregulated				
Formaldehyde	53.7	43.15	-	
Acetaldehyde	522.45	15.53	-	

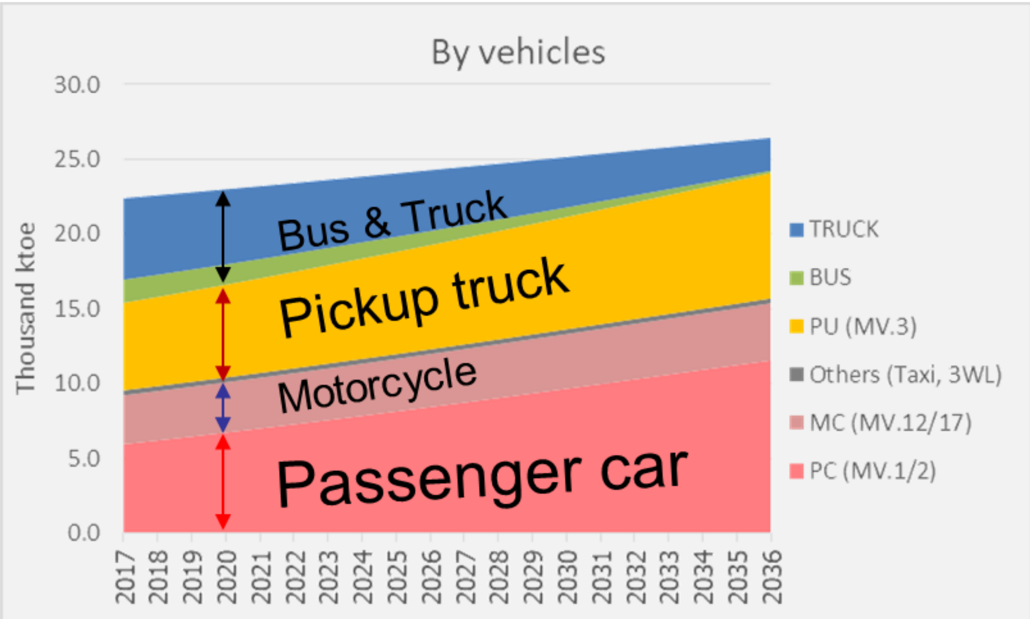
*calculated from HC+NOx limit

As discussed in Chapter 1, emission from bioethanol-blended gasoline is referred to [7], as shown in Fig. 4. On the other hand, emission from biodiesel-blended diesel varies with engine size, as shown in Fig. 5. The present analysis assumes Fig. 5(a) for heavy duty vehicle (HDV) [8] and Fig. 5(b) for light duty vehicle (LDV) [9]. Since both Fig. 4 and Fig. 5 report as percentage change from baseline emission, emission improvement from biofuel usage can be quantified.

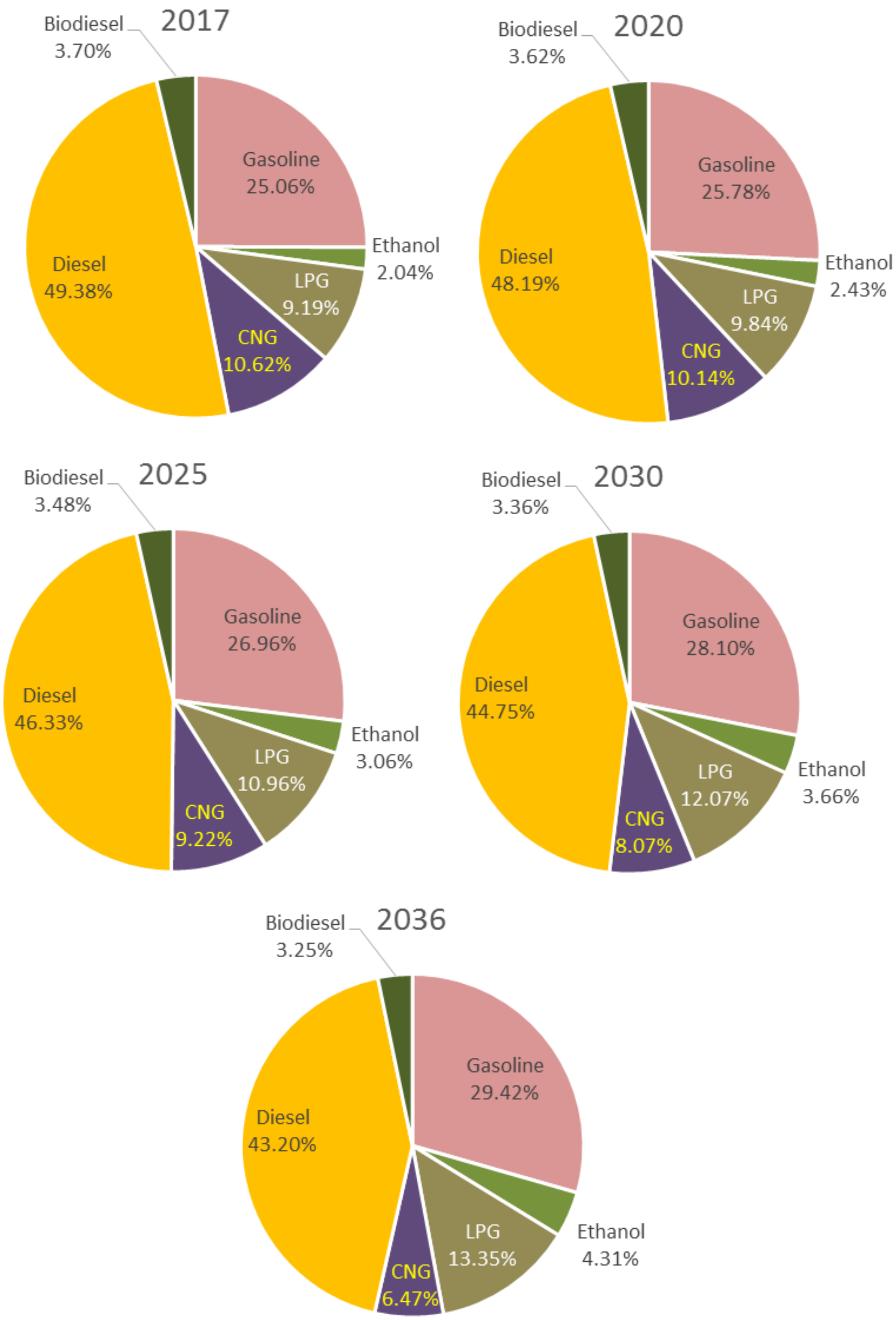
CHAPTER 5 RESULTS & DISCUSSION

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) policy will be analyzed in order to quantify the effect on emission reductions. Fig. 15(a) shows projection of energy consumption by vehicle types till 2036, where passenger car and pick up seem to dominate with rather constant consumption by motorcycle. With snapshots of various fuel types used in future shown in Fig. 15(b), diesel still dominate but with decreasing trend over time from approximately 50% to 43% while gasoline is increasing from 25% to 30%. As for biofuel, biodiesel percentage slight drops due to decreasing diesel consumption while ethanol percentage increases due to increasing gasoline consumption.



(a)



(b)

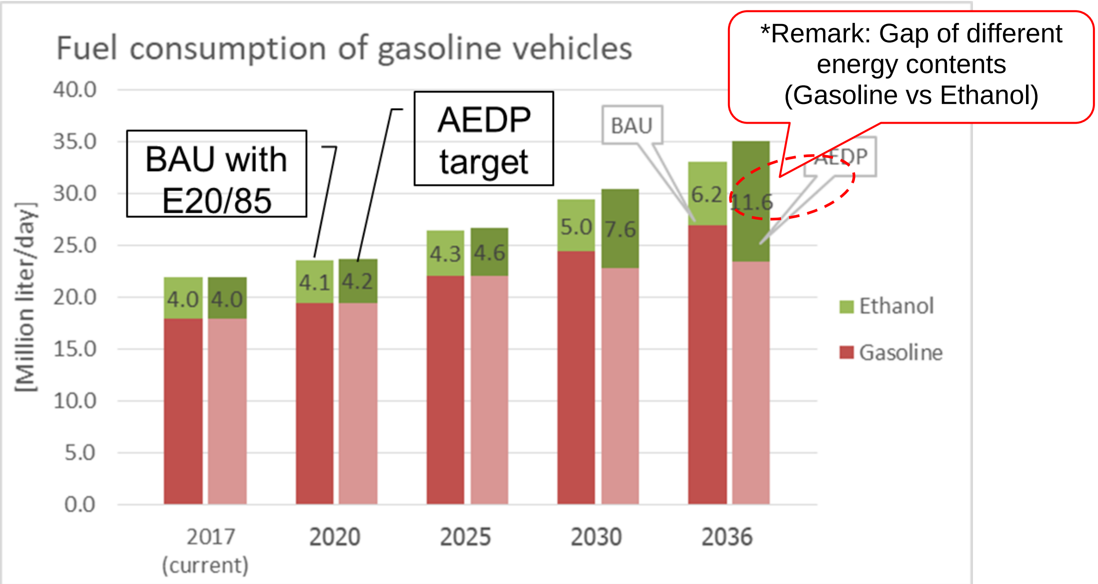
Fig. 15 BAU projection of (a) energy demand by vehicle types with (b) snapshots of fuel mixes (2017 is actual)

5.2 AEDP scenarios

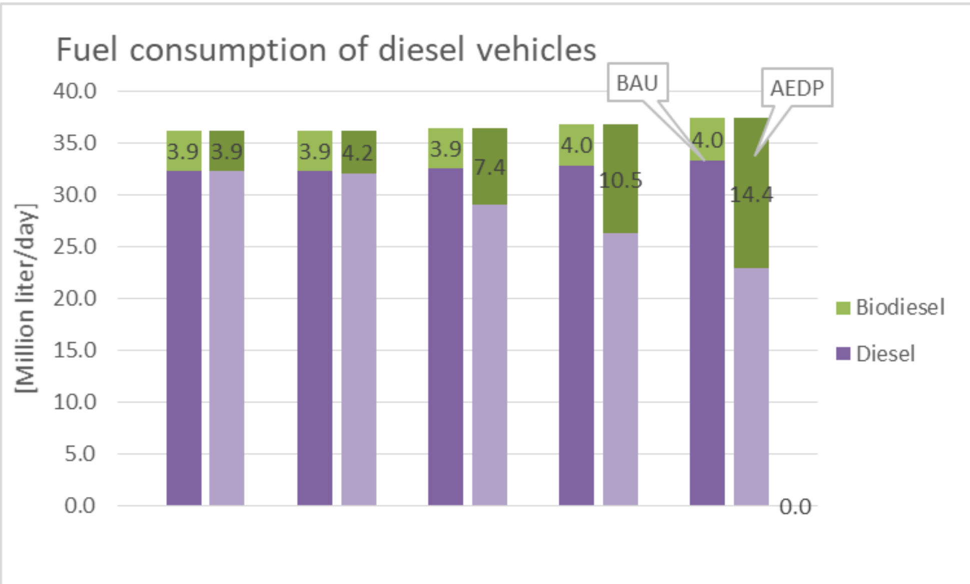
According to fuel consumption projection of gasoline vehicle, AEDP ethanol target of 11.3 ML/d in 2036 cannot be achieved from current share of gasohol vehicle (E20 and E85) in BAU scenario, as shown in Fig. 16(a). The gasohol E85 retrofit device will need to be installed

in the on-road vehicles so that ethanol target can be achieved having E85 fuel share of 45.9% from 37.7 million liter per day of gasoline-based fuels.

Similarly for biodiesel demand, AEDP biodiesel target of 14.0 ML/d in 2036 cannot be achieved with current biodiesel blended fraction of 7% in BAU scenario, as shown in Fig. 16(b). With projected total diesel consumption of 43.3 ML/d, biodiesel blended fraction must be increased to 38.5%.



(a)

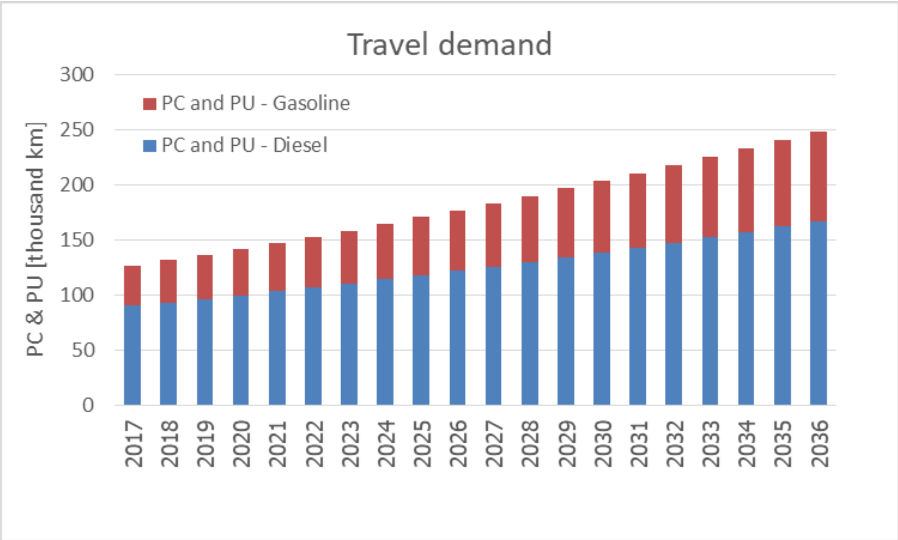


(b)

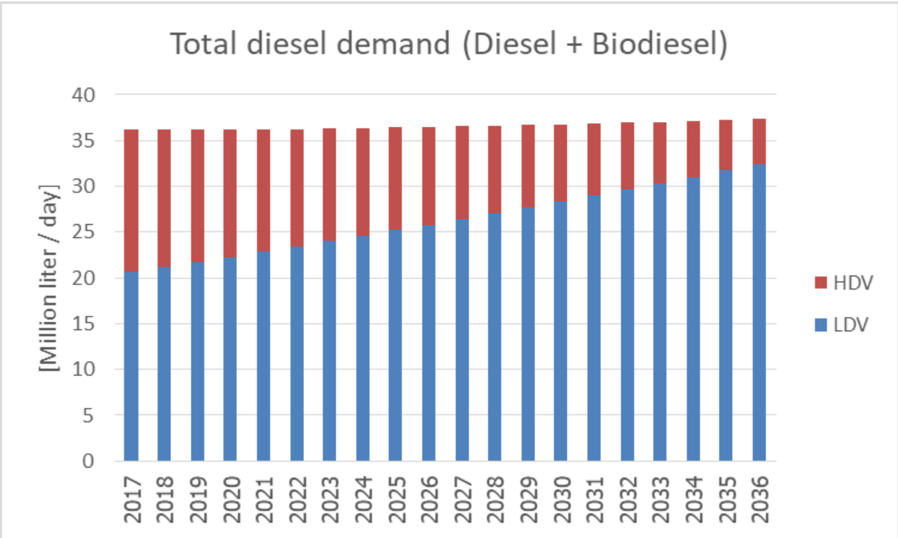
Fig. 16 BAU and AEDP projection for energy consumption by (a) gasoline and (b) diesel vehicles

5.3 Emission modelling results

From the vehicle projection, VKT and FE, accumulated emission level from all vehicles can be estimated from the assumption of vehicle emission regulation. Since emissions for LDV (Euro4 passenger car & pickup) and HDV (Euro3 bus & truck) are expressed differently in term of driving distance (km) and consumed energy (kWh), reference emission level for BAU can be calculated from Fig. 17(a) and Fig. 17(b), respectively.



(a)

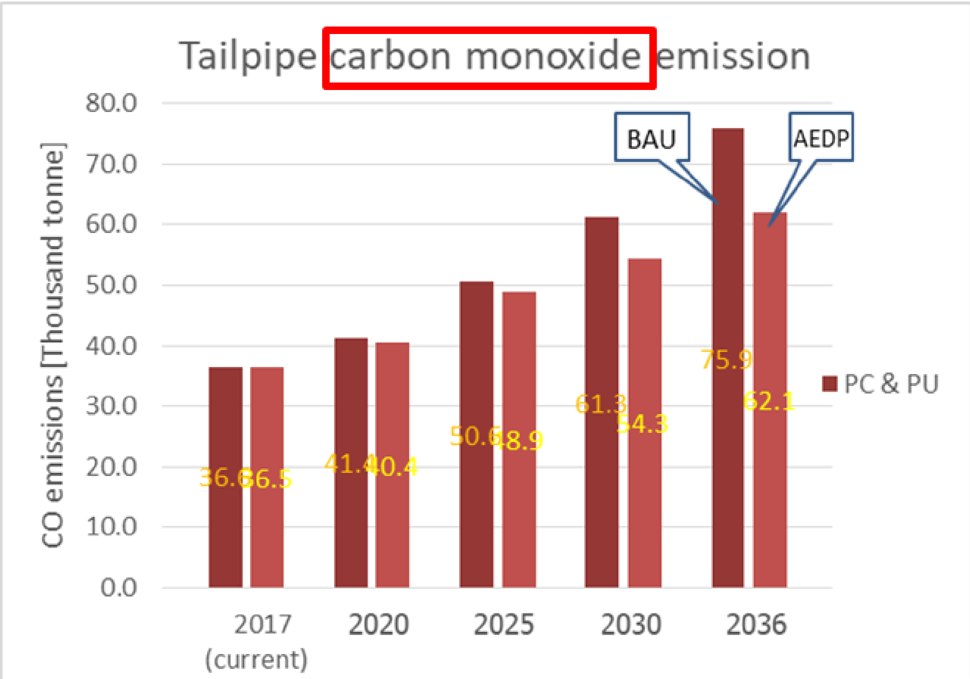


(b)

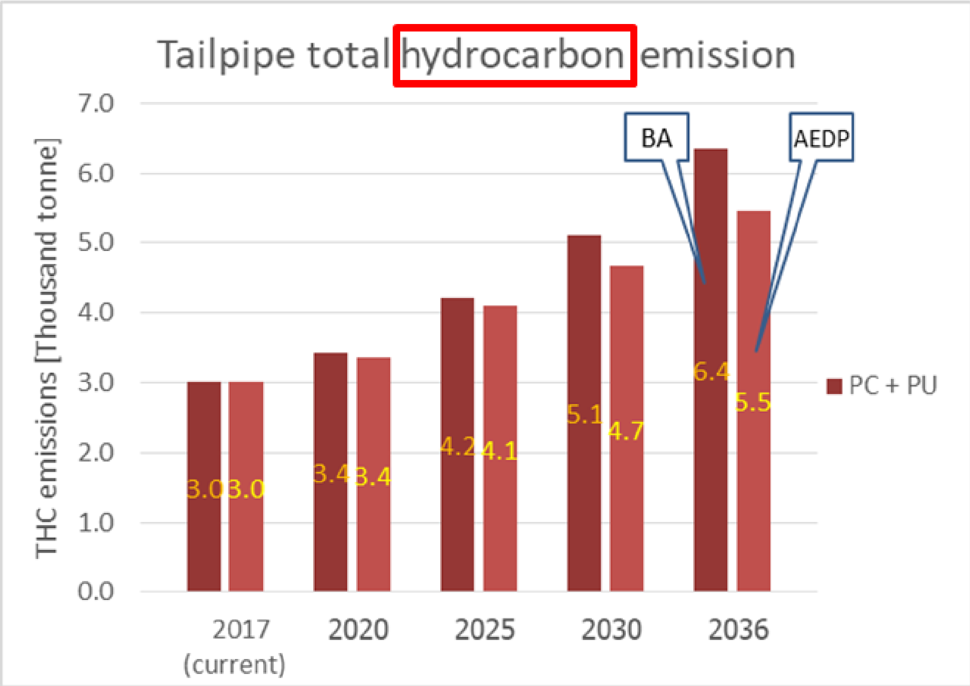
Fig. 17 BAU and AEDP projection for energy consumption by (a) gasoline and (b) diesel vehicles

Regulated (CO, HC, NOx, PM) and unregulated (formaldehyde and acetaldehyde) emissions can be quantified from Fig. 4, Fig. 5, Fig. 15, Fig. 17 and Table 12 for the cases of gasoline and diesel vehicles, as shown in Fig. 18 and Fig. 19, respectively. For gasoline vehicle in Fig. 18, it is expected that CO emission will be higher than other regulated emission

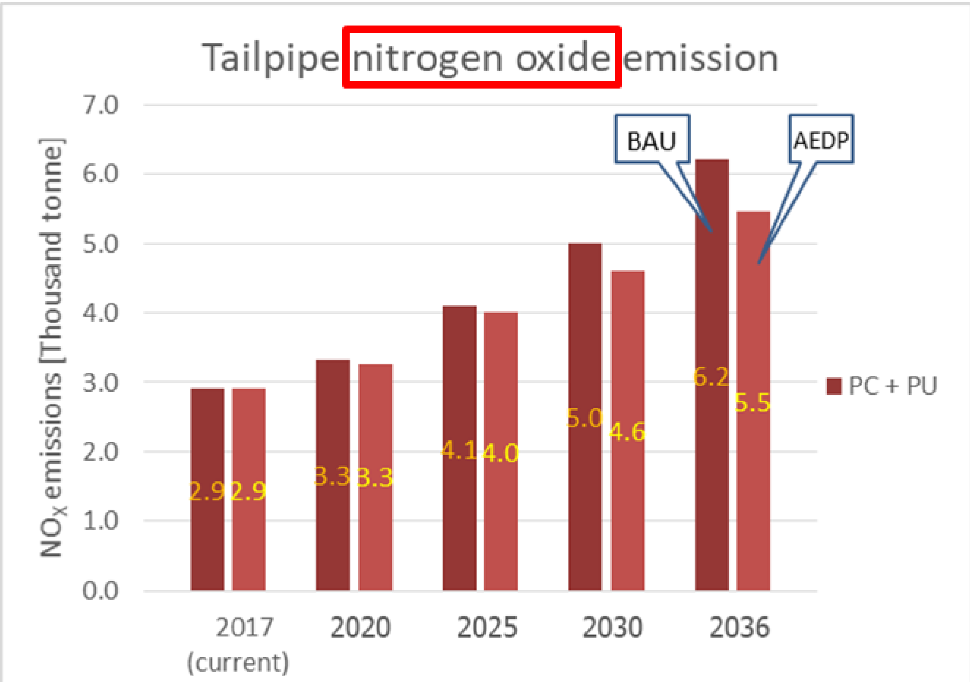
due to higher limit allowed in the emission regulation as shown in Table 12. Percentage reduction of regulated emission from Fig. 4 has reflected in Fig. 18(a)-(c) for AEDP scenario where ethanol is blended with gasoline. On the other hand, the use of ethanol will increase unregulated emission, as shown in Fig. 18(d)-(e). For diesel vehicle in Fig. 19, HDV is expected to emit more than LDV, especially NOx and HC, at the present due to higher limit allowed for HDV emission regulation in Table 12. However, HDV emission will reduce in the future due to the forecast trend of reducing HDV number in Fig. 15. Percentage change of regulated emission from Fig. 5 has reflected in Fig. 19(a)-(d) for AEDP scenario where biodiesel is blended with diesel. With exception of NOx, biodiesel will help reduce CO, HC and PM.



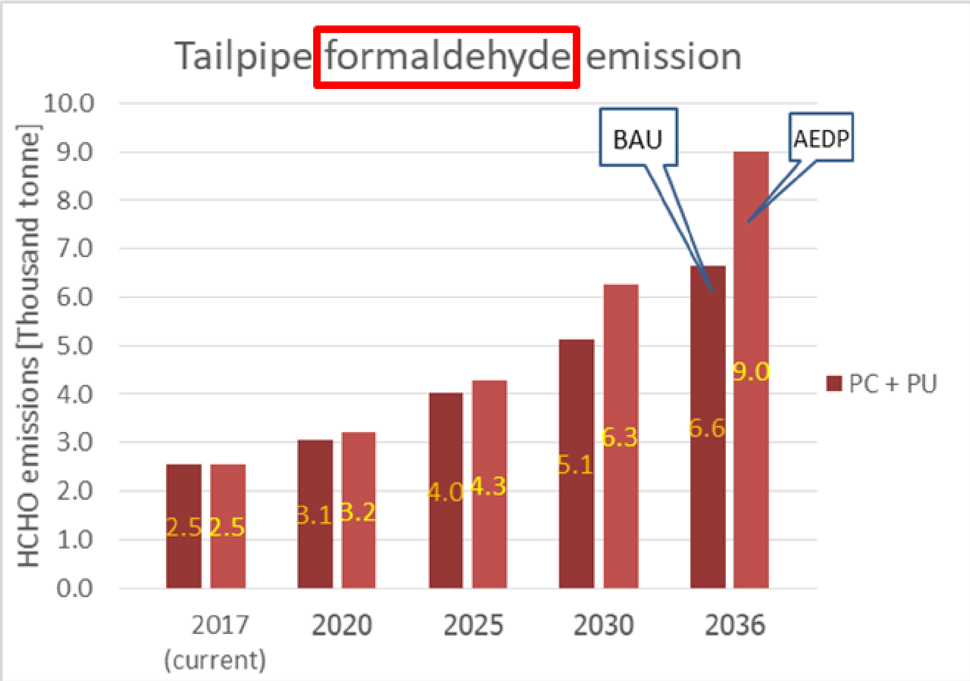
(a)


Tailpipe total hydrocarbon emission
THC emissions [Thousand tonne]
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
BA
AEDP
3.0
3.0
3.4
3.4
4.2
4.1
5.1
4.7
6.4
5.5
PC + PU
2017
(current)
2020
2025
2030
2036

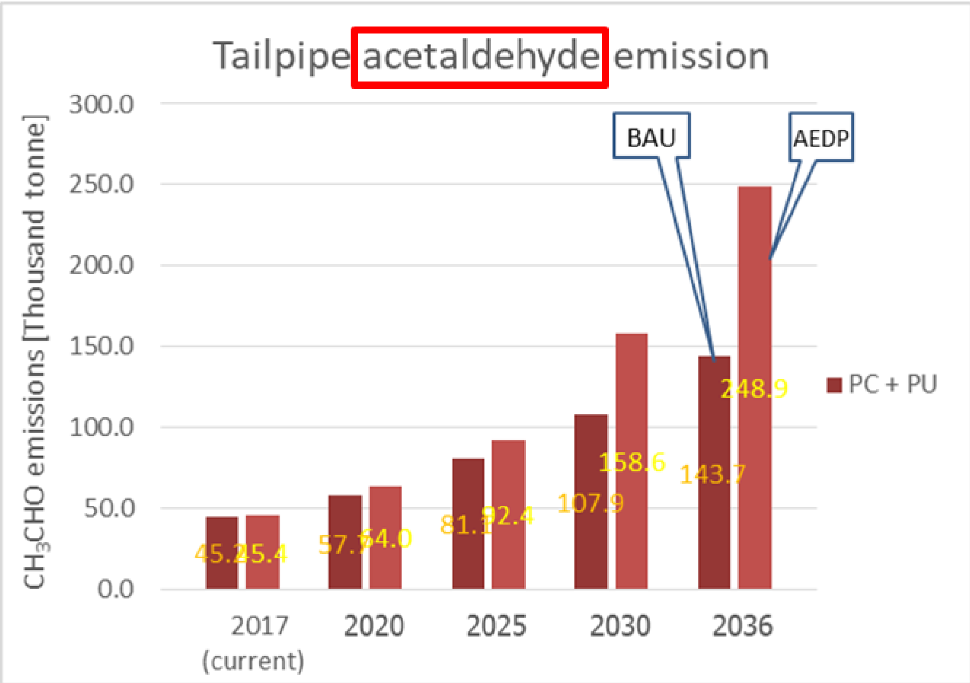
(b)


Tailpipe nitrogen oxide emission
NOX emissions [Thousand tonne]
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
BAU
AEDP
2.9
2.9
3.3
3.3
4.1
4.0
5.0
4.6
6.2
5.5
PC + PU
2017
(current)
2020
2025
2030
2036

(c)

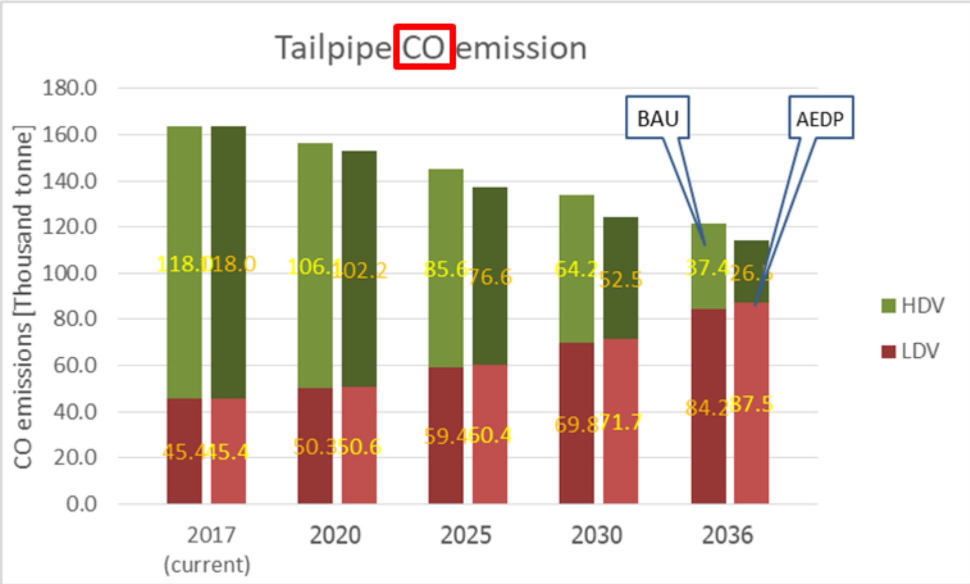


(d)

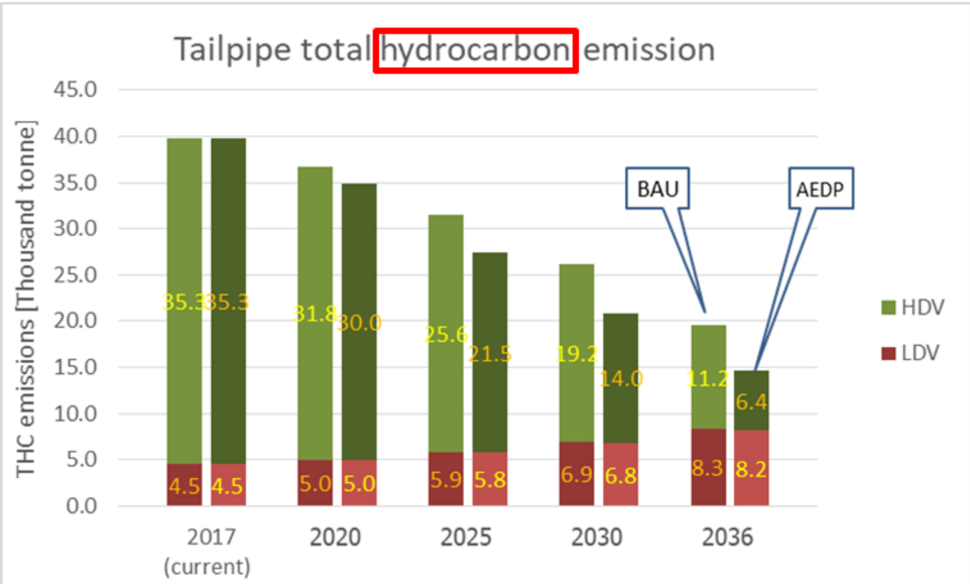


(e)

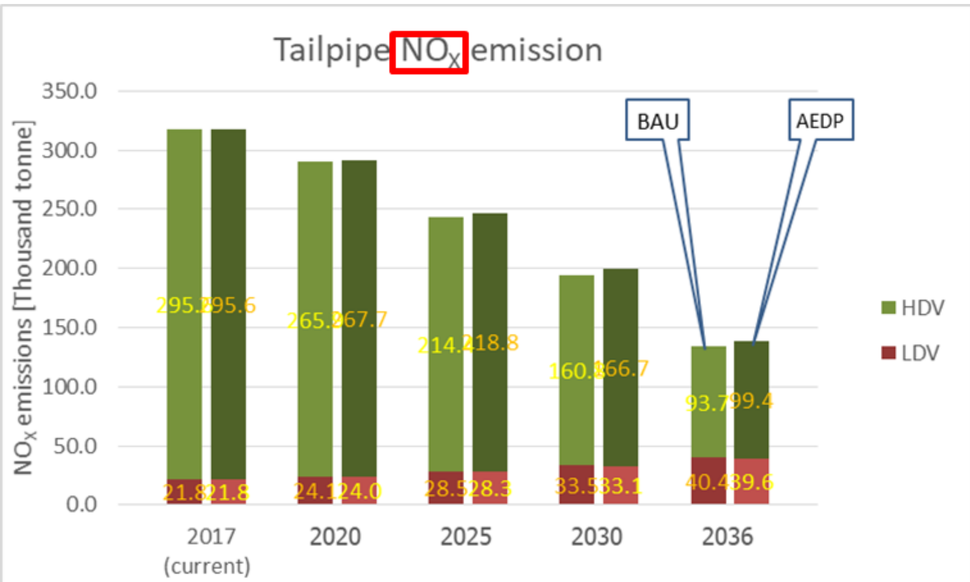
Fig. 18 Emission level for gasoline vehicles in BAU and AEDP scenarios: (a) CO. (b) HC, (c) NOx, (d) formaldehyde and (e) acetaldehyde


Tailpipe CO emission
CO emissions [Thousand tonne]
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
2017 (current)
2020
2025
2030
2036
BAU
AEDP
HDV
LDV

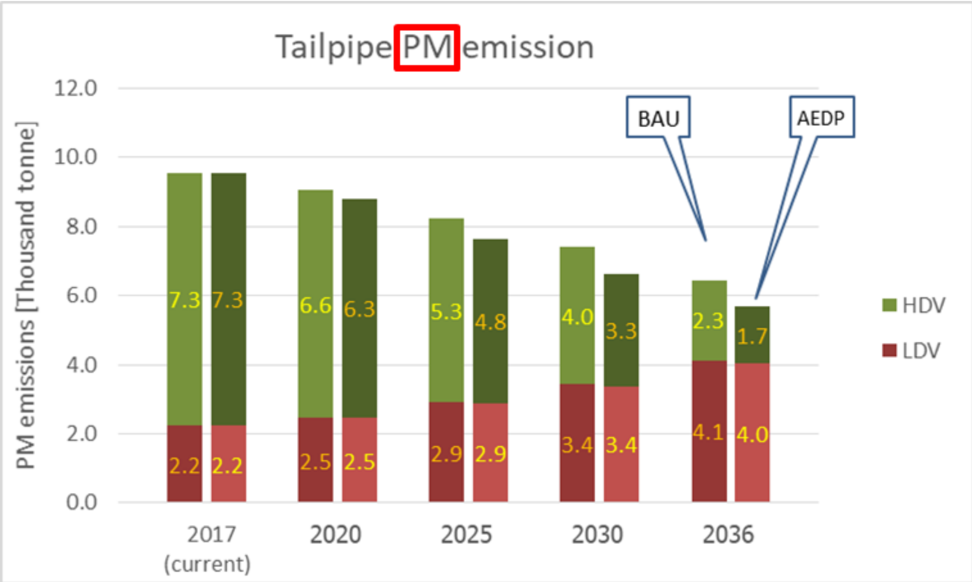
(a)


Tailpipe total hydrocarbon emission
THC emissions [Thousand tonne]
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2017 (current)
2020
2025
2030
2036
BAU
AEDP
HDV
LDV

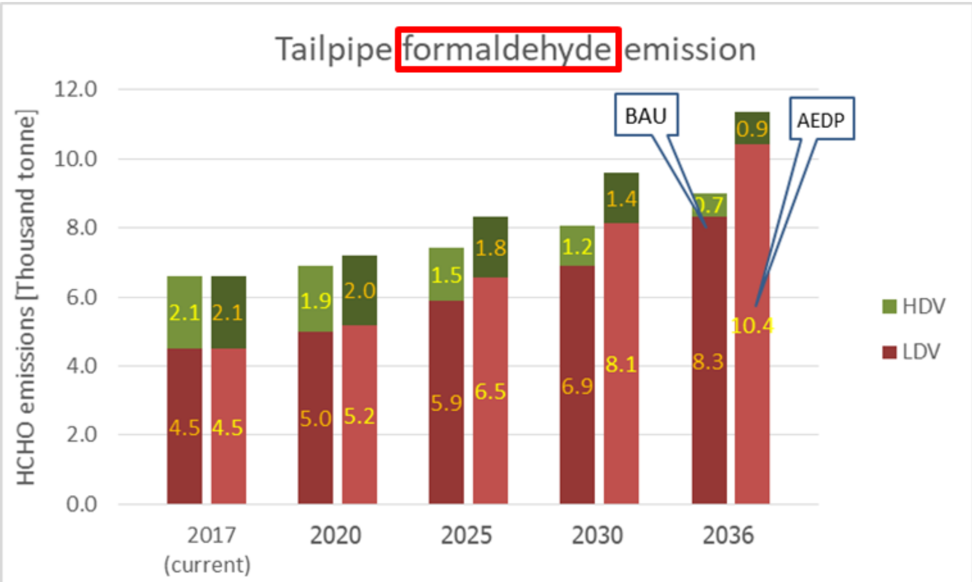
(b)


Tailpipe NO_X emission
NO_X emissions [Thousand tonne]
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
2017 (current)
2020
2025
2030
2036
BAU
AEDP
HDV
LDV

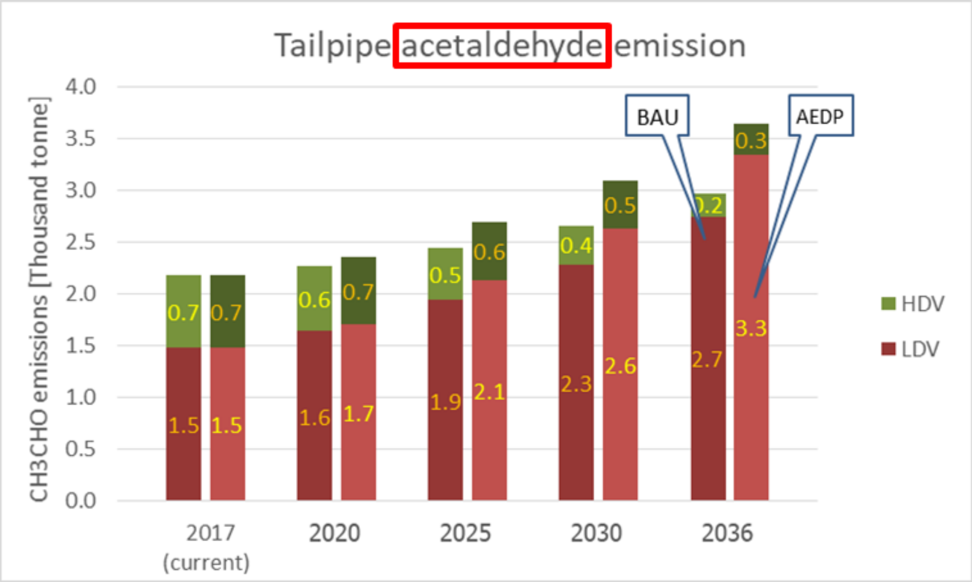
(c)


Tailpipe PM emission
PM emissions [Thousand tonne]
12.0
10.0
8.0
6.0
4.0
2.0
0.0
BAU
AEDP
7.3 7.3
6.6 6.3
5.3 4.8
4.0 3.3
2.3 1.7
2.2 2.2
2.5 2.5
2.9 2.9
3.4 3.4
4.1 4.0
2017
(current)
2020
2025
2030
2036
HDV
LDV

(d)


Tailpipe formaldehyde emission
HCHO emissions [Thousand tonne]
12.0
10.0
8.0
6.0
4.0
2.0
0.0
BAU
AEDP
2.1 2.1
1.9 2.0
1.5 1.8
1.2 1.4
0.7 0.9
4.5 4.5
5.0 5.2
5.9 6.5
6.9 8.1
8.3 10.4
2017
(current)
2020
2025
2030
2036
HDV
LDV

(e)



(f)

Fig. 19 Emission level for diesel vehicles in BAU and AEDP scenarios: (a) CP. (b) HC, (c) NOx, (d) PM, (e) formaldehyde and (f) acetaldehyde

5.4 Conclusion

With rising economic activity and GDP per capita, transportation activities, for both passenger and commodity, are expected to increase, which inevitably increase tailpipe emission into atmosphere. However, quantitative prediction of increased tailpipe emission is lacking in the literature. Hence, this study has improved previous ATRANS model [11, 25] to predict number of vehicles growth in the future with recent calibration of transport fuel. Simple assumption of tailpipe emission from present emission regulation offers insight into quantitative regulated emission; whereas, unregulated emission data is taken from literature. Complete prediction of regulated and unregulated emissions from LDV using gasoline and diesel, as well as HDV using diesel, can be captured. Scenario analysis on the use of biofuel, both bioethanol and biodiesel, according to AEDP offers solution to reduce tailpipe emission, in addition to well-known carbon-neutral benefit to mitigate greenhouse effect. This quantitative results on tailpipe emission with and without biofuel can help policy makers adjust national energy plan in the future.

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