Analysis of the Effect of the Royal Thai Government's Electric Vehicle Promotion Strategy on Future Energy demand, Energy Mix and Emissions from Passenger Land Transport

Ashok Paudel[1] and Boonruang Marungrsi[1,*]

A R T I C L E I N F O

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A B S T R A C T

This paper presents the future energy demand scenario of the land passenger transport system based on the Thai government's proposed Zero Emission Vehicle (ZEV) promotion roadmap, which insists that by 2030 all newly registered vehicles would be ZEV (mainly Electric vehicles) and all by 2035. Two scenarios were Business as Usual (BAU) and government electric vehicle (GEV). The future car registration number is predicted using the log-linear regression method considering the gross domestic product, unemployment rate, and population above 14 years. Other necessary data are collected from various sources. The LEAP-based analysis mechanism is employed to analyze the energy demand and supply scenario from 2020 to 2040. The result shows that the total energy demand will be about 53 Mtoe, an increase of 24% from base year demand (42.3Mtoe) in BAU, but a drop of 4% is evident in GEV. A substantial reduction in diesel and gasoline demand was seen in the GEV scenario, and that energy is supplied by electricity. 36% of total demand is supplied by electricity in 2040 in the GEV scenario. Even in the GEV scenario, the carbon emission from vehicles is still considered up to 2030 but will be half of BAU in 2040. This may indicate a room for additional environmental legislation is still available as it does not meet the government target of reducing emissions by 20% of BAU emission by 2030.

1. INTRODUCTION

Global warming and climate change is this century's most serious global problem. Greenhouse gas (GHG) emission from fossil fuel burning is the primary cause of global warming. Numerous technologies and policy measures are developed or are in the process of development to limit the GHG emission from fossil fuels consumption. In today's context, virtually all vehicles on the road are powered by some fossil fuel, but in the past few years, electric vehicles (EVs) have also started to appear on the road. The electrifying transport sector or so-called green or clean transport is now the talk of the town. Concern policymakers are formulating the strategies, visions, and modalities of EV promotion in their respective jurisdiction. In this context, it is not a surprise to know that, according to the international energy agency (IEA), 7% of the vehicle running on the road will be EVs of some sort in 2030 under standard policy scenarios and even become as high as 12% if sustainable policy measures are implemented [1]. EV30@30 campaign, the product of the clean energy ministerial (CEM), an international forum of leading economics and international development agencies to promote sustainable energy practices, aims to make 30% of their transport fleet to be electric by 2030 [2]. Thailand, the leader in economy and vehicle manufacturing in the ASEAN region, can not lag in this race of electrifying the transport fleet and is not lagging in this regard by formulating the EV promotion roadmap [3]. The government initially proposed that one-third of newly registered vehicles in 2030 would be electric, but they revised the target to make that 50% later on; this might indicate the willingness and ambition of Thailand regarding climate issues [4].

Emission from the internal combustion engines (ICE) is one factor behind the global push for EVs other is energy efficiency. In the case of Thailand, the official energy demand forecast for the year 2036 is about 182700 ktoe. However, the government also commits that about 51700 ktoe can curb demand by implementing various energy efficiency measures. From the annual energy outlook of 2018, it is evident that the transportation sector consumes 39.4% of total energy [5]. On the flip side, this sector also has the potential for demand curtailment. It is estimated that almost half (44.7%) of demand can be eliminated using energy efficiency-related policy and actions [6].

Owing to these facts, it is evident that the number of EVs will skyrocket on the roads in the future. Consequentially, the electricity demand will also increase

[1]*School of Electrical Engineering Suranaree University of Technology, Nakhon Ratchasima, Thailand.*
**Corresponding author:* Boonruang Marungrsi; E-mail: bmshvee@sut.ac.th.

as the fuel exchange from fossil fuel to electricity happens. This may have an impact on the existing electricity system and also on future expansion planning. Adequate estimation of the extent of fuel transition from fossil fuel or ICEs to electricity and subsequent peak load is essential for the utility to ensure supply quality. One estimation suggests that the additional energy demand will be around 12000GWhr in 2036 [6]; however, this estimation does not account for the revied ambitious EV expansion plan by the government and hence might not be as reliable as it should be since EV promotion roadmap expects that all newly registered vehicle will be electric by 2035.

Many papers discuss the energy use pattern and the alternative perspective future of the Thai power system. However, they are relatively old, and the recent government policies have made more substantial climate commitments and renewable targets, so the result might not be favorable anymore. Article [7] presents the effect of renewable targets prescribed by the power development plan 2015 on Thailand's Paris commitment. It evaluates the scenario of fulfilling 100% target renewable integration, 50% of target, and 25% of renewable target integration. Results showed that if the renewable target is fully met, emissions will reduce by 41.71%, is only 50% of the targeted renewable is added to the system. The emission will reduce by 23.75%, and if only 25% of projected renewable integration is possible, then the emission will reduce by about 10% compared to the business-as-usual scenario. It shows that the 50% target renewable integration will be sufficient to meet the government's climate commitment. However, this is only concerned with power sector emissions, not national emissions. The analysis period is 2005 to 2030. The major shortcoming is that it does not include a government EV roadmap. Similar scenarios are analyzed more extensively (2010-2050), and the results are almost consistent [8]. It also argues that if new technologies like hydrogen fuel and tidal energy are considered, the decarbonization of power systems will be achieved much earlier but does not provide the economic and financial analysis of such transformation. A bottom-up econometric approach-based integrated planning model for the Bangkok metropolitan area is presented in [9]. The critical takeaway of this research is that the transportation sector has the highest emission reduction potential. Even though the study period is from 2000 to 2025, it presents a more extensive overview of energy-related issues around Bangkok, which can be extrapolated nationwide with recent trends and government policies. These results are similar to the more recent studies, which also show that transportation and industries are two major energy consumer and possesses the highest potential to reduce consumption either by energy efficiency or by policy intervention like the promotion of mass transit instead of private vehicle [10].

It is safe to assume that to meet the government emission and energy efficiency target, the volume and proportion of EVs will increase in the vehicle fleet. On the contrary, some articles criticize this approach and doubt the possibility of desired success as the policy lacks socio-economic analysis. Furthermore, the policy does not give a clear view of how the power system will be eliminated from fossil fuel or how renewable dominated electricity system will be achieved within that planning horizon and argues that alternatives like reliable and convenient mass transit or public transport might be more feasible [11-12].

This article analyzes the different scenarios of future energy demand based on the government EV promotion roadmap using Low Emission Analysis Platform (LEAP), a scenario-based energy modeling software developed by the Stockholm environment institute. It is beneficial to simulate energy demand, energy generation, the cost involved in energy production, replacement analysis, comparison of alternative energy production options, related environmental impact, etc. LEAP may use any bottom-up, end-use, top-down macroeconomic approach, etc., to simulate the various aspects of the energy system. It is advantageous in short to medium-term operational planning and long-term expansion planning. It has an inbuilt Technology and Environment Database (TED), which is the library of techno-economic as well as environmental characteristics of numerous energy technologies defined by credible international organizations working in the field of climate change and global energy safety and security; Like IEA, intergovernmental panel on climate change, etc. This database makes it easier to compute and verify the environmental impact of various energy production technologies globally and make policy decisions locally. In simple words, LEAP is an optimization framework used for energy system analysis [13].

2. PROCEDURE

Study Model and Variables

The energy demand (ED) model used in the LEAP is primarily based on the number of vehicles (N), vehicle kilometers traveled (VKT), and the fuel economy (FE) of the vehicle. ED model can be expressed as follows:

$$ED_{i,j} = N_{i,j} \times VKT_i \times FE_{i,j} \qquad (1)$$

where, *i* represents the fuel used in the vehicle and *j* is the category of the vehicles. The department of land transport registers the same type of vehicle with different service designations taxis are registered as fixed routes and hotel taxis but are treated as the same and placed in the same category for simplicity. A total of six types of vehicles are considered in this study. They are as follows:

I. Cars (less than seven passengers)

II. Minivan (cars with more than seven passengers, minivans, and minitrucks)
III. Taxis (fixed-route taxis and hotel taxis)
IV. Tricycles (tricycles and tuk-tuks)
V. Bikes (private and public)
VI. Buses (fixed route and flexible route)

Generally, vehicles other than bikes, tricycles, and buses are classified as a more generic light driving vehicle (LDV) group.

Relevant data for this study is obtained from various resources, including government databases, policy reports, previous research, and websites of international organizations, and proper citation is provided wherever necessary. Fuel used in the vehicle is also challenging in Thailand as various types of hybrid fuels are available here, like alcohol blended gasoline with different blending percentages, etc.

For this research, five types of fuel are considered they are as follows:

1. Gasoline, including alcohol blended gasoline (gasohol)
2. Diesel
3. CNG, including gasoline duel fuel
4. LPG, including gasoline duel fuel
5. Hybrid Electric (HE) is dominated by gasoline, so all hybrids are considered gasoline hybrid
6. Battery electric (BE) plus plugin electric (PHE) (plugin hybrids are assumed to be driven by electricity for the majority of the time)

Fuel economy standard for all types of vehicles is not available in Thailand. One assumption is made by the world bank based on the Japanese fuel economy standard and the road condition of non-European nations, as the Thailand vehicle market is dominated by Japanese engines [14]. So, IEA's non-European members' average of 9 km/l for LDV can be used in the case of Thailand. On the other hand, the ASEAN fuel economy roadmap assumes around 13.33 km/l for the LDVs [15]. Similarly, article [16] has assumed the FC of bikes, cars, and buses to be 25.5km/l, 10-12.3km/l, and 7.3 to 8.5km/l, respectively. These variations are due to insufficient data and references. These estimates also lack the FE for EVs and other types of vehicles. The values of FE used in this study are presented in Table 1. Vehicle Kilometer Travelled (VKT) is another factor to be considered in this analysis. VKT of different types of vehicles differs significantly, and the driving area and driving condition also considerably impact annual VKT. In this study, VKT described in [17] is used. This includes both urban and suburban profiles and is more accurate in predicting the driving behavior of the different vehicles. However, the VKT degradation in the first two years is relatively high; for example, the VKT of buses falls to 50% in the second year compared to the first year.

Table 1. Fuel Economy

Vehicle type	Fuel Economy (FE) km/l			Reference
	ICE	*HE*	*BE/PHEV*	
LDV	12.28	17.48	25.73	[18]
Bikes	25.75	-	37	[18]
Bus	7.3	9.41	11.09	[16],[18],

Vehicle registration data, both age-wise and fuel type-wise, is obtained from the department of lad transport, the government of Thailand [19]. Even though the base year of the study is 2020, the new registration in 2019 is considered the base year of new buying as 2020 is heavily affected by the COVID-19 pandemic. Fig.1 presents the age-wise vehicle fleet as of December 2019. The graph's irregularity is due to the historic auto boom that occurred between 2012 to 2014. Thailand's vehicle survival probability profile is assumed to be similar to Manila, Philippines, considering the similar environment and driving behavior [20].

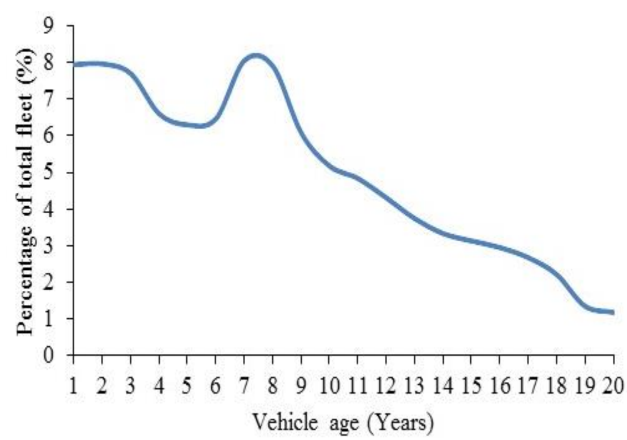

Fig.1. Age of Vehicle Fleet of Thailand as of 2019 [19].

Generally, emission from the vehicle depends on the traveled distance and energy consumption. The total emission is the product of energy demand and emission factor or emission standard. Moreover, An emission standard is a predefined regulation enforced by the regulators. Throughout a vehicle's lifetime, the emission factor also changes and sometimes might exceed the predefined limit. If so, happens regulators take such vehicles off the road. However, in this study, such degradation is not considered due to the unavailability of the relevant data and resources. The current emission standard of Thailand follows the Euro-IV standard, which was promulgated in 2012; however, the fleet consists of the older vehicle as well, so the previous emission standard Euro-III (enforced in 2005) and Euro-II (enforced in 1999 for gasoline LDV and in 2001 for diesel vehicles) are also used in the study.

Estimation of Future vehicle Registration

The estimation of vehicle registration in the future is a difficult task. The vehicle buying decision of a person depends upon various factors, like income, necessity, technology, availability of public transport, etc. GDP or GDP per capita is generally used alongside inflation, unemployment rate, demographics, and consumer price index at a national level. In this study, GDP, unemployment rate, and the population above 14 years are considered independent variables, and the number of vehicles registered is a dependent variable. A log-linear regression model is used for the data analysis.

A log-linear regression model establishes a relationship between independent variables and dependent variables. The model equation of log-linear regression is given below:

$$\ln y = \beta_0 + \beta_1 \ln x_1 + \beta_2 \ln x_2 + \beta_3 \ln x_3 + \varepsilon \qquad (2)$$

The equation has been solved using the data since 1995. Vehicle registration data is obtained from [19], and the other macroeconomic data is obtained from the world bank database [21].

Finally, the unemployment data is fitted to the normal distribution, and random numbers are generated based on the normal distribution. The normal distribution parameters viz mean and the standard deviation is 1.27 and 0.78, respectively.

Equation 2 was solved using MATLAB, and the results are as follows:

Table 2. Parameters of Regression Analysis

parameter	estimate	t-stat	p-value
β_0	4.94	-0.3	0.76
β_1	1.47	2.1	0.042
β_2	-0.50	-4.8	0.00007
β_3	-1.71	-0.93	0.36

The R^2 value is 0.898, and the adjusted R^2 is 0.884

Results show that unemployment is very sensitive and can hugely impact car registration.

The forecasted vehicle registration values based on the developed model are shown in Fig. 2.

3. SIMULATION SETUP AND SCENARIOS

This study is primarily based on the government EV promotion roadmap but also includes the idea from other resources supporting the roadmap. The growth of the LDV section is projected to remain at 2.9% in this decade [22]. Converting a tuk-tuk to an electric one collaborates with various universities and industries. Government is also keen to introduce electric buses in the country, and it is expected that 3000 buses will be on the road by 2025 and 10000 by 2030 [23-16]. An estimate suggests that electric vehicles will occupy around 38% share, distributed among HEV, PHEV, and BEV as 18%,16%, and 4%, respectively [18]. Two scenarios, Business as Usual (BAU) and Government EV plan (GEV), are analyzed using the LEAP modeling tool.

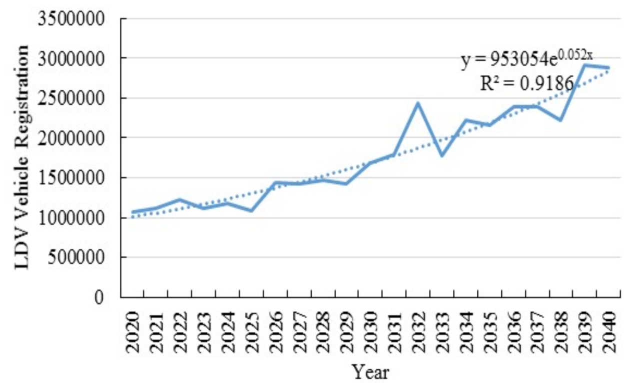

Fig. 2. Future Vehicle Registration Projection.

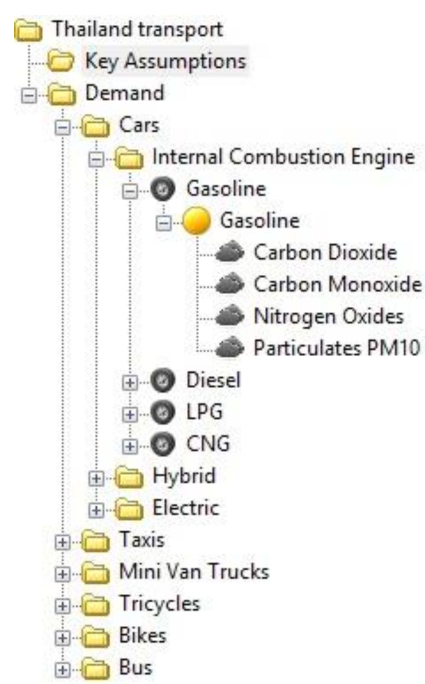

Fig. 3. Simulation Model Created in LEAP Software.

The total demand is the summation of six members' energy consumption, i.e., cars, taxis, minivans, tricycles, motorbikes, and buses. Each vehicle type is divided into three categories: internal combustion engine, hybrid, and electric (including plugin electric). Further division is based on the type of fuel required, and finally, the emission from each fuel is also depicted. Fig. 3 presents the LEAP simulation model used for the simulation purpose, which depicts the detailed classification of the car; other vehicle types simply follow the same pattern.

BAU scenario analyzes the future energy demand based upon the existing policy and practices or the continuation of the current trend. One thing to be noted in the BAU scenario is that the number of EVs has been increasing in both numbers and percentage (as the base is very insignificant) in recent years. It can be expected to continue even in the BAU scenario. However, such growth is in the range of hundreds. Without good government policy and intention to promote EVs, such spontaneous growth will remain negligible, and the composition of the whole vehicle fleet will remain largely unaffected.

4. RESULTS AND DISCUSSION

The results obtained from the simulation show that the final energy demand in the BAU scenario will reach the mark of 52.5 million tonnes of oil equivalent (Mtoe) in 2040, an increase of 24.11% (42.3 Mtoe) compared to the base year of 2020. On the contrary, the GEV plan will reduce the final energy requirement by about 4% (40.6 Mtoe and 42.3 Mtoe in 2040 and 2020, respectively) in 2040 than the year 2020, as shown in Fig. 4. As the number of EVs increases in the vehicle fleet, the overall demand will decrease compared to the BAU as the fuel economy of the EVs is significantly higher than the IC vehicles.

The composition of the energy supply is another point of interest and is evident from the result that in the BAU scenario, the share of electricity is extremely insignificant, and almost all demand is supplied by diesel and gasoline, as presented in Fig.5. Subsequent figure Fig. 6 depicts the final energy composition in 2040 in the GEV scenario. It is seen that the share of diesel will decrease significantly, followed by gasoline and that energy directly adds up to the share of electricity. The enormous impact on the diesel share is mainly due to the higher number of diesel vehicles initially. A diesel engine almost exclusively drives the minivan and mini trucks as time passes that get electrified. The primary concern of this study is to determine the share of electricity in the final energy demand as it serves as the basis for future energy demand determination and expansion planning. Electricity will supply about 36.2% (14.7 Mtoe, 171.1 TWhr) of demand in 2040. The annual electricity demand and year-on-year (YOY) percentage change in demand is presented in Fig.7. It is to be noted that some initial values of YOY change are not shown in the figure as the actual value is shallow to make the figure more readable. The electricity demand skyrocketed from 0.1 TWh in 2020 to 171 TWh in 2040.

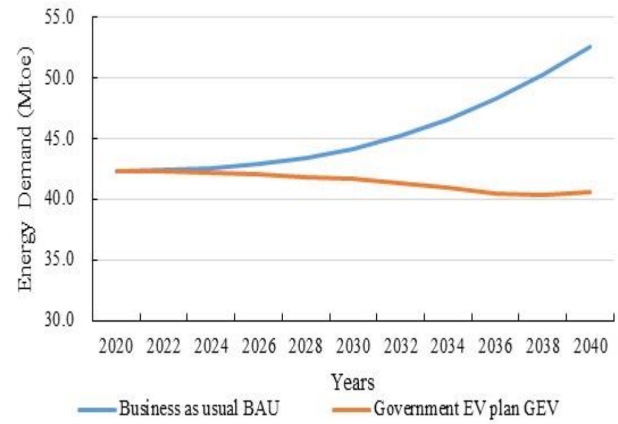

Fig. 4. Projection of Final Energy Demand

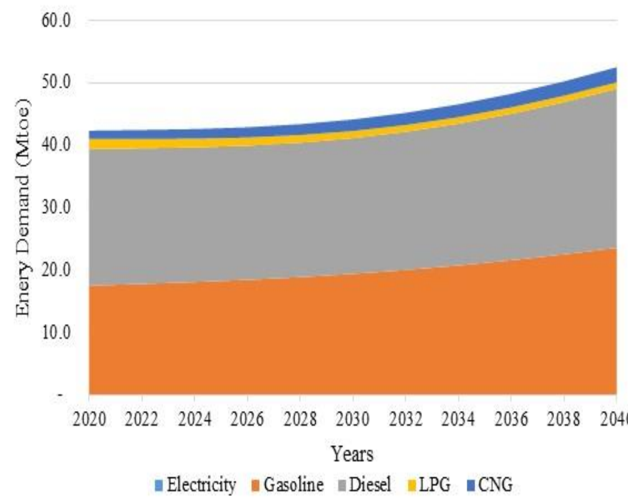

Fig. 5. Energy Supplied by Fuel Type BAU Scenario

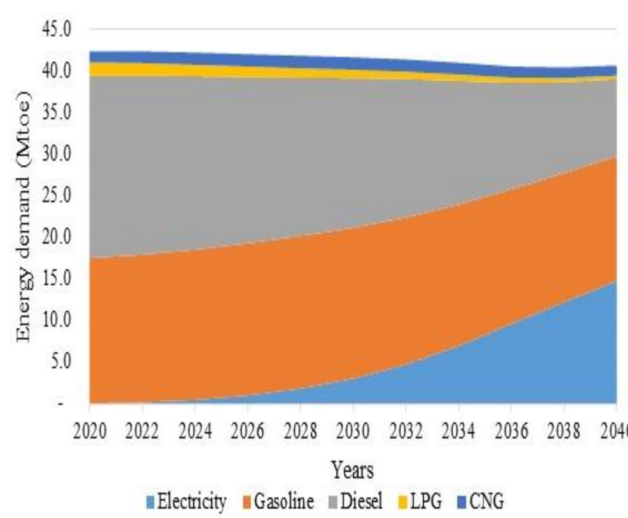

Fig. 6. Energy Supplied by Fuel Type in GEV Scenario

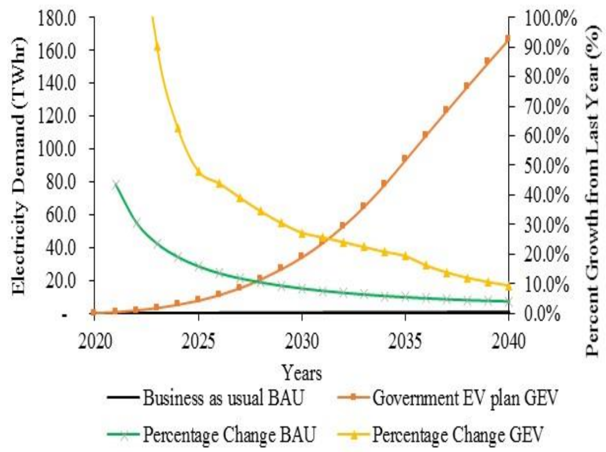

Fig. 7. Electricity Demand and year-On-Year Percentage Change

Energy demand is also related to distance traveled. VKT of vehicles is presented in Fig.8. The VKT in 2020 is about 750 billion km, reaching about 950 billion km in 2040, which is about 27% higher than the base year. The distance traveled is precisely equal in both scenarios as it should be as the distance traveled should not change just because of the type of fuel used in the vehicle. Since both lines are overlapped, only one color is visible in Fig. 8. The increase in VKT suggests the increased motorization rate in Thai society.

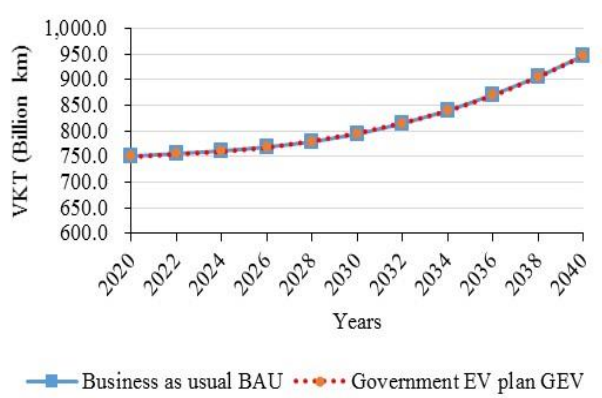

Fig. 8. VKT Travelled.

The primary objective of the EV promotion is to reduce greenhouse gas emissions. The Government of Thailand has agreed to reduce its emission by 20% by 2030 using various measures compared to the business-as-usual scenario of the national economy. So, it is expected that GEV will also reduce emissions from a section of the transport sector by at least 20% by 2030 compared to the BAU scenario.

The CO_2 emission result is presented in Fig. 9. In the BAU scenario, emission decrease for some time and then increases again. This effect is due to the presence of the old vehicle in the fleet. Since 2012 new emission standard has been enforced in Thailand. Up to 2032, those older, more polluting vehicles get replaced, and in 2032, the emission is minimal. After that, emission follows the vehicle growth.

The government target of trimming emissions by 20% of BAU in 2030 appears unachievable without new emission regulations. However, the GEV plan does help to ax emissions by 21% in 2030 compared to the base year 2020. On the contrary, in the GEV scenario, emission follows a downward trend from starting as the emission factor of EVs is shallow (Hybrid EVs). On the positive side, GEV emissions will equal 75% of BAU emissions in 2034 and 49% in 2040. The emission amount of other pollutants like carbon monoxide, nitrogen oxides, and PM10 in BAU and GEV is given in Table 3. GEV emission amount is given in terms of percentage of BAU and is placed in parenthesis.

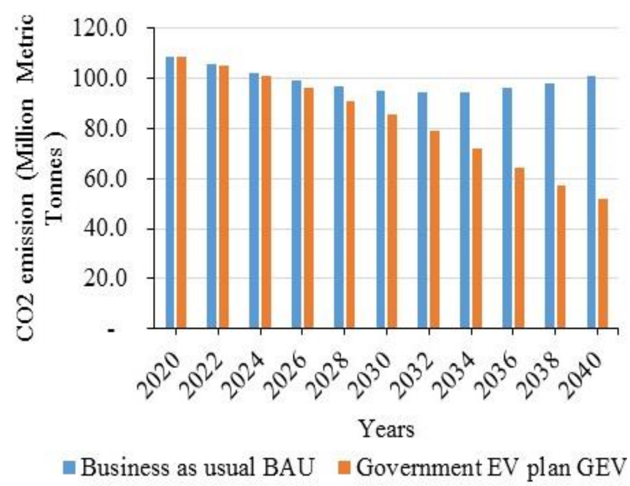

Fig. 9. CO_2 Emission Comparison.

Table 3. BAU Emission (GEV Emission = % of BAU)

pollutants	Years			
	2025	2030	2035	2040
CO_2 (million metric tons)	100.4 (98%)	95 (90%)	95.1 (71%)	100.9 (51%)
CO (thousand metric tons)	558.1 (99%)	433.8 (94%)	313.7 (75%)	341.5 (58%)
NO_x (thousand metric tons)	224.4 (97.4%)	200.1 (88.5%)	178.7 (66%)	195.3 (44)
PM10 (thousand metric tons)	65.5 (98.7%)	61.1 (92%)	59 (74%)	64.8 (57%)

5. CONCLUSION

Climate change and its mitigation have been the prime concern of the global community in recent times. Countries are developing new policies and technologies to limit greenhouse gas emissions. Promoting zero-energy vehicles, mainly EVs, is an attempt to limit the emission from the transport sector. Thailand has declared to register only zero-emission vehicles after 2030. This article attempts to determine the final energy consumption, energy mix, and emission from Thailand's passenger land transport system from 2020 to 2040, considering BAU and GEV scenarios. Projection of annual vehicle registration is carried out by macroeconomic analysis, and that result is used to make a LEAP model. The model suggests that the final energy demand will reach 53Mtoe in 2040 in the BAU scenario and 41 Mtoe in the GEV scenario from the base demand of 42Mtoe in 2020. In 2040, GEV emission will be about half of the BAU emission. Electricity will supply about 36% of demand in 2040 in the GEV scenario despite its negligible presence in the initial years. CO2 and other pollutant emissions are controlled significantly, but stricter regulations might be necessary to limit emissions within the targeted limit.

The result obtained is helpful in the power expansion planning process. This bottom-up approach to determining energy demand will help estimate future electricity demand and the subsequent impact on the grid. The grid impact assessment is out of the scope of this article, which can be attributed to its future extension.

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REFERENCES

[1] International Energy Agency, "Global EV outlook 2020 Entering the decade of electric drive?" International Energy Agency.

[2] Clean Energy Ministerial, Retrieved May 18, 2021, from http://www.cleanenergyministerial.org/campaign-clean-energy-ministerial/ev3030-campaign

[3] Office of National Higher Education Science Research and Innovation Policy Council. Retrieved May 12, 2021, from https://www.nxpo.or.th/th/en/report/5606/19

[4] Thananusak, T.; Punnakitikashem, P.; Tanthasith, S.; Kongarchapatara, B. The Development of Electric Vehicle Charging Stations in Thailand: Policies, Players, and Key Issues (2015–2020). World Electr. Veh. J. 2021, 12, 2. https://doi.org/10.3390/ wevj12010002

[5] Thailand Energy Efficiency Situation 2018. Department of Alternative Energy Development and Efficiency, Ministry of Energy, (2018).

[6] P. Saisirirat, N. Chollacoop, M. Tongroon, Yossapong L. and J. Pongthanaisawan, "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". Energy Procedia 2013, 34, 459-470.

[7] T.V. Kusumadewi, P. Winyuchakrit, P. Misila, and B. Limmeechokchai. "GHG Mitigation in Power Sector: Analyzes of Renewable Energy Potential for Thailand' s NDC Roadmap in 2030." Energy Procedia, 2017, 138: 69–74. https://doi.org/10.1016/j.egypro.2017.10.054.

[8] T.V. Kusumadewi, P. Winyuchakrit, and B. Limmeechokchai, "Long-Term CO2 Emission Reduction from Renewable Energy in Power Sector: The Case of Thailand in 2050." Energy Procedia, 2017, 138: 961–66. https://doi.org/10.1016/j.egypro.2017.10.089.

[9] A. Phdungsilp, "Integrated Energy and Carbon Modeling with a Decision Support System: Policy Scenarios for Low-Carbon City Development in Bangkok." Energy Policy, 2010, 38(9): 4808–17. http://dx.doi.org/10.1016/j.enpol.2009.10.026.

[10] S. Traivivatana, and W. Wangjiraniran, "Thailand Integrated Energy Blueprint (TIEB): One Step towards Sustainable Energy Sector." Energy Procedia, 2019, 157: 492–97. https://doi.org/10.1016/j.egypro.2018.11.213.

[11] S. Selvakkumaran, E. O. Ahlgren, P. Winyuchakrit, and B. Limmeechokcha, "Electric Vehicle (EV) Transition in Thailand: Is it Beneficial," CUE 2018 on Green Energy for Sustainable Development, 2018, Phuket.

[12] K. Chantharaphaha, "Future Directions of Electric Vehicles and the Thai Automobile Industry," Asian Administration and Management Review 2020, 3(1), 15-21.

[13] C.G. Heaps, "LEAP: The Low Emissions Analysis Platform.", [Software version: 2020.1.36] Stockholm Environment Institute, 2021. Somerville, MA, USA. https://leap.sei.org

[14] The World Bank, "Thailand: Making Transport More Energy Efficient," 2007, Retrieved 5 2, 2021, from https://documents1.worldbank.org/curated/en/470771468173950665/pdf/500340WP0p10951y0Updater01310812009.pdf

[15] ASEAN Secretariat, "ASEAN Fuel Economy Roadmap for the Transport Sector 2018-2025: with Focus on Light-Duty Vehicles," ASEAN Secretariat, 2019.

[16] Penwadee Cheewaphongphan, A. Junpen, S. Garivait, and S. Chatani, "Emission Inventory of On-Road Transport in Bangkok Metropolitan Region (BMR) Development during 2007 to 2015 Using the GAINS Model," Atmosphere,2017, 8(167). doi:10.3390/atmos8090167

[17] T. Limanond, J. Pongthanaisawan, D. Watthanaklang, and O. Sangphong, "An Analysis of Vehicle Kilometers of Travel of Major Cities in Thailand," ATRANS: Asian Transportation Research Society, Bangkok,2009.

[18] L.Yosaphong, (2015). "Assessment of Electric Vehicle Technology Development," National Science and Technology Development Agency (NSTDA), 2015. Retrieved from http://waa.inter.nstda.or.th/stks/pub/2015/20151222-electric-vehicle.pdf

[19] Department of land Transport, New Car Registration Statistics, (Government of Thailand). Retrieved 5 19, 2021, from https://web.dlt.go.th/statistics/

[20] M Monorom Rith, A. M. Fillone and J. B. Manuel Biona, "Development and application of the Weibull distribution-based vehicle survivorship models for a metropolis of a developing country," Songklanakarin Journal of Science and Technology, 2020, 46(6), 1233-1238.

[21] The World Bank, Data, Retrieved 6 21, 2021, from https://data.worldbank.org/country/thailand

[22] GIZ (German International Cooperation), "Development of a National Urban Mobility Programme for Thailand An Inventory and Assessment of National Urban Mobility in

Thailand," GIZ, 2019.
[23] Thai Electric Vehicle Company Ltd. (TEV), Company Profile," 2021. Retrieved 5 24, 2021, from http://www.tev.co.th/about.php
[24] National Science and Technology Development Agency (NSTDA), "Electric bus prototypes unveiled to Prime Minister," 2021. Retrieved 5 23, 2021, from https://www.nstda.or.th/en/news/news-years-2020/1128-electric-bus-prototypes-unveiled-to-prime-minister.html
[25] S. Twarath, "Thailand's Energy 4.0," (Energy Policy and Planning Office). Retrieved 5 21, 2021, from https://iecc.energy.go.th/wp-content/uploads/2019/03/00_Energy-4.pdf
[26] K. Pongpan, "Thailand's Automotive Industry," (Thailand Board of Investment). Retrieved 5 21, 2021, from https://www.boi.go.th/upload/content/2.%20[PPT]%20Thailand's%20Automotive%20Industry%20and%20Current%20EV%20Status_5c864c90761f6.pdf