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SCENARIO ANALYSIS OF ELECTRIC VEHICLE AND ITS IMPACTS ON ENERGY SYSTEM OF ROAD TRANSPORT SECTOR IN THAILAND

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ABSTRACT

Transport sector around the world is in a transition era by experiencing a disruption of electric vehicle (EV) technology. This transition brings both challenges and opportunities to energy system and energy pattern in transport sector, such as increasing of electricity demand and reduction of greenhouse gas (GHG) emissions. This study aims to analyse the potential future scenarios of the penetration of EV in Thailand's road transport sector. In addition, the impacts of such technology to energy demand and supply and potential of GHG emission reduction in transport sector will also be assessed.

Policy commitment of the government plays a crucial role for EVs market in Thailand. Therefore, the future scenarios can be explored by two cases: Current Policy Scenario (CPS) represents the current actions of government support on EVs, whereas Proactive Policy Scenario (PPS) represents full package of government supports on both supply and demand sides. High penetration rate of EVs will impacts on Thailand energy system, especially road transport sector. This include total energy demand pattern, load profile of electricity demand and GHG emission. The results present that total number of EVs in PPS scenario will consume electricity more than that of CPS scenario around 1,650 ktoe (19,363 GWh), however, they can reduce 474 ktoe of total energy consumption and 10 $MtCO_2eq$ by 2040.

KEYWORDS: Electric vehicle, Disruptive technology, scenario analysis, Transport energy demand model, Energy efficiency in transport sector

NONMENCLATURE

Abbreviations	
EV	Electric Vehicle
GHG	Greenhouse Gas
CPS	Current Policy Scenario
PPS	Proactive Policy Scenario
ktoe	kilo ton of oil equivalent
GWh	Gigawatt-hour
MJ	Megajule
MW	Megawatt
$MtCO_2eq$	million ton of CO_2eq
wtw	well-to-wheel
wtt	well-to-tank
ttw	tank-to-wheel
Symbols	
ED	Energy demand
FE	Fuel economy
f	GHG emission factor of fuel
i	Type of vehicle
j	Type of fuel
k	Age of vehicle
t	Year
VKT	Vehicle kilometer of travel
ψ	Percentage share of fuel
φ	Survival rate of vehicle

1. INTRODUCTION

Transport sector around the world is experiencing a transition era of disruptive technologies, e.g. electric vehicles (EVs). Such transition brings both challenges and opportunities to energy system and energy pattern in transport sector. This include increasing of electricity demand and reduction of greenhouse gas (GHG) emissions in this sector. Therefore, a comprehensive analysis of the impacts of these technologies will be crucial for various related agencies in energy system, i.e. policy makers, electricity utilities, automotive industries, etc.

This study aims to analyse the potential future scenarios of the penetration of electric vehicle (EV) in Thailand's road transport sector. Moreover, the impacts of such technology to energy demand and supply and potential of GHG emission reduction in transport sector will also be assessed.

2. METHODOLOGY

In order to analyse the possible penetration rate of EV and impact of the technology to energy system in transport sector, this study is divided into two parts, as follows.

2.1 Scenario building

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).

Scenario building is a method used to determine the feasibility of the future on issues of interest, suitable for policy and strategic planning. Initially, it starts with a look at the relevant qualitative future. This methodology is based on the brainstorming of experts from all sectors, e.g. public, private and academic. The steps of scenario building are presented as diagram shown in Figure 1.

Firstly, the focal issues were identified. Relevant driving forces or drivers to the focal issue such as social drivers, technological drivers, economic drivers, environmental drivers, and political drivers, were analyzed and ranked regarding their importance and uncertainty. Then the most important and highest uncertainty drivers would be selected to examine the interaction each other by using scenario logics. From scenario logics, the scenarios would be named and all driving forces in each scenario would be characterized to represent the characteristic of the scenarios. Finally, the important indicators for monitoring the development of scenario were selected. Details of each step can be described as below.

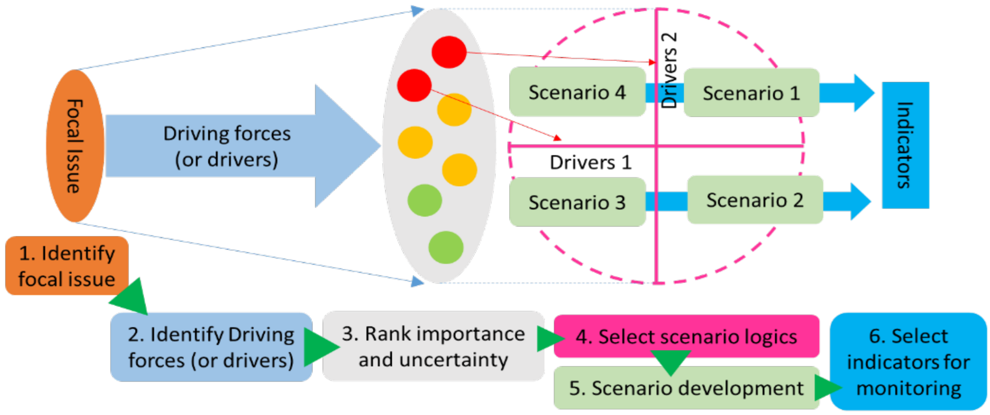

Fig 1 Scenario building methodology [1]

1) *Identify focal issue:* The focal issue represents the questions about the future that related cities are confronting.
2) *Identify driving forces:* The driving forces or drivers represent the key variable and trends in the environment that influence the focal issues. This study used the "STEEP" analysis to identify the key driving forces. The STEEP analysis is a tool to evaluate related external and internal factors. STEEP is stand *for Social, Technology, Economic, Ecological, and Political.*
3) *Rank importance and uncertainty:* The identified driving forces were ranked in terms of uncertainty and importance (impact) which related to the focal issue in order to find the critical uncertainty as shown in Figure 2. The two most important and uncertainty drivers that would impact to focal issue will be selected in order to construct the scenario logics.
4) *Select scenario logic:* The scenario logics are defined by exploring the interactions of the most important and uncertain drivers. The scenario logics represent the possible futures in different cases through the plausibility, challenge, differentiation, and decision-making utility to focus issues.
5) *Scenario development:* The scenarios are developed by exploring the implication of alternative trajectories on the focal issue under the appointed parameters defined by the interactions between key driving forces. Each scenario will be characterized through different perspectives, driving forces, and future development directions.

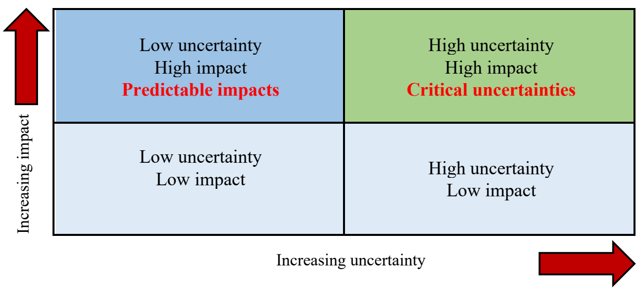

Fig 2 Critical uncertainty analysis

2.2 Energy demand model

Energy model for Thailand's energy system were developed as shown in Figure 3. In the demand module, final energy demand in each sector is derived by the product of key drivers and energy intensities. In the energy transformation module, the requirement of final energy is initially fulfilled with the production of

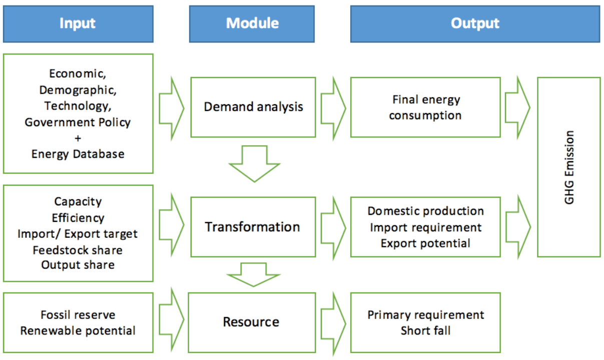

Fig 3 Structure of Thailand's energy system [2]

existing capacities. Primary resource is withdrawal by the required feedstock during the transformation process. The entire energy system is balanced by exporting the surplus and importing the shortage energy.

or transport sector, the end-use energy demand model will be applied for stock turnover analysis. The systematic of end-use energy demand model for road transport sector for this study is illustrated in Figure 4.

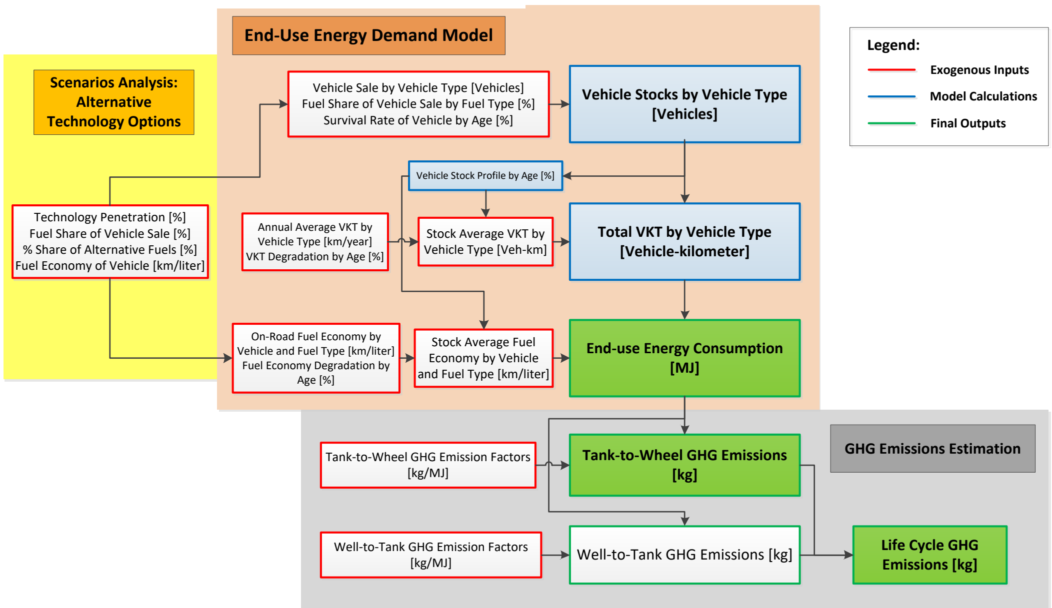

Fig 4 End-use energy model of road transport sector [2]

The total energy demand of all type of vehicles in the road transport sector in a given calendar year, the energy demand (ED) was calculated from a product of total number of each vehicle stock by a given vehicle type and fuel used, $V_{stock,i,j}$ *(t)* the stock's average vehicle kilometer of travel by that given vehicle type and fuel used, $VKT_{stock,i,j}$ *(t)* and inverse of the stock's average fuel economy by that given vehicle type and fuel used, $FE^{-1}{}_{stock,i,j}$ *(t),* as shown in equation (1) below:

$$ED_{(t)} = \sum_i \sum_j [V_{stock,i,j}(t)\ x\ VKT_{stock,i,j}(t)\ x\ FE^{-1}{}_{stock,i,j}(t) \quad (1)$$

where *ED(t)* is the total energy demand in a calendar year *t* (MJ), $V_{stock,i,j}$ *(t)* is the total stock of vehicle type *i*, which use fuel type *j*, in a calendar year *t* (vehicles), $VKT_{stock,i,j}$ *(t)* is the stock's average annual vehicle kilometer of travel of a given vehicle type *i,* which use fuel type *j*, in a calendar year *t* (kilometers), $FE_{stock,i,j}$ *(t)* is the stock's average fuel economy of that given vehicle type *i,* which use fuel type *j*, in a calendar year *t* (vehicle-kilometer per MJ).

The total number of vehicle stock in a given calendar year *t* of vehicle type *i* which use fuel type *j*, $V_{stock,i,j}$ *(t),* was calculated from a summation of multiplication of three parameters, which are the number of vehicle sales for vehicle, survival rate of vehicle and percentage share of fuel, as shown in equation (2) below:

$$V_{stock,i,j}(t) = \sum_{v=v'}^{v=t} [V_{sale,i}(v)\ x\ \varphi_i(k)\ x\ \psi_{i,j}(v) \quad (2)$$

where $V_{sale,i}$ *(t)* is the number of new vehicle type *i* that sold in vintage year *v* (vehicles), φ_i *(k)* is the survival rate of vehicles type *i* with age *k* (%) *k* is the age of vehicle, where *k = t – v* (years), as shown in Figure 5 and $\psi_{i,j}$ *(v)* is the percentage share of fuel type *j* within the sales of vehicle type *i* in the vintage year *v* (%).

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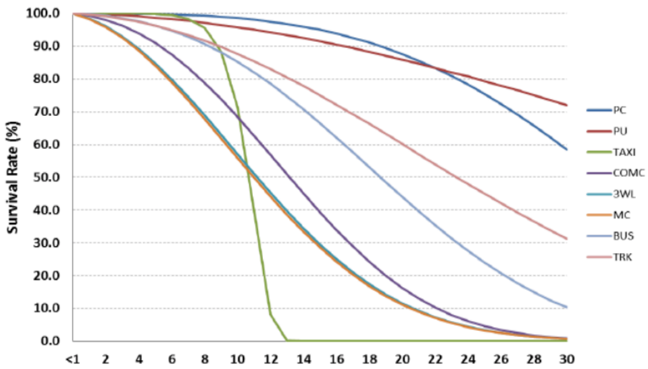


Fig 5 Survival rate of vehicle in Thailand [2]

Vehicle sales are number of new vehicles enter into road transport sector in each year. Normally, the number of vehicle sale in each year depends on socio-economic dominant factors. In this study, an econometric model of each vehicle type was used to forecast the total number of vehicle sale in each year. GDP and population were used as the key driving socio-economic parameters. The vehicle sale estimation models were calculated as shown in equation (3) below:

$$InV_{sale,i}(t) = a_i + b_i\, InG_{cap}(t) + c_i\, D_{econ}(t) \quad (3)$$

where, $V_{sale,i}(t)$ is the number of vehicles sales type *i* in year *t* (vehicles), $G_{cap}(t)$ is the per capita GPD in year *t* (Thai baht constant price at 1988), $D_{econ}(t)$ is the dummy variable for the economic crisis in year *t*, and *a*, *b*, and *c* are coefficients of driving parameters.

Vehicle kilometer of travel (VKT) is an average annual travel distance of vehicle. An annual average VKT of a total number of vehicle stock type *i* which use fuel type *j* in a given year *t* can be defined as a stock's average annual vehicle kilometer of travel, $VKT_{stock,i,j}(t)$. It can be calculated by using equation (4).

$$VKT_{stock,i,j}(t) = \frac{\sum_{v=v'}^{v=t}[V_{remain,i,j}(t,v) \times VKT_{veh,i,j}(k)]}{V_{stock,i,j}(t)} \quad (4)$$

where $VKT_{stock,i,j}(t)$ is the stock's annual average vehicle kilometer of travel of vehicles type *i* which use fuel type *j* in a calendar year *t* (kilometers per vehicle), $V_{remain,i}(t,v)$ is the number of vehicle type *i* that sold in vintage year *v*, which still remains on road in a calendar year *t* (vehicles), and the corresponding annual average VKT of vehicles by vehicle age, $VKT_{veh,i,j}(k)$, as presented in Figure 6.

Fuel economy of vehicle presents energy intensity of a vehicle. It is an average vehicle-distance travelled per unit of fuel used, which generally presented in term of vehicle-kilometer per liter (or vehicle-mile per gallon). An average fuel economy of a total number of vehicle type *i* which use fuel type *j* in a given year *t* can be defined as a stock's average fuel economy, $FE_{stock,i,j}(t)$. It can be calculated by equation (5).

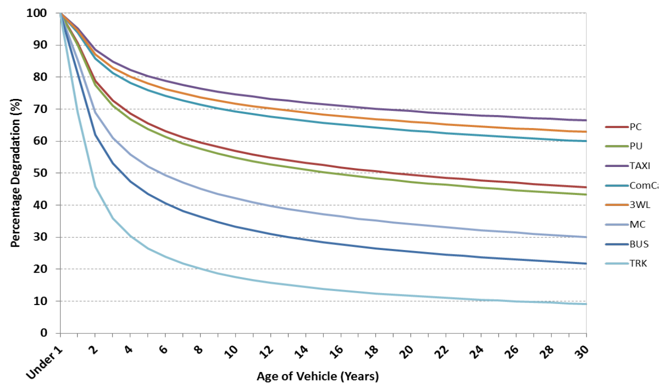


Fig 6 Degradation factors of VKT by age of vehicle [3]

$$FE_{stock,i,j}(t) = \frac{\sum_{v=v'}^{v=t}[V_{remain,i,j}(t,v) \times FE_{veh,i,j}(k)]}{V_{stock,i,j}(t)} \quad (5)$$

where $FE_{veh,i,j}(t)$ is the stock's average fuel economy of vehicle type *i* which use fuel type *j* in a calendar year *t* (vehicle-kilometer per MJ).

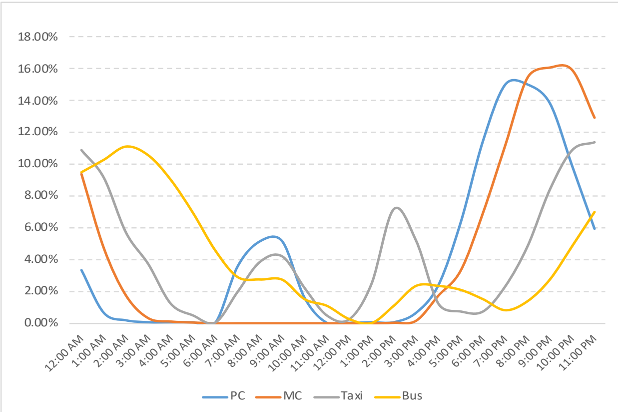


Fig 7 Daily load profile of EV in Thailand [5]

The life cycle (well-to-wheel) GHG emission is a summation of GHG emission in both well-to-tank stage and tank-to-wheel stage, as shown in Eq. (6**)**. The well-to-tank GHG emissions can be calculated from the multiplication of energy supply to end-use and the corresponding factors, as usually presented in term of g of CO_2 eq. per a unit of energy supply for end-use, as presented in Eq. (7). The tank-to-wheel GHG emissions can be estimated from the final energy consumption at the end-use and its corresponding GHG emissions factor, which normally presented in term of g of CO_2 eq. per a unit of energy used, as shown in Eq. (8).

$$GHG_{wtw,j} = GHG_{wtt,j} + GHG_{ttw,j} \qquad (6)$$

where $GHG_{wtw,j}$ is the well-to-wheel greenhouse gas emission of fuel type *j* (g of CO_2 eq.), $GHG_{wtt,j}$ is the well-to-tank greenhouse gas emission of fuel type *j* (g of CO_2 eq.), $GHG_{ttw,j}$ is the tank-to-wheel greenhouse gas emission of fuel type *j* (g of CO_2 eq.).

$$GHG_{wtt,j} = ED_{ttw,j} \times f_{GHG,j}^{wtt} \qquad (7)$$

where $GHG_{wtt,j}$ is the well-to-tank GHG emission of fuel type *j* (g of CO_2 eq.), $ED_{ttw,j}$ is the tank-to-wheel energy supply to end-use (or consumption at end-use) of fuel type *j* (MJ), $f_{GHG,j}^{wtt}$ is the well-to-tank GHG emission factor of fuel type *j* (g of CO_2 eq./MJ of fuel use).

$$GHG_{ttw,j} = ED_{ttw,j} \times f_{GHG,j}^{ttw} \qquad (8)$$

where $GHG_{ttw,j}$ is the tank-to-wheel GHG emission of fuel type *j* (g of CO_2 eq.), $ED_{ttw,j}$ is the tank-to-wheel energy consumption at end-use of fuel type *j* (MJ), $f_{GHG,i}^{ttw}$ is the tank-to-wheel GHG emission factor of fuel type *j* (g of CO_2 eq./MJ of fuel use).

2.3 Daily load profile and peak demand of EV

Based on the study of Energy Policy and Planning Office (EPPO) [4], the expected daily load profile of various road transport vehicles, i.e. private car (PC), motorcycle (MC), taxi (TAXI) and bus (BUS), are shown in Figure 7. Normally, the electricity demand of private vehicle EV, i.e. PC, MC and TAXI, will be increasing in evening time. From this study, the peak demand of these vehicles will be around 7pm to 9pm. In contrast, electricity peak demand of BUS will be at early morning time during 1am to 3am.

3. RESULTS

3.1 Scenario mapping and growth of EVs

According to the brainstorming session among key stakeholders, key drivers affecting future EVs market in the future, within 2040, have been identified as shown in Figure 8. The results come up with the conclusion that Thai government role on policy commitment is crucially identified as a critical uncertainty to initiate EVs market in Thailand. It is not only the incentives to car makers, but also the requirement from end-user side, e.g. subsidization of vehicle upfront price to reduce total cost of vehicle ownership, readiness of public charging infrastructure and etc. Thus, the future scenarios can be explored by two cases as follows:

1) ***Current Policy Scenario (CPS)*** represents the current actions of government support on EVs. It is mostly based on the incentives directly to car makers, e.g. discounted excised taxes, promotional privilege on investment, without any other supportive scheme on consumer side. Public electric vehicle supply equipments (EVSEs) are introduced individually by private sectors, causing the low ratio of public EVSE per unit EV. Market is driven by individual interest and limited by purchasing power. Revenue loss of internal combustion engine (ICE) industry is more concern on EVs policy support.
2) ***Proactive Policy Scenario (PPS)*** represents full package of government supports on both supply and demand sides, e.g. individual and corporate tax exemption. Public EVSEs are set as agenda for public private partnership. EVs are treated as a key option to solve air pollution problem. Market is driven by government lead. Automotive industry is rapidly transformed from ICE to EVs component exporter.

According to the aforementioned scenarios,

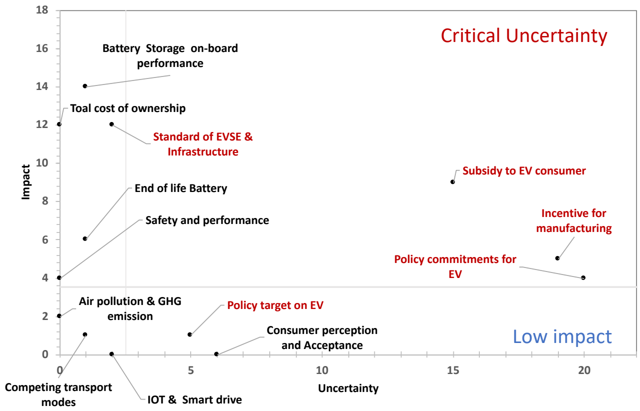
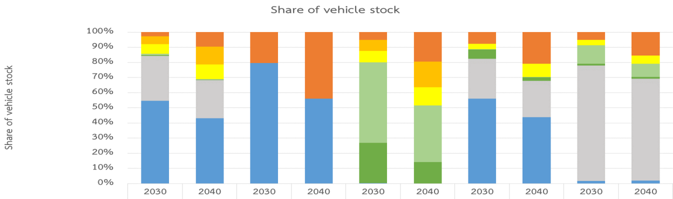


Fig 8 Key drivers and critical uncertainties affecting EVs market to 2040 in Thailand [5]

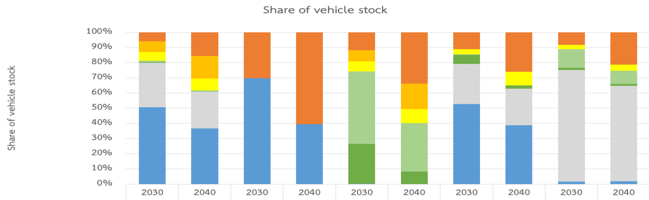
participants allow to give perspectives on possible market sale of EVs in 2040. The obtained voting results are discussed and translated to the number of vehicle stock by taking the account of vehicle survival rate for the calculation, as illustrated in Figure 8. In term of vehicle stock share, motorcycles, taxis and private cars are the top three that EVs can possibly take over. Long life span of averaged survival rate in Thailand causes slower penetration of EVs in term of vehicle stock.

For the CPS, EVs can take over less than half (42%) for motorcycle, following by taxi (36%), private car (22%), commercial car (20%) and bus (16%). For the PPS scenario, only E-motorbike can take over more than half (60%) to total stock in 2040. It follows by taxi (50%), private car (30%), commercial car (25%) and bus (20%) respectively, as illustrated in Figure 9.



Vehicle stock (1000 units)	Private Car 2030	Private Car 2040	Motorcycle 2030	Motorcycle 2040	Taxi 2030	Taxi 2040	Commercial Car 2030	Commercial Car 2040	Bus 2030	Bus 2040
BEV	484	2388	7239	21546	10	53	2	7	15	54
PHEV	904	2864			14	46				
HEV	1091	2372			15	33	1	3	11	19
CNG	151	113			104	102	0	0	36	30
LPG	81	60			52	38	1	1	4	4
Diesel n Biodiesel	5160	6189			0	0	5	8	224	235
Gasoline n Gasohol	9455	10625	28180	27570	0	0	11	14	5	6

(a) Current Policy Scenario (CPS)



Vehicle stock (1000 units)	Private Car 2030	Private Car 2040	Motorcycle 2030	Motorcycle 2040	Taxi 2030	Taxi 2040	Commercial Car 2030	Commercial Car 2040	Bus 2030	Bus 2040
BEV	1016	3819	10729	29670	23	92	2	9	25	74
PHEV	1250	3679			14	46				
HEV	961	1949			13	25	1	3	8	14
CNG	151	113			94	87	0	0	36	30
LPG	81	60			52	22	1	1	4	4
Diesel n Biodiesel	5104	5954			0	0	5	8	216	220
Gasoline n Gasohol	8762	9038	24690	19446	0	0	10	13	5	6

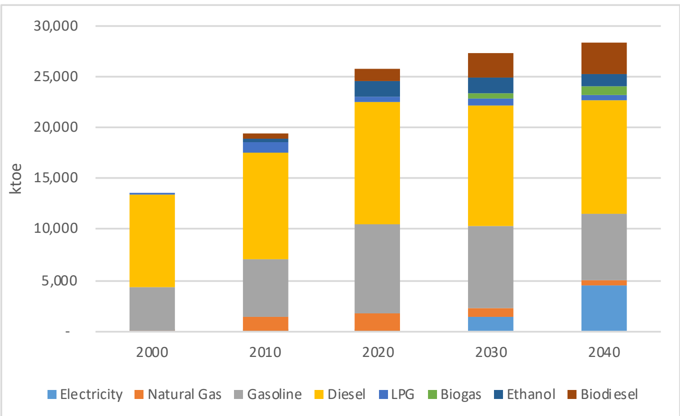
(b) Proactive Policy Scenario (PPS)

Fig 9 Forecasting of number and share of EV in vehicle stock in each scenario in 2030 and 2040 [4]

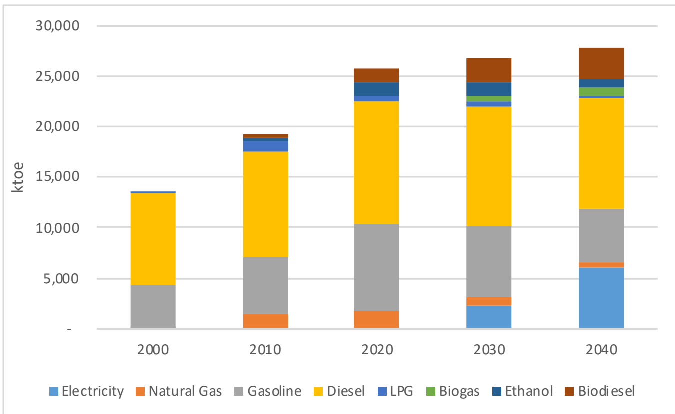
3.2 Impacts on energy demand in transport sector

The number of EVs will increase gradually in Thai's road vehicle stock. Penetration of EVs in the stock will raise up electricity demand in road transport sector in the future. Figure 10 presents total energy demand in road transport sector by fuel type in CPS and PPS. By 2040, electricity demand in road transport sector will increase to 4,407 ktoe (51,712 GWh) and 6,057 ktoe (71,076 GWh), in CPS and PPS, respectively. This is accounting for 15.5% and 21.7% of total energy demand in road transport sector.

Comparison of energy demand in these two scenarios is presented in Figure 11. Despite higher number of EVs in PPS will consume electricity more than that of CPS around 1,650 ktoe (19,363 GWh), they can reduce 474 ktoe of total energy consumption. These include reduction of 1,312 ktoe of gasoline, 241 ktoe of diesel, 327 ktoe of biofuels, etc.



(a) Current Policy Scenario (CPS)



(b) Proactive Policy Scenario (PPS)

Fig 10 Forecasting energy demand by fuel type in each scenario

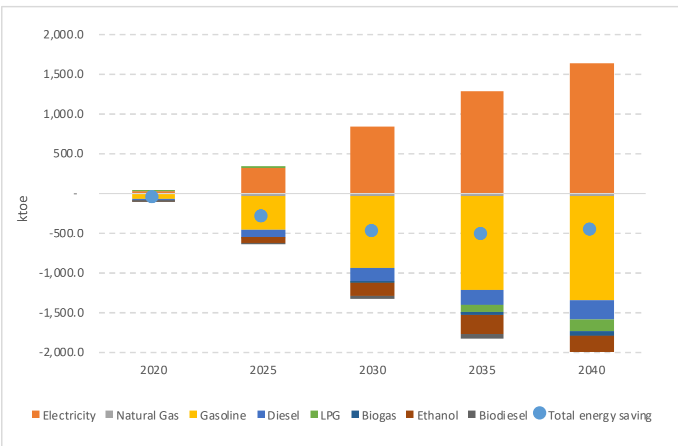


Fig 11 Difference of energy consumption in road transport sector between PPS and CPS

3.3 Impacts on electricity supply and peak load

Impacts of EVs will not only increase the electricity demand in transport sector, but also affect to daily load demand pattern. Figure 12 presents daily load profile of EVs in 2030 and 2040 by scenario.

Electricity peak demand of EVs is expected to be at evening time during 8pm to 10pm. In CPS, peak demand of electricity will be 3,628 MW in 2030 and increase to 10,066 MW in 2040. For PPS, electricity peak demand will be 5,675 MW and 13,955 MW in 2030 and 2040, respectively.

Due to number of vehicles, fuel economy and average travel distance, among those of EVs, bus will share the highest demand of electricity, follow by motorcycles and private cars, respectively. Electricity demand of bus will take place in early morning during 12am to 5am, while electricity of private vehicle (cars and motorcycles) will be in the evening during 7pm to 9pm.

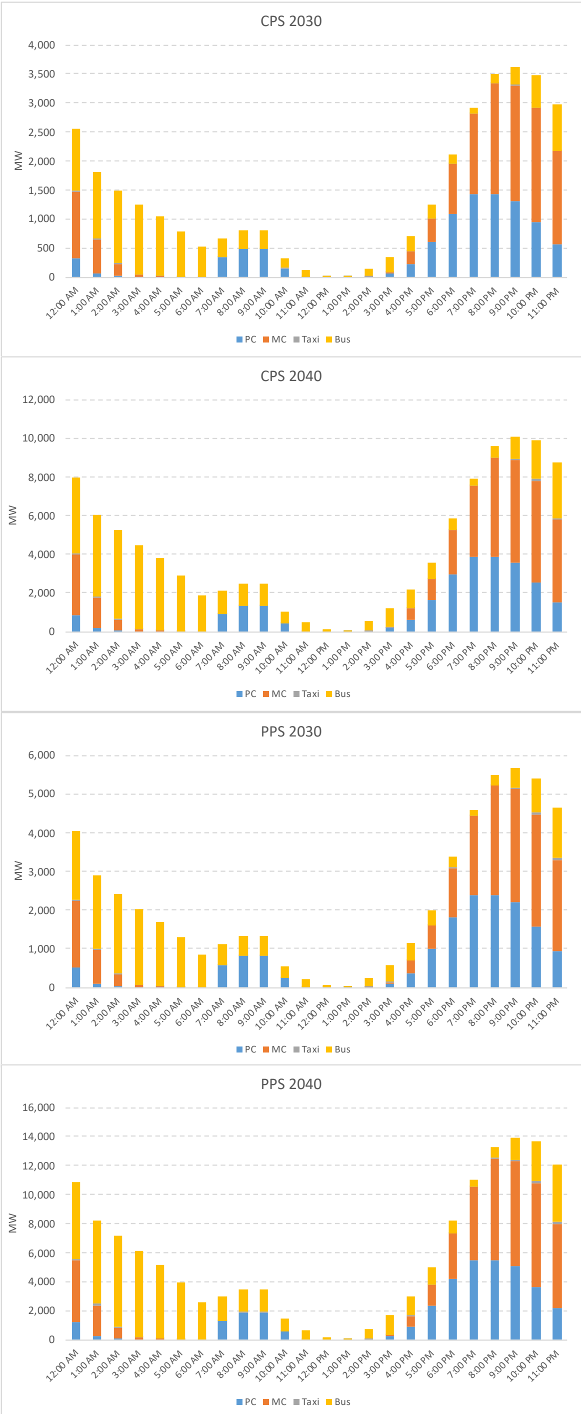


Fig 12 Daily load profile of EVs in 2030 and 2040

3.4 GHG emission

Although the increasing of EVs will reduce fossil fuel demand as well as GHG emission of end-users in road transport sector, it will raise the demand of electricity and also increase GHG emission in power generation sector. However, from well-to-wheel basis, increasing of number of EVs in PPS scenario will reduce GHG emission about 4 million ton of CO_2eq (MtCO_2eq) and 10 MtCO_2eq by 2030 and 2040, respectively, as presented in Figure 13

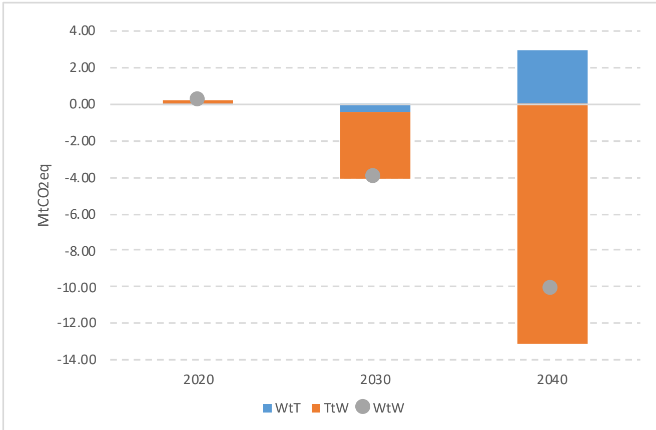


Fig 13 Difference of well-to-wheel GHG emission in road transport sector between CPS and PPS

4. CONCLUSIONS

Policy commitment of the government plays a crucial role for EVs market in Thailand. To increase number of EVs in road vehicle stock, not only the incentives to car makers in supply side, but subsidy of vehicle upfront price for end-user and expansion of public charging infrastructure are also required.

The future scenarios can be explored by two cases. *Current Policy Scenario (CPS)* represents the current actions of government support on EVs, whereas *Proactive Policy Scenario (PPS)* represents full package of government supports on both supply and demand sides.

High penetration rate of EVs will impacts on Thailand energy system, especially road transport sector. This include total energy demand pattern, load profile of electricity demand and GHG emission. The results present that total number of EVs in PPS scenario will consume electricity more than that of CPS scenario around 1,650 ktoe (19,363 GWh), but they can reduce 474 ktoe of total energy consumption and 10 MtCO_2eq by 2040.

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