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Scenario Analysis of Electric Vehicle Technology Penetration in Thailand: Comparisons of Required Electricity with Power Development Plan and Projections of Fossil fuel and Greenhouse Gas Reduction

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Abstract

In this study, the benefits and trade-off for penetration of electric vehicle (EV) technology in Thai road transportation were analyzed by using offend-use energy demand model. Two vehicle types (motorcycle and passenger car) were considered for possible EV penetration as partial EV, which are hybrid EV (HEV) and plug-in hybrid EV (PEV) and full EV, which is battery EV (BEV). The assumption for EV penetration was derived from Thai government policy target and available technology perspective into four different scenarios, e.g. Business As Usual (BAU), electric motorcycle (eMC), passenger car EV (PcEV) and the extremely case of combined EV penetration in both motorcycle and passenger car. The energy demand model for road transportation from our previous works was constructed using

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Keywords: electric vehicle (EV); scenario analysis; Long-range Energy Alternative Planning (LEAP) System; Power Development Plan 2012

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the Long-range Energy Alternatives Planning system (LEAP) program. Electricity requirements for charging the EV were considered as the additional electricity demand of annual accumulative electric energy and the level of daily load curve from averaged charging behaviors. The results show that the electricity requirements in all scenarios were still within the buffer level (difference between power generation capacity and forecasted electricity demand without EV consideration) in the Power Development Plan 2010 revision 3 (PDP2010r3). Furthermore, other benefits on reductions of fossil fuel import and Greenhouse Gas (GHG) emission were also computed, and discussed in the context of upcoming ASEAN Economic Community (AEC) in 2015.

Nomenclature

ED	Energy demand
EEDP	Energy efficiency development plan
eMC	Battery-electric motorcycle
FC	Fuel economy
NV	Number of vehicles
PcEV	Passenger car electric vehicle
PDP	Power development plan
VKT	Vehicle kilometre of travel

1. Introduction

1.1. Thailand Energy Situation, Future Projection and Measures

Nowadays, energy consumption contributes to 18 percent of Gross Domestic Products (GDP) in Thailand, where half of the energy is imported [1]. Within this large economic value, energy is consumed for various sectors, e.g. transportation, industry, residential, commercial etc., with transportation and industry being accounted for 35-37 percent each [2]. The energy consumption from historical record and future projection are shown in Figure 1. Therefore, Thai government has adopted the 20 Years Energy Efficiency Development Plan (EEDP) [3] as national agenda to reduce domestic energy intensity (energy demand per GDP) 25% compare the energy intensity in 2005.

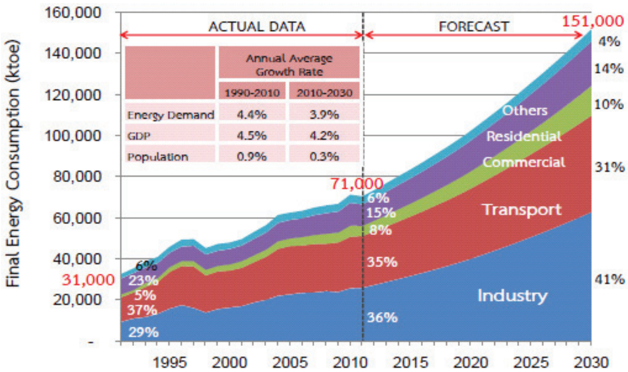

Fig. 1. Statistic record and projection of Thai energy demand under the BAU case

According to EEDP, transportation sector, which is the high energy consumption sector, has largest potential on reducing energy consumption, (44.7 percent of total energy conservation potentials) because it is mostly dominated by relatively low fuel conversion efficiency at the present, the internal combustion engine technology. Therefore, three technical approaches are proposed for transportation sector especially an aim to improve vehicle fuel economy for both new and on-road vehicles.

1.2. Electric Vehicle Technology

Nowadays, electric vehicle (EV) is one of the high efficiency energy vehicles technology, which has largest potential to reduce energy consumption. It also produces less life-cycle Greenhouse Gas (GHG) emissions, operates with less noise and produces zero tail-pipe emissions [4, 5]. Due to specific power aspect of battery technology, EV is categorized into four classes for passenger car, namely Battery EV (BEV, or full EV), hybrid EV (HEV, usually ICE-EV hybrid), plug-in HEV (PHEV, electric chargeable EV) and fuel-cell EV (FCEV) shown in Figure 2.

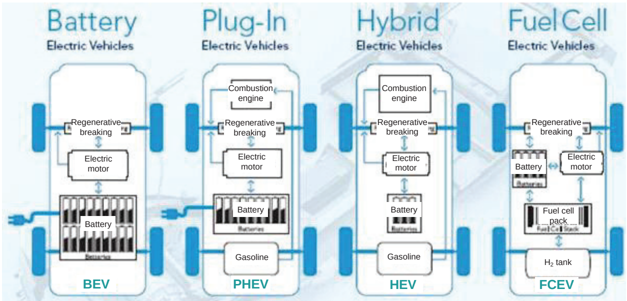

Fig. 2. Graphic definition of all EVs [6]

Due to its advantage on energy conversion efficiency and environmental friendly, the EVs are included in government targets for many countries in response to reducing fossil fuel consumption and mitigating global warming effects. For Thai EEDP [3], the battery-electric motorcycle (eMC) is regarded as high efficiency vehicle for the new motorcycle. The eMC sale share is targeted to achieve 70% within 2030. On the other hand, the passenger car EVs has been considered by the International Energy Agency (IEA) as the technology solution for road transportation [7, 8]. The market shares for HEV, PHEV and BEV are considered in IEA-blue map scenario. With regard to technology development and current market situation, the HEV sale is already contributed some portion of passenger car while the new model of PHEV and BEV are introduced at low production volumes in 2010, especially for OECD countries. Then, the battery technology for EV can be reliable by 2015 with the PHEV and BEV mass production levels penetration as shown in Figure 3 [7].

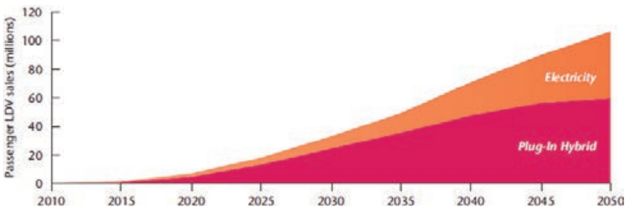

Fig. 3. Annual global BEV and PHEV sales in blue map scenario [7]

2. The Objective of This Study

Since the EVs technology provides many benefits as mention above, however, the EVs still face many issues that governments have to be concerned, e.g. electricity requirement, charging infrastructure preparation, charging standard, battery management, etc. Hence, the objective of this work is to analyze some benefits and trade-off for EV technology penetration in Thai road transportation. From our previous works [9, 10], which mainly focus on reduction of fossil fuel and GHG emission, this study will mainly focus in more details on additional electricity requirements for charging the predicted EVs. The annual accumulative electricity will be analyzed by using the energy demand model for road transportation. The driving and charging behavior of vehicle owner, adopted from literature, will be used to analyze maximum electricity requirement. Moreover, several projects which will be initiated by ASEAN Economic Community (AEC) initiation and can enhance the opportunity of EV technology penetration are informed.

3. Methodology

3.1. Scope of Study

In this study, the analysis and forecasting of the energy demand and the GHG emissions are only focused on the road transport sector in Thailand. The study will limit and scope on common type of vehicles for the road transport in Thailand; it included both of passenger transport and freight transport, ie., light duty vehicle, small pickup truck, three wheeler, taxi, car for hire, motorcycle, bus and truck. The fuels used in road transport are including conventional fossil fuel: gasoline, diesel, liquefied petroleum gas (LPG), and compressed natural gas (CNG), biofuels: bioethanol and biodiesel, and electricity. The GHG emissions from road transport vehicles are only limited to carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O).

3.2. Energy Demand Model for Road Transportation

The energy demand model was adopted from the previous works [9-13] and used to predict the effects of EVs penetration in Thai road transportation sector. The bottom-up approach was selected because it can explicitly integrate energy consumption from each vehicle type of interest in details. The model was constructed and executed in the Long-range Energy Alternatives Planning program (LEAP) [14] to make prediction from 2010 until 2030. The energy demand (ED) was calculated from keyed variables, which are the number of vehicle (NV), the vehicle kilometer of travel (VKT) and the fuel consumption (FC) as shown in equation (1):

$$ED_{i,j} = NV_{i,j} \times VKT_j \times FC_{i,j} \quad (1)$$

where i is fuel type and j is vehicle type. From previous works [9-13], the vehicle types were re-categorized from that of the DLT, e.g. light duty vehicle, small pickup truck, three wheeler, taxi, car for hire, motorcycle, bus and truck. The fuel types are from commercially available fuel types in Thailand composed of liquid/gas fuel, diesel-like/gasoline-like fuel, fossil/bio-fuel etc. The vehicle population models for various vehicles were fitted with the most recent data from DLT [15]. Due to limitation of LEAP program in incorporating fuel-switching behavior of consumers (especially liquid to gas fuel), new vehicle input into the model has to be mathematically increased at a higher fraction so that the overall fuel-sharing of vehicle stock match DLT record.

Furthermore, with regard to government support and promotions of gasohol and natural gas, fuel sharing of the spark ignition (SI) cars, motorcycles and buses were assumed as follows [12, 13]:

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

For technology penetration, the new technology/fuel are considered to be penetrated as the S-curve function from technology development, niche market, achieving competitiveness and mass market; as shown in Figure 4.

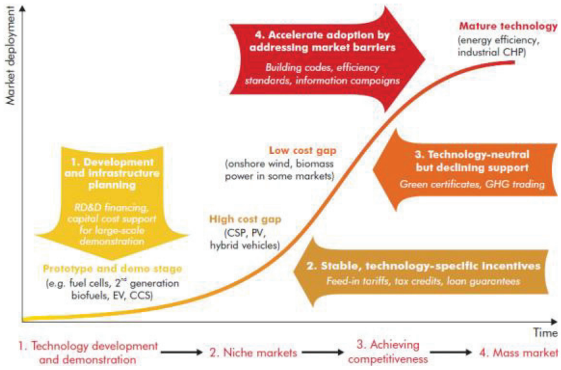

Fig. 4. S-curve of market penetration [8]

3.3. Scenario Analysis

Regarding to IEA mention [7, 8], the PHEV and BEV are forecasted to penetrate from 2010, but can be commercially competitive in 2015, especially for the OECD countries. As for non OECD countries like Thailand, the scenarios for EV technology penetration were defined by including a period of technology penetration delay with consideration of EEDP by Thai government [3]. The scenario definitions can be described as follows for battery-electric motorcycle (eMC) and passenger car EV (PcEVs):

- Battery-electric motorcycle (eMC): Some portion of new motorcycle will switch to eMC from 2015. Then the eMC sale share will develop as the S-curve shown in Figure 4 until it reaches 70% of new motorcycle at 2030.
- Passenger car EV (PcEVs): First, new passenger car will switch to HEV within 10 years from 2010, in a small scale shares. Then at 2015, the PHEV and BEV will contribute in new passenger car in the market shared development as proposed in IEA reports [7, 8] (Note that the PHEV and BEV market penetration begins at 2010 in IEA reports but the 5 years of technology lag was assumed in the case of Thailand).

In addition, the area of consideration is separated to two regions, i.e. Bangkok (BKK) and provincial area (PRO). The EVs penetration rate for passenger car and motorcycle are assumed to be the same rate with annual vehicle population growth with retirement rate depending on each area.

3.4. Assumptions of EV Fuel Economy and Charging Behavior

In general, the fuel consumption (FC in equation 1), which is an important input parameter for calculating transport energy demand and depends on averaged driving behavior, is gathered from available statistic record in Thailand. Unfortunately, the FC for EV has not been officially recorded in Thailand. Therefore, this work assumes fuel consumption improvement from conventional vehicle as the gasoline-compared FC instead. The gasoline-compared FC was estimated from the fuel economy guide of US-EPA [16] as the relative percentage from conventional vehicles. The FC of 453 conventional vehicles, ranging from two seaters, sub-compact, compact to midsize classes were averaged with regard to their respective engine sizes. Then, the FC of new 2012 EVs (20 HEV, 2 PHEV and 4 BEV) in the comparable vehicle-passenger cabin volume and classes were compared as the FC improvement, as shown in Table 1. The estimated FC values for private passenger car are also shown, according with their FE unit shown in the last column. Furthermore, the contribution of gasoline fuel and electricity for driving PHEV was calculated as the fuel share of 68.25% and 31.75% as respectively.

Table 1. Gasoline-compared FC, adapted from [16]

	SI-FC improvement (%)	Estimated FE (passenger car)		FC unit
		Bangkok	Provincial	
HEV	29.74	15.11	17.48	km/liter
PHEV	52.27	22.25	25.73	km/liter GE*
BEV	71.51	37.27 (23.68)	43.11 (20.47)	km/liter GE (kW-hr/100 km)
PC01 (gasoline)	-	10.62	12.28	

*liter GE is the liter of gasoline equivalent

4. Results

4.1. Number of Vehicle Stocks

The on-road eMC and PcEV are shown in Figures 5 and 6, respectively. In details, while the numbers of total motorcycles and passenger cars at 2030 achieve 2 and 4 times of current values, respectively, the numbers of EVs, which require external electric energy, can be summarized as follows.

- The on-road eMC will achieve 18.5 million motorcycles (44.16%)
- The on-road PHEV and BEV of passenger cars will achieve only 1.1 million cars (5.85%).

These numbers of vehicles would require additional electric charging, as discussed in the next section.

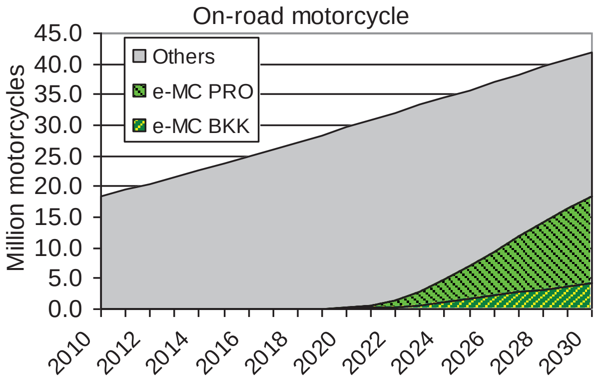

Fig. 5. On-road eMC and all other motorcycles

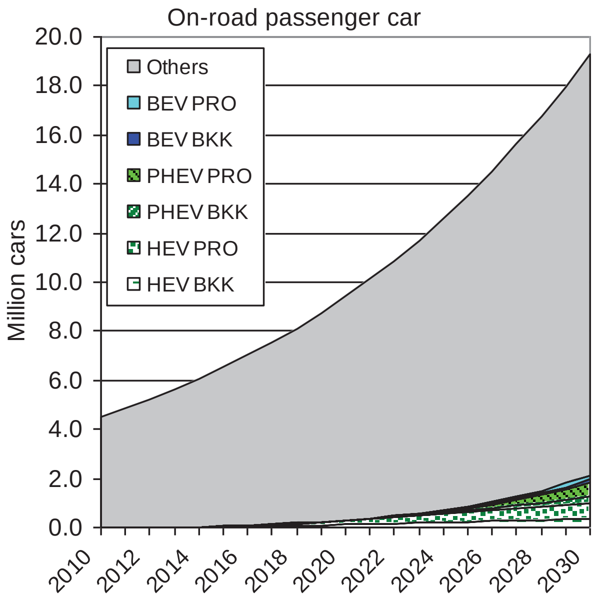

Fig. 6. ON-road EVs and other passenger car

4.2. Electricity Demand for Charging Electric Vehicle

This section focuses on the additional electricity demand for charging EVs by comparing to the reserve (buffer) margin of Thai power generation plan. The Thai Power Development Plan 2010 revision 3 (PDP2010r3) [17] specifies that Thailand should have the proper level of reserve margin to be not less than 15-20 percent of peak power demand.

4.2.1. Increase of Annual Electric Energy Demand

The results of additional annual electricity demand for charging EVs in comparison to Business as Usual (BAU) scenario is shown in Figure 7. It is found that the large numbers of eMC account for large quantity of road transport electricity demand, according to the eMC and PcEV numbers shown in Figures

5 and 6. The projection of additional EV electric demand at 2030 is less than 3.5% of total domestic demand in 2030 (346,767 GW-hr), as predicted in the PDP2010r3.

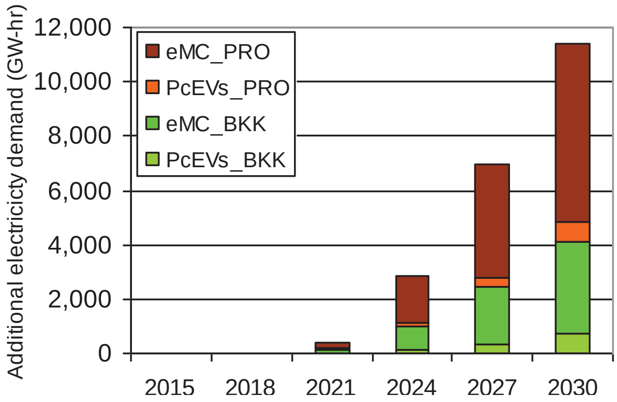

Fig. 7. Development of electric demand for charging EVs

4.2.2. Impact of Charging Behavior on Daily Load Curve

For energy security concern, the worst case possible for undesirable electricity demand may occur if all EVs (PHEV and BEV) are immediately plugged into the electric grid at the peak daily load period. Therefore, the charging behaviors of vehicle owners, analyzed by Park et al. [18], were considered with reference to Thai daily load curve from annual report of electric power in Thailand [19]. It is found that in the case of continuous charging (charge wherever parking with Level I charging standard), the maximum period of EV charging load is occurred at the third peak of daily load curve, about evening at 7:30-9:30 PM. However, since Thai electricity voltage is different from US standard, and the charging load of eMC is also different to that of passenger car EVs, the present study calculates the magnitude of EV charging load by arithmetic interpolation, as defined in Table 2. Therefore, the maximum possible electricity requirement in this worst case can be calculated by multiplying charging load in Table 2 with on-road EV numbers in Figures 5 and 6, as shown in Figure 8. The maximum possible EVs charging power is accounted for 14.26% of electric generation of planned capacity in the PDP2010r3 (70,686 MW).

Table 2 Magnitude of EV charging load

	Voltage (V)	Current (A)	Individual peak EV load (kW)	Grid load (kW/100 vehicles)	Ref.
Park et al. Level I US	110	20	1.40	74.02	[18]
Level I (Thai)	220	20	3.11	164.43*	-
Level II (Thai)	220	32	4.98	263.30*	-
eMC	220	-	0.84	44.41*	[20],*

*Estimated in this work

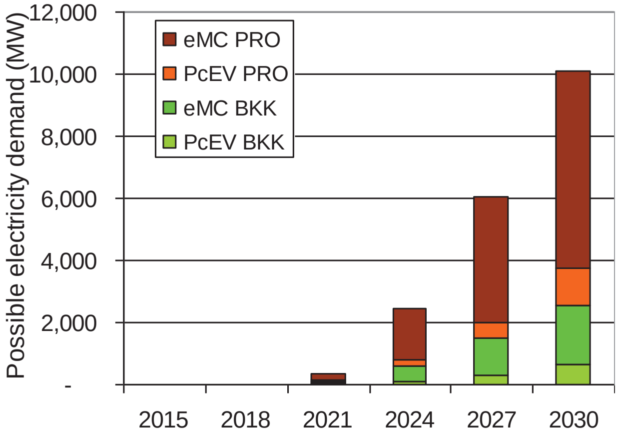

Fig. 8. Highest possible electric load at peak daily hour cause by undesired charging behavior (charge wherever parking with Level I charging standard)

4.3. Benefits on Reductions of Fossil Fuel and Greenhouse Gas Emission

In comparison to conventional vehicle, the consumed fossil fuel and Greenhouse Gas (GHG) emission were analyzed using the well-to-wheel life cycle analysis. The energy mixed for electricity generation in the PDP plan is shown in Figure 9.

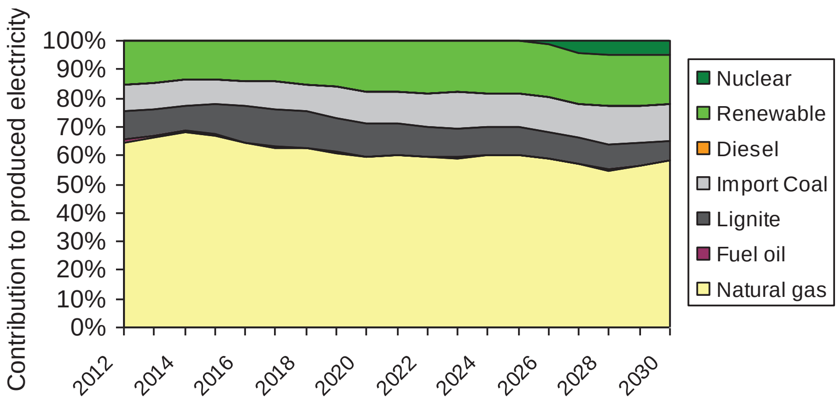

Fig. 9. Electricity produced from energy mixed [17]

The EV technology consumed less fossil fuel and produced less GHG emission due to the contribution of renewable energy and also the better of fuel consumption, as previously discussed. Hence, the reductions of fossil fuel and GHG emission are shown in Figures 10 and 11, respectively. The results show that the EVs technology can help reduce 4.51% of energy consumption in transportation sector in 2030 (transportation sector accounts for 46,810 ktoe of energy consumption [3]), and 14.09% of GHG emission from Thai road transportation at 2008 value (road transportation sector accounts for 50.65 Million Ton of CO2,eq of GHG emission [21]).

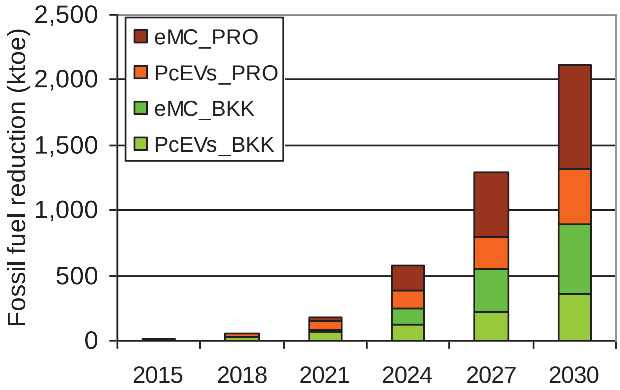

Fig. 10 Benefit on fossil fuel reduction

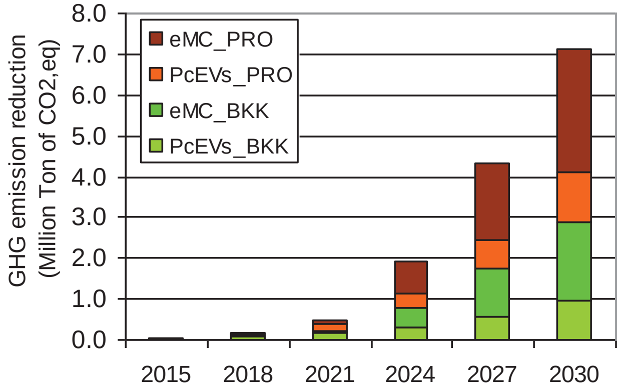

Fig. 11. Benefit on GHG emission reduction

It can be seen that the benefits of PcEV on both reducing fossil fuel (Figure 10) and GHG emission (Figure 11) are comparable to the benefits of eMC, even though the PcEV requires less electricity demand. This shows the potentials of HEV and PHEV to reduce energy intensity without external electricity requirements. Beside, the benefits of using EV in Bangkok are higher than having more numbers of EV in provincial area due to different driving behaviour and fuel consumption.

4.4. EV Penetration Enhancement by ASEAN Economic Community (AEC) Initiation

With current capacity and infrastructure for automotive production, Thailand has large opportunity to initiate EV incentive measures in response to reducing fossil fuel consumption and mitigating global warming crisis. With upcoming ASEAN Economic Community (AEC) planned in 2015, several declared projects can enhance the opportunity of EV technology penetration as follows:

- The ASEAN Power Grid, which is being implemented, will facilitate energy transfer from high renewable energy resource to high energy consumption country such as interconnection between Thailand-Cambodia and Thailand-Laos.

- The ASEAN Power Grid can help ease electricity import from neighboring countries to supply sudden electricity demand from instantaneous charging of all EVs for the unforeseen case in future.
- There are opportunities to initiate charging infrastructure such as the electric highways [22] along the road network of the ASEAN Highway Network project.
- There are opportunities for collaboration between automotive market/manufacturer with the ASEAN Automotive Federation to solve the issue of EV price competitiveness.

5. Conclusion

With regard to higher energy efficiency vehicle technology than conventional vehicles in current situation, the benefits and trade-off to promote electric vehicle (EVs) have been discussed in this work as follows:

- The electricity generation capacity, forecasted by Electricity Generating Authority of Thailand (EGAT) can support additional electricity demand caused by predicted numbers of EVs for the whole country in both vehicle classes of battery-electric motorcycle (eMC) from EEDP and passenger car EV (PcEV) adopted from IEA forecast.
- Worst case possible instantaneous electricity demand from all EVs in Thailand is still within the reserved electricity generation level.
- The EV technology can help decrease both fossil fuel consumption and Greenhouse Gas (GHG) emission with the benefits of renewable fuel option and high energy conversion efficiency.

Acknowledgment

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