



## Economy-wide Impacts of Policy on Promotion of Electric Motorcycles in Thailand

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### **Abstract**

The economy-wide impacts of promotion on substitution of electric motorcycle for gasoline motorcycle were assessed in terms on total primary energy supply (TPES), CO<sub>2</sub> emission, and employments. Influences of the measure on the inter-industry relationship in Thai economy through 2011-2030 were evaluated by Input-output (I-O) analysis according to the structural change in Thai economy. Embodied energy intensities of 180 commodities produced from 2011 - 2030 were derived from 2005 I-O table and 2000 energy I-O table. In the business-as-usual (BAU) case, the I-O data are annually updated by the changes in the power sector corresponding to 2010 Thailand's power development plan (PDP 2010). By adoption of promotion on electric motorcycles of 60% replacement in the gasoline ones in 2030, fuel mix effect, structural effect, and final demand effect were presented in this study. As a result, the promotion was expected in positive economy-wide impacts in energy and CO<sub>2</sub> emissions. The TPES under the program of electric motorcycle was found to be 6.9% less than the BAU. In 2030, the total CO<sub>2</sub> emissions would also be 0.38% less than the BAU. However, the household income would be 0.03% less than the BAU.

**Keywords:** Input-output analysis, Economy-wide impacts, Electric motorcycle, Total primary energy supply, GHG emissions.

### **1. Introduction**

Regarding to increasing in final energy consumption in Thailand, the 20-year energy conservation plan between 2011 and 2030 studied by the Joint Graduated School of Energy and Environment (JGSEE-KMUTT) was adopted by Energy Policy and Planning Office (EPPO),

Ministry of Energy. The plan included policies on energy conservation and energy efficiency in transportation, industries, commercial buildings, and households [1]. Increasing fuel economy by substitution of electric motorcycle for gasoline motorcycle is a measure as described in the energy conservation plan. [1]



Electric motorcycle is a motor-driven vehicle which is preferable in its silent and zero emission when running on the road. In a comparative energy efficiency aspect, the fuel economy is seemed to be higher than the conventional gasoline one. On the other hand, since electricity is generated upstream and combustions were incurred by other upstream energy sources, i.e. natural gas, coal and fuel oil in the grid-connected power plants and related emissions were definitely emitted indirectly outside the road. The emission is believable relocated and energy efficiency transformation should be considered totally within the country boundary.

In a view of comparable data provided to the country energy planning, Input-output (I-O) analysis is a suitable methodology that can depict embodied energy and CO<sub>2</sub> emission directly and indirectly. Induced activities incurred inside the economy could be totally taken into accounted in various aspects i.e. fuel mix effect, economic structural effect, import effect, and final demand effect.

Economy-wide impacts were measured in a comparative manner, including total primary energy supply (TPES), household wage, and CO<sub>2</sub> emissions, between the economies without and with proposed electric motorcycle instead of purchasing a new conventional motorcycle. Since I-O table and energy I-O data are conventionally not static and during the past decade, evolution on Thai economy was found to be dynamic particularly on the energy structure in electricity generation.

The current 2010 Power Development Plan (PDP2010) was considered in this study as a

business-as-usual economy where the expected economy with the electric motorcycle could be compared by the I-O model. According to the PDP2010, the trends of the Gross Domestic Product (GDP) were projected in the I-O model. Fuel mix in the power sector was adjusted accordingly.

## 2. Methodology

### 2.1 Input-Output Analysis

Input-Output Analysis (IOA) is an economic tool introduced by Wassily Loentief that can explain economic, energy, and environmental relationships within a considered economy. The I-O model could depict inter-industrial relationships, including service sector, household, and final consumers, under a single activity change within the economy. A beneficial aspect of the I-O model is that it assumes energy and resource flows among industries transferred in direct proportion to their monetary value and it could provide a tabulating energy consumption and environmental burdens throughout the inter-industrial links. When the intensities are provided, the evaluation will be not only direct burdens associated with economic activity, but also induced burdens that come along with circulation of resources and wastes throughout the economy. [2]

In an I-O table, total requirement of the  $i$ 's product from the economy is a summation of input quantity requirements ( $X_i$ ) of  $i$  for intermediate sector and final quantity consumption for consumer ( $y_i$ ) as: [3]

$$X_i = x_{i1} + x_{i2} + \dots + x_{in} + y_i \quad (1)$$

Economy-wide total requirement in the based year is the total production of the country

including import quantity ( $M$ ) from nation boundary which can be written in vector form as: [3]

$$X = [I - A - M]^{-1} Y \quad (2)$$

Total energy input ( $F$ ) can be applied to economy-wide total energy requirement in the base year ( $EI$ ) as: [3]

$$EI = F[I - A - M]^{-1} Y \quad (3)$$

The consequence emission from total energy consumption in economy is [2]

$$EF = \mathcal{E}F[I - A - M]^{-1} Y \quad (4)$$

Where  $\mathcal{E}$  could be provided as a vector of CO<sub>2</sub> emission that considers emissions from every single step of fuel combustion in the element of matrix  $F$ . For emission factors, the IPCC 2006 Guideline [4] was used in this study.

## 2.2 Revised Input-Output Tables

Due to energy and economy evolution in the real situation, the economy and energy I-O data are not static. The I-O tables of 2005 [5] and energy I-O data of 2000 [6] were used as the base year for representing the economic structure and individual sectoral energy consumption. The economy-wide total requirement was linearly extended through the studied period by adjusting the final consumption  $y_n$  corresponding to GDP that are forecasted in Thailand PDP2010 [7]. Economy-wide total requirement of year  $n$  then can be written as:

$$X_n = [I - A - M]^{-1} Y_n \quad (5)$$

Since electricity is significant in embedded energy consumption and CO<sub>2</sub> emission throughout the economy [8] and its fuel mix has been changed apparently seen in Fig.1, the energy input data  $F$  of the power sector were adjusted from the energy input data of 2000 throughout the studied period. Fuel-mix updating factors referring to the share of electricity generation sources were used in the study. Fuel-mix updating factor,  $M_{f,k}$  used for structural change is: [9]

$$f_{k,n} = \frac{SH_{k,n}}{SH_{k,b}} \cdot \frac{\eta_{k,avg,n}}{\eta_{k,avg,b}} \cdot \frac{P_n}{P_b} \cdot \frac{\eta_{gen,n}}{\eta_{gen,b}} \cdot \frac{1 - TD_{l,n}}{1 - TD_{l,b}} \cdot \frac{1 - U_n}{1 - U_b} \quad (6)$$

The factor taken into account percentage of share of electricity generation by each fuel type ( $SH$ ), the average country electricity generation efficiency ( $\eta_{avg}$ ), electricity price ( $P$ ), total country electricity generation efficiency ( $\eta_{gen}$ ) transmission and distribution loss ( $TD$ ), and self-used electricity ( $U$ ) between considered year and the base year. Each type of fuel  $k$  consumed in the power sector in the base year ( $b$ ) was updated to represent as the  $f_{k,n}$  in year  $n$  by multiplying  $f_{k,b}$  in the base year with the factor  $M_{f,k}$ .

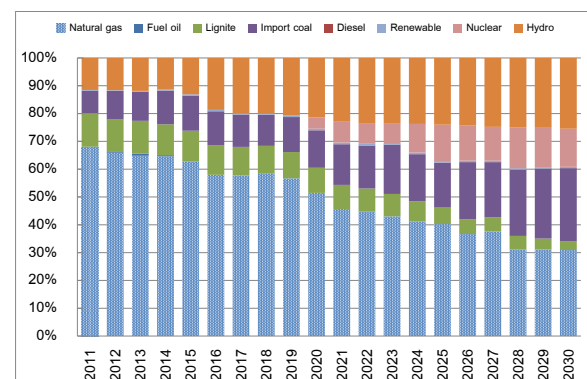


Fig. 1 Electricity generation by fuel sources.

### 2.3 Effects of New Final Demand

The promotion on substitution of electric motorcycle for gasoline motorcycle does not change in economy structure but it changes final demand of consumer taken by  $\Delta Y$ . This makes change in economy-wide total energy requirement as:

$$\Delta EI = F[I - A - M]^{-1} \Delta Y \quad (7)$$

This includes an increase of direct energy demand in the final consumers and increase of indirect energy demand in intermediate sectors within the economy. The annual amount of total CO<sub>2</sub> emissions affected by a new final demand vector is

$$\Delta EF = \mathcal{E}F[I - A - M]^{-1} \Delta Y \quad (8)$$

Which includes direct emissions from combustions in final consumption and indirect emissions induced by increasing activities in upstream processed, by the increase in final demand.

## 3. Assumptions in Analysis

### 3.1 Number of Motorcycles

When the promotion on electric motorcycle was implemented, the new gasoline motorcycle would be penetrated by electric motorcycle in an increasing rate. Fig. 2 presents annual number of new motorcycles in the country during 2011 to 2030. It is assumed to annually increase by the rise of earning incomes with the population growth [10]. This number will increase from 2.14 million in 2010 to 5.47 million in 2030. The promotion of new motorcycle would be implemented by substitution of new motorcycles with electric

ones for 60% in 2030. Existing motorcycles have to be served on road until end of lifetime, therefore related assumption made is that estimated lifetime of motorcycles was five years until replacement by new motorcycle. Therefore, impacts in five-year accumulated number of motorcycle are considered in this study.

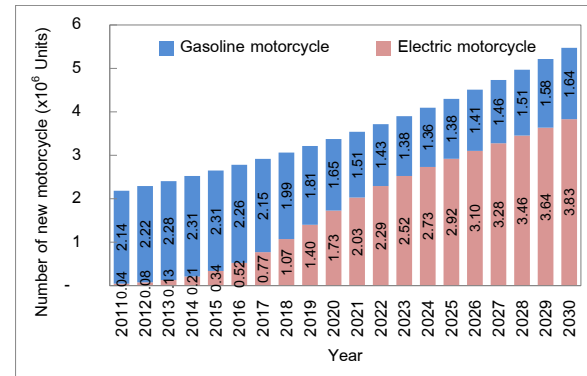


Fig. 2 Number of new motorcycles

### 3.2 Fuel Economy

Due to different fuel economy in the penetration of on-road electric motorcycle, related assumptions used in this study are presented in Table 1. Energy economy of electric motorcycle is assumed to be approximately 30% of energy usage in gasoline motorcycle [1]. The annual distance of travel in Nakornratchasima and Bangkok were 5,662 and 4,015 kilometers [11], so the average distance was assumed to be 4,372 kilometers. The direct impacts on the energy consumption and CO<sub>2</sub> emission were estimated as shown in Fig. 3 and Fig. 4, respectively. Information received for evaluation was that the electric motorcycle has fuel economy beyond the conventional one, therefore, low energy consumption and low CO<sub>2</sub> emission were found at the apparent direct aspects.

Table 1 Fuel economy of motorcycles

Type of motorcycles	Fuel economy	
	per unit	MJ/100 km
Gasoline motorcycle	28.74 km/litre <sup>a</sup>	109.5
Electric motorcycle	9.96 km/kWh	36.1

Note: <sup>a</sup> Data from [12]

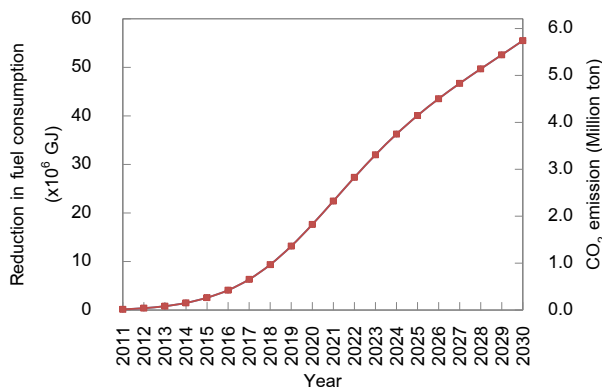


Fig. 3 Direct reduction in energy consumption and CO<sub>2</sub> emission of the promotion

### 3.3 Prices of Gasoline and Electricity

Through the studied period, gasoline and electricity prices were not treated in a constant manner, but predicted by linear least square regression. Average prices of 2007 to 2010 and of 1998 to 2009 are used to estimate future prices of gasoline and electricity during 2011 to 2030 respectively as shown in Fig. 4.

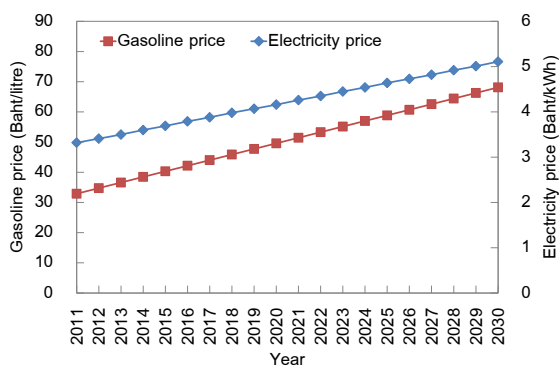


Fig. 4 Prices of gasoline and electricity

### 3.4 Effect on Final Consumption

Generally, substitution of electric motorcycle for gasoline motorcycle would directly changes the household final consumption. Gasoline and auto lube conventionally used in gasoline engine are penetrated by electricity used for electric motor. Therefore, the country's final demands on gasoline and auto lube would be decreased, while final electricity demand was higher due to consumption in the electric vehicle. Due to the nature of electric motorcycle, energy storage was required. Consequently, demand of larger battery would be induced within the economy. However, it was assumed that the input structure of motorcycle manufacturing sector was constant under economy of scale.

## 4. Results and Discussions

The economy-wide impacts of promotion on substitution of electric motorcycle for gasoline motorcycle were assessed in terms of total primary fossil energy supply (TPES), CO<sub>2</sub> emission, and employments. Influences of the measure on the inter-industry relationship in Thai economy through 2011-2030 were evaluated by Input-output (I-O) analysis according to structural change in Thai economy as described in the previous sections and results are presented in Fig.5 to Fig.9 as in the following details.

Fig. 5 presents the expected annual TPES from 2011-2030 in the business-as-usual (BAU) and the implemented electric motorcycle program (Program) cases. The annual TPES of the program case is expected to be lower than in the BAU case through the studied period. In 2030 the TPES of the program case will be reduced by  $617 \times 10^6$  GJ, and accounted for 6.9%

reduction when compared with the BAU case. To describe the reasons of the effect, Fig. 6 presents changes in the TPES in 2030 consisting of energy diversify from four sectors. Apparently, TPES reduction of the program was mostly a result from the petroleum sector (sector#93). Effect from unnecessary lubricant, higher electricity consumption and higher battery capacity is comparatively small.

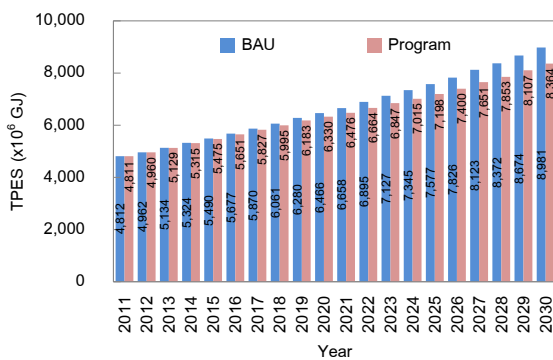


Fig. 5 Total primary energy supply of BAU and program cases.

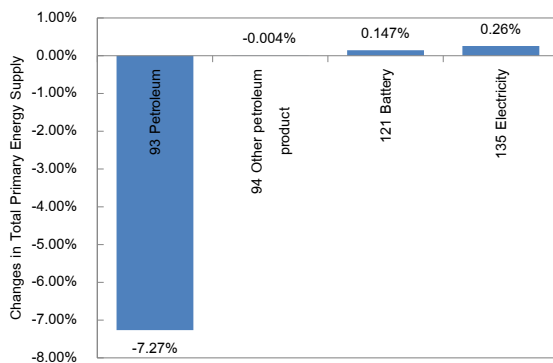


Fig. 6 Changes in the total primary energy supply of year 2030.

Fig. 7 presents annual accumulated reductions in TPES through the studied period. It could be stated that the promotion of electric motorcycle could save total energy by  $4,399 \times 10^6$  GJ. Smaller TPES by the program would be caused by direct and indirect energy

consumptions. It is because that electric motorcycle consumes less energy than gasoline motorcycle due to very high fuel economy as shown in Table 1. In the latter case, more electricity will be generated from other types of fuel sources that have high electricity generation efficiency. In 2030, for instant, 40% of electricity will be generated from nuclear, other renewable energy, and hydro energy as in Thailand PDP2010 [8].

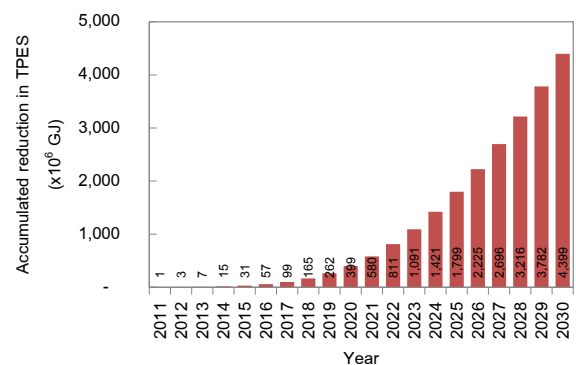


Fig. 7 Accumulated reduction in TPES of electric motorcycle case.

The effect on household income assessed by the I-O analysis during 2011 to 2030 is presented in Fig. 8. Substitution of electric motorcycle by gasoline motorcycle would reduce usage of gasoline that indirectly affects the household income. In 2030 the household income of the BAU case is 12,229 million Baht, while that of the program case are 12,224 million Baht or 0.03% less. The accumulated wage will be 20,673 million Baht throughout the studied period.

By the program, although direct CO<sub>2</sub> emission will be less through the studied period, but the embodied CO<sub>2</sub> emission will not be at a same reduction rate. A comparison of embodied and direct CO<sub>2</sub> emissions is presented in Fig.9.

### 5. Conclusions

Implementation of electric motorcycle on the new motorcycle after the end of lifetime in this study was expected to start the portion of 0% in current year and reach 60% of replacement in 2030. The technology substitution would directly affect the fuel switching from gasohol to electricity in final consumers, auto lube demand would be avoided in the new technology, larger capacity of vehicle battery would be required for extra electricity storage for driving, and electricity demand would therefore be higher than usual, however higher efficiency in the new technology was assumed. The direct effects and indirect effects were considered in the I-O model with fuel mix structural changes according to the country current PDP, economic structural changes, and final demand changes. The assessment through the 20 years study period, under the given assumptions presents rather positive in the country TPES and CO<sub>2</sub> emissions mitigation, but less household income would be trade-off. Recommendation for the study is to verify fuel economy of the proposed technology.

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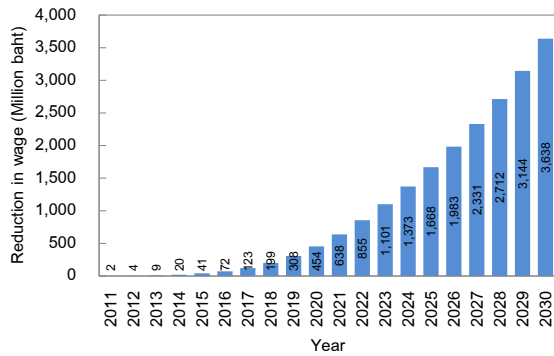


Fig. 8 Economy-wide impact of household income.

Positive result could be found from the direct emission, but slightly result could be expected. In the upstream process of electricity generation that the electric motorcycles for driving cause indirect CO<sub>2</sub> emissions. As presented in Fig. 9, the embodied emission is comparatively higher during 2011 to 2019, therefore, it would be lower during 2020 to 2030. The fuel sources of electricity generation were planned for shifting from fossil fuel to nuclear in 2020 as mentioned in Thailand PDP2010. Therefore, after implementation on electric motorcycle, the related emission will be accounted by the fuel combustion of the power sector according to the type of fuel sources for electricity generation.

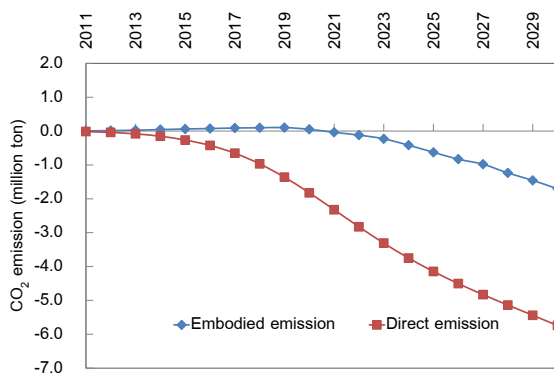


Fig. 9 Comparison of embodied and direct CO<sub>2</sub> emissions of the electric motorcycle case.



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