

การวิเคราะห์ทัศนภาพจากการขยายตัวของเทคโนโลยียานยนต์ไฟฟ้า:
กรณีศึกษาสำหรับภาคการขนส่งทางถนนในกรุงเทพมหานคร
**Scenario Analysis of Electric Vehicle Technology Penetration:
Case Study for Bangkok Road Transportation**

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Received : 15 October 2012 ; Accepted : 10 December 2012

บทคัดย่อ

เช่นเดียวกับการจราจรในเมืองใหญ่ทั่วไป ปัญหาการจราจร (Traffic jam) ในกรุงเทพมหานครเป็นปัญหาสำคัญในการเดินทางในเขตเมือง (Urban travelling) และจากข้อจำกัดของระบบสาธารณูปโภคเพื่อการเดินทางสาธารณะ การเดินทางด้วยรถยนต์ส่วนตัวจึงเป็นทางเลือกหลักของคนกรุงเทพฯ อย่างไรก็ตามจากแนวโน้มราคาเชื้อเพลิงฟอสซิลและปัญหามลพิษในเขตการจราจรคับคั่ง ส่งผลให้เทคโนโลยียานยนต์ไฟฟ้าได้รับความสนใจด้วยความที่เป็นเทคโนโลยีสะอาด และมีประสิทธิภาพสำหรับการเดินทางในอนาคต งานวิจัยนี้จึงมีวัตถุประสงค์เพื่อประเมินผลกระทบที่จะเกิดขึ้น หากเทคโนโลยียานยนต์ไฟฟ้าเกิดการขยายตัวในกรุงเทพมหานคร จากการวิเคราะห์ทัศนภาพ (Scenario analysis) โดยผลกระทบที่ต้องการศึกษาได้แก่ ความเปลี่ยนแปลงปริมาณความต้องการพลังงานไฟฟ้า (Electric energy demand) และปริมาณความต้องการเชื้อเพลิงฟอสซิล สถานการณ์จำลองการขยายตัวของยานยนต์ไฟฟ้าถูกสร้างขึ้นจากสถานการณ์ปัจจุบันจนกระทั่งปี พ.ศ. 2573 โดยเน้นเฉพาะการขยายตัวของเทคโนโลยียานยนต์ไฟฟ้าในการเดินทางด้วยยานพาหนะส่วนตัว ได้แก่รถจักรยานยนต์และรถยนต์ส่วนบุคคล ความต้องการพลังงานไฟฟ้าจะถูกคำนวณด้วยแบบจำลองความต้องการพลังงานในภาคการขนส่งทางบก บนพื้นฐานของโปรแกรม Long-range Energy Alternatives Planning System (LEAP) ผลจากงานวิจัยนี้สามารถใช้เป็นข้อมูลพื้นฐานเพื่อการเตรียมความพร้อมสำหรับภาคการผลิตและบริการไฟฟ้า ตลอดจนการกำหนดนโยบายสนับสนุนการใช้พลังงานอย่างมีประสิทธิภาพและเป็นมิตรต่อสิ่งแวดล้อม

คำสำคัญ: การเดินทางในเขตเมือง การวิเคราะห์ทัศนภาพ ความต้องการพลังงานไฟฟ้า ปัญหาการจราจร

Abstract

Like other urban areas, the traffic jam is always an important problem for urban dwellers in Bangkok and vicinity. Due to limitations of public transport infrastructure, private transport modes are the most popular choices for many in Bangkok. However, with dramatically rising fuel prices and air pollution problems in traffic congested areas; electric vehicle (EV) technology has received much interest as a clean and efficient technology for future transportation. Therefore, this work aims to assess the future consequences from EV technology penetration into Bangkok by recourse to Scenario analysis. The evaluation included the demands for both electricity and fossil fuel. Several model scenarios for EV technology penetration were constructed between the present year to 2030, especially for the technology penetration in private transportation sector, e.g. private motorcycle and private passenger car. The electricity demand was calculated from the energy demand model from road transportation, by recourse to Long-range Energy Alternative Planning System (LEAP) program. The results from this study can be used as preliminary guideline for electricity production/service plan, as well as for implementing national policy to support efficient energy usage under environmental friendliness.

Keywords: Traffic jam, urban travelling, scenario analysis, electrical energy demand

Introduction

As the capital city of a developing country for more than 230 years, Bangkok has grown with over tens million inhabitants. With skyrocketing cost of urban living, many Bangkok workers have no choice but to live in the suburb and commute to the city central for daily work¹. With limited coverage of reliable-and-comfortable public transportation infrastructure, about thirty percent of Bangkok people use their own vehicles, i.e. private passenger cars and motorcycles, to travel into Bangkok¹. In addition, the rapidly developing Bangkok economy over the past few decades has resulted in the rapid growth of transport demand.

Meanwhile, the fuel price has been rising together with the spread of the global warming crisis, which results in many disasters around the world. One solution is to reduce energy intensity (the amount of energy use per unit of gross domestic product, GDP) in all participating sectors of energy usage, including a mode shift from private vehicles to highly efficient public transport. However, this cannot be easily achieved in the short term, e.g. decreasing vehicle ownership and average travel distance per vehicle. More plausible choices for private vehicle have been suggested by Thailand Ministry of Energy² and the International Energy Agency (IEA)³. The solutions can be classified into three points: subsidizing biofuels as alternative fuels, supporting high efficiency vehicle and promoting user-oriented eco-driving.

In the case of high efficiency vehicle, the electric vehicle (EV) technology is appropriate for urban vehicle. It has high efficiency, contributes to less life-cycle greenhouse gas (GHG) emissions, operates more quietly and produces zero tailpipe toxic emissions^{4,5}. The definitions of all EVs, including fuel cell EV (FCEV), are graphically shown in Figure 1.

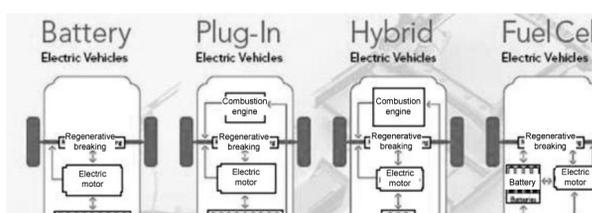


Figure 1 Graphic definitions of all EVs [6]

For hybrid electric vehicle (HEV), Pongthanaaisawan and Sorapipatana⁷ concluded that the HEV will eventually match and surpass the GHG emissions reduction in comparison to fuel switching to biofuels (bioethanol and biodiesel), in the long term. However, more competitive EV, i.e. plug-in hybrid EV (PHEV) and battery EV (BEV) were not considered in their study. These alternative EVs have higher efficiency with longer electric driven distances, in comparison to HEV, but require more government support for replacing conventional vehicles. For example, since either partial- (PHEV) or full- (BEV) electric driven vehicles require a recharging station at owner's house, their office and during their journey, the battery should be compatible for many vehicle models and have enough electricity for average daily driving distance. Moreover, the FCEV is possible only in the far future.

This work aims to evaluate the future consequences if PHEV and BEV have penetrated to the private vehicle sectors in Bangkok. The electricity demand is considered for future electricity production plan. Reduction of fossil fuel demand is also evaluated since it serves as positive information to rationalize supporting policy for the EV technology.

Energy Demand Calculation

The electricity demands of both PHEV and BEV were calculated in the energy demand in transportation sector. The bottom-up approach was used following previous works^{8,9}. The statistic records from all elementary branches in the transportation sector were gathered in the bottom-up model. With proper calibration against actual historical data during 2006-2010, the model was constructed and executed in the Long-range Energy Alternative Planning program (LEAP)¹⁰ to make a prediction till 2030. The energy demand (ED) was calculated from a simple relationship of several variables, which are the number of vehicle (NV), the vehicle kilometer of travel (VKT) and the fuel consumption (FC), as shown in equation (1)

$$ED_{ij} = NV_{ij} \times VKT_j \times FC_{ij} \quad (1)$$

where *i* is fuel type and *j* is vehicle type. Similar to previous works [8, 9], the vehicle types were re-categorized from that of the Department of Land Transport (DLT) as light duty vehicle, taxi / car for rent, motorcycle, bus and truck. The vehicle population models for various vehicles were fitted with the most recent data from DLT. The fuel sharing was taken from the shares of fuel type registered to DLT. Due to the limitation of the LEAP program in incorporating fuel-switching of in-use vehicle (especially liquid to gas fuel), new vehicle input into the model has to be increased at a higher fraction so that the overall fuel-sharing of vehicle-in-stock matches DLT record.

However, the information of FC and electricity requirement for EV has not been recorded in Thailand. Therefore, the fuel consumption data of USA 2012-modeled EVs from the fuel economy guide, distributed by the US-EPA¹¹, were referred too. To apply the USA information on Thai EVs FC in this work, the fuel consumption improvements from gasoline vehicles were considered as the gasoline-compared FC as shown in Table 1. The estimated FC of all EVs are shown in the brackets in comparison to FC of conventional gasoline vehicle in Bangkok.

Otherwise, the shares of electricity on mobilizing PHEV were also estimated by regarding different daily driving distances between USA and Thai's vehicle from^{11,12} in this work as the fuel sharing (FS), shown in Table 2. Moreover, the HEV and PHEV were assumed as the gasoline-electric hybrid vehicle.

Table 1 Gasoline-compared FC (passenger car), adapted from

	Percent, relative to gasoline	(FC unit)
	SI vehicle (estimated FC)	
Conventional (gasoline)	- (10.62)	(km/liter)
HEV	60.13% (17.66)	(km/liter)
PHEV	36.79% (28.86)	(km/literGE*)
BEV	24.29% (43.72 / 20.19)	(km/literGE / kW-hr/100 km)

*literGE is the liter of gasoline equivalent

Table 2 Fuel share (FS) of PHEV, adapted from^{11, 12}

Electricity	31.67%
Gasoline	68.33%

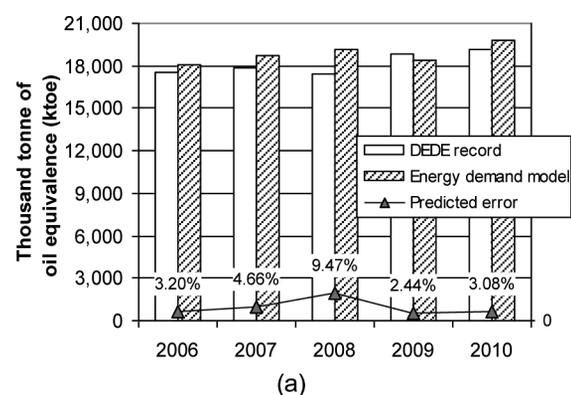
Model Validation

The model results were validated with statistic records from annual reports of energy consumption in Thailand by Department of Alternative Energy Development and Efficiency, Thailand Ministry of Energy^{13,14}. The results of national energy demand between the validated years (2006-2010) are shown in Figure 2, for total energy consumption, gasoline consumption and diesel consumption. Furthermore, the energy consumption is also validated by separating to two regions of Bangkok and provincial areas, as shown in Figure 3.

The validated results show that the accuracy of the constructed model is in an acceptable level:

In 2008, the oil price reached a maximum values since several decades, resulting in too quickly decreased statistics for LEAP model to capture this anomaly.

In 2009, the gross domestic product (GDP) decreased in Thailand from 2008 oil price crisis. Since the vehicle population models were related to the GDP value, the vehicle number predicted in the model decreased, resulting in a decreased predicted fuel consumption in 2009.



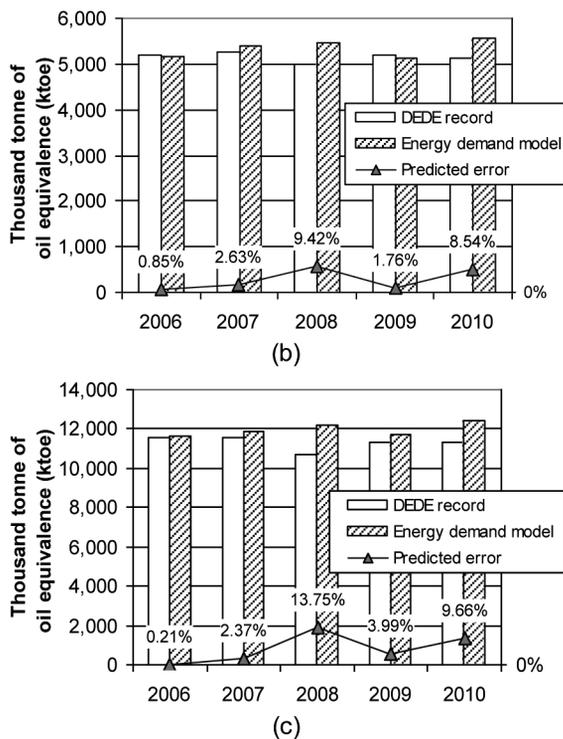


Figure 2 Validations of predicted results and historical records (a) total energy consumption, (b) gasoline consumption and (c) diesel consumption

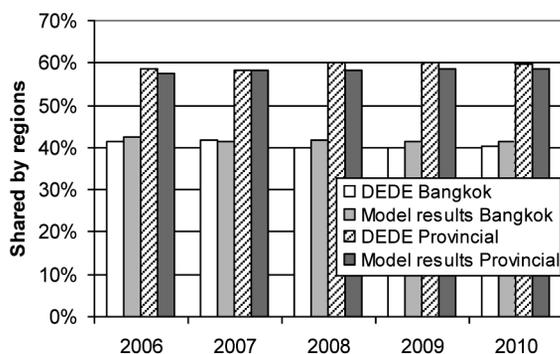


Figure 3 Energy consumption shared by different regions

Definitions of Scenarios Analysis

In Thailand, there are many fuel types, which can be categorized by various properties, i.e. liquid fuel or gas fuel, diesel-like fuel or gasoline-like fuel, fossil fuel or bio-fuel etc. The vehicles are specified for the compatible fuels. Therefore, there are many possible ways of vehicle owner's decisions for fuel chosen.

However, the trend could follow the government supports and promotions, i.e. vehicle tax exemption, biofuel price subsidy, domestic-fuel price subsidy (e.g.

CNG in Thailand) etc. Therefore, the Business As Usual (BAU) scenario is defined in accordance with current governmental regulations as follows ⁹:

New SI vehicles will switch to gasohol E20 (20% ethanol blended in gasoline) within 10 years from 2010.

New SI motorcycles will switch to gasohol E10 (10% ethanol blended in gasoline) within 10 years from 2010.

New fixed route buses will switch to natural gas vehicle (NGV) within 10 years from 2010.

In fact, every newly introduced technology will go through several sequences for penetrating in the market: market introduction, developing period and self-supporting development. These sequences may be described as an S-curve of technology penetration. As a result, the fuel-switching in all cases were specified by equation (2) in this work

$$P(t) = \frac{1}{1 + e^{-15.23(t-0.5)}} \tag{2}$$

where P(t) is the S-curve function, the constant coefficients of 15.23 and 0.5 are selected for a smooth S-curve, t is the technology development duration between 0 (begin of market introduction) and 1 (end of self-supporting development). Figure 4 shows the conceptual trace of the technology penetration.

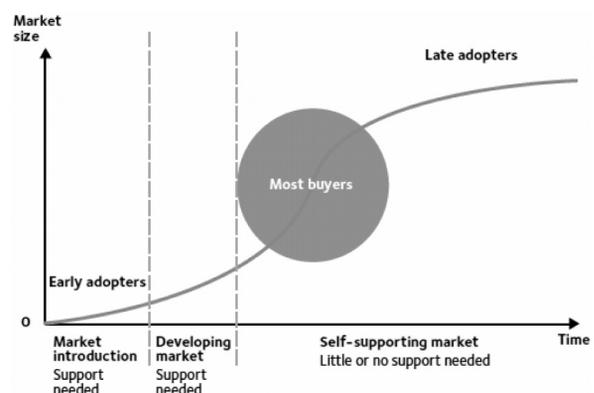


Figure 4 S-curve of market penetration [15]

Considering the EV technology penetration in Bangkok market, the private vehicles were separated to private light duty vehicles (including private passenger

cars and pickup trucks) and motorcycles. It was figured in¹⁶ that the PHEV and BEV will penetrate from 2010, but can be commercially competitive in 2015.

Hence, the scenarios for EV penetration were considered to begin from 2015. Regarding available technology perspective/predict sources, the development of EV for motorcycles was referred to [2] and the development of EV for private light duty vehicles was referred to^{3,16}. The scenario definitions can be described as followed: Motorcycle BEV (MC-BEV): 70% of new motorcycle will switch to battery motorcycle within 10 years of 2015, with the S-curve development in equation (2)

Light duty EV (LD-EV): First, new LDV will switch to HEV within 10 years of 2010, in a small sale shares. Then at 2015, the PHEV and BEV will contribute in new LDV in the market shared development proposed in IEA reports^{3,16} (the PHEV and BEV market penetration begin at 2010 in IEA reports, but the 5 years of technology retard was assumed in the case of Thailand). The market share of the private passenger cars is shown in Figure 5.

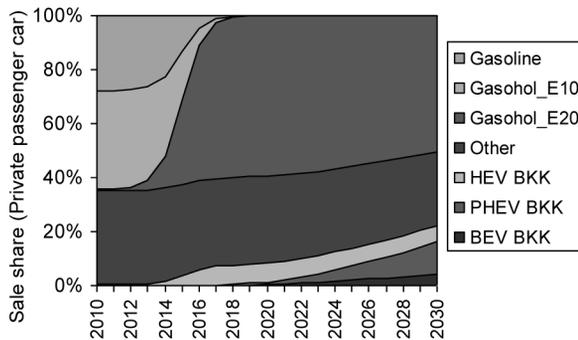


Figure 5 Sale share evolutions of the LDV in the scenario LD-EV

Projected results

The projection of energy consumptions from BAU scenario are shown in the Figure 6, by various vehicle types. The results show that the private LDV contributes largest energy consumption for both areas of Bangkok and province. Contrarily, the motorcycles are the largest number in Thailand but they consume a small fraction of the energy consumption in road transportation.

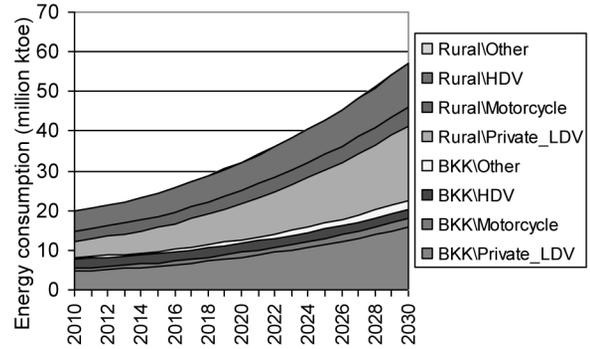


Figure 6 BAU energy consumptions

Figure 6 shows the potentials of EV technology penetration on the fuel switching from fossil fuel to electricity in the energy unit of tonne of oil equivalence (toe). The energy consumption for both scenarios of MC-BEV and LD-EV were compared to the results of BAU scenario.

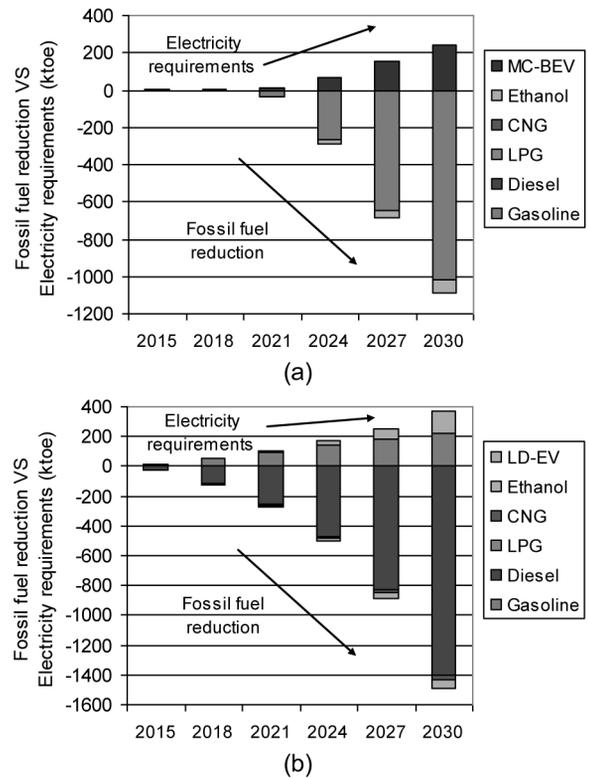


Figure 7 Fuel switching of private vehicles from fossil fuel to electricity, comparison between (a) MC-BEV vs BAU and (b) LD-EV vs BAU

With higher efficiency, it can be seen that the electricity requirements are lower than fossil fuel reductions for both cases. Gasoline can be reduced with supporting EV on motorcycle and Diesel can be reduced with

supporting EV on the private passenger car and pick-up truck. The results show the different potentials on reducing transport energy as the ratio of electricity requirements to fossil fuel reduction between the MC-BEV and LD-EV. It can be seen that the potential of LD-EV is higher with lower ratio of about 1.1 (150/1420@2030) in comparison to 2.2 (244/1100@2030) of MC-BEV. This shows the potential of HEV and PHEV for LD-EV to reduce energy intensity without external electricity requirements. Moreover, the results for LD-EV vs BAU show negative gasoline reduction with large diesel reduction. It can be noted that gasoline fuel increases with penetrating HEV and PHEV shares in small pick-up truck, which consume diesel fuel in the BAU case.

Figure 8 shows the energy saving potentials of EV technology penetration in Bangkok road transportation. The results show that by introducing EV technology to Bangkok, about 2.1 million toe can be saved.

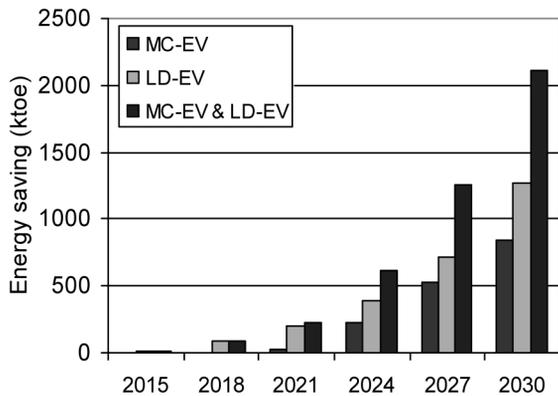


Figure 8 Energy saving potentials of EV technology penetration in Bangkok and its vicinity

Table 3 Projected demand and current electricity consumption in Bangkok and its vicinity

Projected electricity demand from EV in Bangkok						
Year	2015	2018	2021	2024	2027	2030
MC-BEV	0.02 (0)	0.38 (4)	8.20 (95)	64.32 (748)	154.75 (1,799)	244.61 (2,844)
LD-EV	0.00	0.83 (10)	5.62 (65)	24.05 (280)	67.91 (790)	149.90 (1,743)
Total	0.02 (0)	1.21 (14)	13.82 (161)	88.37 (1,028)	222.66 (2,589)	394.51 (4,587)

Planned power plant capacity [17] (GWh)						
Whole country	200,727	227,761	255,591	284,640	314,924	346,768
Current electricity supply [18] (GWh)						
Year	2007	2008	2009	2010		
Whole country	133,178	135,449	135,209	149,320		
Bangkok	42,036	42,237	41,734	45,061		

Table 3 shows the projected electricity demands with EV introducing to Bangkok, the annual capacity of planned power plant ¹⁷ and current annual electricity consumption ¹⁸ in Bangkok and whole country. The fuel electricity demands are shown in both units of ktoe and Giga Watt-hour (within the brackets). It can be seen that the planned capacity of Thai power plants are sustained for the Bangkok EV. In addition, the electricity requirements for 2030 Bangkok EV account for about 6.31% (battery motorcycle), 3.87% (private passenger car and pickup truck) and 10.18% (all electric vehicles) of current electricity consumption.

Conclusion

From the Thailand energy efficiency development plan ², the effects of efficient technology, the electric vehicle, were evaluated in this study. The energy demand model was improved from previous work [9] with updated statistic records. Two scenarios were constructed and analyzed only on Bangkok private vehicles for the consequences of EV technology penetration.

The calculation results confirm that EV technology has potentials on reducing energy demand in road transportation sector. It is found that EV technology can save more than 2.2 million toe at 2030 by both vehicles of motorcycle and private light duty vehicle (equivalent to 3.7% of energy demand in road transportation). However, it requires more supported measures, e.g. electricity generation reserves, to ensure minimal adverse effect.

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