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CO_2 Mitigation in the Road Transport Sector in Thailand: Analysis of Energy Efficiency and Bio-energy

Nicha Sritong, Kamphol Promjiraprawat, Bundit Limmeechokchai*

Sirinhorn International Institute of Technology, Thammasat University, P.O. Box 22, Pathum Thani, 12121,Thailand

Abstract

Road transport is the major mode in the transport sector in Thailand, which accounted for about 78% of the total energy consumption in the transport sector. This study investigates the effect of two scenarios of realistic and idealistic scenarios in three actions: 1) electric vehicles, 2) fuel switching and 3) modal shift to reduce energy demand and CO_2 emission during 2010 - 2030. This study employs the Long-range Energy Alternative Planning (LEAP) model to estimate energy demand and CO_2 emission in Thai road transport sector. Energy demand in the road transport will increase from 19,221 ktoe in 2010 to 42,852 ktoe in 2030 while CO_2 emission increases from 42,852 kt-CO_2 in 2010 to 80,717 kt-CO_2 in 2030. Finally, the energy consumption and CO_2 emission in realistic scenario is reduced to 34,998 ktoe and 71,355 kt-CO_2, respectively while in idealistic scenario they are reduced to 32,116 ktoe and 62,179 kt-CO_2 in 2030, respectively.

Keywords: Bio-Energy; CO_2 Mitigation; Energy Efficiency; LEAP Model; Road Transport

1. Introduction

In Thailand, number of vehicles has dramatically increased by approximately 26% from 2005 - 2010 [1]. Substantial amount of oil is required to satisfy the rapid increment of vehicles in the transport sector.

* Corresponding author. Tel.: +66 2 986 9009; fax: +66 2 986 9112.
E-mail address: bundit@siit.tu.ac.th.

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Oil plays an important role in this sector since it is needed to drive the engine and is the main energy resource responsible for the massive energy consumption and CO_2 emission. Domestic oil resources in Thailand are outnumbered to satisfy the need of all usage. Therefore petroleum imported from overseas accounted for 65,052 ktoe in 2010 [2]. To avoid import oil dependence and due to expensive oil price, bio-fuels have been introduced by blended products of gasoline with ethanol and diesel with bio-oil. Currently, gasoline is blended with ethanol by 10% (gasohol E10), 20% (gasohol E20) and 85% (gasohol E85) while diesel is blended with bio-oil by 5% (B5). Apart from awareness of oil price, increment of CO_2 emission from energy sector is also a major challenge for policy maker, especially transport sector being the second highest emission sector in Thai energy sector. Various mitigation actions have been proposed to reduce the CO_2 emission. Introduction of more effective and efficient technologies has been investigated to determine its mitigation potential and other impacts such as economic and co-benefits. Modal shift from carbon intensive vehicles to public transport and non-motorized options is an attractive policy because energy consumption and CO_2 emission are able to be reduced together without any replacement of energy source [3]. Additionally, fuel switching plays an important role in reducing undesirable dependency of fuel import and high-carbon-content energy. In the case of Thailand's transportation, petroleum products blended with alternative fuel such as ethanol and bio-fuel has been paid serious attention to investigate the feasibility of blended products [4]. Development in vehicle technology has a long and successful history. Up to now, there exist various alternatives to be selected in both passenger and freight transport. Hybrid vehicle was first launched approximately in 2010 and will be an attractive candidate technology for sedan, taxi, passenger van and pick-up to provide energy efficiency improvement and CO_2 emission reduction. Electric vehicle is an interesting option to reduce oil import and fossil-fuel dependency. However, it is very difficult to investigate CO_2 emission reduction because it depends on which technology is used to generate the electricity.

In this study, analysis of energy efficiency improvement, transport modal shifts and introduction of advanced technologies are investigated to the expected CO_2 mitigation potential and energy savings. This study employed the Long-range Energy Alternatives Planning (LEAP) model developed by the Stockholm Environmental Institute (SEI) to set up different scenarios of mitigation actions [5]. The LEAP framework is disaggregated in a hierarchical tree structure containing category and technology branches. The model requires historical data at least from the base year to any of the future years. For example in Pakistan, the data from year 2000 was used in LEAP as the base year to estimate total energy demand and the vehicular emissions during 2001-2030 [6]. Researches in Thailand have also employ LEAP to project transport energy demand in Thailand and to analyze energy consumption in the transport sector under different CO_2 mitigation actions.

2. Methodology

In order to estimate the energy consumption and CO_2 emission under the business-as-usual and different transport actions, the study employs the end-use analysis called LEAP. This study can be separated into two parts where the first part is the prediction for number of vehicles in each type from 2011 to 2030 and the second part is the estimation of energy consumption and CO_2 emission.

2.1. Data collection and assumptions

Thailand road transport sector can be divided into two areas: Bangkok and Provincial areas, which are 23% and 77% [1], respectively, from the total number of vehicles in the country. Various vehicles types in the road transport sector are grouped together under passenger and freight transports. Passenger transport is a grouping of seven vehicle types; sedan, motorcycle, motor-tricycle, taxi, passenger van, bus and others, while freight transport is composed of only two vehicle types; van and pickup, and truck. Motorcycle is found with the highest proportion of use in Bangkok and provincial area, of 40% and 67%, respectively. Presently consumption of four fuel types in both areas is made up of gasoline, high speed diesel (HSD), liquefied petroleum gas (LPG) and compressed natural gas (CNG). Gasoline is furthermore used in three blended products: gasohol E10, gasohol E20 and gasohol E85, whereas diesel is used in one blended product called B5. The highest fuel consumption in the road transport sector is from gasohol E10 and diesel which accounted for 28% each from the total fuel consumption in 2010. Fig.1 shows the structure of vehicle and fuel types in Thai road transport.

Vehicle kilometer travelled (VKT) is the total distance travelled by each vehicle type in each year. Each vehicle type has different average distance travelled due to different purpose of usage in each type. In this study average distance travelled of all fuel types in the same vehicle type is assumed to be the same except in CNG. According to cheaper price of CNG, customers' main purpose of investing on the CNG vehicles is for heavier use than vehicle with other fuel types, for example, average distanced travelled of sedan is 15,000 km but with CNG it is 18,000 km of average distance travelled in each year. In addition, average distance travelled of all vehicle types is presumed to be equivalent in Bangkok and provincial areas. In Bangkok, sedan has the highest VKT of 44% while motorcycle in provincial area has the highest VKT of 37% from the total VKT in 2010.

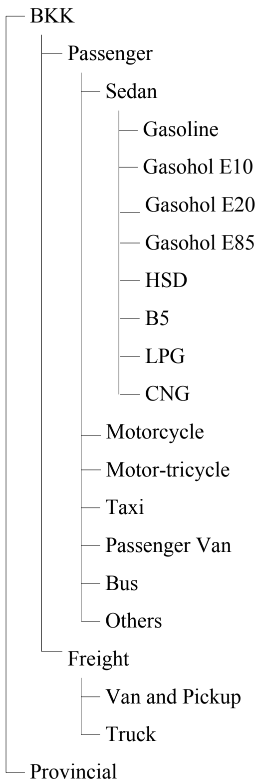

Fig. 1. Structure of vehicles and fuel types in the road transport

Assumption of same fuel economy in Bangkok and provincial used in this study is accumulated from prior researches [7-8] to meet the obtained range in Thailand. Fuel economy is the average distance travelled per certain amount of fuel type consumed by the vehicle in the unit of kilometers per litre. Table 1 provides the fuel economy for various vehicle type corresponding to the particular fuel type. From the assumptions of VKT and fuel economy, fuel consumption of different vehicle types is estimated from the division of VKT by fuel economy which shows the highest fuel consumption in van and pickup up to approximately 9 billion litres in 2010

Table 1. Fuel economy of vehicles by fuel types

Vehicle Type	Fuel economy by fuel Type (km/l)							
	Gasoline	Gasohol E10	Gasohol E20	Gasohol E85	HSD	B5	LPG	CNG
Sedan	12.0	11.7	11.5	6.0	12.8	12.4	11.2	6.6
Motorcycle	36.5	35.5	34.8	18.4	-	-	-	-
Tuk Tuk	17.3	16.9	16.5	8.7	17.4	16.9	11.3	4.4
Taxi	9.2	8.9	8.7	4.6	9.5	9.2	11.7	3.7
Passenger Van	8.8	8.6	8.4	4.4	12.3	11.9	7.5	2.6
Bus	2.2	2.2	2.1	1.1	4.4	4.3	2.0	1.0
Others	-	-	-	-	10.8	10.5	-	-
Van and Pickup	5.9	5.8	5.6	3.0	11.6	11.3	5.3	2.0
Truck	3.8	3.7	3.6	1.9	7.6	7.4	3.4	1.5

CO_2 emission is estimated from the LEAP model under the function called the Technology Environmental Database (TED) [5]. Information about the CO_2 emission factor in t-CO_2/toe is obtained from the Intergovernmental Panel on Climate Change (IPCC) [9]. However, the CO_2 emission factor is needed to be calibrated in order to indicate the actual CO_2 emission from the report "Thailand Energy Situation 2010" [2] as shown in Table 2.

Table 2. CO_2 emission factors by fuel type

Fuel Type	CO_2 Emission Factor (t-CO_2/toe)
Gasoline	2.321
Gasohol E10	2.159
Gasohol E20	2.159
Gasohol E85	0.482
HSD	2.395
B5	2.284
LPG	2.041
CNG	1.737

2.2. Scenarios description

Assumption of same fuel economy in Bangkok and provincial used in this study is accumulated from prior researches [7-8] to meet the obtained range in Thailand. Fuel economy is the average distance travelled per certain amount of fuel type consumed by the vehicle in the unit of kilometers per litre. Table

1 provides the fuel economy for various vehicle type corresponding to the particular fuel type. From the assumptions of VKT and fuel economy, fuel consumption of different vehicle types is estimated from the division of VKT by fuel economy which shows the highest fuel consumption in van and pickup up to approximately 9 billion litres in 2010

Business -as-usual scenario

The BAU scenario acts as the case that helps estimate and study the exact amount of mitigation that may be attained from the various scenarios in the study. This scenario can be expressed as a frozen efficiency where no new technology is implemented and no energy efficiency increase from 2010 - 2030.

Number of vehicles is forecast by the linear regression function by using historical data of GDP, from the national income of Thailand [10], and the annual population in Thailand, from the Department of Local Administration, Ministry of Interior (DOPA) [11], as independent variables for all vehicle types. The coefficients of the linear regression model for each vehicle type are reported as shown in Table 3.

Table 3. Linear regression model for road transport

Vehicle type	Number of vehicle	R^2
Sedan	-22,087,234+0.37POP+109.42GDP	0.94
Motorcycle	-101,330,452+1.87POP-50.40GDP	0.98
Motor-Tricycle	-0.43GDP	0.99
Taxi	-416,526+0.007POP+1.10GDP	0.93
Passenger Van	0.005POP+1.08GDP	0.99
Bus	-200,817+0.005POP+0.24GDP	0.97
Others	0.001POP+5.69GDP	0.97
Van and Pickup	-25,347,563+0.44POP+72.20GDP	0.97
Truck	-2,934,325+0.05POP+4.74GDP	0.98

Modal shift action

Modal shift action in the transport sector is the replacement of transportation mode from private vehicle to public vehicle or from motorized vehicle to non-motorized vehicle to a more sustainable and efficient transport. In this study three specific actions are implemented in Bangkok and provincial areas: 1) replacement of sedans by buses, 2) replacement of motorcycles by walking and 3) replacement of buses by bicycles.

In the first action, due to modifying number of vehicle from one mode to the other, passenger per vehicle is taken into consideration to find the number of bus to replace the reduced number of sedans in the action. In the realistic scenario modal share of sedans gradually decreases to 10% by 2030 while the modal share of sedans drops to 30% by 2030 in the idealistic scenario. Modal shift from motorized to non-motorized, is the share reduction of motorcycle and bus to non-energy modes such as walking and cycling from 2010-2030 until it reaches 10% in the realistic scenario and 30% in the idealistic scenario.

Fuel switching action

Due to high oil dependency and oil price in Thailand, clean fuel such as CNG and currently used blended product (gasohol E10, gasohol E20, gasohol E85 and B5) are pushed forward into action together with new blended products (B10 and B20) being introduced into the road transport sector. Furthermore, fuel switching is able to provide CO_2 mitigation since CNG and all blended products have lesser CO_2 emission factor than fuel type currently being used as shown in Table 2.

In this study the fuel switching is dealt in both Bangkok and provincial areas concerning all vehicle types where in the realistic scenario the share of cleaner fuel will be replaced with approximately 10% and eventual replacement of approximately 30% in the idealistic scenario by 2030.

Advanced technology action

In this scenario, new technologies are introduced to replace conventional vehicles to reduce energy demand and CO_2 emissions. This study implemented three new vehicle types to Bangkok and provincial areas including hybrid vehicles, plug-in hybrid vehicles and electric vehicles (EVs). They are focused to replace sedans, motorcycles, taxis, passenger vans, and pickups for cleaner technology by reducing energy demand and CO_2 emissions.

Introduction of new technologies takes slower time than pushing forward the existing technology. Table 4 shows the amount of hybrid vehicles, plug-in hybrid vehicles and EVs implemented in each action. Since hybrid is the first technology to be introduced so in the realistic scenario, hybrid vehicle is implemented with the highest share while EV is implemented with the least share because of its high expense.

Table 4. Advanced technology implemented in each action

Vehicle Type	Realistic Scenario			Idealistic Scenario		
	Hybrid	Plug-in Hybrid	EV	Hybrid	Plug-in Hybrid	EV
Sedan	15%	2%	2%	21%	8%	8%
Motorcycle	-	-	6%	-	-	14%
Taxi	8%	4%	4%	15%	7%	7%
Passenger Van	3%	-	-	5%	-	-
Van and Pickup	7%	-	-	18%	-	-

3. Result

Results of the number of vehicles forecast from 2011-2030 are forecast by the linear regression technique. Furthermore, result of energy consumption and CO_2 emission from the BAU scenarios and two scenarios with three mitigation actions are estimated through the end use LEAP model.

Table 5 presents the results obtained from the linear regression model as mentioned in the previous section. Most of vehicle types are predicted to increase due to population and economic growth, except that motor-tricycles would decrease down to 14 thousand by the year 2030 due to inconvenience of travel and lack of renewal implementation. Passenger demand of sedans would see the highest growth and pick-up would be employed as the main vehicle for freight transport. It is noted that number of motorcycles in 2030 will be tripled when compared to sedans. However, number of vehicles is not the only one factor to indicate quantity of energy consumption and the corresponding CO_2 emission, but also fuel economy and average distance travel of specific technology are important factors in the model estimation.

Table 5. The number of vehicle stocks in Thailand by vehicle type

Vehicle Type	No. of Vehicle (1,000 units)				
	2010	2015	2020	2025	2030
Sedan	4,497	5,501	6,841	8,311	9,956
Motorcycle	17,300	19,813	22,630	25,474	28,328
Motor-tricycle	23	21	19	17	14
Taxi	104	121	141	162	186
Passenger Van	392	405	422	440	460
Bus	138	147	157	168	179
Van and Pickup	4,895	5,975	7,195	8,511	9,950
Truck	817	927	1,054	1,187	1,331
Others	320	287	328	374	428
Total	28,485	33,198	38,786	44,644	50,832

As shown in Fig.2, Thailand's road transport would require up to 36,077 ktoe of various energy sources by the year 2030 in the BAU scenario. From all the proposed actions as mentioned in the previous section, the energy demand would be reduced by 3% in the realistic scenario compared to that of the BAU scenario in 2030. Moreover, the reduction would be achieved by 11% when intensive countermeasures are implemented in the idealistic scenario in 2030. It can be seen that more energy savings can be obtained at the end of the planning period since all countermeasures require a long period of time to be introduced to the transport system and also requires more time to remove the traditional inefficient technologies. In realistic scenario, action with the highest energy saving of 1,076 ktoe is resulted from the modal shift action followed by the energy saving of 689 ktoe from the advanced technology action in 2030. Additionally, results from modal shift action have also been observed with the highest energy saving accounted for 3% followed by the advanced technology with 2% reduction in 2030. Moreover, modal shift action is also remark to have the highest energy saving in the idealistic scenario.

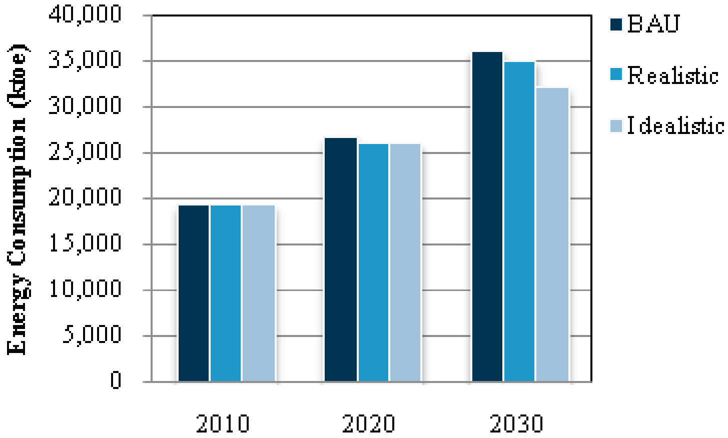

Fig. 2. Comparative energy consumption in all the mitigation actions.

In the BAU scenario, the CO_2 emission in Thai road transportation would increase from 42,852 kt-CO_2 in 2010 to 80,717 kt-CO_2 in 2030 due to deployment of technology mix in the base year 2010. Fig.3 shows mitigation potentials of all proposed actions in both mitigation scenarios. In general CO_2 mitigation is correlated to the energy savings. However in this case, the countermeasures involved implementation of fuel switching that provide alternative fuel with low emission content but degrade fuel economy of vehicle performance. Therefore, during 2020-2030 different proportion of reduction in energy savings and CO_2 emission are illustrated in Fig.1 and Fig. 2.

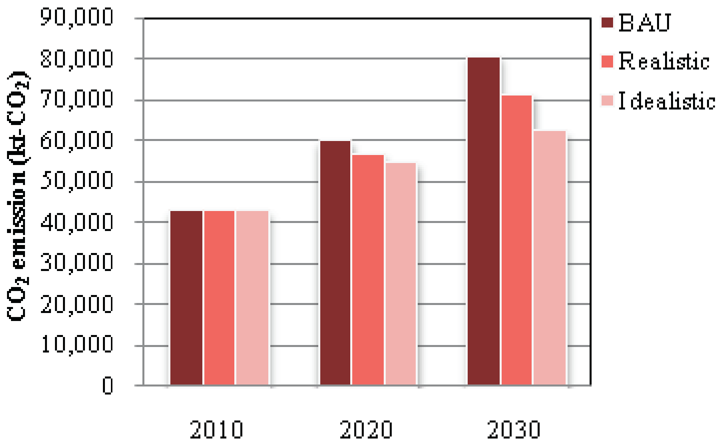

Fig. 3. Comparative CO_2 emission in all the mitigation actions.

As shown in Fig. 4, reduction of total CO_2 emission in the modal shift drops by 3% in the realistic scenario and 95% in the idealistic scenario by 2030. In all modal shift actions, replacement of sedan to bus exhibit the greatest potential for CO_2 mitigation which contributes to 1,068 kt-CO_2 and 3,669 kt-CO_2 of total reduction by 2030 in the realistic and idealistic scenarios, respectively. Motorized to non-motorized vehicles actions such as modal shift of motorcycles and buses to walking and cycling can also reduce CO_2 emission. However, motorcycles and buses require less energy than sedans. Therefore, policy implication on minor technology would provide a small share of CO_2 emission reduction. In comparison in this study, private to public transportation is more efficient and effective than motorized to non-motorized transportation.

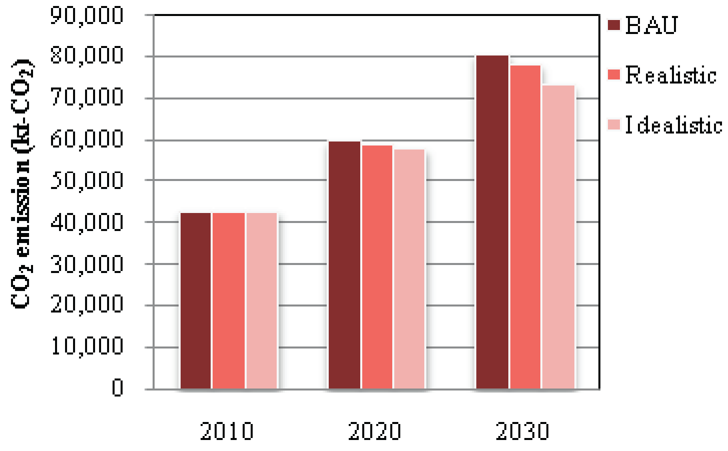

Fig. 4. Comparative CO_2 emission in the modal shift action.

In Thailand, fuel mix in the road transport is dominated by high-content carbon fuel such as diesel and gasoline. In the idealistic scenario, introduction of blended products to replace the requirement of pure gasoline and diesel would contribute to substantial CO_2 emission of 77,367 kt-CO_2 by the year 2030, as shown in Fig. 5. Fuel switching would not provide energy saving due to degrading combustion efficiency in most vehicles. However, emission reduction is still obtained because reasonable efficiency of blended products provides a suitable fuel for road transportation with low CO_2 emissions. On the other hand, the emission in realistic scenario would not be reduced as much as the realistic scenario because most vehicles would consume fossil fuel to avoid rapid change in fuel price infrastructure.

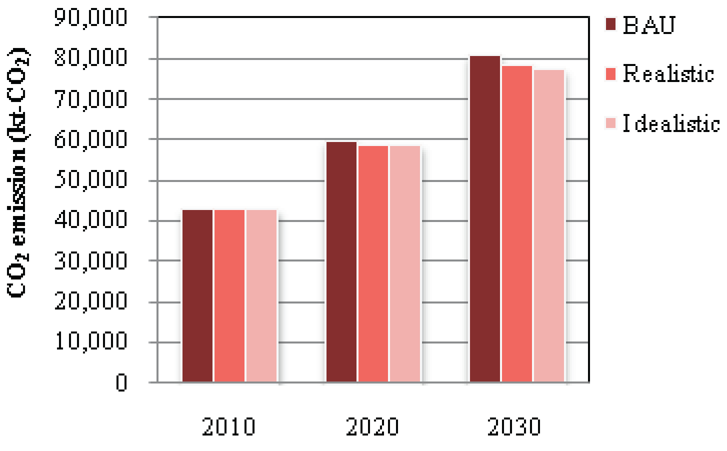

Fig. 5. Comparative CO_2 emission in the fuel switching action.

Introduction of advanced technologies including hybrid vehicles, plug-in hybrid vehicles and EVs are to improve overall energy efficiency in the road transportation. The CO_2 reductions are 4,838 kt-CO_2 and 7,894 kt-CO_2 in realistic and idealistic scenario, respectively in 2030. Fig.6 shows the decreased CO_2

emissions in the three technologies compared to the BAU scenario. Due to adaptation time of new technologies, CO_2 reduction in realistic scenario is accounted to only be 2% while in the idealistic scenario, CO_2 reduction is accounted to be 4%. In this study hybrid vehicle has the greatest potential to reduce the CO_2 emission to 4,313 kt-CO_2 in 2030, since hybrid vehicle is the first technology to be implemented into Thai road transport.

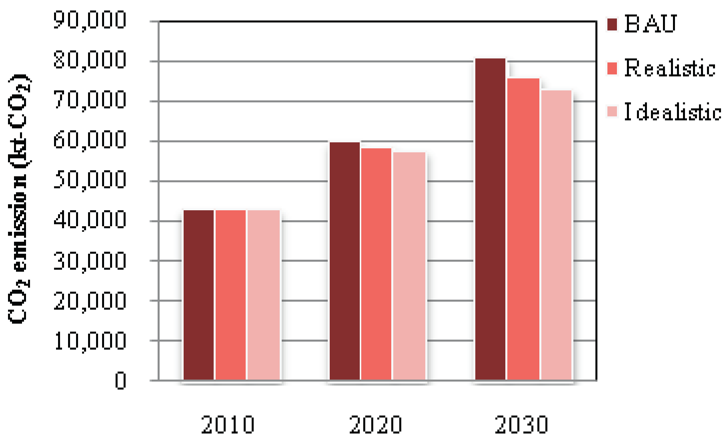

Fig. 6. Comparative CO_2 emission in the advanced technology action

Table 6 shows the cumulative CO_2 mitigation from 2010-2030 from each mitigation action proposed in this study. In this study, the total different cumulative CO_2 mitigation of the realistic and idealistic scenario is approximately 45%.

Table 6. Cumulative CO_2 mitigation in each mitigation action

Mitigation Actions	Realistic	Idealistic
Modal Shift (kt-CO_2)	25,371.6	67,030.3
Fuel Switching (kt-CO_2)	19,050.1	27,294.2
Advanced Technology (kt-CO_2)	36,045.5	62,080.0

4. Conclusion

Transport sector is the second highest sector to consume energy and is also contributes to a large amount of CO_2 emissions. The main objective of this research study is to analyze three mitigation actions and to estimate future number of vehicles, energy consumption and CO_2 emission in 2030. Each action is computed under two scenarios: realistic and idealistic scenarios, to estimate for the energy savings and CO_2 emission reduction that are likely to occur in the upcoming years and the extreme reduction under three mitigation actions. The three actions proposed in the study are modal shift, fuel switching and advanced technology. Modal shift action is mainly the replacement of private and motorized vehicles with public and non-motorized vehicles, while fuel switching is to encourage people to use more efficient fuel with low CO_2 emission factor. Lastly, the advanced technology action implemented new and more efficient potential vehicles to the transport system in Thailand which are hybrid vehicle, plug-in hybrid vehicle and EV.

The result in the transport sector shows that the highest energy saving action is achieved in the modal shift action followed by advanced technologies action and lastly in the fuel switching action. However, in terms of CO_2 mitigation, the highest CO_2 reduction action is the advanced technology action followed by modal shift action and fuel switching action. In realistic scenario, the percentage reduction is 6% in advanced technology, 3.0% in modal shift action and 2.6% in fuel switching action. Moreover, the percentage reduction in idealistic scenario is 9.8% in advanced technology action, 9.0% in modal shift action and 4.2% in fuel switching action. The energy consumption in the BAU scenario in Thai road transport will increase from 19,221 ktoe in 2010 to 36,077 ktoe in 2030. The corresponding CO_2 emission will increase from 42,853 kt-CO_2 in 2010 to 80,717 kt-CO_2 in 2030. The total energy consumption and the CO_2 emission of this study in 2030 are reduced by 1,079 ktoe and 9,362 kt-CO_2 in 2030 for realistic scenario. Of all mitigation proposed in the study, modal shift action is estimated to best action for energy consumption and CO_2 emission reduction.

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References

[1]Department of Land Transport, Number of Vehicle Registered in Thailand. Available at: http://apps.dlt.go.th/statistics_web/vehicle.html [accessed 25.04.2010]

[2] Department of Alternative Energy Department and Efficiency (DEDE), Thailand Energy Situation 2010, Ministry of energy, 2010

[3] Winyuchakrit P., Limmeechokchai B., Matsuoka Y., Gomi K., Kainuma M., Fujino J., Suda M.; *Thailand's low-carbon scenario 2030: Analyses of demand side CO_2 mitigation options*. Energy for Sustainable Development, Vol. 15, 2011, pp. 460-466.

[4] Pongthanaisawan J., Sorapipatana C.; *Greenhouse gas emissions from Thailand's transport sector: Trends and mitigation options*. Applied Energy, Vol. 101, 2011, pp. 288-298.

[5]Community for energy, environment and development, tools for sustainable energy analysis. Available at: http://www.energycommunity.org/default.asp?action=47 [accessed 21.08.2011].

[6] Shabbir R., Ahmad S.; Monitoring urban transport air pollutant and energy demand in Rawalpindi and Islamaban using LEAP model energy, Energy, Vol. 30, No. 3, 1996, pp. 403-412.

[7] Department of Alternative Energy Department and Efficiency (DEDE), Thailand Energy Situation 2010, Ministry of energy, 2010.

[8] Tanavatvanit S., Limmeechokchai B., Chungpaibulpatana S.; *Sustainable energy development strategies: implications of energy demand management and renewable energy in Thailand*. Renewable and sustainable energy reviews, Vol. 7, No. 5, 2003, pp. 367-395.

[9] Intergovernmental Panel on Climate Change, fuel emission factor. Available at: http://www.ipcc.ch/ [accessed 10.08.2011]

[10]National Income of Thailand. Chain volume measures 1990-2010 edition. Available at http://www.nesdb.go.th/Default.aspx?tabid=94 [accessed 12.05.2011]

[11] Department of Provincial Administration, ministry of interior. Available at http://www.dopa.go.th/ [accessed 2.05.2011]