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ASIAN TRANSPORTATION RESEARCH SOCIETY

A Case Study on Energy and CO$_2$ Intensities in Thai Freight Transport by Trucks

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List of Abbreviations and Acronyms

BAU	Business as usual
BRT	Bus rapid transit
DEDE	Department of Alternative Energy Development and Efficiency
EE	Energy efficiency
EPPO	Energy Policy and Planning Office
GDP	Gross domestic product
GHG	Greenhouse gas
HOV	high occupancy vehicle
IPCC	Intergovernmental Panel on Climate Change
OECD	Organization for Economic Co-operation and Development
TDM	Traffic demand management

CHAPTER I INTRODUCTION

1.1 Rationale

Thailand is heavily dependent on oil-import, accounting for more than 80% of country's demand. Transportation is a dominant end-use sector of the oil supply, where more than 70% of total petroleum products are consumed by this sector, as shown in Fig. 1(a) [1]. Furthermore, it correspondingly contributes about 25% of energy-related carbon dioxide (CO_2) emissions, as shown in Fig. 1(b) (DEDE, 2009). However, transportation is recognized as a main driving force for the country's economic development, particularly the freight transport, which supplies trade activities. Since the logistic cost of Thailand is relatively high comparing with other countries, e.g. Japan, Korea, Taiwan [2], the government has recently projected a clear target to reduce logistic cost to be 15% of GDP by next 5 years. Transportation shares even half of the country's logistic cost.

More specifically, energy efficiency improvement and CO_2 reduction in Thai freight transport sector is of crucial importance, and need a well-planned policy to achieve the target. However, based on recent work in energy conservation and GHG (Greenhouse Gas) mitigation in transport sector for Thailand, there is no available data of energy and environment efficiency indicators for freight transport, particularly for truck transport, which is a major mode of freight movement. Energy consumed for a unit of transportation activity or so-called energy intensity, as shown in Fig. 2 [3, 4], is useful for planning and implementing policies. For the environment aspect, CO_2 intensity, or CO_2 emitted for a unit of transport activity, can also be calculated from the GHG guideline proposed by IPCC [5] on fuel used in the energy intensity calculation.

UNIT : THOUSAND TONS OF OIL EQUIVALENT

BIOFULE 782

OTHER 304

LIGNITE 4,775

CRUDE OIL 7,585

CONDENSATE 3,792

HYDRO & OTHERS 1,586

DOMESTIC PRODUCTION OF PRIMARY ENERGY 64,890

NATURAL GAS 26,525

RENEWABLE ENERGY 19,541

IMPORTS 62,006

CRUDE OIL 41,382

NATURAL GAS 8,294

STOCK CHANGE (639)

ELECTRICITY 208

PETROLEUM PRODUCTS 429

COAL & ITS PRODUCTS 10,270

CONDENSATE 1,390

RENEWABLE ENERGY 53

ENERGY AVAILABILITY 126,257

EXPORTS 12,547

TOTAL PRIMARY ENERGY SUPPLY 113,710

RENEWABLE ENERGY 19,578

OTHER 304

BIOFUEL 798

NGL (109)

PETROLEUM PRODUCTS (10,213)

CRUDE OIL 47,733

NATURAL GAS 34,819

ELECTRICITY 1,661

COAL & ITS PRODUCTS 14,207

CONDENSATE 4,932

FINAL ENERGY CONSUMPTION 66,698

TRANSFORMATION 35,036

OWN USES & LOSSES 4,534

NON-ENERGY USES 7,442

PETROLEUM PRODUCTS 31,661

ELECTRICITY 11,521

NATURAL GAS 3,568

RENEWABLE ENERGY 12,455

COAL & ITS PRODUCTS 7,493

FINAL ENERGY CONSUMPTION BY SECTOR 66,698

MANUFACTURING 23,798

TRANSPORTATION 24,132

AGRICULTURE 3,477

RESIDENTIAL 10,089

COMMERCIAL 4,940

CONSTRUCTION & MINING 262

Notes :   1. Petroleum products exclude bitumen, naphtha, and lubricants.

2. Hydro & Others include Hydro geothermal, solar cell, and wind power.

3. Other include Black Liquor.

(a)

ESTIMATED CO$_2$ EMISSIONS BY TYPE FROM ENERGY CONSUMPTION
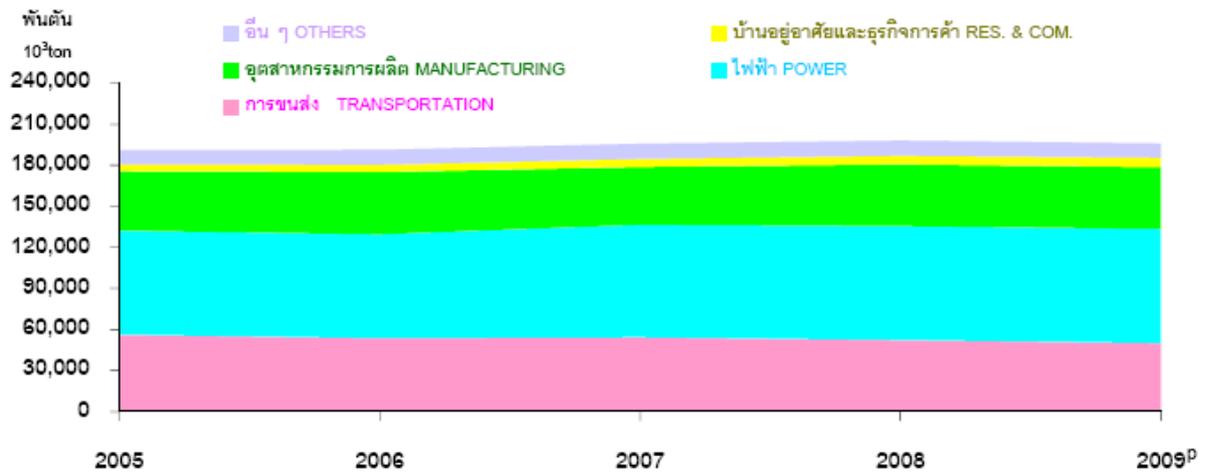
(b)

Fig. 1 (a) Thailand energy flow chart and (b) estimated CO2 emission by sectors in 2009
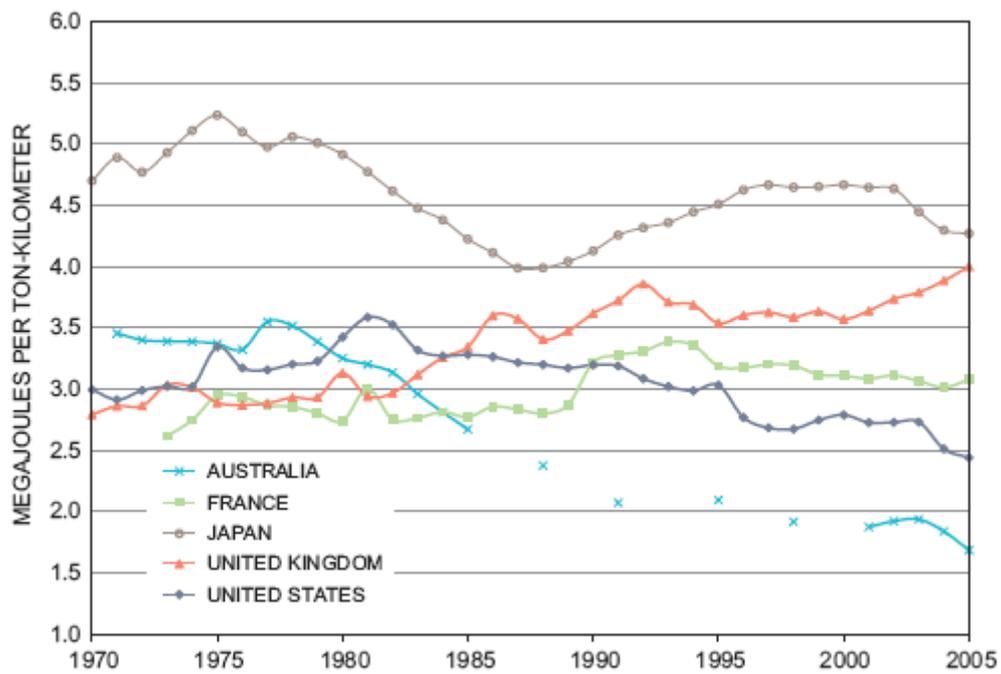
(a)
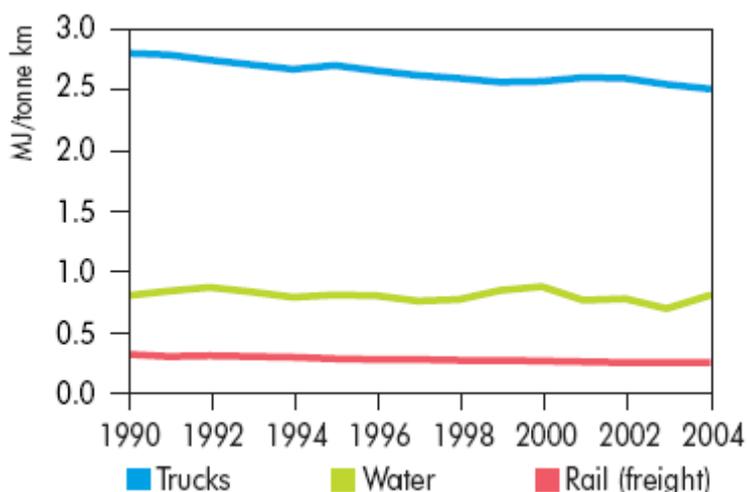
(b)

Fig. 2 Energy intensities of the freight transport in (a) selected and (b) OECD countries

1.2 Objectives

This study aims to develop energy and CO_2 intensities of truck transport in Thailand. The proposed study would deliver essential and informative results for further studies on transportation efficiency improvement in Thailand.

1.3 Methodology

The research method/technique of this study is as follows:

1. Data acquisition: collect necessary data such as transported distance, transported weight, goods type, load factor, average vehicle speed, running time, idling time, origin-destination (O-D), fuel consumption and driver behavior from potential logistic companies who are willing to cooperate. The collected data will be attempted for a variety of truck types, geographical routes and time in the year. Due to the small size of the project, the current investigation will focus on secondary data obtained from the literature and cooperated organization.

2. Data analysis: analyze the collected data for energy and CO_2 intensities of freight transport according to type of trucks. The factors influencing energy and CO_2 intensities of truck transport are also analyzed.

3. Result discussion and application: the obtained energy and CO_2 intensities of truck transport will be discussed and compared to other countries. Moreover, energy consumption and CO_2 emission from truck transport in Thailand will be projected as a business as usual (BAU) case. Policy and measures in order to realize energy saving and CO_2 mitigation in freight transport will also be discussed.

CHAPTER 2 LITERATURE REVIEW

2.1 Energy and CO$_2$ intensities

2.1.1 International data

With rising concern on energy availability and climate change, energy fuel and its emission characteristics are often discussed and analyzed. Of course, transportation sector has been of great focus especially in the new rising economies, where economic prosperity increases transport of passengers and commodities. Fig. 3 shows example of when GDP per capita increases, the demand for goods will then drive truck energy intensity per capita in the case of selected OECD countries [3]. Although transportation serves economic and social development through distribution of goods/services and through people mobility, transportation also leads to air pollution and climate change. As proposed by UN [6], reduction of energy intensity (improving energy efficiency) in transportation sector can reduce environmental impacts of transportation while maintaining economic and social benefits.
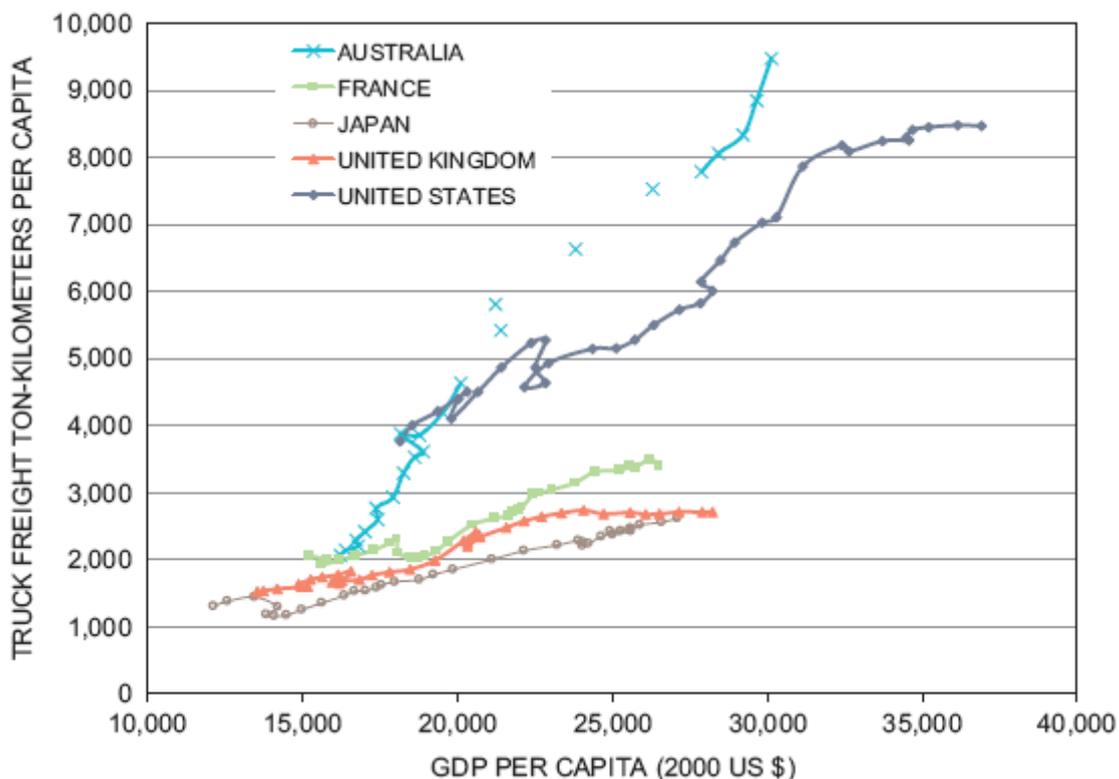
Fig. 3 Relationship between truck energy intensity and GDP in selected OECD countries (1973-2005)

From 1990 to 2005, CO$_2$ emission from transport sector has increased by 36%, and accounted for 23% of global energy-related CO$_2$ emission [4]. Two main factors affecting

emissions in transport sector have been identified as the volume of travel and efficiency of transport mode.   In case of OECD countries between 1990 and 2004, passenger travel in light-duty vehicles increased by 20% (from approximately 13,000 to 15,000 km/person.year) while freight travel in truck increased by 36% [4].   Efficiency of transport mode is further complicated by vehicle technology, fuel mix, vehicle loading, traffic and relative mode share [3].

In addition to the representation of truck energy intensity shown in Fig. 2, other plots such as fuel intensity and average truck loading shown in Fig. 4 [3], can be taken into consideration for final analysis. Despite the difficulty in disaggregate fuel data in the truck [7], truck carbon intensity can be estimated as shown in Fig. 5.

(a)

(b)
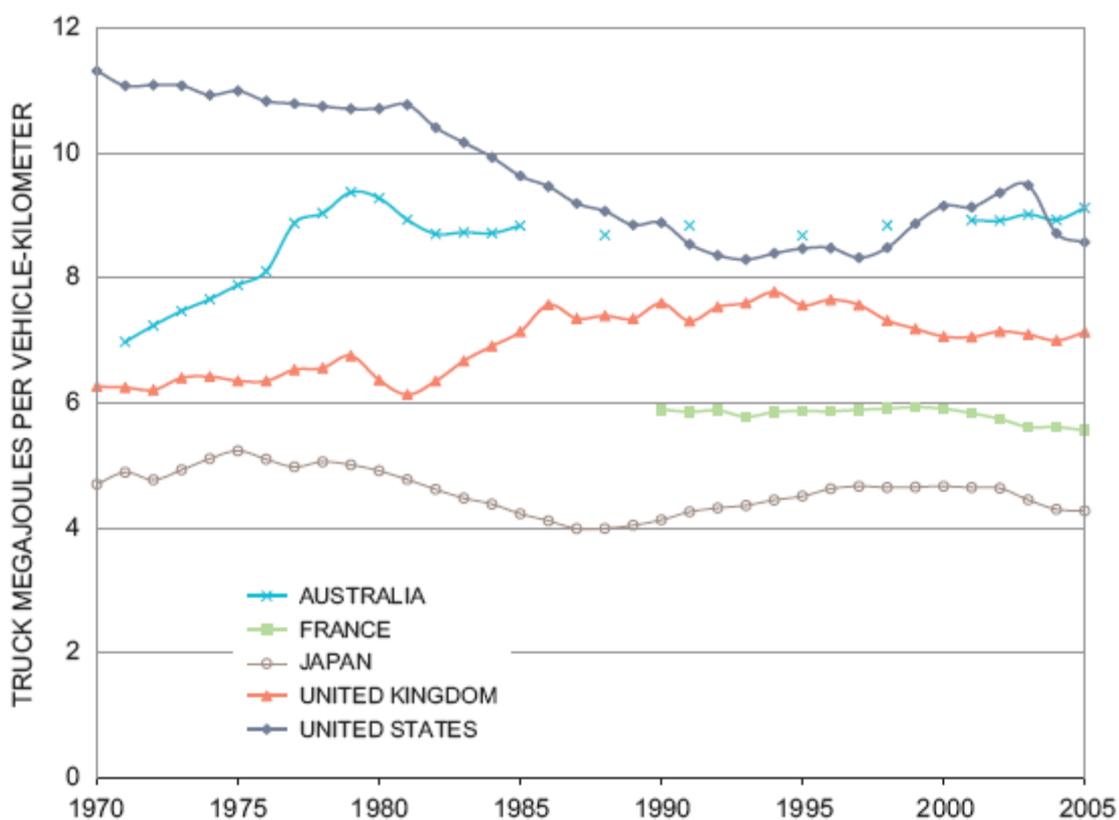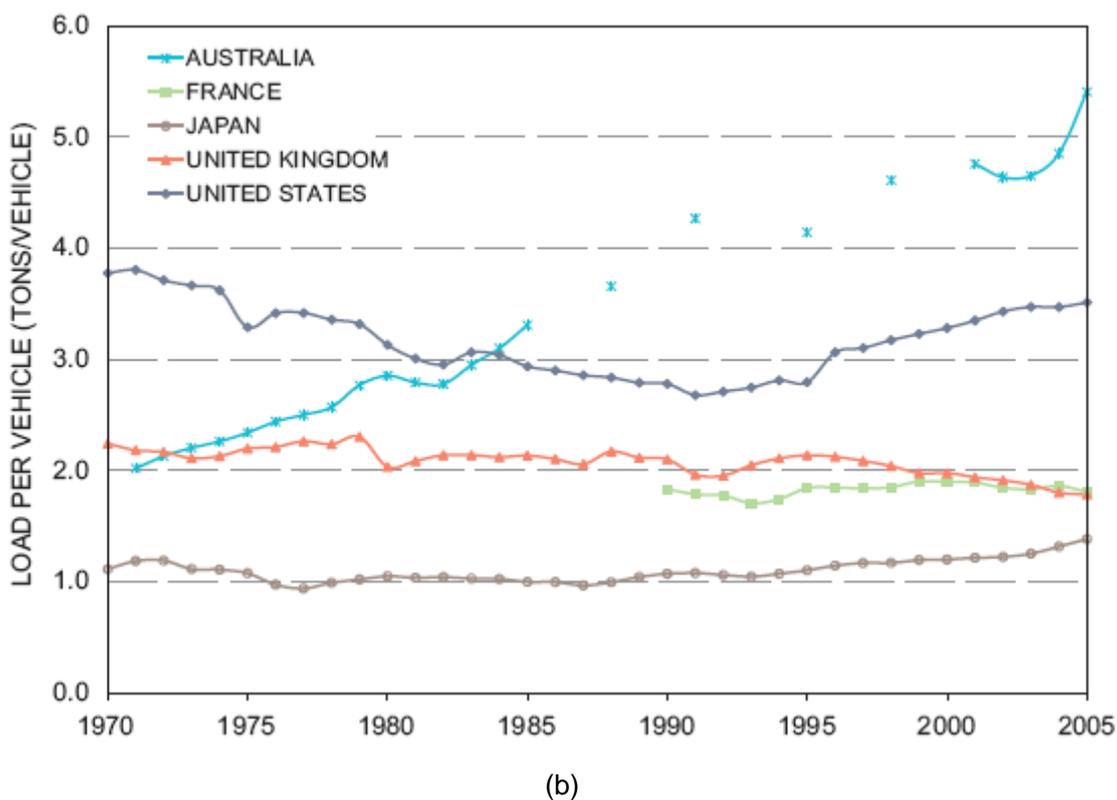
Fig. 4 (a) Truck fuel intensity and (b) average truck loading in selected OECD countries (1973-2005)
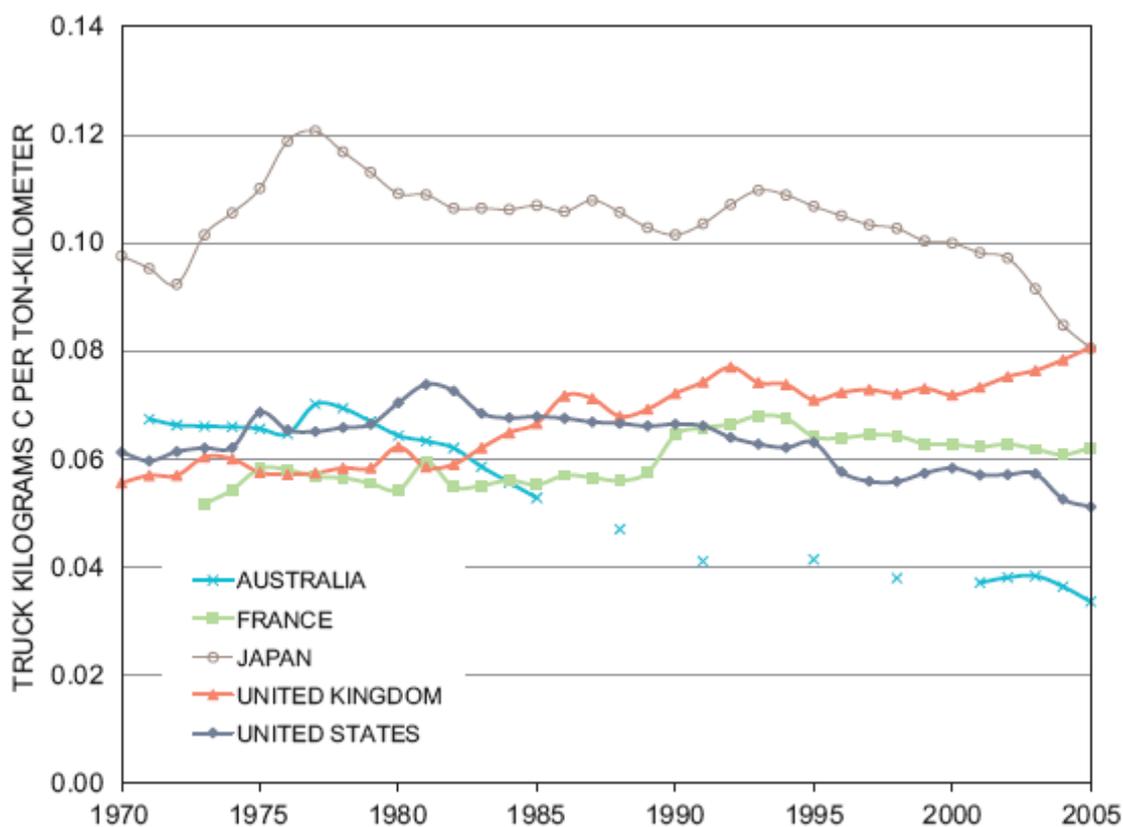
Fig. 5 Truck carbon intensity in selected OECD countries (1973-2005)

2.1.2 National data

Unlike historical data from foreign countries shown in previous section, Thailand does not have regularly collected and analyzed data on energy intensity. Only project-based data from certain years are available for comparison. Hence, this section will discuss relevant national data necessary for the calculation of energy intensity. First, the energy used in transportation sector has been recorded from the sale of each transport fuel, as shown in Fig. 6 [1]. However, similar to [7], segmentation of the amount of various fuels used in various classes of vehicles did not exist, which prompts for some assumption and model to estimate such figures. Although the number of vehicles in each categories have been annually recorded, as shown in Table 1 [8], the critical parameter like Vehicle Kilometers Traveled (VKT) is not known, and has only been updated on the project basis. This limitation would require energy demand modeling to estimate the fuel used by particular vehicle types of interest.
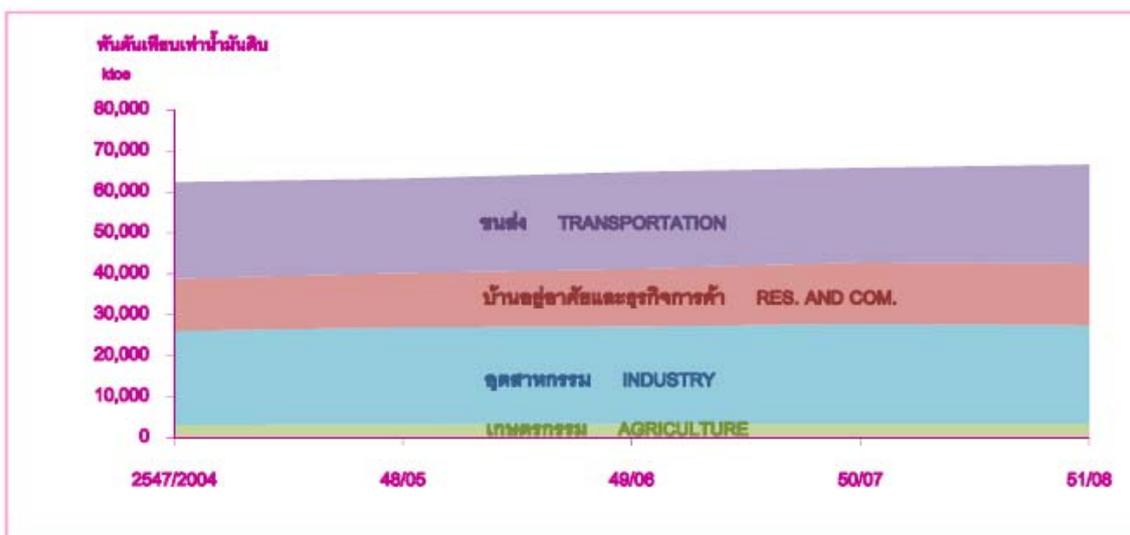
(a)

(b)

8
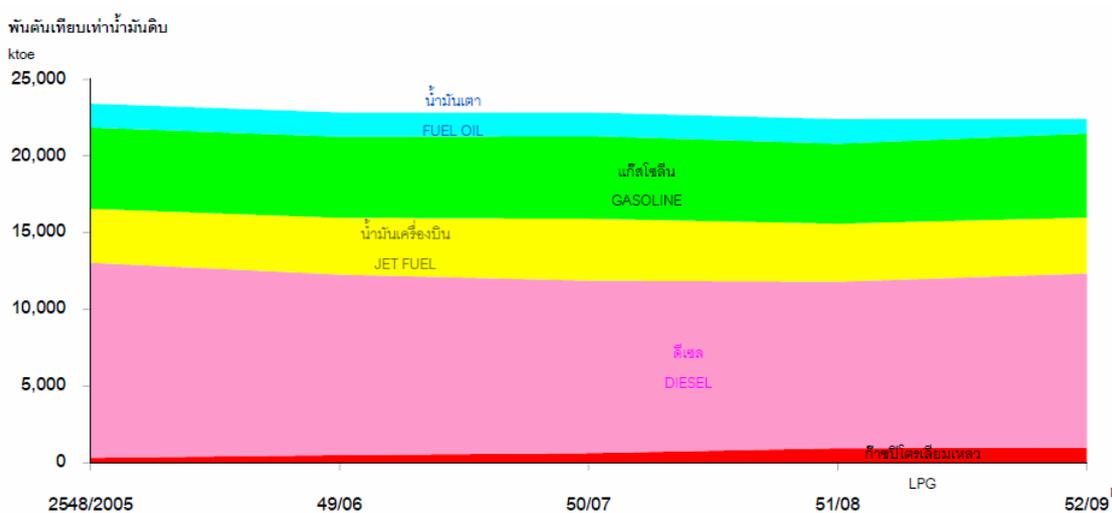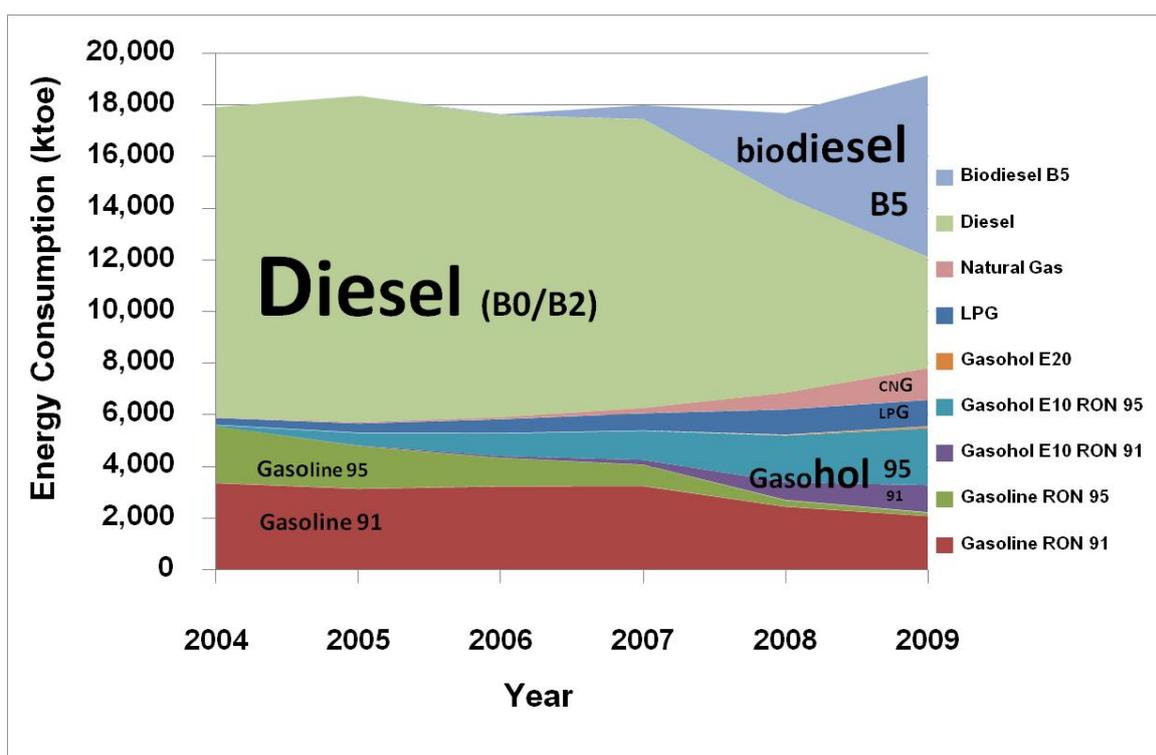
(c)

Fig. 6 (a) History of Thai energy consumption by economic sectors truck fuel intensity with detailed consumption of various fuels in (b) transportation sector and (c) land transport

Table 1: List of 2008 vehicles in Thailand by fuel type

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

For the estimation of ton-km of goods transported, there exists a historical data for the amount of goods being transported and associated distances, as shown in Fig. 7 [9]. Detailed calculation of energy intensity from existing national data will be shown in Chapter 4.

Transport of Goods in Thailand

Transport of Goods-Distance in Thailand
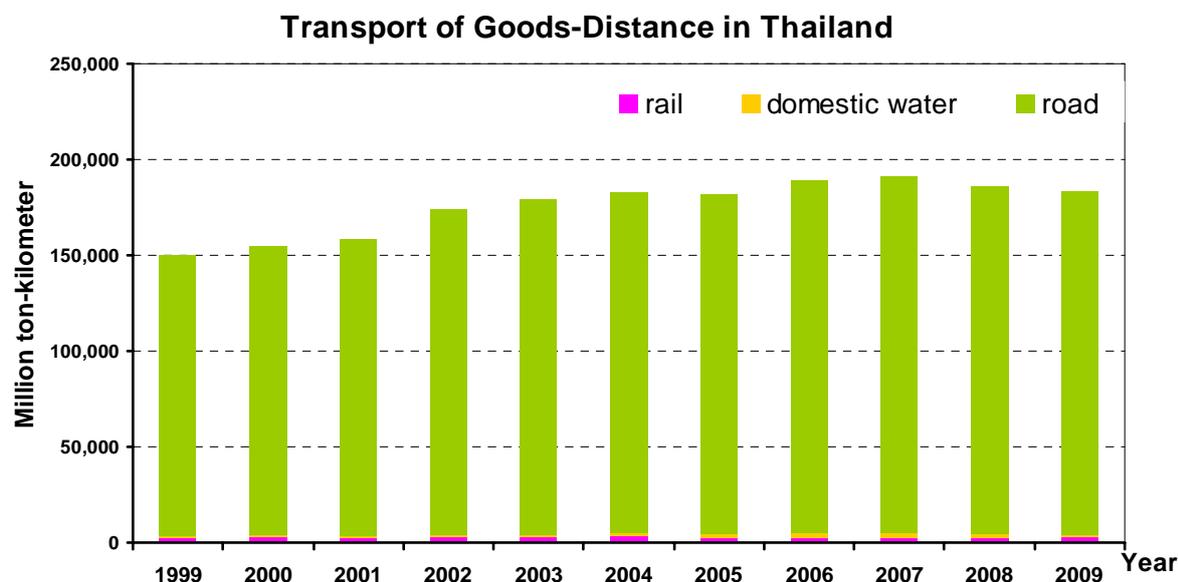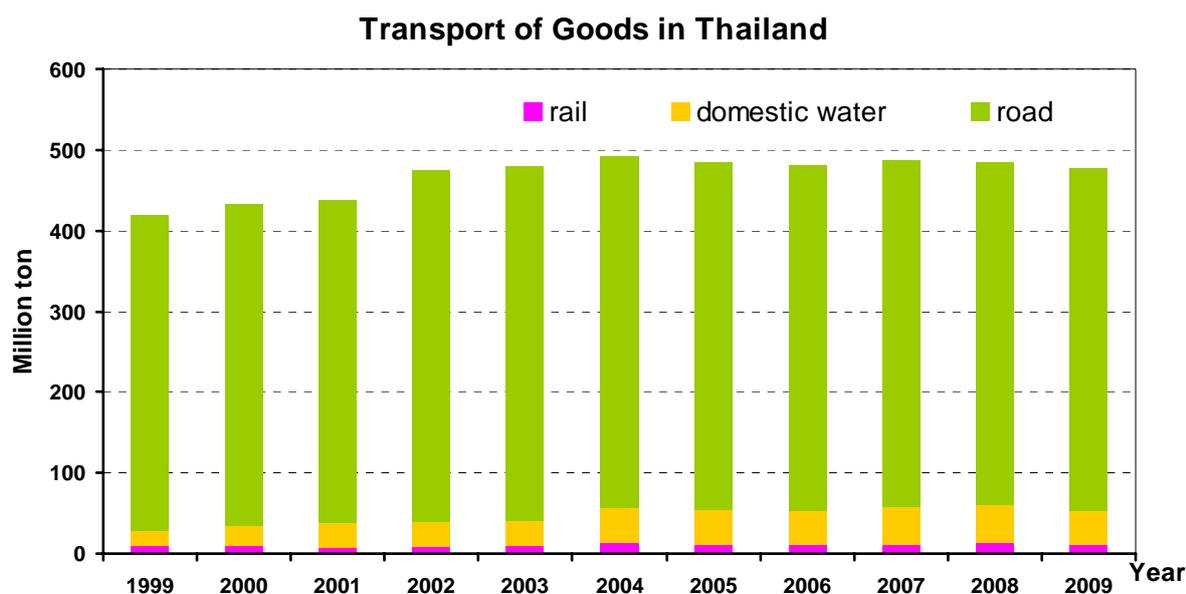
Fig. 7 Transport of (a) goods and (b) goods-distance in Thai freights

2.2 Energy efficiency plan in transport sector

As stated earlier, the current investigation aims to obtain energy and CO_2 intensity figures, which are the necessary data in assessing the energy saving potential in transport sector. Recent 20-year EE draft by EPPO [10] has identified 3 measures as follows.

1. Vehicle fuel economy improvement, such as car labeling, fuel economy standard and eco-driving

2. **Modal shift to public transport, such as subway (MRT), Bus rapid transit (BRT), Traffic Demand Management (TDM) by road pricing, bus lane, high occupancy vehicle (HOV) lane and license plate restriction**

3. **Modal shift to rail & water freight transport with an aim to achieve lower energy intensity**

CHAPTER 3 RESEARCH PLAN

3.1 Project Schedule

Table 2 shows the project planning schedule corresponding to the methodology listed in Section 1.3.

Table 2: Project planning schedule

Activity	2010			2011								
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Data acquisition	███	███	███	███	███	███	███	███				
Data analysis				███	███	███	███	███	███			
Result discussion and application							▬▬	▬▬	▬▬	▬▬	▬▬	
Inception report submission		●										
Progress report presentation				●								
Interim report presentation						●						
Interim report submission							●					
Seminar/workshop										●		
Final report presentation											●	
Final report submission												●

3.2 Project Expenditure

Table 3 shows the breakdown of the project expenditure.

Table 3: Project expenditure

No.	Item	Unit cost	# of units	Sub total
1	Project leader (3,000 THB/month x 12 months)	3,000	12	36,000
2	Advisors participation in project meeting (1,000 THB/day x 2 persons x 4 days)	2,000	4	8,000
3	Members participation in project meeting (1,000 THB/day x 2 persons x 12 days)	2,000	12	24,000
4	Research assistant (part time at 200 THB/hr x 5 hrs/day x 6 days/month) for 12 months)	6,000	12	72,000
5	Food and drink for meeting	1,000	12	12,000
6	Project meeting misc. expenses	1,500	12	18,000
7	Open-seminar/workshop activity/ Secretariat's participation	10,000	1	10,000
8	Report publishing	20,000	1	20,000
			Total	200,000

CHAPTER 4 Methodology

4.1 Energy Intensity

This section will discuss how energy intensity data in selected countries was analyzed, which serves as a guideline for an analysis of Thai national data for comparison.

4.1.1 Schipper's analysis

In a study of 10 industrialized countries over a period of 1973-1992 [11], Schipper found that a significant fraction (90%) of total energy use in the transportation were used for travel and freight. In Schipper's analysis, only 85% of such energy was subjected to further analysis, which has omitted

- energy use for pipelines
- energy use for some miscellaneous/non-freight trucks like cranes/fire engines
- energy associated with air freight, international sea bunker, natural gas and electricity

due to insufficient data and difficulty to segment the amount. In most countries, national energy and transport statistics were based on surveys of three main freight modes (truck, rail and water) with the estimates for fractional energy use in Schipper's analysis, excluding freight carried on vehicles of another country and all sea/air freights between countries.

Model energy intensity was calculated by two characteristics, the energy required to transfer the vehicles and vehicle capacity utilization. The energy required to move the vehicle was determined by fuel used, transport conditions and vehicle characteristics. On the other hand, vehicle capacity utilization gave impact on fuel consumption by loading levels of individual vehicles. In Schipper's approach, trucks can be classified into three categories,

- combination trucks (over 6 ton),
- medium truck (1.5-6 ton), and
- small truck (under 1.5 ton).

Examples of Schipper's analysis are shown in Fig. 8 for 10 countries studied. It is clear from Fig. 8(a) that the larger the truck, the higher absolute fuel consumption, with better fuel economy over time. From Fig. 8(b), average energy intensity has varied from countries to countries, depending on the nature of freight transport, over time. In Japan, rather high energy intensity mainly came from the choice of smaller truck delivery within congested cities, as well as the "just-in-time" logistic concept not to carry large loads for long period storage. On the other hand, rather high energy intensity in Denmark (especially after 1983) came from the rather cheap price of diesel subsidized by the government. For countries like Finland and Sweden, rather low energy intensity was achieved by trucking of

forest products and other bulk materials in the largest permissible trailer sizes in EU, as well as a greater fraction of water and rail transports.

L per 100 km

Source: Lawrence Berkeley National Laboratory

(a)

MJ per tonne-km

Includes light trucks
Source: Lawrence Berkeley National Laboratory
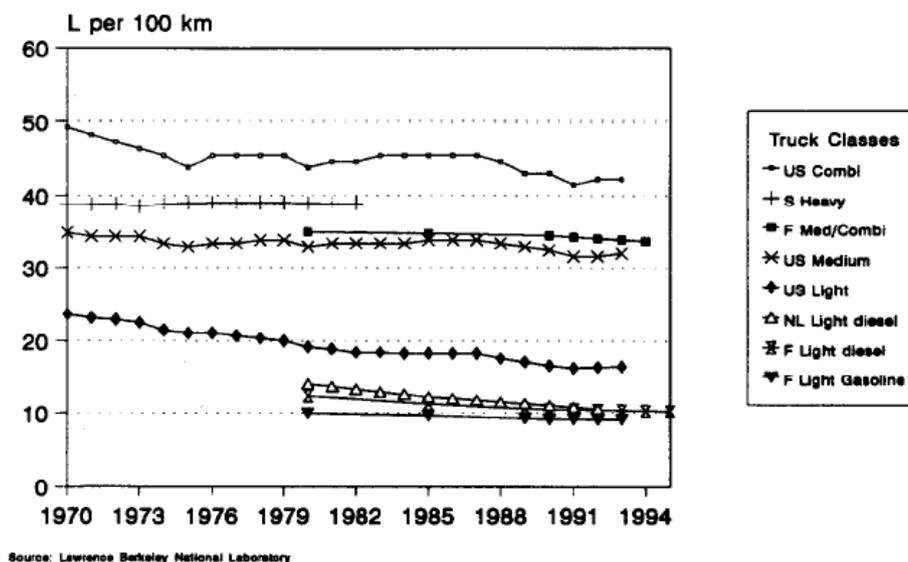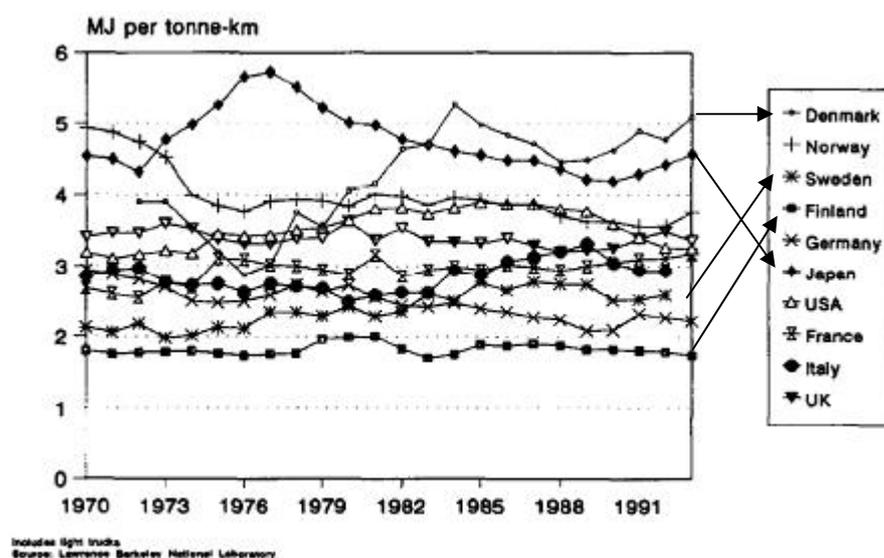
(b)

Fig. 8 (a) Fuel consumption by truck classes and (b) average energy intensity of 10 selected industrialized countries between 1973-1992

Nonetheless, uncertainty and barrier of the research results were mainly from inaccurate data in fuel use in freight transportation, which the model sometime could not reflect the reality [7]. Other limitations were the number of vehicles and the distance driven per vehicle, often over counting. Circularity among fuel consumption, traveled distance and number of vehicles could lead to serious errors in the analysis, as shown in Fig. 9.
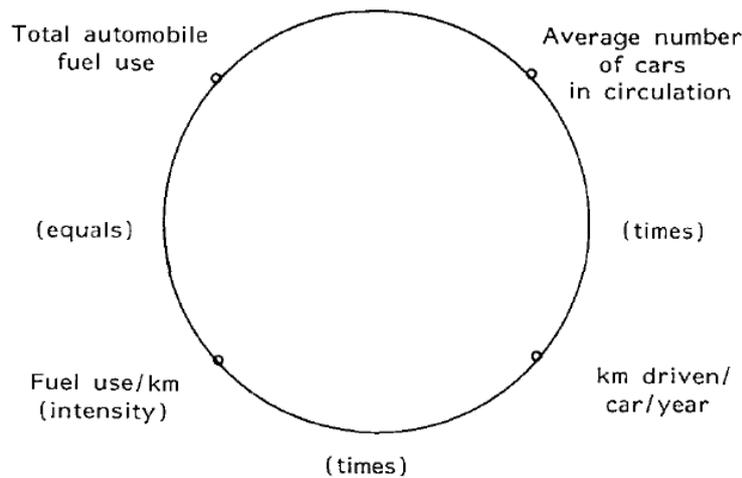
Fig. 9 Circularity of automobile fuel use calculation

Similar analysis was extended to selected OECD countries from 1973-2005, as shown in Section 2.1.1 [3]. Road diesel used by truck was separated from those by bus, car and special vehicles like fire engine. Gasoline and alternative fuel used by smaller truck in freight transport was also included. National data from Australia, France, Japan, UK and US were collected on the annual basis, except for Australia during 1985-2000 that was only available in every third year. Truck classification was defined as broadest as possible to compromise the differences among selected OECD countries. Energy associated with pipeline transport, e.g. oil and natural gas, was unfortunately excluded due to the difficulty in estimation.

In general, the energy to move each vehicle depends on
- types of vehicle (light or heavy trucks)
- vehicle load (full, partial or empty/backhaul)
- vehicle fuel intensity
- fleet fuel mix (diesel, gasoline or alternative fuels)
- types of trips (length, terrain)
- driving conditions (urban, rural or congestion)

As shown in Fig. 10 for two snapshots in time (1973 vs 2005), different behaviors for three modes of freight transport were observed. As expected, truck mode has dominated freight transport energy intensity. Together with Fig. 2 and Fig. 4, various conclusions can be made.
- First, Fig. 2(a) and Fig. 8(b) showed highest energy intensity in Japan due to the small truck usage in congested cities.
- Second, Fig. 2(b) indicated lowest energy intensity in Australia due to a high share of three-unit trucks used for transportation across the dessert interior.
- Next, two key factors affecting freight trucking energy intensity, namely average truck fuel intensity and average load per vehicle, are illustrated in Fig. 4(a) and Fig. 4(b), respectively.

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- Third, truck fuel intensity depends on characteristics of fleet mix. From Fig. 4(a), Japan, as dominated by smaller truck in fleet, showed lower truck fuel energy intensity (MJ/vehicle-km) than Australia or US, as dominated by larger truck in fleet.

- Forth, load per vehicle, which is calculated by a ratio of ton-km to vehicle-km, depends on average truck capacity and capacity utilization. To achieve better efficiency, empty backhaul truck should be avoided. From Fig. 4(b), average load per vehicle of Australia clearly showed significant increase from the three-unit truck while US showed some fluctuations due to the share of commercial light trucks being used in the freight transport. Other countries showed moderately stable trend with some improvement in Japan for higher efficiency light truck.

- Taken the third and forth points, higher average loads, longer distances and lower congestion would yield less energy intensive trucking in Australia and US.
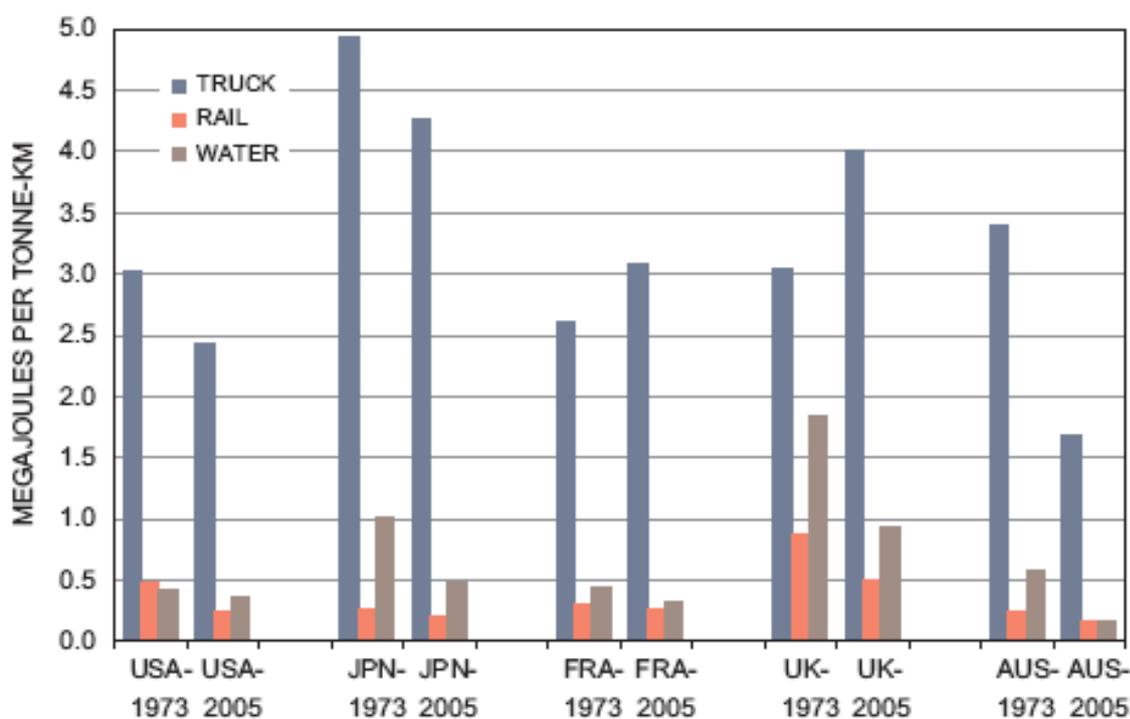
Fig. 10 Energy intensity in freight transport by truck, rail and water of selected OECD countries at two snapshots in times (1973 vs 2005)

4.1.2 Macro-level approach

The present investigation will follow Schipper's analysis on available national data of Thai freight transport. As previously mentioned [11], since energy consumption in truck freight transport alone has not been properly recorded, some energy demand modeling is required.

The energy demand models by end-use approach have been developed to estimate energy demand in road transport sector. The models included the demand of fuel used in nine types of vehicles, e.g.

- private car (PC),
- pick-up truck (PU),
- urban taxi (TAXI),
- commercial car (COMC),
- three-wheeler (3WL),
- motorcycle (MC),
- fixed route bus (FBUS),
- non-fixed route bus (NBUS) and
- truck (TRK).

Most of these vehicles lie upon an internal combustion engine (ICE) technology, which use six types of fuel, including

- gasoline,
- gasohol (ethanol-blended gasoline),
- diesel,
- biodiesel-blended diesel,
- liquefied petroleum gas (LPG) and
- compressed natural gas (CNG).

By using end-use approach, the energy demand in road transport sector can be calculated from a product of three important driving factors, as shown in Eq. (1), e.g.

- total number of vehicle stock,
- average travel distance of vehicle and
- fuel consumption rate of vehicle.

The methodology to estimate all three important parameters is described in details as follows.

$$ED_t = \sum_{i}^{n} \sum_{j}^{m} VS_{i,j,t} \times FAVKT_{i,j,t} \times FAFE_{i,j,t} \tag{1}$$

where

ED_t is a total energy demand (MJ) in year t,

$VS_{i,j,t}$ is the total stock of vehicle (vehicles) type i which use fuel type j in in year t,

$FAVKT_{i,j,t}$ is the fleet average annual vehicle kilometer of travel (kilometer) of fuel type j for vehicle type i in year t, and

$FAFE_{i,j,t}$ is the fleet average on-road fuel economy (MJ/km) of the fuel type j for vehicle type i in year t.

(a) Vehicle stocks

The vehicle stock turnover was taken into consideration for estimating the total number of each vehicle type in road transport. In this analysis, the total number of vehicle stock in a given year is a summation of vehicles sold on the past years that are still on the road, as presented in Eq. (2).

$$VS_{i,j,t} = \sum_{k=0}^{l}(S_{i,t-k} \times SR_k \times FS_{i,j,t}) \tag{2}$$

where

$VS_{i,j,t}$ is the total number of a vehicle stock (vehicles) type i using fuel type j in in year t,

$S_{i,t-k}$ is the number of vehicles sales (vehicles) type i in model year t-k,

SR_k is the survival rate (%) of vehicle at age k,

$FS_{i,j,t}$ is the share (%) of fuel type j within the vehicle sales type i in year t,

k is the age of vehicle in year t, and

l is a possible longest life time of the vehicles.

A vehicle sale is a number of new vehicles in road transport sector in each year. The data of new registered vehicles during 1997 to 2008 was obtained from Department of Land Transport (DLT) [8]. Survival rate of vehicle is the fraction of vehicles still being used in the road transport sector. Generally, the survival rate of vehicles is related to an age of vehicle, where the vehicle will be retired after a certain time period has met. Hence, the survival rate of vehicle is reduced when the age of vehicle increases. This relationship is normally presented by an inverse S-shape curve, as shown in Eq. (3). Historical data of new registered vehicles and total registered vehicles by age were obtained from Department of Land Transport (DLT) during 1997 to 2008 for each vehicle type defined previously. The coefficients of variable in the survival rate equation can thus be estimated. The results of survival rate of each vehicle type are presented in Fig. 11.

$$SR_k = SR_{k-1} \times e^{-fk} \tag{3}$$

where

SR_{k-1} is survival rate of vehicle at age k-1 (%) and

f is coefficient of variable
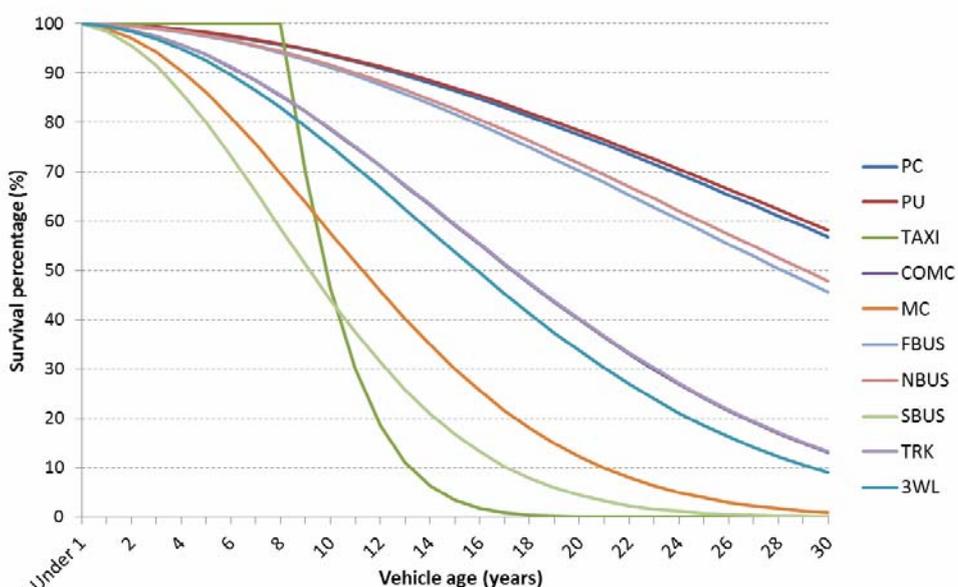
Fig. 11 Estimated survival rate of Thai road transport vehicles (%)

Fuel share is percentage of a number of vehicles by fuel used. As abovementioned, six types of fuel have been considered for road transport in Thailand, including gasoline, gasohol, diesel, biodiesel, CNG and LPG. In this study, the fuel share of vehicle sales and stocks data in 1997 are obtained from the National Energy Policy Office (NEPO) study in 1997 [12] due to lack of reliable survey data. In addition, the fuel share of vehicle sales during 1998 to 2006 has been estimated by the authors, based on fuel share data from the study of NEPO (1997) and the recorded data of the Department of Land Transport (DLT). The fuel share for different fuel types of vehicle stocks and new vehicles in each vehicle type are shown in Table 4.

Table 4: Fuel share data of vehicle stocks and vehicle sales for different fuel types (%)

Vehicle type	Fuel type	Percent share of vehicle stock in 1997 (%)	Percent share of vehicle sales (%)			
			1997	2000	2005	2008
PC	Gasoline/Gasohol	68	76.7	75	72.3	68.7
	Diesel/Biodiesel	32	23.3	25	27.7	29.3
	CNG	0	0	0	0	2
PU	Gasoline/Gasohol	10	4.1	3.5	2.6	2.1
	Diesel/Biodiesel	90	95.9	96.5	97.4	96.9
	CNG	0	0	0	0	1
TAXI	Gasoline/Gasohol	61	10	0	0	0
	LPG	39	90	100	87.5	80
	CNG	0	0	0	12.5	20
COMC	Gasoline/Gasohol	70	50	65	83.3	91.7
	Diesel/Biodiesel	30	50	35	16.7	8.3

3WL	Gasoline/Gasohol	37	87.5	66.6	19.8	6.6
	Diesel/Biodiesel	2	0	0	0	0
	LPG	61	12.5	33.4	80.2	93.4
MC	Gasoline/Gasohol	100	100	100	100	100
FBUS	Diesel/Biodiesel	98.5	100	100	100	99
	CNG	1.5	0	0	0	1
NBUS	Diesel/Biodiesel	99.8	100	100	100	99
	CNG	0.2	0	0	0	1
SBUS	Diesel/Biodiesel	100	100	100	100	100
TRK	Gasoline/Gasohol	0.4	0.2	0.1	0.1	0
	Diesel/Biodiesel	99.6	99.8	99.9	99.9	95
	CNG	0	0	0	0	5

(b) Vehicle kilometer of travel (VKT)

Vehicle kilometer of travel (VKT) is defined as an average distance of vehicle traveling in one year. Generally, the VKT of each vehicle reduces with increasing vehicle ages. To incorporate this characteristic, relationship between the average reduction of VKT and the average age of vehicles is applied from the NEPO (1997) data [12]. Results of estimated VKT of new vehicles and the degradation percentage of VKT are presented in Table 5 and Fig. 12, respectively. Then, a fleet average for annual vehicle kilometer of travel is calculated by Eq. (4), as shown in Table 6.

Table 5: Annual vehicle kilometer of new vehicles by type in 1997

| Vehicle type	Vehicle kilometer of travel (km)
PC	23,248
PU	28,912
TAXI	63,389
COMC	26,758
3WL	13,766
MC	12,812
FBUS	75,973
NBUS	43,695
SBUS	36,950
TRK	98,111
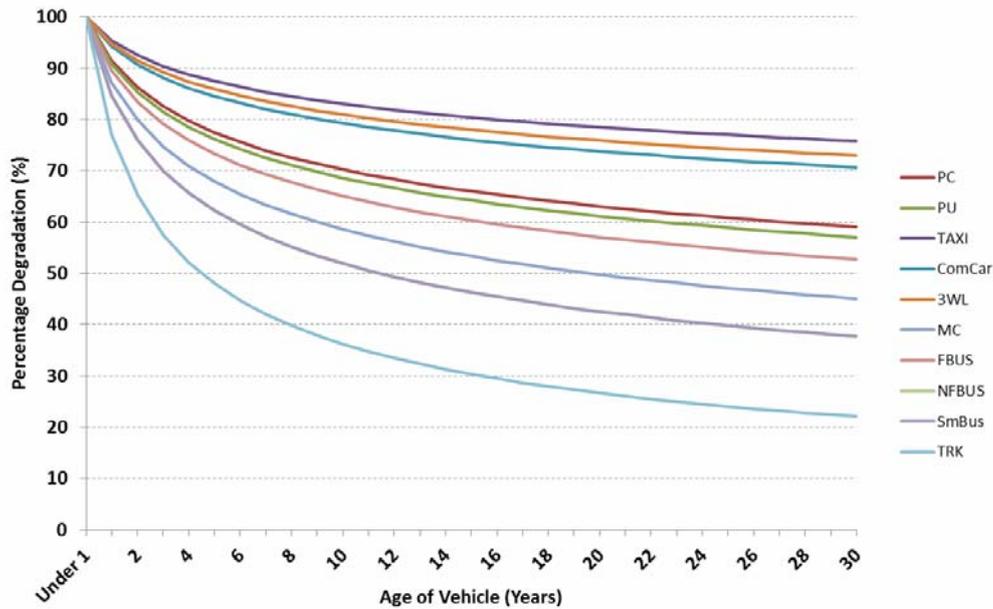
Fig. 12 Degradation factors of annual vehicle kilometer of vehicle (VKT)

$$FAVKT_{i,j,t} = \frac{\sum_v (VS_{i,j,t,v} \times VKT_{i,j,v})}{VS_{i,j,t}}$$ (4)

where

$VKT_{i,t,v}$ is the average annual vehicle kilometer of travel during the lifetime of vehicles type i with fuel type j and vintage v.

Table 6: Estimation of the FAVKT of vehicles during 1997 to 2008

Vehicle type	1997	2000	2005	2008
PC	18,961	16,230	14,931	13,163
PU	28,241	24,258	23,425	17,923
TAXI	59,479	57,518	60,728	61,587
COMC	25,232	22,405	19,209	16,708
3WL	10,054	9,378	8,586	8,159
MC	10,027	8,215	7,659	6,500
FBUS	67,917	59,804	59,342	47,081
NBUS	26,853	22,285	24,462	21,684
SBUS	26,694	22,753	23,317	17,871
TRK	34,582	23,803	27,305	21,332

(c) Fuel economy of vehicles

Fuel economy of vehicle is one of the indicators for energy intensity of a vehicle. It is the average fuel consumption of vehicle-distance travelled. In this study, the on-road fuel economy of vehicles is obtained from the studies of NEPO [12] and later EPPO (Energy Policy and Planning Office) [13]. The fuel economy of all vehicle types is presented in term

of liters per 100 kilometer, as shown in Table 7. Furthermore, the fleet average fuel economy of each vehicle type, which could potentially comprise of multiple fuels, over a time period of interest was calculated from Eq. (5). The results of fleet average are shown in Table 8.

Table 7: Fuel economy of vehicles by fuel types

Vehicle type	Fuel economy (liters per 100 kilometer)			
	Gasoline	Diesel	LPG	CNG
PC	8.58	9.02	9.51	8.46
PU	8.96	8.35	8.89	9.59
TAXI	7.41	10.00	10.36	8.96
COMC	12.47	11.04	9.24	11.50
3WL	6.47	5.63	9.33	9.06
MC	3.66	-	-	-
FBUS	32.67	28.41	36.93	47.84
NBUS	29.14	25.34	32.95	42.68
SBUS	16.79	14.60	18.98	35.99
TRK	27.31	23.75	30.88	58.55

$$FAFE_{i,j,t} = \frac{\sum_v (VS_{i,j,t,v} \times FE_{i,j,v})}{VS_{t,j,t}}$$
(5)

where

$FE_{i,t,v}$ is the average fuel economy of vehicles type i with fuel type j and vintage v.

Table 8: Average fuel economy of fleet vehicles over times

Vehicle type	Fleet average fuel economy of vehicle (liters of gasoline per 100 kilometers)			
	1997	2000	2005	2008
PC	8.60	8.60	8.61	8.58
PU	8.97	8.98	8.99	9.02
TAXI	7.52	7.82	8.49	8.73
COMC	11.89	11.90	11.90	11.89
3WL	11.31	11.85	12.73	13.69
MC	3.48	3.48	3.48	3.48
FBUS	27.11	27.10	27.08	28.12
NBUS	23.31	23.30	23.27	23.77
SBUS	16.04	16.04	16.04	16.04
TRK	25.17	25.17	25.17	26.32

(d) Energy demand estimation

From the model setup above, Fig. 13 presents the energy consumption in the road transport sector during 1997 to 2008. Due to economic crisis, the total energy consumption of transport sectors suddenly decreased from 17,223 ktoe in 1997 to 14,945 ktoe in 1998, but

started to increase after the economy recovered from 16,017 ktoe in 2002 to 17,953 ktoe in 2008.


(a)   (b)
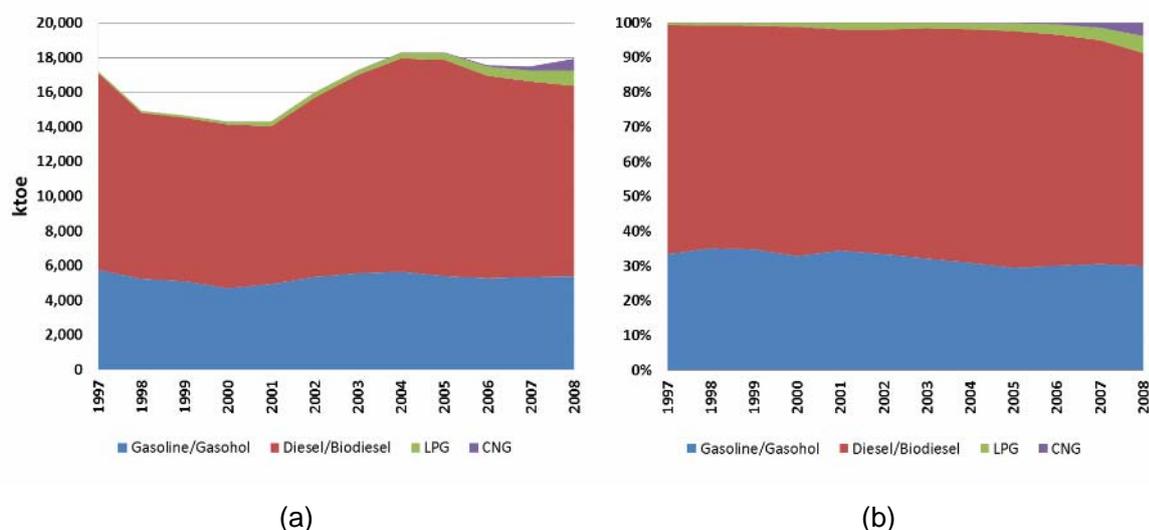
Fig. 13 Fuel Consumption of the Road Transport Sector by Fuel Type in (a) ktoe and (b) percentage

In 1997, diesel, which was mostly used in public transport vehicles (e.g. buses) and freight transport vehicles (e.g. pick-up trucks and trucks), shared the highest proportion up to 66% (11,361 ktoe) of the total fuel consumption of the road transport sector; whereas, only about 33% (5,754 ktoe) was shared by gasoline, which was mostly used in private passenger vehicles (e.g. passenger cars and motorcycles). The rest was LPG. Even though the fuel proportion has slightly changed in 2008, diesel still shared the highest proportion of 61% (10,999 ktoe) and gasoline shared about 30% (5,388 ktoe) of the total fuel consumption. With governmental promotion on biofuels as alternative fuel, small proportion of transport fuels have been replaced by bioethanol and biodiesel, which were blended with conventional fossil fuels as gasohol E10 (gasoline blended with bioethanol 10% v/v) and diesel B2 (diesel blended with biodiesel 2% v/v) or B3. In 2008, the bioethanol and biodiesel have accounted for around 2% and 1% of the total energy consumption in road transport sector, respectively. Another option was CNG, which has been heavily promoted in both gasoline (mostly taxi) and diesel vehicles. Since 2004, there has been a fuel switching to use the relatively low price fuels of LPG and CNG. Therefore, these fuels showed rapid growth up to 4.9% (879 ktoe) and 3.8% (687 ktoe) of the total energy consumption, relatively.

The energy demand of the road transport sector by vehicle types during 1997 to 2008 is presented in Fig. 14. Freight transport (mainly TRK & PU) shared higher proportion (~52–55%) of the total fuel consumption than passenger transport (~45–48%). Within the freight transport mode, pick-up trucks shared higher consumption of 30–33%, while heavy duty trucks shared about 19–25% of the total fuel consumption. For the passenger transport, private vehicles, e.g. private cars (PC) and motorcycles (MC), shared the highest proportion

(~37–38%) for passenger transport, while public transport vehicles, e.g. buses, shared only about 6–7% of the total fuel consumption. This segmentation of energy consumption (MJ) in freight transport (TRK & PU) will be used in further calculation of energy intensity in Chapter 5.


(a)   (b)
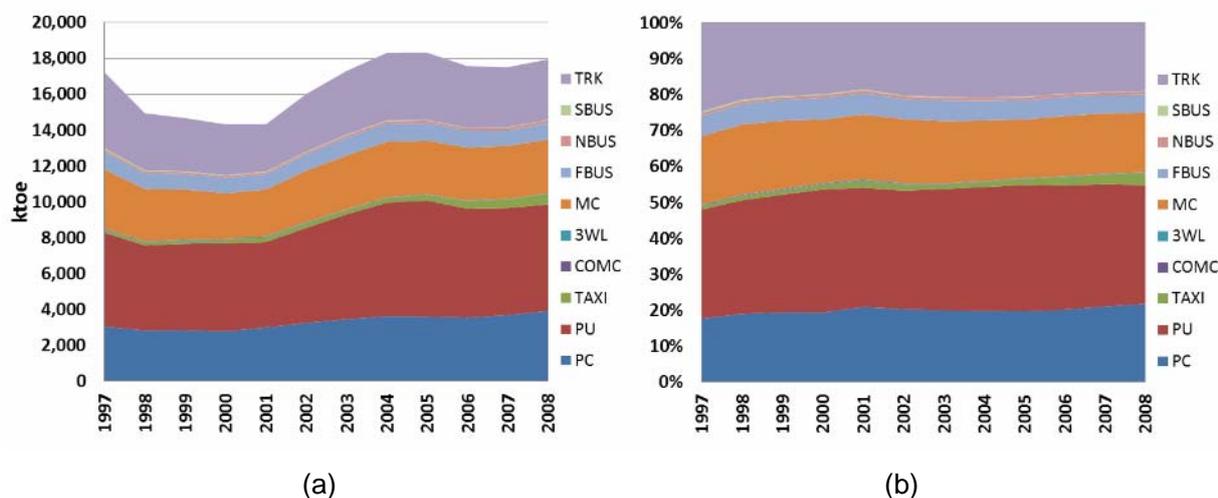
Fig. 14 Estimation of energy demand of the road transport sector by vehicle type in (a) ktoe and (b) percentage

**(e) Economic activity (ton-km) of freight transport**

As shown in Fig. 7 [9], the freight economic activity data (ton-km of goods being transported) has been annually recorded by Ministry of Transport since 2002, as shown in Fig. 15. Clearly, top commodities that have used most energy for transport are among rice, construction metal and petroleum products, as shown for 2009 figure in Fig. 15(c).   This ton-km data will be used in further calculation of energy intensity in Chapter 5.

(a)

(b)

2009 Freight Road Transport of Commodities (MTon-km)

9,620; 5% 12,536; 7.00% 16,010; 8.94%

9,544; 5.33% 11,406; 6.37%

9,872; 5.51%

9,971; 5.57% 11,952; 6.68%

16,311; 9.11%

8,228; 4.60% 15,613; 8.72% 10,174; 5.68%

☐ live animal	☐ rice	☐ corn
☐ cassava	☐ sugar cane	☐ rubber
☐ wood	☐ other agricultural products	☐ animal feed
☐ sugar	☐ other edible	☐ mineral & fuel
☐ petroleum products	☐ elements	☐ construction metal
☐ soil, rock and sand	☐ cements	☐ construction materials
☐ fertilizer	☐ chemical substancs	☐ household utilities
☐ misc.		

(c)

Fig. 15 Historical data for ton-km of goods in freight transport by truck in (a) ton-km and (b) percentage with (c) detailed breakdown of goods-distance fraction in 2009

Another freight economic activity data (ton-km of goods being transported) was collected from a roadside interview survey [14] during 2008-2009 in 6 major economic provinces, e.g. Bangkok, Nakhon Sawan, Songkla, Nakhon Ratchasrima, Khon khaen and Chiangmai. The survey was conducted for 2 days/week (both weekday and weekend) in Bangkok while only 1 day/week in other provinces. The survey was conducted at 2 different times of the year to include harvesting season of major economic crops. Examples of the survey data include starting point-destination point, vehicles in each category, type of carried products and mass. However, this data contributed only for 1 year to the annual record by Ministry of Transport since 2002, as shown in Fig. 15.

4.1.3 Micro-level approach

In parallel to macro approach, a specific data set obtained from cooperating logistic companies will be calculated for comparison. This study will analyze data from the Logistics and Transport Management (LTM) project, funded by ENCON fund [15]. In LTM project, fuel consumption of over 200 freight vehicles of various types were recorded for a period of time before and after the implementation of energy saving measures like changing to radial tires, installing GPS and improving transmission. During each period (before and after), accumulated ton-km data were also recorded. For energy intensity (MJ/ton-km) calculation, only the weight of carried commodities is used [16], where the weight of the

vehicles will be analyzed as one of the factors (vehicle size, engine age, traveled distance and fuel type) affecting the energy intensity. Since calculated energy intensity is based on mostly loaded truck transport, the real value of average energy intensity over the country may be lower from the unavoidable empty backhaul [17].

4.2 CO_2 Intensity

With consumption of fossil fuel, the CO_2 or greenhouse gas (GHG) emission will reluctantly be emitted into atmosphere worsening global warming problem. The GHG emission for the transportation sector is calculated in the CO_2 equivalence scale. It is calculated according to the Intergovernmental Panel on Climate Change (IPCC) methodology [18]. The emissions considered here are the exhaust of mobile combustion: CO_2, CH_4 and N_2O. However, the methodology to calculate the GHG emission can be simplified as below equation while Table 9 shows default emission factor (EF) and the global warming potential (GWP) of some relevant fossil fuel consumed [19].

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

where   **EM**   =   Emission (kg CO_2 equivalence)
  EC   =   Energy consumption (TJ)
  EF_i   =   Emission factor of emission i (kg/TJ)
  GWP_i   =   Global warming potential of emission i (g CO_2/g emission i)
  i   =   Emission type (CO_2, CH_4, N_2O)

Table 9: Emission factors for some fossil fuel [19]

Fuel types	Emission factors (kg/TJ of energy consumed)		
	CO_2	CH_4	N_2O
Gasoline	69,300	33	0.96
Diesel	74,100	3.9	3.9
LPG	56,100	62	0.2
CNG	56,100	92	3

Table 10: Global warming potential of emission i [19]

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

In term of CO_2 equivalent emission, gasoline and diesel did not vary much while that from electricity depended on the fuel used to generate. It was found that differences in

trends of emissions among 10 countries studied [11] came from the changes in overall energy use, rather than the changes in fuel mix, as shown in Fig. 16 together with Fig. 5.

kgC/10e3 tonne-km

Source: Lawrence Berkeley National Laboratory
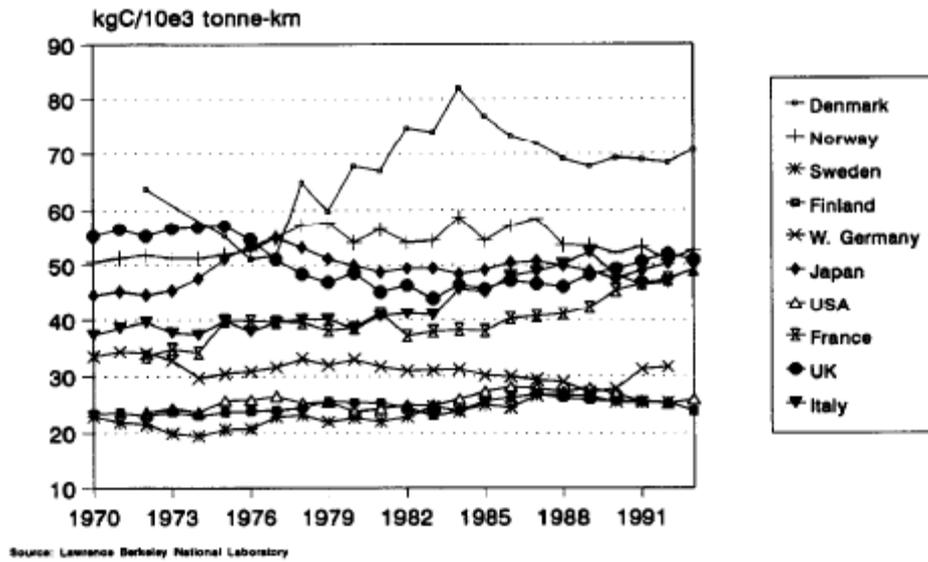
Fig. 16 CO_2 intensities of 10 industrialized countries

CHAPTER 5 RESULTS & DISCUSSION

5.1 Macro-level analysis

From Fig. 14 and Fig. 15, energy intensity parameter in Thai freight transport by truck can be calculated, as shown in Fig. 17, in comparison with other countries from Fig. 2 and Fig. 8. It is clearly shown that the definition of truck in transportation of goods in Thailand should include pick-up truck since it is often used to carry commodities in Thai road transport; otherwise, the value of energy intensity for Thailand is too low in comparison with other countries, as shown in dotted circle in Fig. 17. With data from project-based survey in 2008-9 [14] superimposed in Fig. 17, it is slightly higher than the value from annual record because this project-based survey only sampled from 6 major economic cities, as previously mentioned.
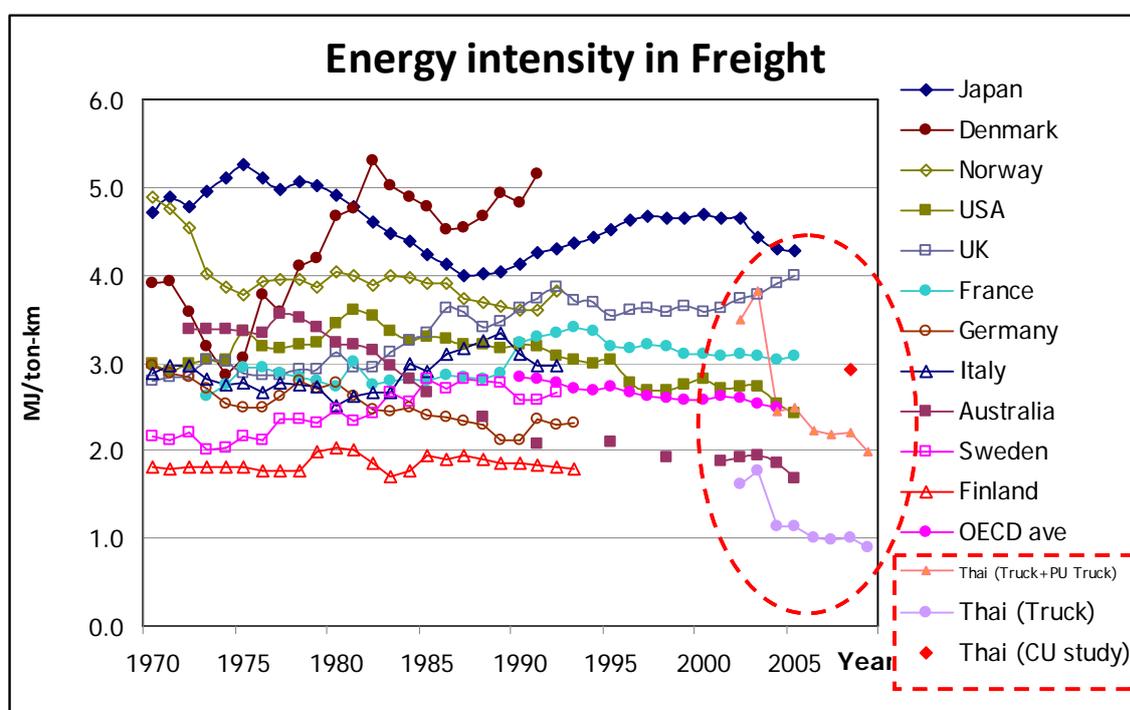

Fig. 17 Calculated energy intensity in Thai freight with comparison to other countries

5.2 Micro-level analysis

From the LTM project [15], a total of 12 logistic companies participating with 10 vehicle class types undergoing various energy-saving mechanisms to monitor the energy intensity with a total of 216 vehicles in database, as shown with details in Table 11 and Fig. 18. Each vehicle will be recorded for its own characteristics such as license plate, type, maker, vehicle age, engine age, engine size, empty vehicle weight. Prior to implementation

of energy-saving mechanism, recorded data are weight of commodities carried, distances traveled and type of fuel consumed. From Fig. 18(a), vehicles in this LTM project are dominated by 18-wheel semi-trailer, followed 10-wheel truck and tow truck. Most vehicles are equipped with OEM (1st hand) engine with some retrofitting as shown by the different data points in Fig. 18(b). For both vehicle and engine ages, Fig. 18(c-d) shows 50 percentile of about 6-7 years and modes of 3, 4, 7-8 years, which imply that fairly new vehicles dominate the vehicle pool. For the engine size, as large as 49 vehicles unfortunately do not have this information but from available data, the vehicle pool is dominated by rather large trucks with 320 & 400hp with 50 percentile of about 270-280hp engine, as shown in Fig. 18(e). For the empty vehicle weight shown in Fig. 18(f), rather large trucks with 13 and 19 tons of empty vehicle weight dominate the vehicle pool with 50 percentile of about 14 tons. Overall, this fleet characteristics are relative new trucks with rather large engine size.

**Table 11: Details of database from LTM project [15]**

| Variables	Details
No. of companies	12
No. of vehicle types	10 vehicle types from ➢ Trailers (24, 22, 20, 18 and 10 wheels) ➢ Semi-trailer (22 and 18 wheels) ➢ Truck (12 and 10 wheels) ➢ Pickup truck (4 wheels) (see example on the right →) รถพ่วง 22 ล้อ (Trailer) รถพ่วง 18 ล้อ (Trailer) รถกึ่งพ่วง 22 ล้อ (Semi-Trailer) 6 เพลา รถกึ่งพ่วง 18 ล้อ (Semi-Trailer) 5 เพลา รถ 12 ล้อ (12 Wheel) 4 เพลา รถ 10 ล้อ (10 Wheel) 3 เพลา
No. of energy-saving mechanisms	3 (radial tire, GPS and transmission improvement)
No. of vehicles	216 totally
Details which are monitored	➢ Vehicle characteristics (license plate, type, maker, vehicle age, engine age, engine size, empty vehicle weight) ➢ Weight of commodities carried ➢ Distances traveled ➢ Fuel consumed: diesel or CNG
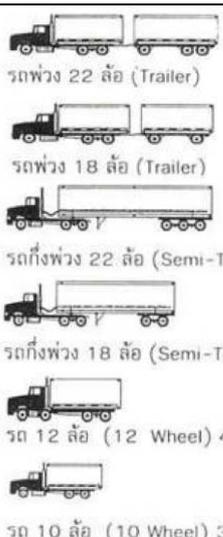
Type of vehicle

(a)

## Vehicle/Engine Age (unknown = 2)
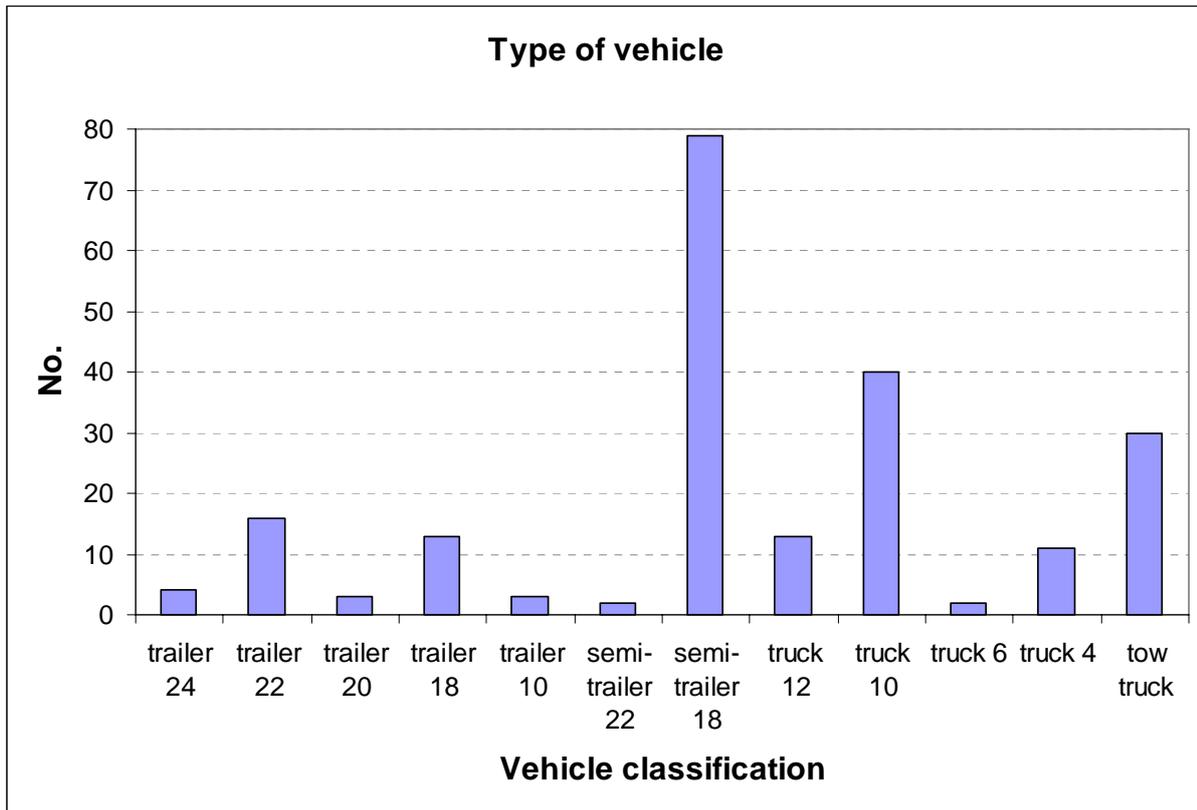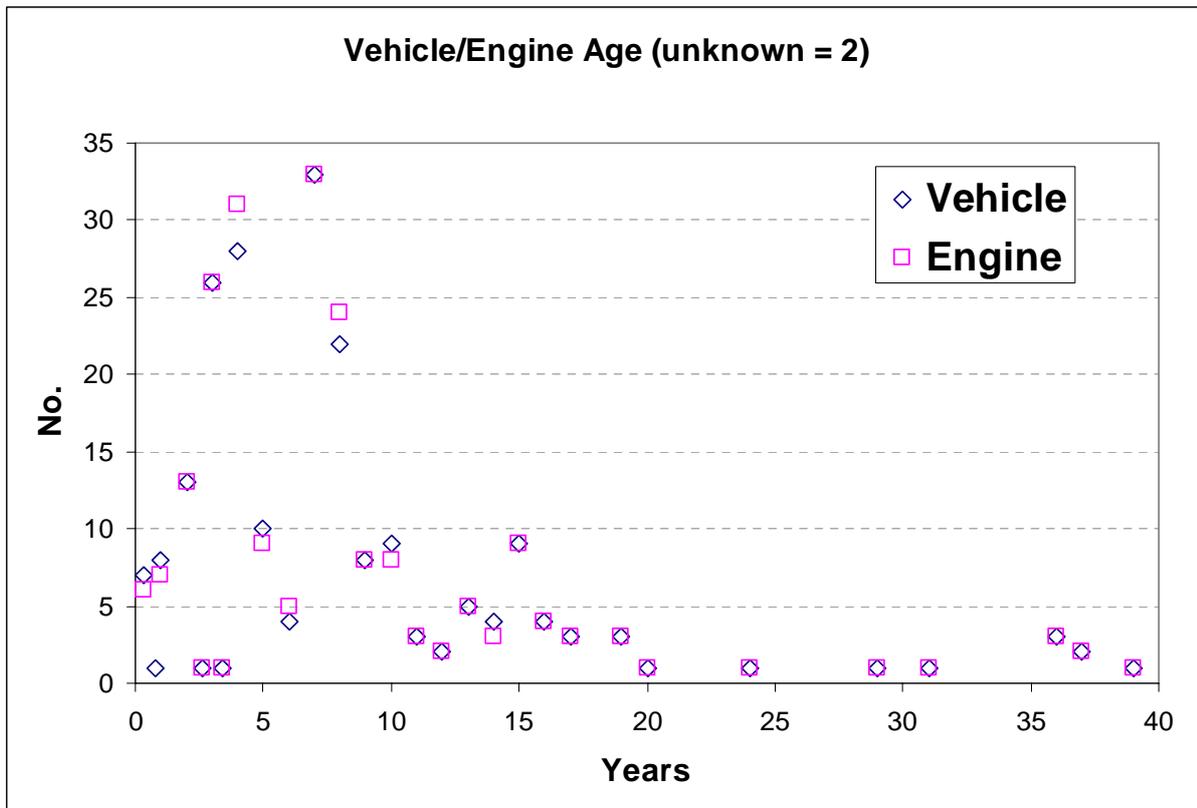
(b)
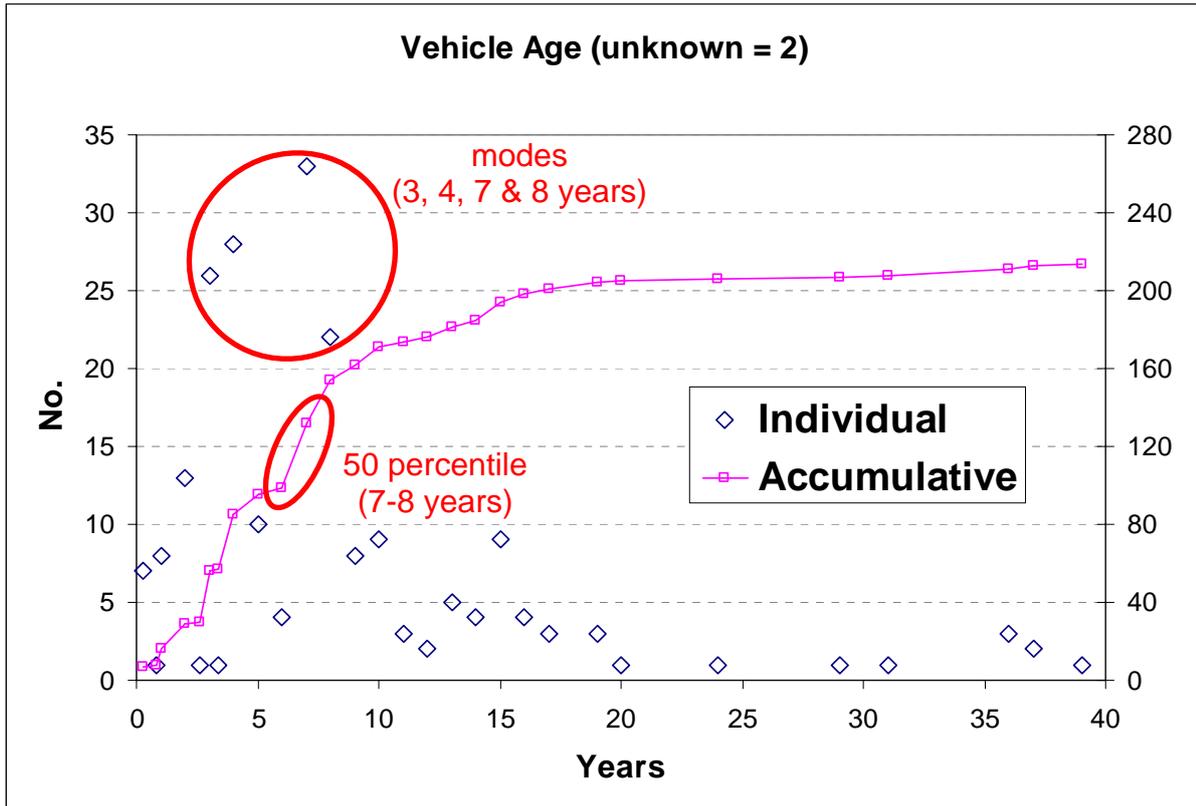
(c)
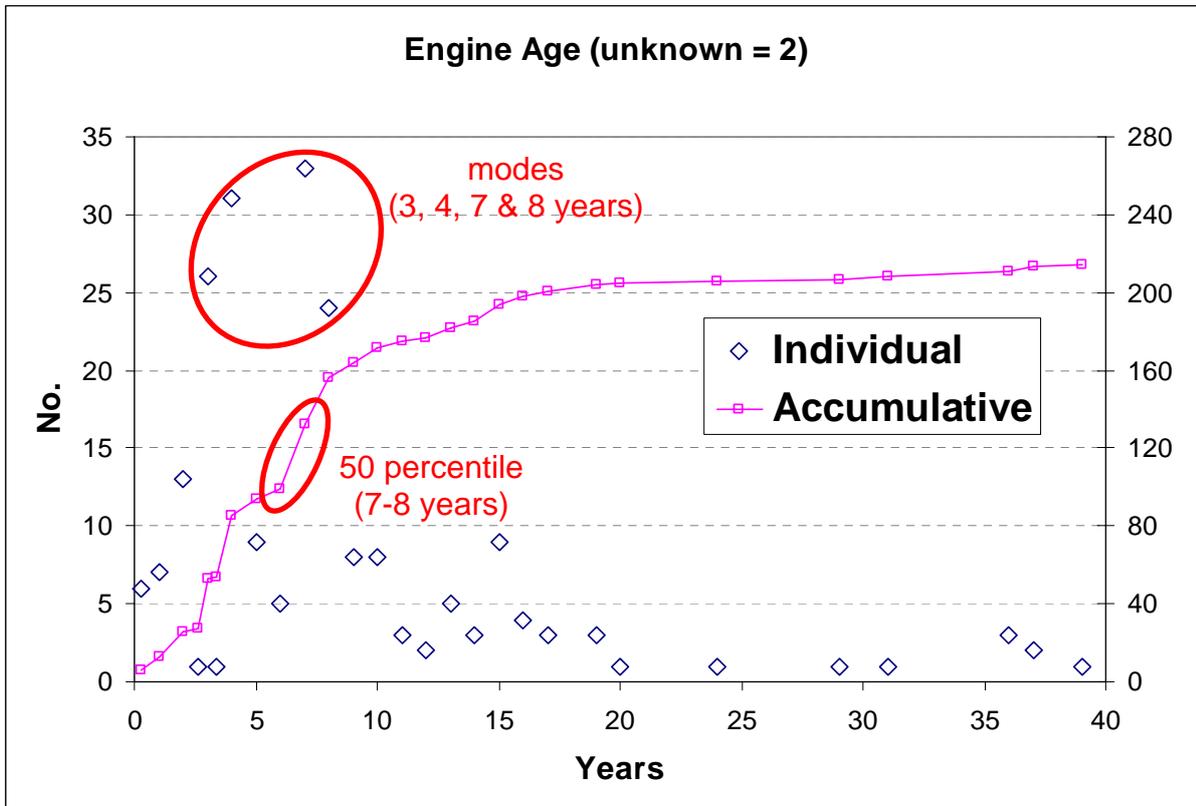
(d)
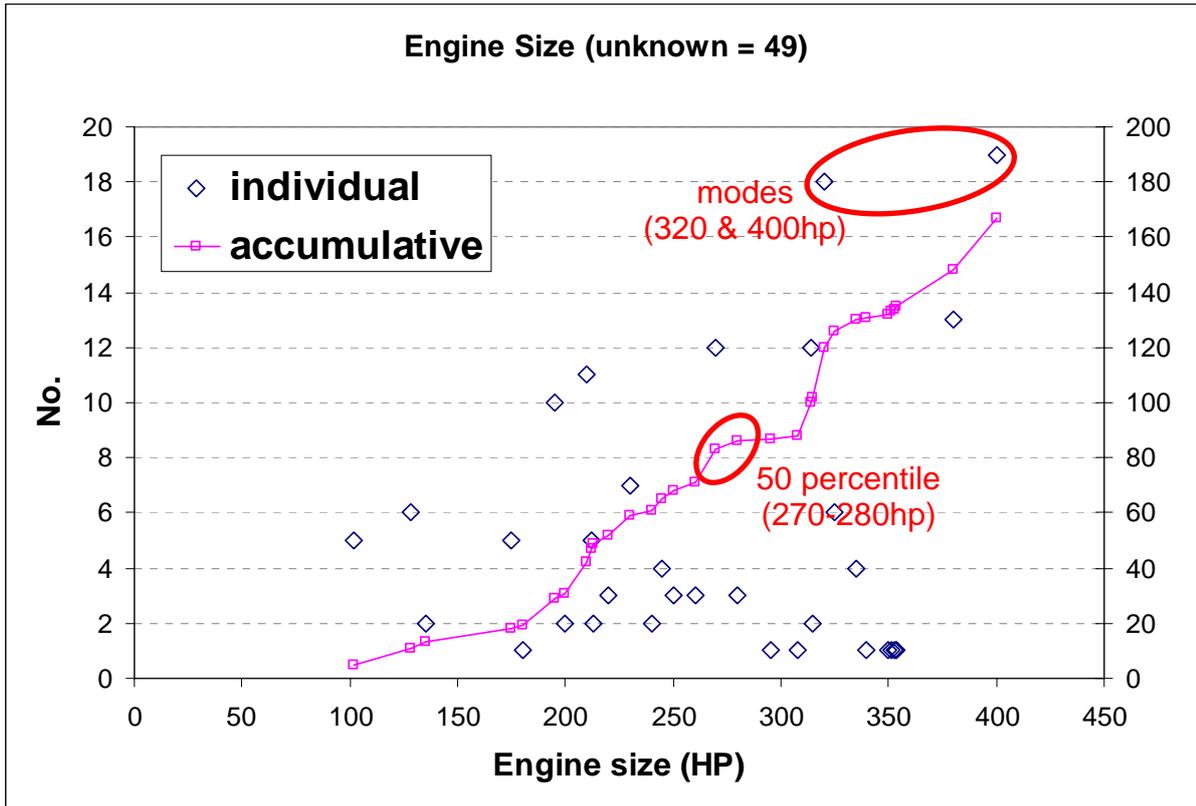
(e)
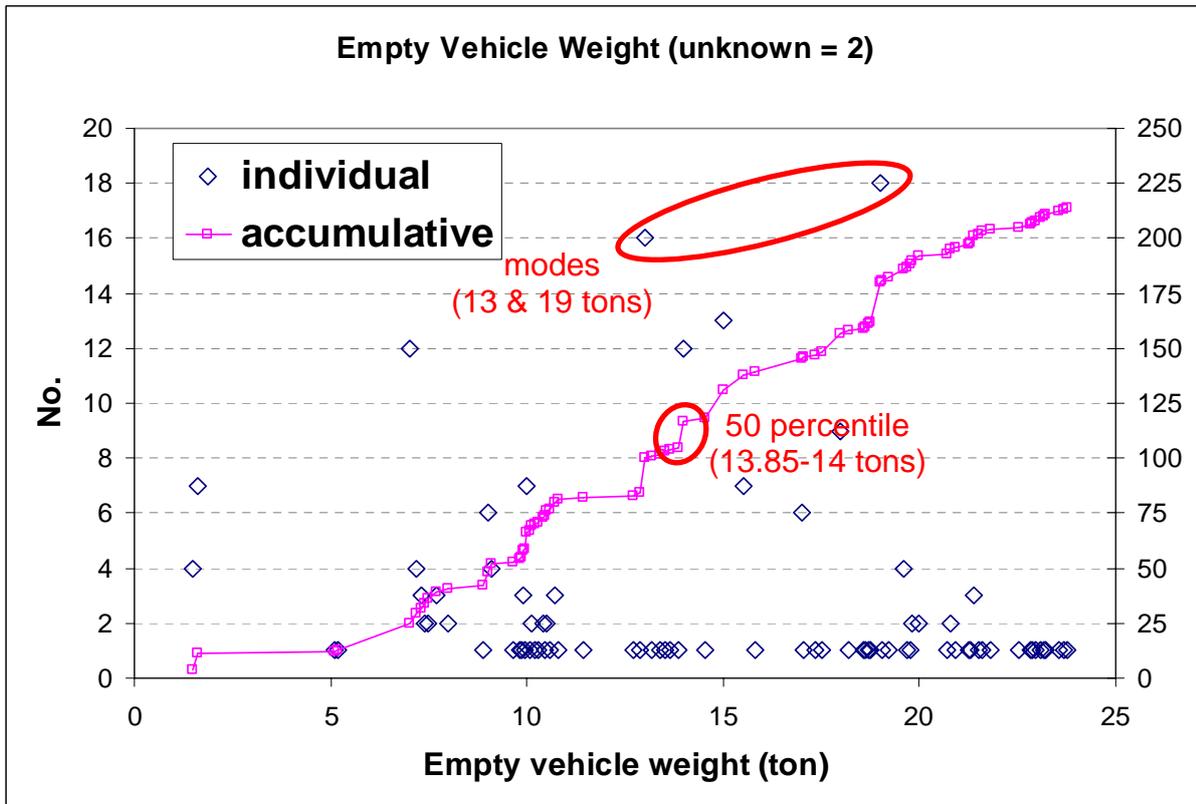
(f)

Fig. 18 Various statistical characteristics of participating vehicles on the basis of (a) vehicle types, (b) age of vehicle/engine, (c) age of vehicle, (d) age of engine, (e) size of engine and (f) weight of empty vehicle

Then, from available database of weight of commodities carried, distances traveled, type of fuel consumed and applied fuel-saving mechanism, various analyses are conducted as followed.

5.2.1 Effected of weight carried

First, the effect of weight carried (or loading weight) is analyzed for both energy and CO_2 intensities, as shown in Fig. 19. It is clear that both energy and CO_2 intensities decrease with increasing weight carried for both oil and gas, before and after energy-saving mechanism applied. This is to be expected from better fuel economy per loading weight of large vehicles, which can carry heavier loads.
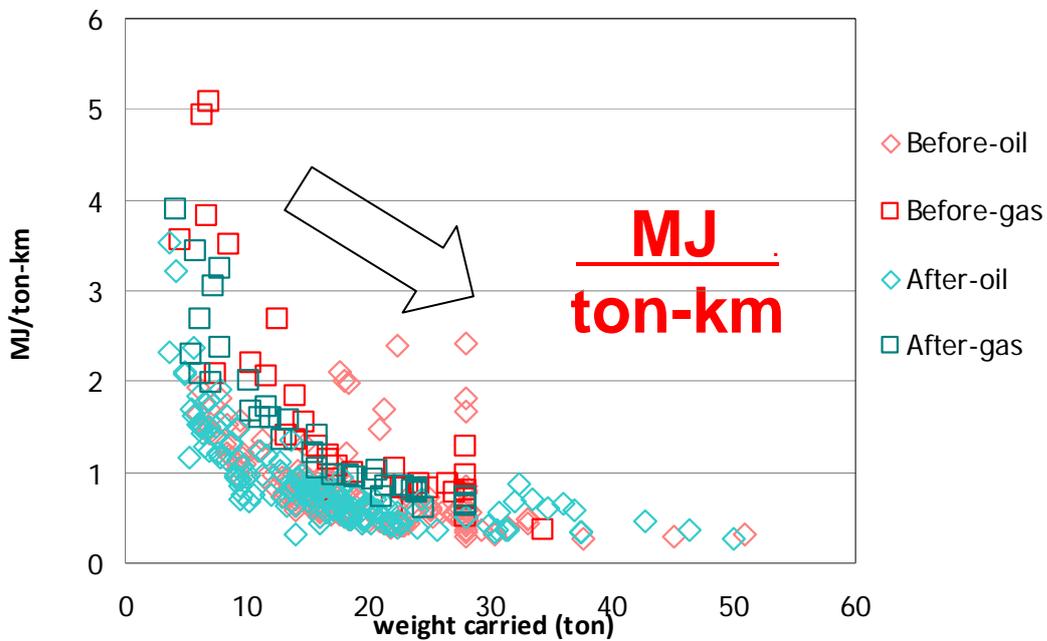

(a)
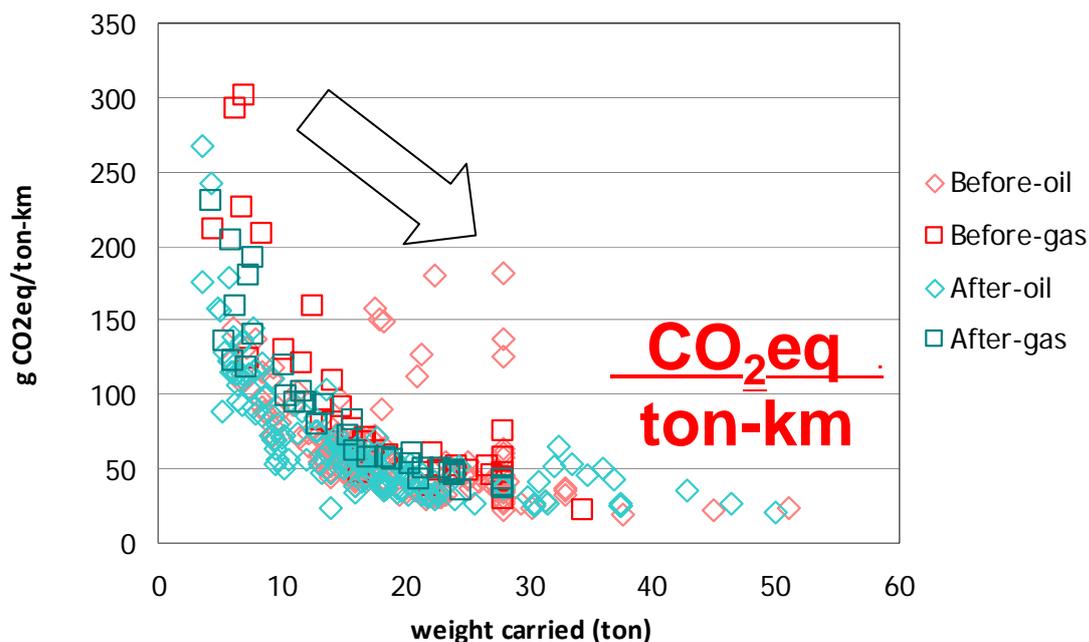
(b)

Fig. 19 Effect of loading weight on (a) overall energy intensity and (b) overall CO2 intensity

To further analyze the effects of fuel (diesel oil vs natural gas) and energy-saving mechanism, Fig. 20(a)-(d) are plotted for pair-wise comparisons. For both oil and gas, Fig. 20(a) and (b) show that gas data are generally above oil data, implying higher energy intensity for gas fuel, which is to be expected from a better fuel efficiency of diesel liquid than natural gas. The energy-saving mechanism is more effective in the case of diesel vehicles with 20-30 tons loading weights, as shown in Fig. 20(c), than that of natural gas vehicles, as shown in Fig. 20(d). The similar conclusion can be drawn for CO_2 intensities, as shown in Fig. 21.
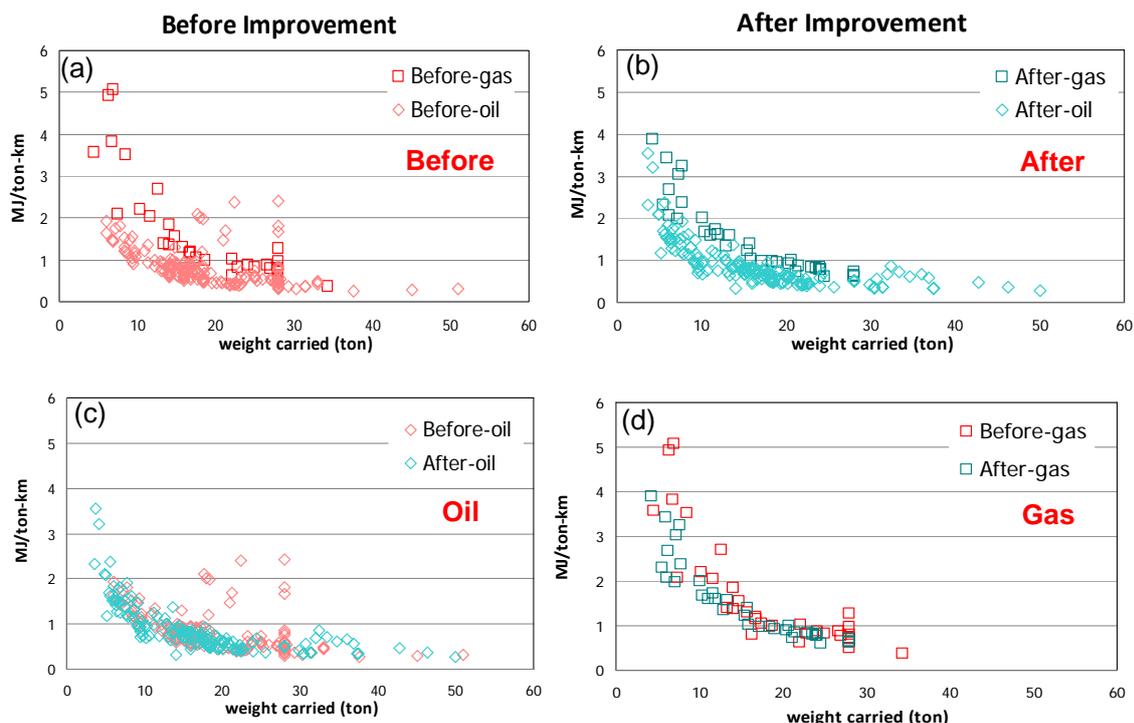
Fig. 20 Effect of loading weight on energy intensity focusing on (a) oil vs gas before improvement, (b) oil vs gas after improvement, (c) oil before vs after improvement and (d) gas before vs after improvement
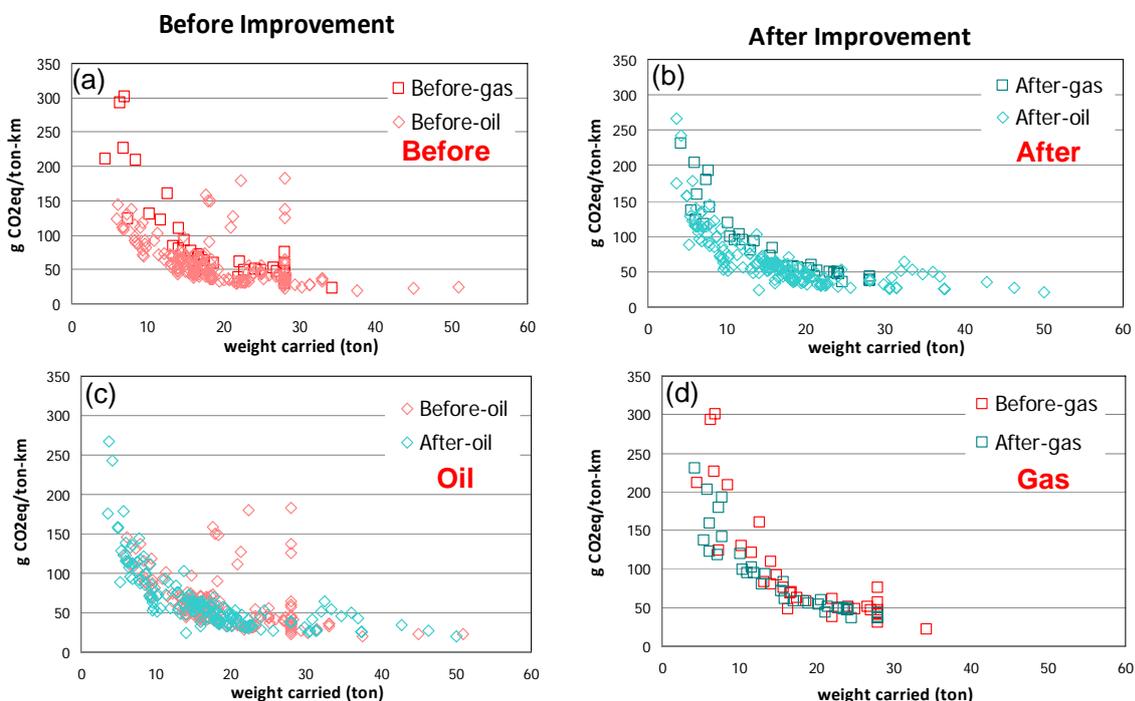
Fig. 21 Effect of loading weight on CO$_2$ intensity focusing on (a) oil vs gas before improvement, (b) oil vs gas after improvement, (c) oil before vs after improvement and (d) gas before vs after improvement

Next, the analysis was repeated to investigate the effect from various vehicle types, as shown in Fig. 22 and Fig. 23. From Fig. 22(a) and Fig. 22(b), it is clearly shown that energy-saving mechanism can effectively help 10-wheel trailer and 18-wheel semi-trailer reduce energy intensity, as well as CO_2 intensity, as shown from Fig. 23(a) and Fig. 23(b). For natural gas vehicles, Fig. 22(c) and Fig. 22(d) also show reduction in energy intensity in trailer (or previously labeled as "tow truck") and 18-wheel semi-trailer. Similar conclusion on CO_2 intensity reduction can be drawn from Fig. 23(c) and Fig. 23(d). However, it must be noted that this database were collected from commercial operation of participating fleet companies, which made it difficult to control parameters such as drivers, routings and loading weights. The discussion is therefore done on the overall average basis.
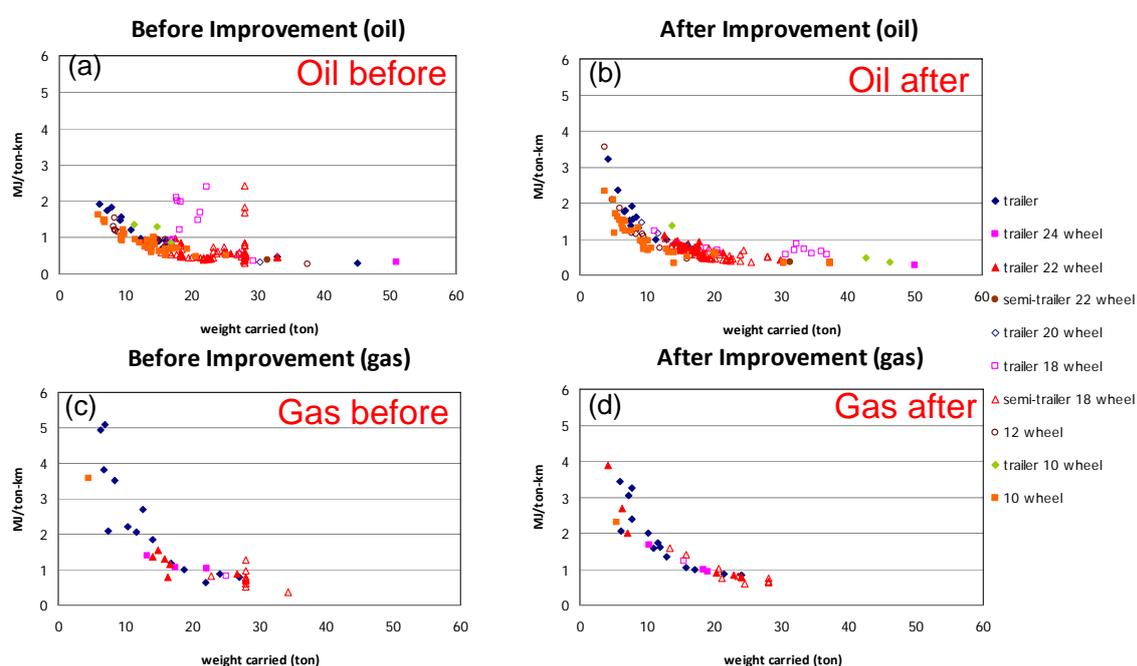

Fig. 22 Effect of loading weight on energy intensity by vehicle types on (a) oil before improvement, (b) oil after improvement, (c) gas before improvement and (d) gas after improvement
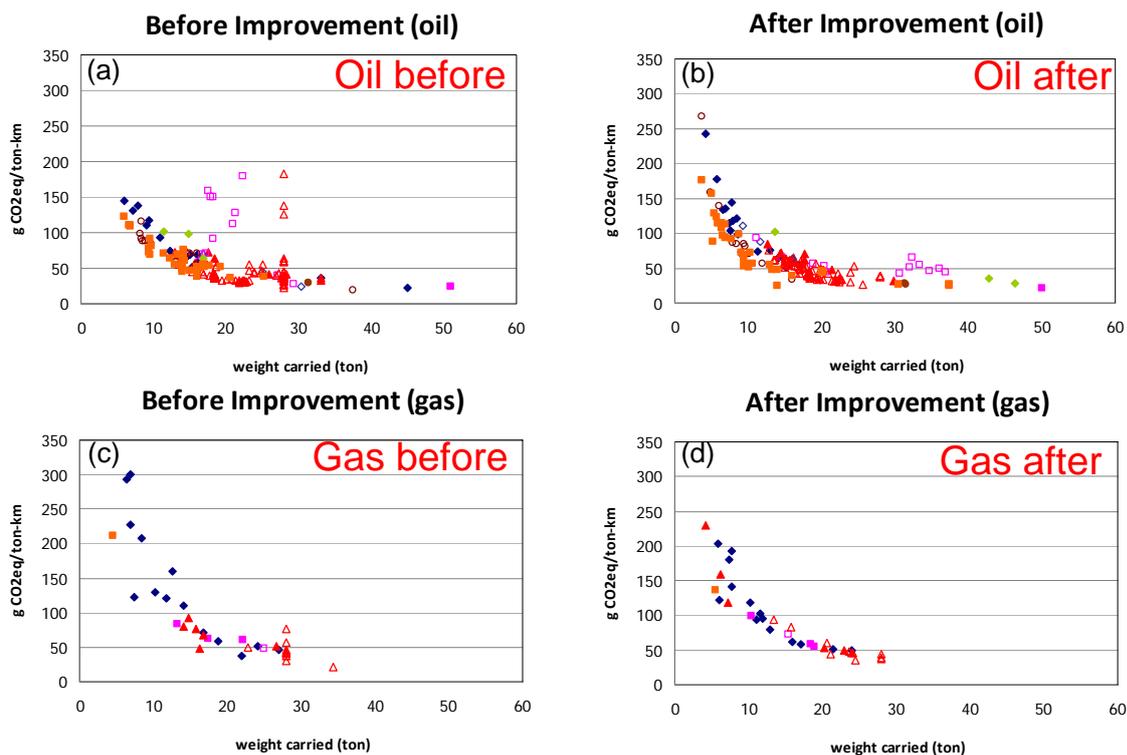
Fig. 23 Effect of loading weight on CO$_2$ intensity by vehicle types on (a) oil before improvement, (b) oil after improvement, (c) gas before improvement and (d) gas after improvement

5.2.2 Effected of engine age

Next, the effect of engine age is analyzed for both energy and CO$_2$ intensities, as shown in Fig. 24. From individual record in Fig. 24(a) and (b), it may look difficult to draw some implication so the data for each vehicle type of the same engine age is averaged out to obtain Fig. 24(c) and (d), with a linear fit for each trend serving as a visual guide only. Then, it is clear that vehicle with older engine age yields higher energy intensity, regardless of diesel or natural gas, as shown in Fig. 24(c). Similar result was found for CO$_2$ intensity, as shown in Fig. 24(d). Furthermore, both energy and CO$_2$ intensities can be more effectively reduced in natural gas vehicle of various engine ages, probably due to the already efficient diesel engine operation.
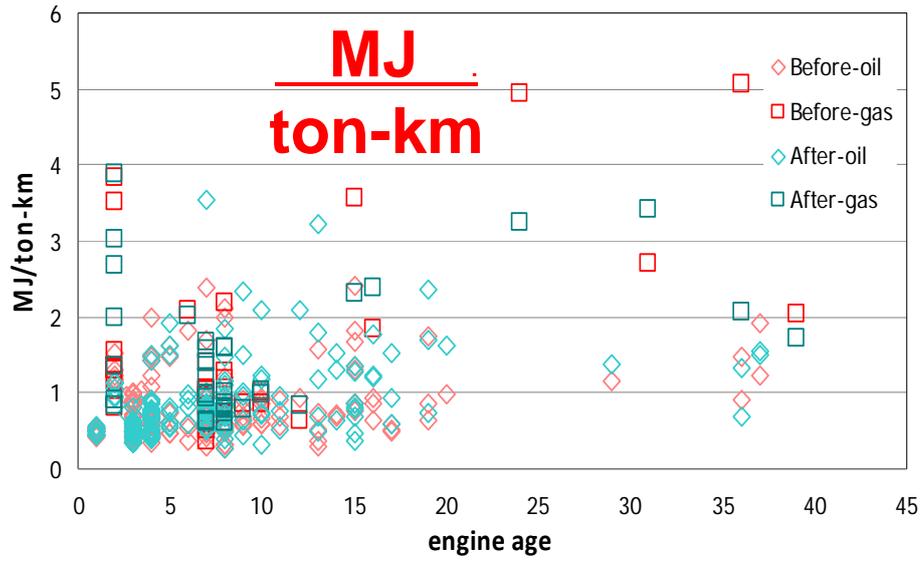
(a)
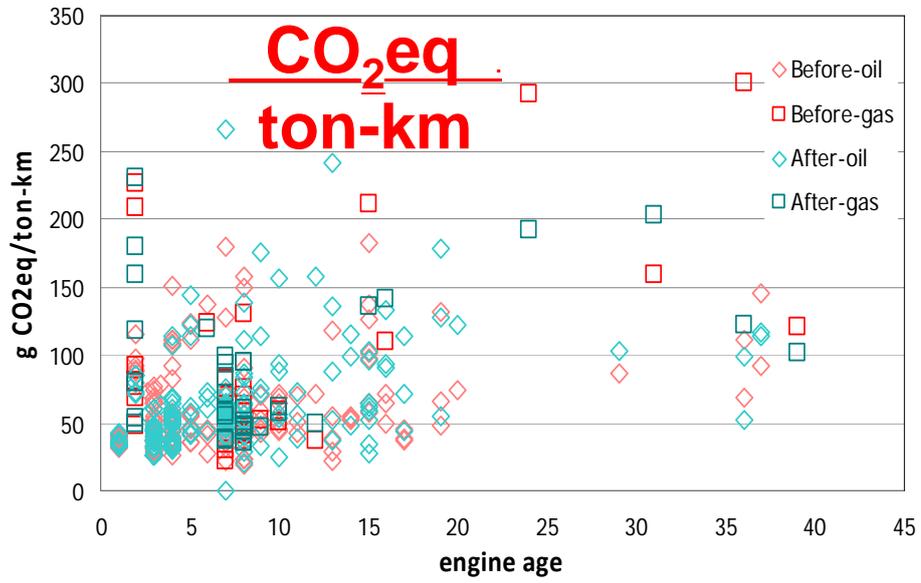
(b)
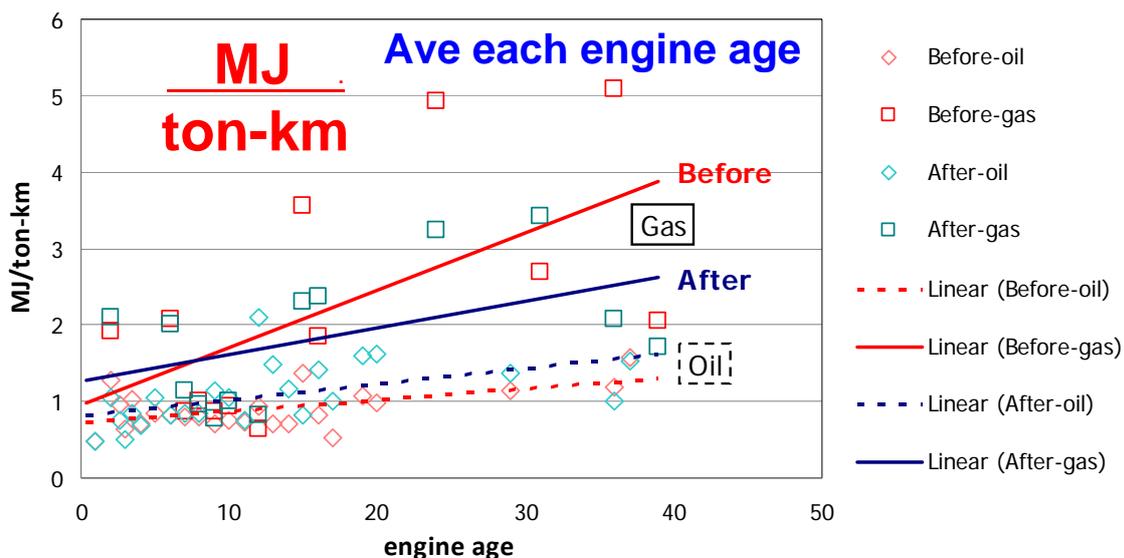
(c)
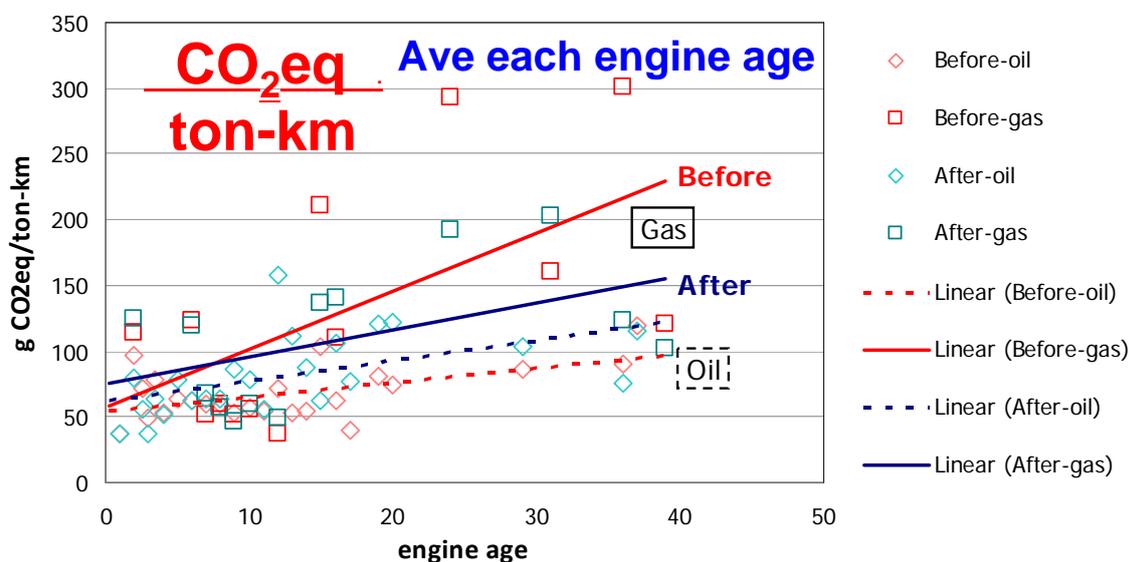
(d)

Fig. 24 Effect of engine age on (a) overall energy intensity, (b) overall CO$_2$ intensity and average (c) energy and (d) CO$_2$ intensity by engine age

To further analyze the effects of fuel (diesel oil vs natural gas) and energy-saving mechanism, Fig. 25(a)-(d) are plotted for pair-wise comparisons. For both oil and gas, Fig. 25(a) and (b) show that the data points are mixed, and clear conclusion could not be drawn unless the data points are average out like in Fig. 24. Similar behavior was found for CO2 intensity, as shown in Fig. 26.
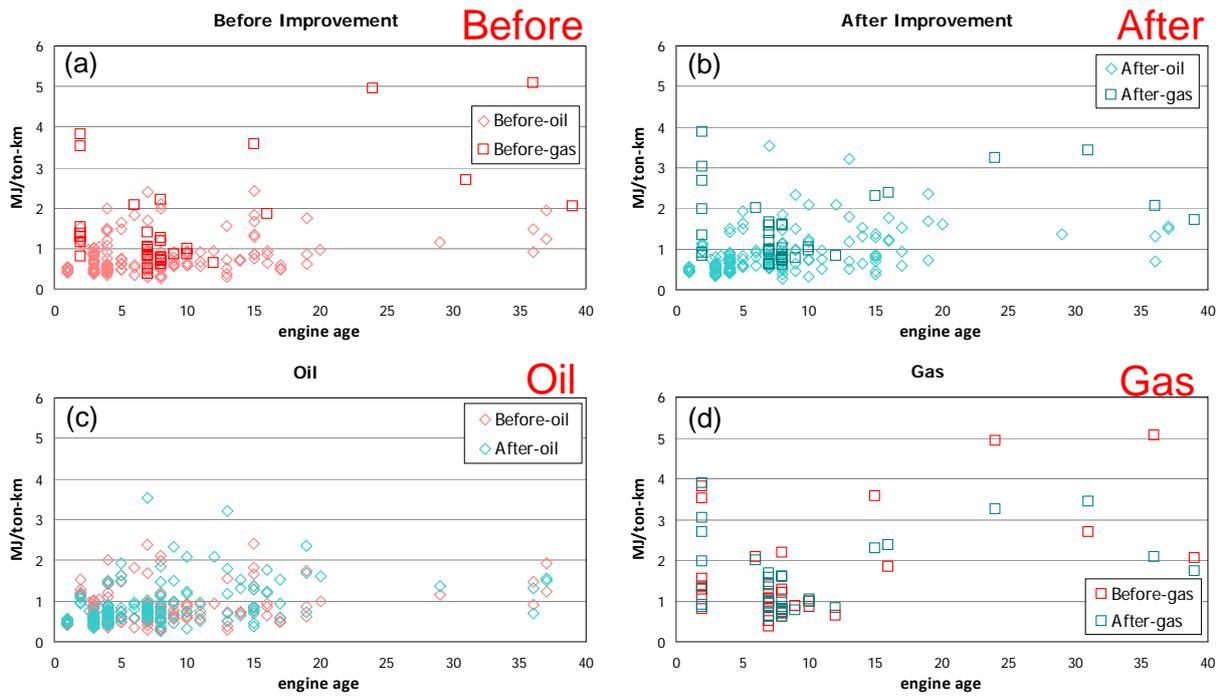
Fig. 25 Effect of engine age on energy intensity focusing on (a) oil vs gas before improvement, (b) oil vs gas after improvement, (c) oil before vs after improvement and (d) gas before vs after improvement
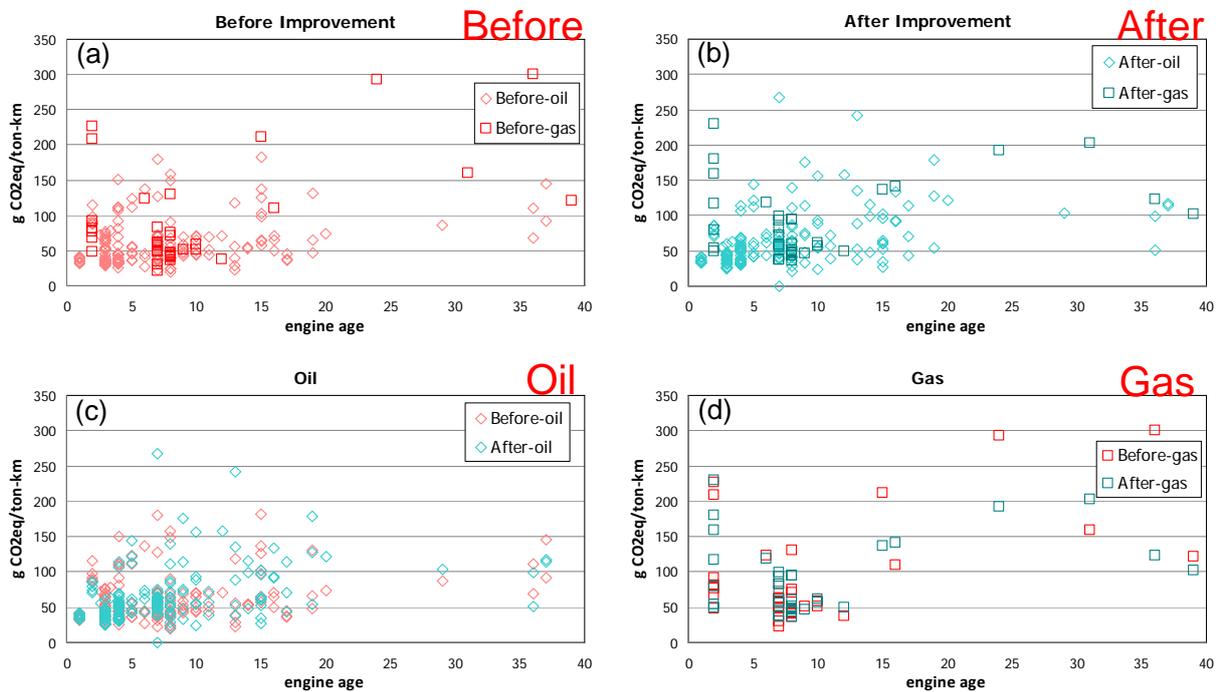

Fig. 26 Effect of engine age on CO$_2$ intensity focusing on (a) oil vs gas before improvement, (b) oil vs gas after improvement, (c) oil before vs after improvement and (d) gas before vs after improvement

However, if each case is plotted for various vehicle types in Fig. 27, the diesel vehicles in Fig. 27(a) and (b) show an envelope of higher energy intensity for vehicles with

41

older engines, depending on the engine ages and types of vehicles. Some interesting points are that 10-wheel trucks of relatively new engine (less than 5 years old) were used inefficiently with high energy intensity prior to implementation of energy-saving mechanism. For gas vehicle data in Fig. 27(c) and (d), no clear conclusion can be drawn. The corresponding CO_2 intensity in Fig. 28 shows the same behavior.
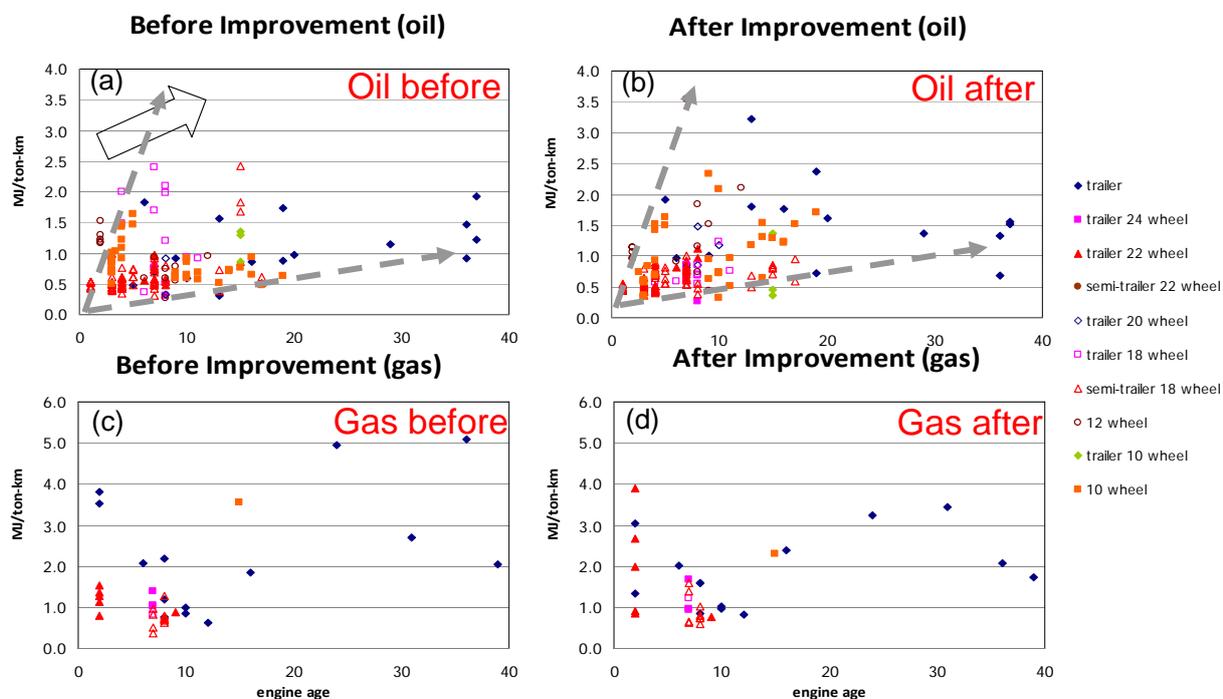

Fig. 27 Effect of engine age on energy intensity by vehicle types on (a) oil before improvement, (b) oil after improvement, (c) gas before improvement and (d) gas after improvement
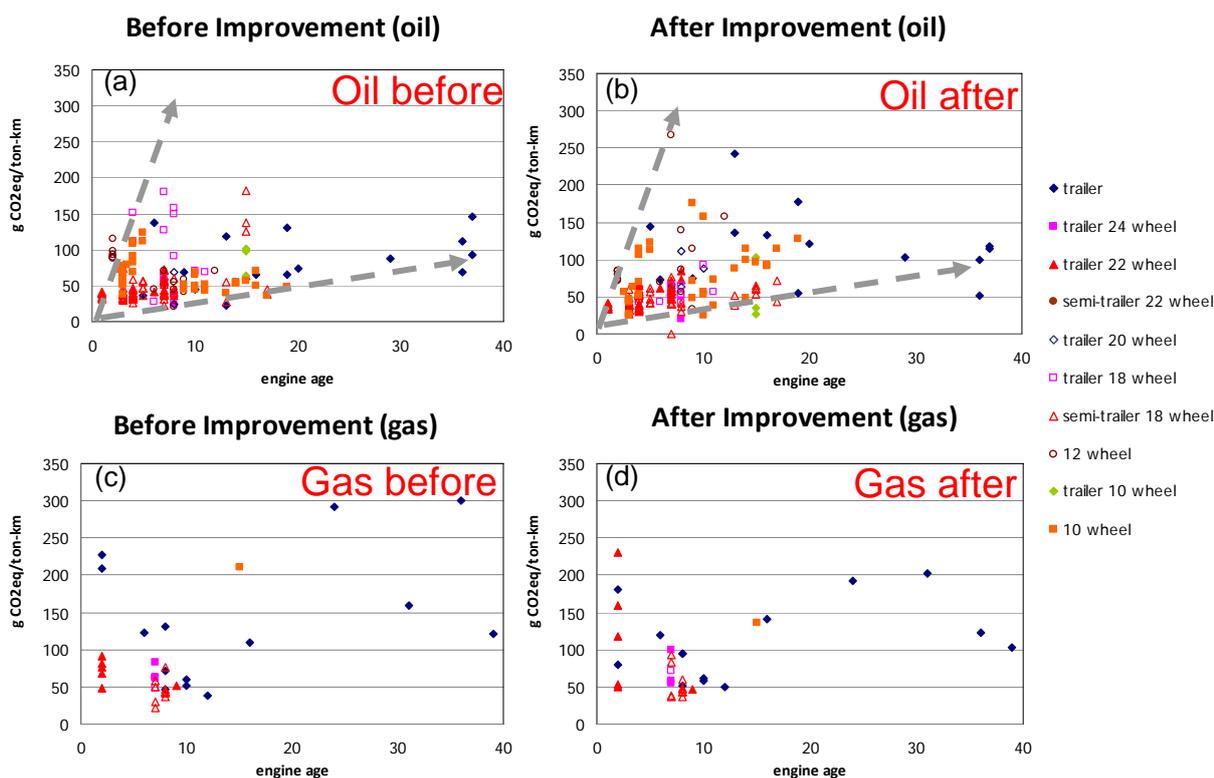
Fig. 28 Effect of engine age on CO$_2$ intensity by vehicle types on (a) oil before improvement, (b) oil after improvement, (c) gas before improvement and (d) gas after improvement

5.2.3 Effect of empty vehicle weight and total distance

Other effects of empty vehicle weight and total distance driven are shown in Fig. 29 and Fig. 30, respectively. For empty vehicle weight, Fig. 29 shows bi-modal statistic, which implies that small (7-9 tons) and large (21-22 tons) vehicles were not efficiently used in transportation of goods with rather high energy and CO$_2$ intensities. Possible reasons are mismatching of loading weight and vehicle size or mismatching of vehicle size with traffic environment. For total distance driven, Fig. 30 shows no clear trend probably because total driving distance in certain period is not a good parameter to analyze. The same total distance could contain many short trips (with typically high energy intensity) or a few long trips (with typically low energy intensity). Hence, another parameter, average driving distance, would be a more interesting parameter to analyze, which unfortunately was not collected in LTM project.
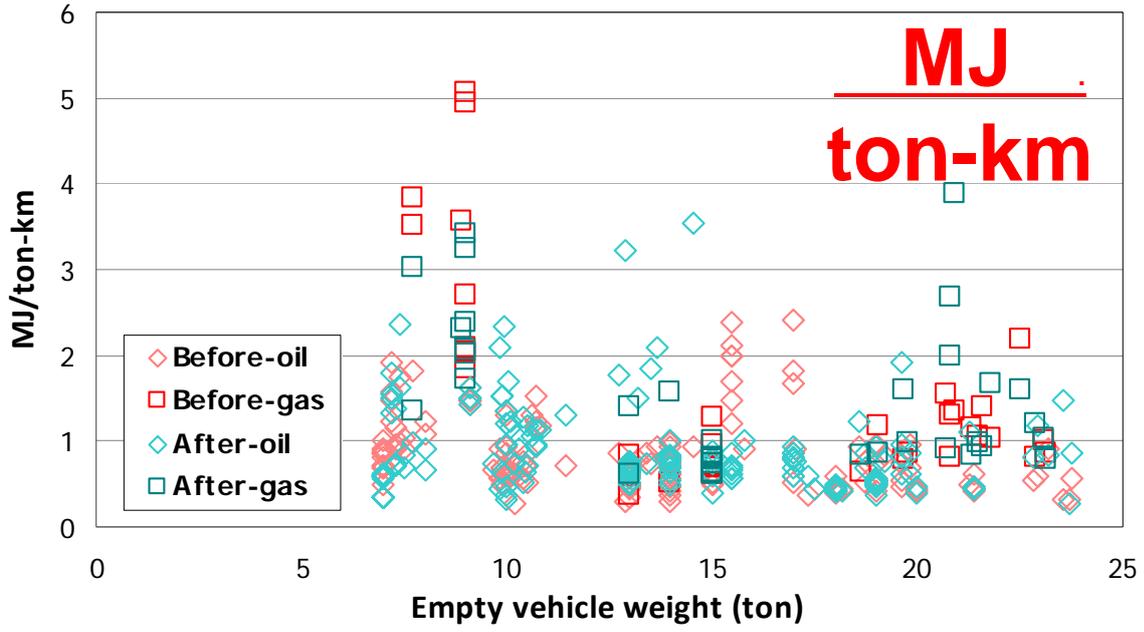
(a)
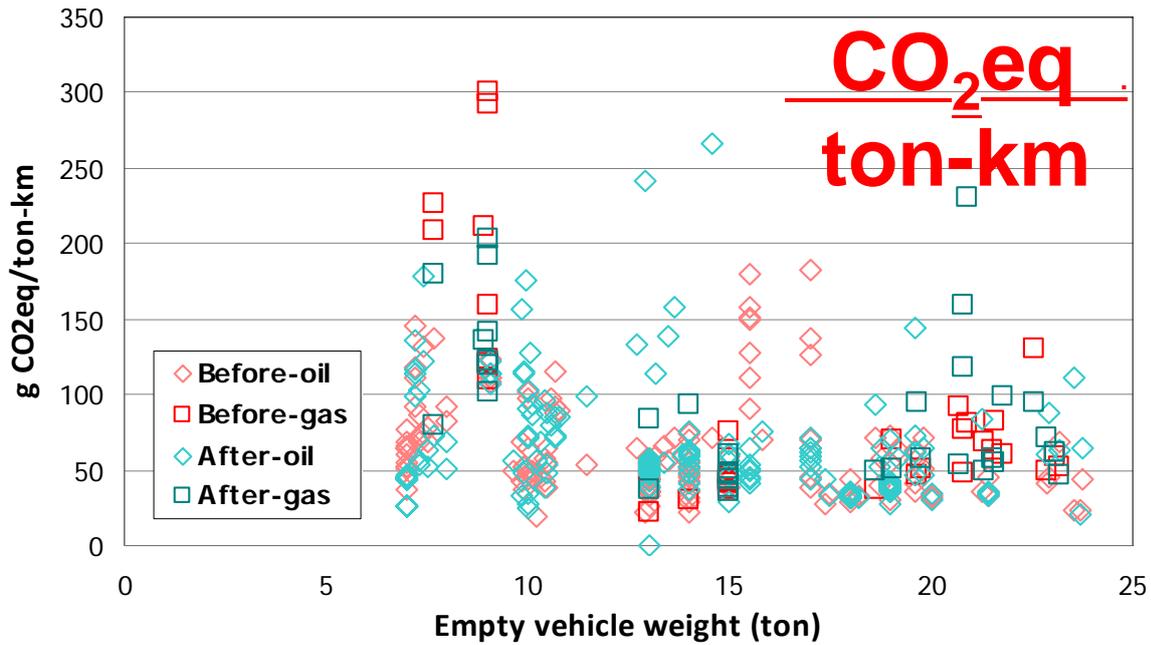
(b)

Fig. 29 Effect of empty vehicle weight on (a) overall energy intensity and (b) overall CO_2 intensity
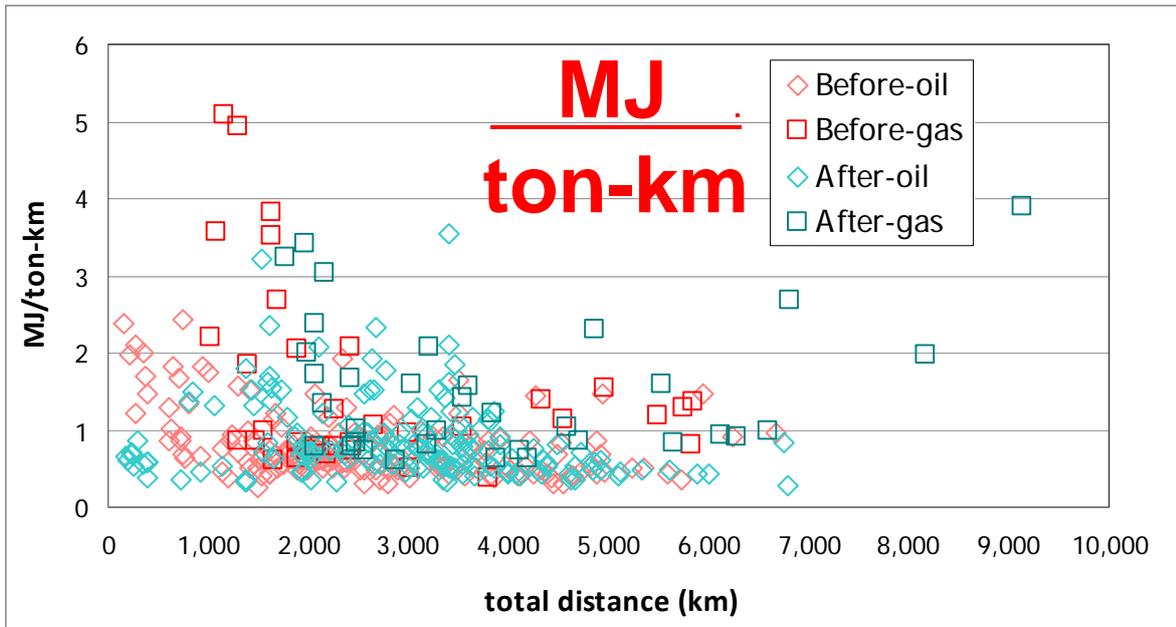
(a)
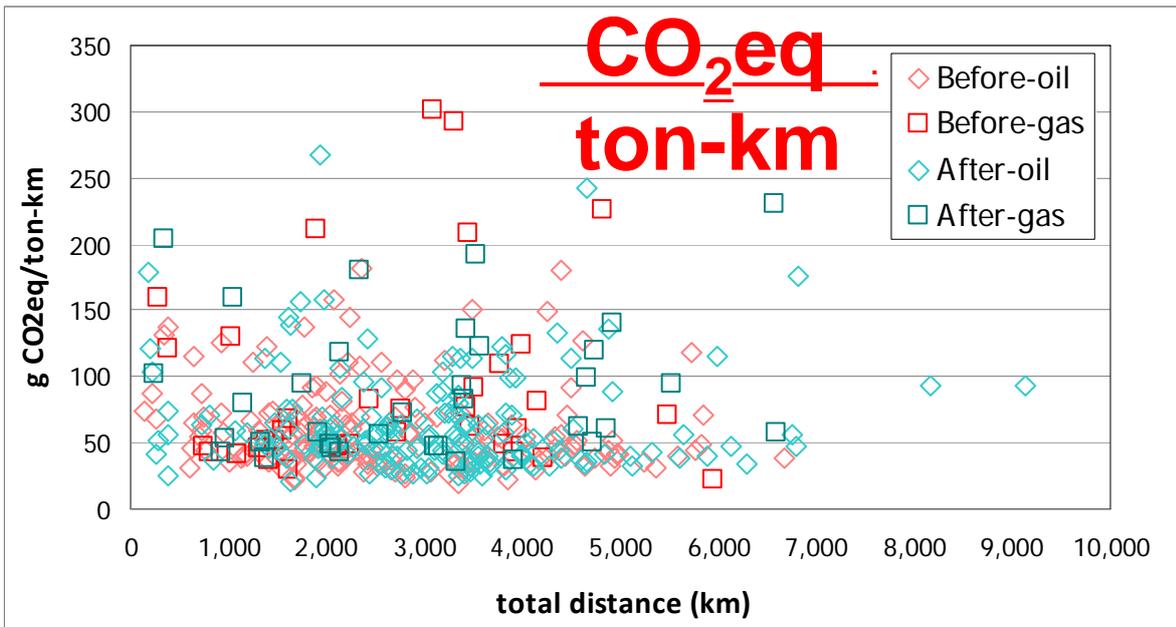
(b)

Fig. 30 Effect of total distance on (a) overall energy intensity and (b) overall CO_2 intensity

CHAPTER 6 CONCLUSION

The present study aims to assess energy and CO_2 intensities (in units of MJ/ton-km and g $CO_{2,eq}$/ton-km, respectively) of truck transport in Thailand on a case study basis. These seemingly simple parameters are not available in any Thai transport authority even though they are very crucial indicators for country logistic effectiveness, which are often used as goal and benchmark in national energy efficiency and environmental mitigation/adaptation plans.

Two analyses, namely macro and micro levels, were conducted. For macro analysis, an energy demand model has to be developed due to unavailable transportation data in Thai freight transport by trucks. A bottom-up approach LEAP program was chosen to construct energy demand model in Thai transportation sector. Numerous statistical and technical data were collected and modeled, such as number and type of vehicles, representative fuel economy, fuel sharing and vehicle kilometer of travel (VKT). With many missing data for complete energy demand model, certain reasonable assumptions needed to be made with reference to other previous works in the literature. Once the model was well calibrated with statistical energy data, the segmentation of energy used in Thai freight transport was conducted to obtain fuel/energy used by trucks. Further complication arose from the fact that 1-ton pick-up truck was commonly used in Thailand to both transport passengers and goods so this segmentation needed to be included in the freight transport. On the other hand, the economic activity data (ton-km of goods transported by trucks) was taken from Ministry of Transport annual portal data, as well as another project-based survey. Hence, a limited series of energy and CO_2 intensities data (2002-9) were obtained for further planning and comparison with other countries.

For micro analysis, a well-document database from LTM project[1] with over 200 vehicles of various types and conditions from 12 participating logistic companies operating at 0-7,000 km each was analyzed for energy and CO_2 intensities on the basis of loading weight, fuel type, fuel-saving mechanism, engine age, empty vehicle weight and total driving distance. Although the value for energy and CO_2 intensities obtained were, as expected, much lower (very efficient) than national data due to small population with no empty back haul, this micro analysis provides useful insight that lower energy/CO_2 intensities could be achieved from larger weight carried on relatively new engine running on diesel fuel. While specific fuel-saving mechanism was not discussed, the results showed energy-saving potential.

While the accuracy of the present investigation depends upon various data, some not available, the obtained results provide some baseline figures for energy intensity in Thai freight transport by truck for further use.

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[1] LTM (Logistic and Transport Management) project was funded by ENCON, Ministry of Energy

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