Chapter 2

Well-to-Wheel Analysis of EVs in ASEAN Countries

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Chapter 2

Well-to-Wheel Analysis of EVs in ASEAN Countries

1. Introduction

In the Association of Southeast Asian Nations (ASEAN), the use of automobiles is rapidly spreading, resulting in various adverse effects such as deteriorating air pollution, increasing oil imports, and increasing greenhouse gas (GHG) emissions. Automobile electrification is effective in reducing oil consumption and air pollution in the road sector. However, energy consumption and GHG emissions for not only tank-to-wheel but also 'well-to-tank should be considered.

This study estimates GHG emissions from passenger light duty vehicles (PLDV) on a well-to-wheel basis for 2030, 2040, and 2050 to contribute policy planning of ASEAN countries in the field of automobile and energy. The study scopes Indonesia, Thailand, Malaysia, Viet Nam, and Brunei Darussalam.

2. Estimation Method

2.1. Scope of the Well-to-Wheel Analysis

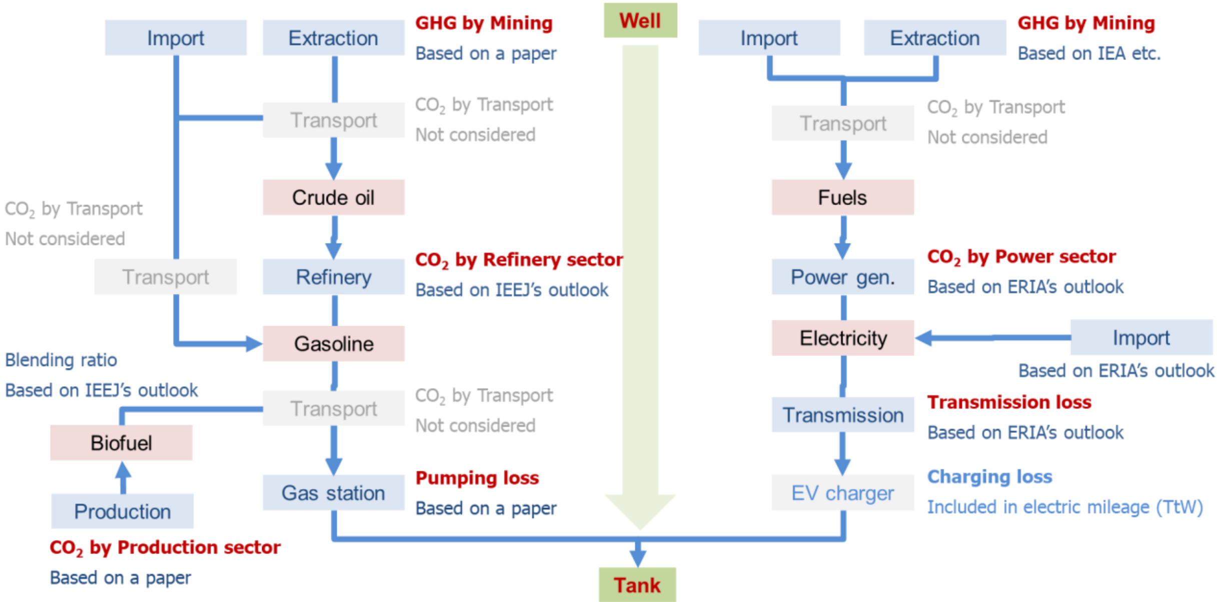
The well-to-wheel (WTW) analysis is to consider GHG emissions (and energy consumption) in automotive fuels throughout the process from fuel mining to transformation, transport, and final consumption. When comparing the amount of GHG emissions by automobiles that use different energies (gasoline, electricity, biofuels, etc.), it is necessary to consider the entire energy supply process, not only at the time of final consumption using automobiles.

Tank-to-wheel (TTW) is the final consumption stage and refers to the time when using an automobile. Fossil fuels (gasoline, etc.) emit CO_2 when burned at the final consumption stage, whilst electricity and biofuels do not.

Well-to-tank (WTT), on the other hand, refers to the energy supply process, from fuel mining to transformation, transport, and filling to automobiles (Figure 2.1). For gasoline, it covers GHG emissions in each process of mining of crude oil, which is the raw material of gasoline, transport to a refinery plant, refining into gasoline in the plant, transport to a gas station, and refuelling an automobile. Viewing in terms of a country, crude oil may be mined and refined into gasoline in the home country, crude oil may be imported and then refined in the home country, or gasoline itself may be imported. In the case of imports, GHG emissions at the mining, transport, and refining stages in the export country should be tracked. Gasoline might be mixed with biofuels and supplied, in which case GHG emissions during the production of the biofuels is also covered.

In the case of electricity, it covers GHG emissions during mining of fossil fuels, which are raw materials, transport to a power generation plant, generation at the plant, transmission to charge station, and recharging to an electric vehicle. For imported fossil fuels or electricity, emissions from mining, transport, and generation must be covered in the export country, as like gasoline.

Figure 2.1. Energy Flow of Well-to-Tank



Note: Transport is out of scope in this study. This is because the form of transport (ships, pipelines, railroads, trucks, etc.) of each country are complicated, and it is not easy to obtain information such as the transportation mix and transportation distance of each mode.
ERIA = Economic Research Institute for ASEAN and East Asia, GHG = greenhouse gas, IEA = International Energy Agency, IIEJ = Institute of Energy Economics, Japan.
Source: Authors.

2.2. Assumptions

This WTW analysis scopes vehicle types such as internal combustion engine (ICE) vehicles, hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs).[4] To make a comparison amongst the powertrain types, we estimate GHG emissions per 1 kilometre of travel distance. The target fuels are gasoline, biofuel, and electricity.

[4] Fuel-cell electric vehicles are out of scope in this study. This is because the hydrogen supply process is complicated and it is unclear what kind of supply system each country plans.

Table 2.1. CO_2 Factor of Energy for Automobiles

	Well-to-Tank	Tank-to-Wheel
Gasoline	varies by country	2,400 gCO_2/L^*
Biofuel (ethanol)	1,200 gCO_2/L^*	0 gCO_2/L^*
Electricity	varies by country	0 gCO_2/kWh

Note: * litre of gasoline equivalent.
G = gram, kWh = kilowatt hour, L = litre.
Source: Authors.

2.2.1. Assumptions for Tank-to-Wheel

TTW calculates GHG emissions when driving a car. Here, the main factors are distance travelled (gas/electric) and CO_2 factors of energy. They are set as shown in Table 2.1 and Table 2.2. We assume the efficiencies are identical amongst the countries and without any improvement in the future.

Table 2.2. Fuel Efficiency by Powertrain

	Fuel Efficiency	Engine / Battery Driving Ratio
ICE	20 km/L	100% / 0%
HEV	35 km/L	100% / 0%
PHEV	35 km/L, 8 km/kWh	30% / 70%
BEV	8 km/kWh	0% / 100%

ICE = internal combustion engine, HEV = hybrid electric vehicle, km = kilometre, kWh = kilowatt hour, L = litre, PHEV = plug-in hybrid electric vehicle, BEV = battery electric vehicle.
Source: Authors.

2.2.2. Assumptions for Well-to-Tank

WTT calculates GHG emissions during the fuel supply process. We describe in detail separately for liquid fuels (gasoline, biofuel) and electricity.

Liquid Fuels

GHG Intensity During Mining

The GHG emissions (per litre of gasoline) during mining crude oil, which is the raw material of gasoline, are set as shown in Table 2.3. For the GHG intensity when mining in domestic oil field, we refer to a paper by Masnadi et al. (2018). Regarding the GHG intensity of imported crude oil, we specify the import source in the trade data in the ASEAN Stats Data Portal (https://data.aseanstats.org/trade-annually), and then estimate average of the intensities of each export country weighted by import value of the top five countries (excluding countries with less than 3%). We set to fix that the intensity at the mining, the import ratio of crude oil and import source mix at the current level.

Table 2.3. GHG Emissions During Crude Oil Mining

	Domestic Crude Oil[1] gCO_2eq/L[*4]	Imported Crude Oil[2] gCO_2eq/L[*]	Import Ratio[3]
Indonesia	489	287	29%
Thailand	163	242	66%
Malaysia	412	258	24%
Viet Nam	283	220	43%
Brunei	182	301	0%

Note: *litre of gasoline equivalent.
GHG = greenhouse gas.
Sources: [1]Masnadi et al. (2018), [2]Authors, [3]Estimated based on IEA (2021), World Energy Statistics and Balances.

GHG Intensity at Refinery

The GHG emissions (per litre of gasoline) during refining crude oil into gasoline are set as shown in Figure 2.5. For the GHG intensity in domestic refinery plant, we estimate based on the International Energy Agency's energy balance statistics. Regarding the intensity of imported gasoline, we specify the import source in the trade data in the ASEAN Stats Data Portal, and then estimate the average of the intensities of each export country weighted by import value of the top five countries (excluding countries with less than 3%). Regarding emissions during crude oil mining for imported gasoline, the intensity of their own country is set in the case of oil-producing countries, whilst in the case of non-producing countries intensity is adopted as the world average assuming importing crude oil. We set to fix that the intensity at the refinery, the import ratio of gasoline and import source mix at the current level.

Table 2.4. GHG Emissions at Refinery

	Domestic Gasoline [*1] gCO_2eq/L	Imported Gasoline [*2] gCO_2eq/L[*]	Import Ratio [*3]
Indonesia	173	405	54%
Thailand	43	377	20%
Malaysia	112	418	56%
Viet Nam	16	494	26%
Brunei	867	463	50%

Note: *litre of gasoline equivalent.
Sources: *[1] Estimated based on IEA (2021), *[2] Authors. Including GHG emissions at refinery and extraction.

GHG Intensity During Biofuel Production

The GHG emissions (per litre of gasoline) during producing biofuels are set as shown in Table 2.5. We refer to a paper by ERIA (2020) for the intensity and set biofuel blending ratio based on IEEJ's outlook.

Table 2.5. GHG Emissions from Biofuel Production

	Biofuel Production *1 gCO_2eq/L*	**Blending Ratio in 2050 *2**
Indonesia	1,200	0%
Thailand	1,200	35%
Malaysia	1,200	0%
Viet Nam	1,200	0%
Brunei	1,200	0%

Note: * litre of gasoline equivalent.
Sources: *1 ERIA (2020),*2 IEEJ (2021).

GHG Intensity at Refuelling

The pumping loss rate at the gas station is tiny but assumed to be 0.5%, referring to a paper by the Japan Automobile Research Institute (JARI, 2011).

Electricity

GHG Intensity During Mining

The GHG emissions (per ton of oil equivalent) during mining fossil fuels, which is the input or power generation, are set as shown in Table 2.6. The GHG emissions during mining of fuels (coal, oil, natural gas) are calculated based on the IEA's GHG statistics. They include emissions through flare and venting. Regarding the intensity of imported fossil fuels, we specify the import source in the trade data in the ASEAN Stats Data Portal, and then estimate average of the intensities of each export country weighted by import value of the top five countries (excluding countries with less than 3%). We set to fix that the intensity at the mining, the import ratio of fuels and import source mix at the current level.

Table 2.6. GHG Emissions During Fuel Mining

	Domestic Fuels * tCO_2eq/toe			**Imported Fuels **** tCO_2eq/toe		
	Coal	Oil	Gas	Coal	Oil	Gas
Indonesia	0.10	0.27	0.13	0.20	0.24	0.19
Thailand	0.27 *	0.13	0.09	0.14	0.37	0.16
Malaysia	0.27 *	0.29	0.07	0.15	0.36	0.08
Viet Nam	0.33	0.32	0.10	0.20	0.12	0.19
Brunei	0.27 *	0.16	0.07	0.10	0.41	0.13

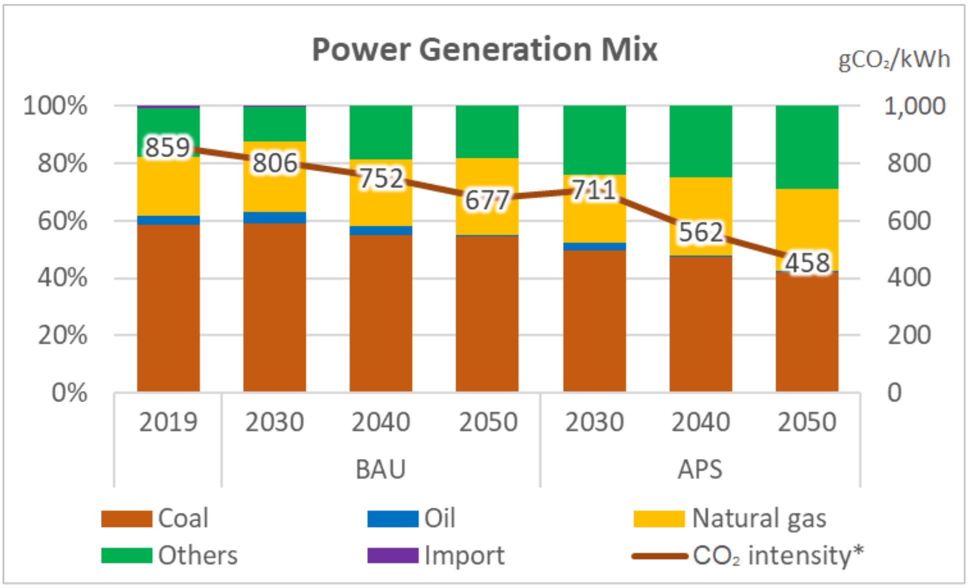
Note: *Global average is applied because data are not available.
Sources: *Estimated based on IEA (2021a, 2021b), ** Authors.

GHG Intensity at Power Generation

The GHG emissions (per kWh) during power generation are estimated based on the power generation mix in ERIA's outlook. The outlook has two scenarios, business-as-usual (BAU) and advanced policy scenario (APS). APS is assumed more aggressive energy efficiency and higher penetration of non-fossil fuels. The power generation mix and GHG emissions are set as shown in Figures 2.2 to 2.6.

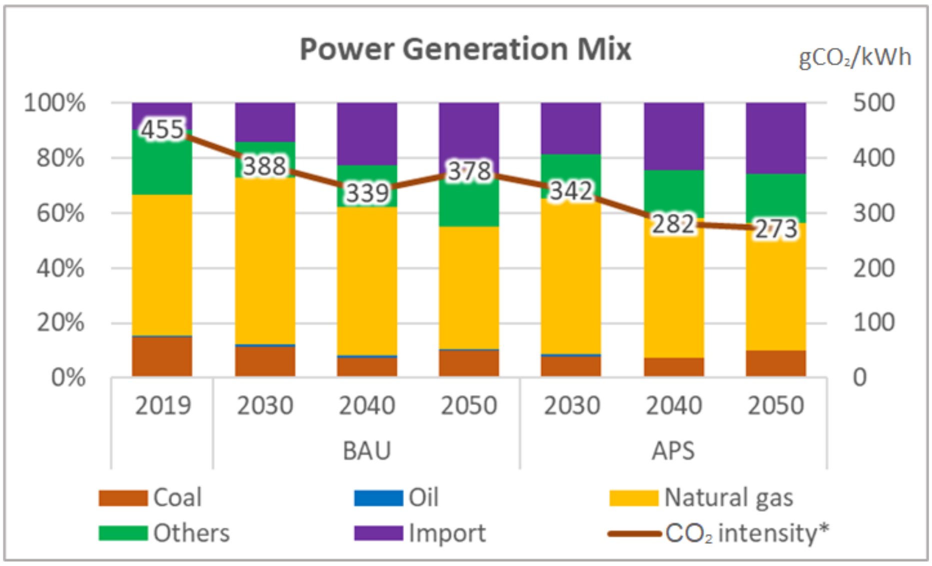
The import of electricity is also included in the power generation mix. The GHG intensities are changing as the generation mix and the import ratio of electricity. Regarding the GHG intensity of imported electricity, we specify the import source in the trade data in the ASEAN Stats Data Portal, and then estimate average of the intensities of each export country weighted by import value of the top five countries (excluding countries with less than 3%). However, it does not cover emissions from mining of imported input fuels in the electricity exporting countries.

Figure 2.2. Power Generation Mix and CO_2 Intensity (Indonesia)



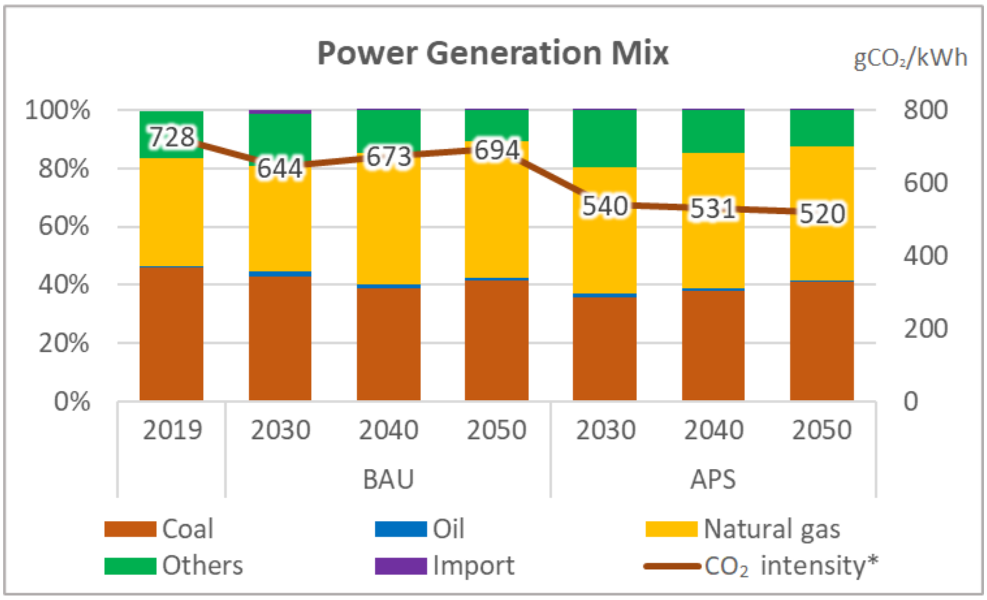
Note: CO_2 intensity is based on receiving end.
BAU = business-as-usual, APS = advanced policy scenario.
Source: Estimated based on ERIA (2021).

Figure 2.3. Power Generation Mix and CO_2 Intensity (Thailand)



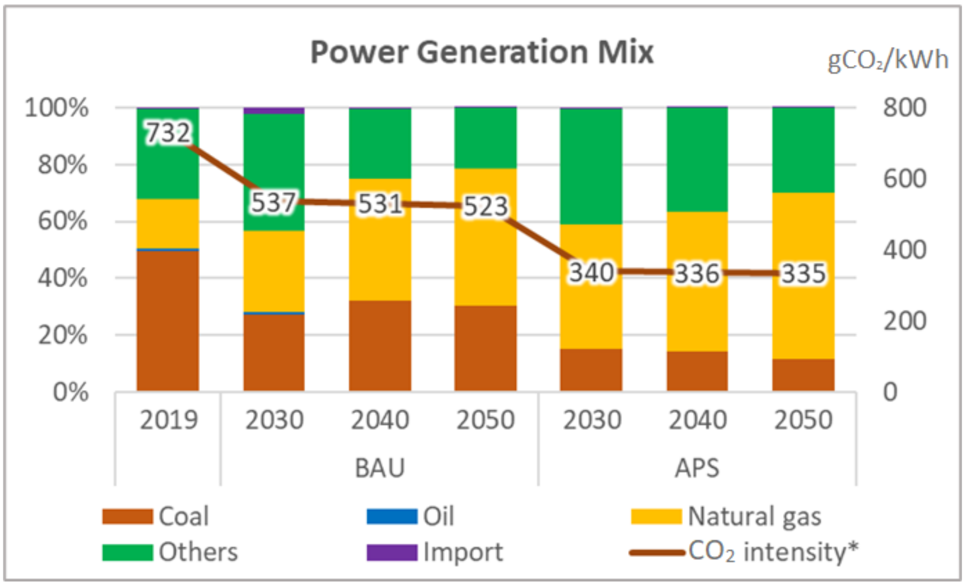
Note: CO_2 intensity is based on receiving end.
BAU = business-as-usual, APS = advanced policy scenario.
Source: Estimated based on ERIA (2021).

Figure 2.4. Power Generation Mix and CO_2 Intensity (Malaysia)



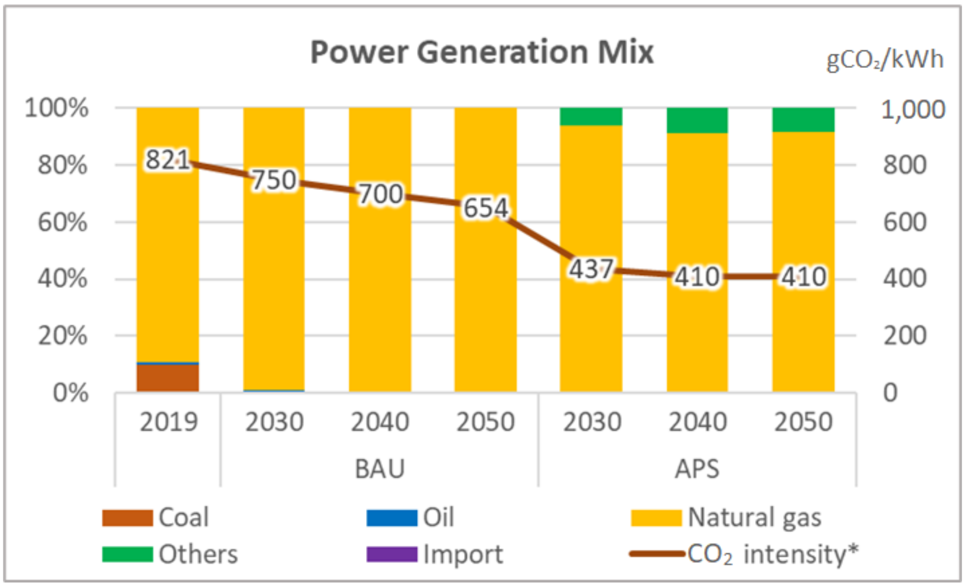
Note: CO_2 intensity is based on receiving end.
BAU = business-as-usual, APS = advanced policy scenario.
Source: Estimated based on ERIA (2021).

Figure 2.5. Power Generation Mix and CO_2 Intensity (Viet Nam)



Note: CO_2 intensity is based on receiving end.
BAU = business-as-usual, APS = advanced policy scenario.
Source: Estimated based on ERIA (2021).

Figure 2.6. Power Generation Mix and CO_2 Intensity (Brunei Darussalam)



Note: CO_2 intensity is based on receiving end.
BAU = business-as-usual, APS = advanced policy scenario.
Source: Estimated based on ERIA (2021).

GHG Intensity at Recharging

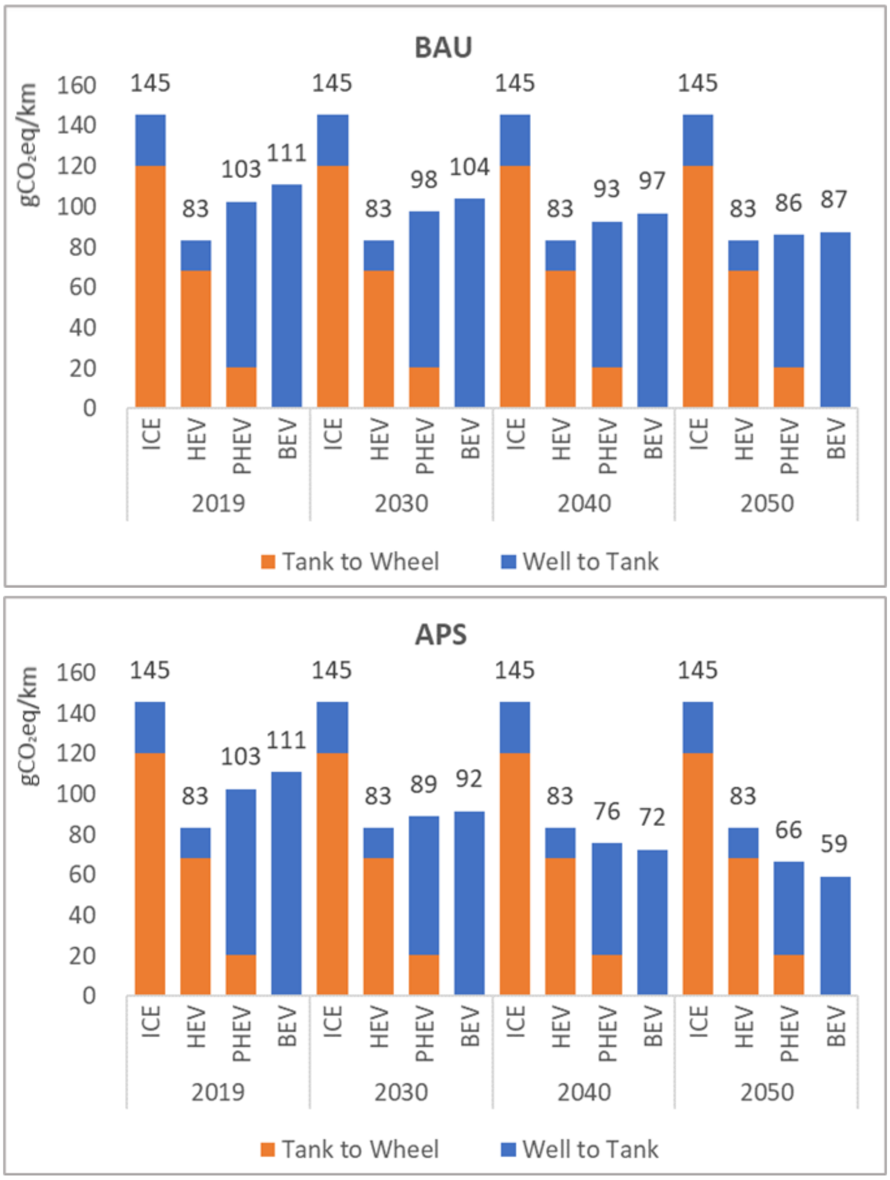
The charging loss is incorporated in the electric mileage of electric vehicles, therefore it is included in TTW but not in WTT.

3. Results

3.1. Indonesia

Figure 2.7 shows the estimation results of the well-to-wheel (WTW) basis emissions based on the BAU scenario and APS generation mix in Indonesia. The country has a large portion of coal-fired power in the generation mix. Therefore, WTW emissions from BEVs are relatively high and emissions from HEVs is the lowest today. In the BAU scenario, HEVs, PHEVs, and BEVs will be at almost the same level, and slightly lower for HEVs, in 2050. Meanwhile, in the APS, where generation efficiency and renewable power are advancing, BEVs will become the lowest emitter from 2040.

Figure 2.7. GHG Emissions based on Well-to-Wheel by Powertrain (Indonesia)

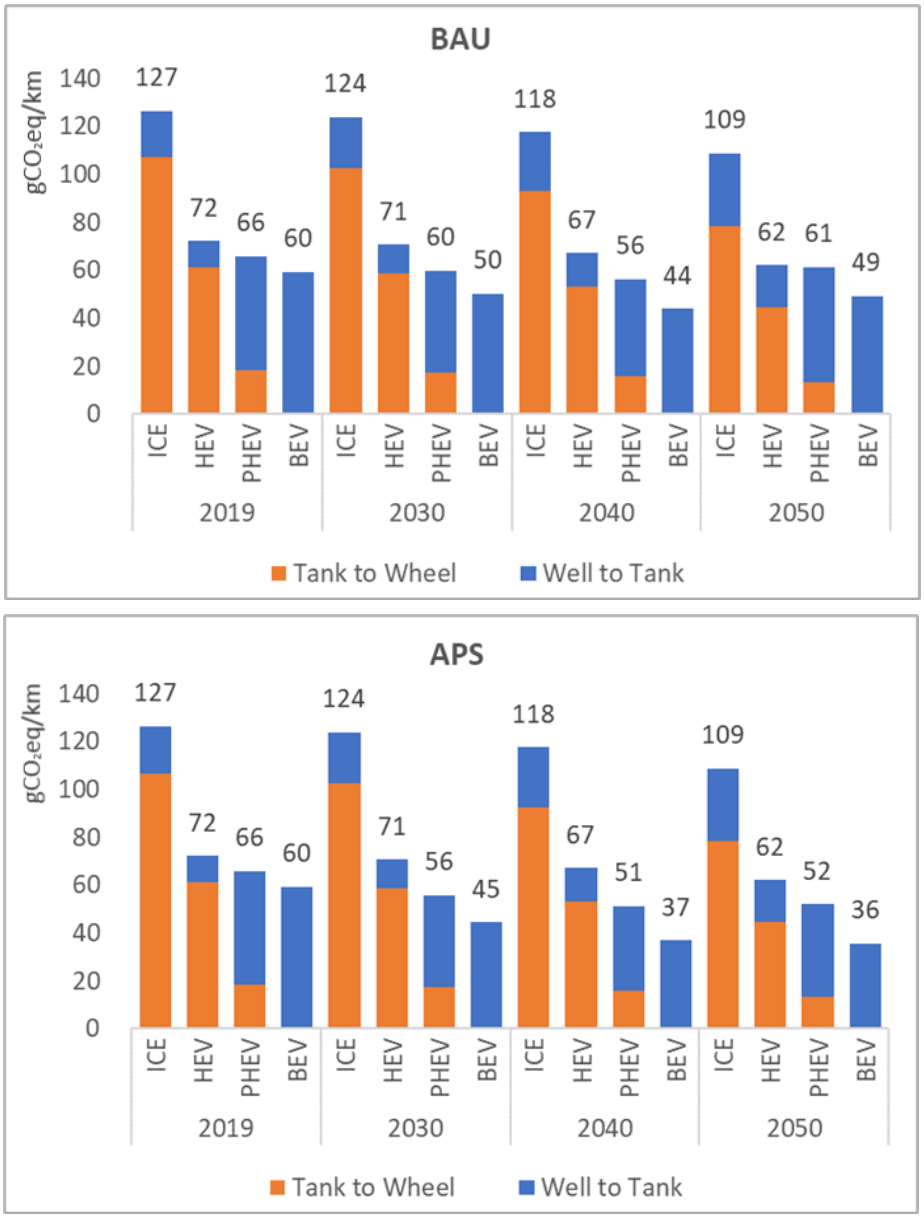


APS = advanced policy scenario, BAU = business-as-usual, BEV = battery electric vehicle, HEV = hybrid electric vehicle, ICE = internal combustion engine, PHEV = plug-in hybrid electric vehicle.
Source: Authors.

3.2. Thailand

Figure 2.8 shows the estimation results of the well-to-wheel basis emissions based on the BAU and APS generation mix in Thailand. The country has relatively clean power with a high proportion of gas-fired power and imported electricity from the Lao People's Democratic Republic, mainly from hydropower. Even at present, BEVs are the lowest emitter, even though TTW emissions are relatively lower due to blending biofuels (E10, E20, E85, etc.). Towards 2050, BEVs will become cleaner relative to other powertrain models.

Figure 2.8. GHG Emissions based on Well-to-Wheel by Powertrain (Thailand)



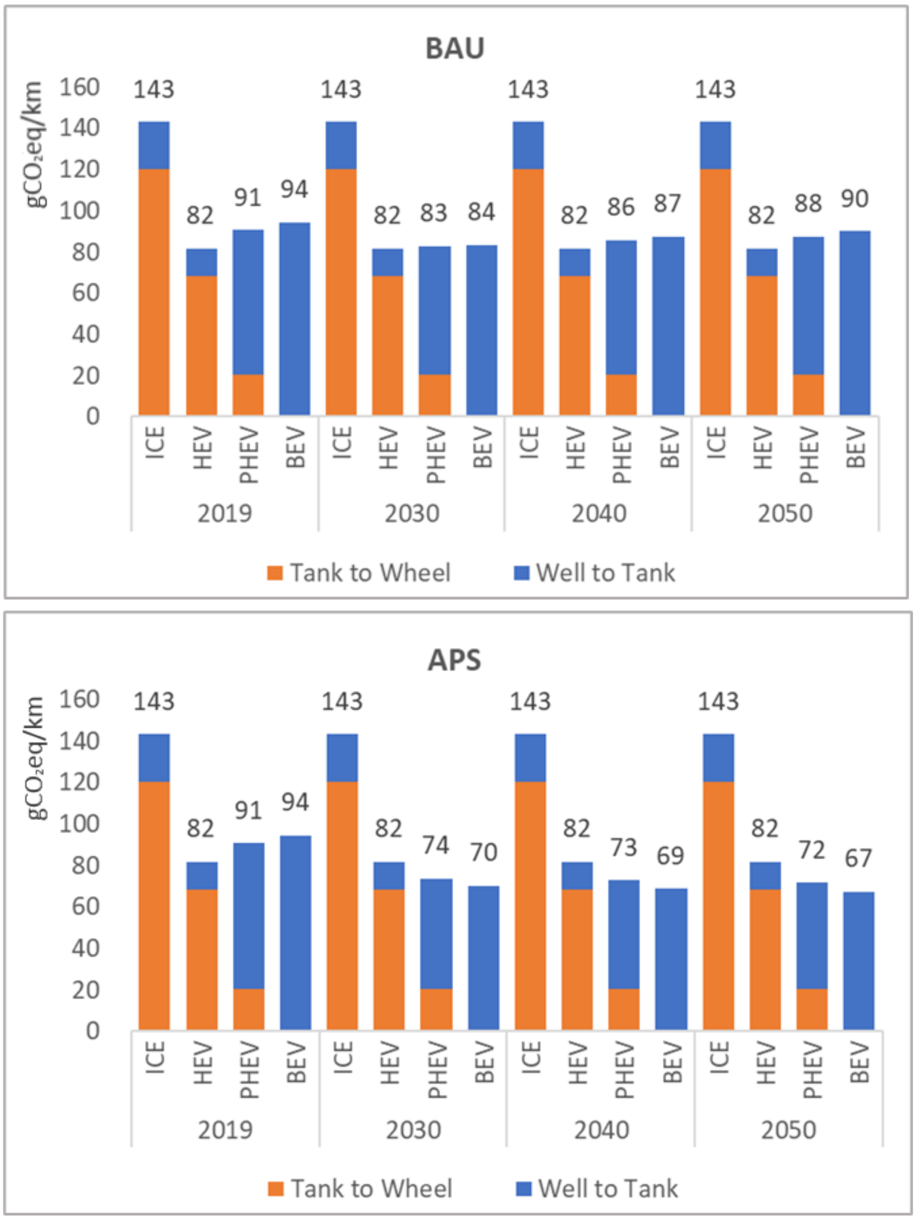
APS = advanced policy scenario, BAU = business-as-usual, BEV = battery electric vehicle, HEV = hybrid electric vehicle, ICE = internal combustion engine, PHEV = plug-in hybrid electric vehicle.

Source: Authors.

3.3. Malaysia

Figure 2.9 shows the estimation results of the well-to-wheel basis emissions based on BAU and APS generation mix in Malaysia. The proportion of coal-fired power is relatively high in the generation mix today. Emissions from HEVs are the lowest today and even in 2050 in the BAU. In the APS, on the other hand, BEVs will become the lowest emitter from 2030.

Figure 2.9. GHG Emissions based on Well-to-Wheel by Powertrain (Malaysia)



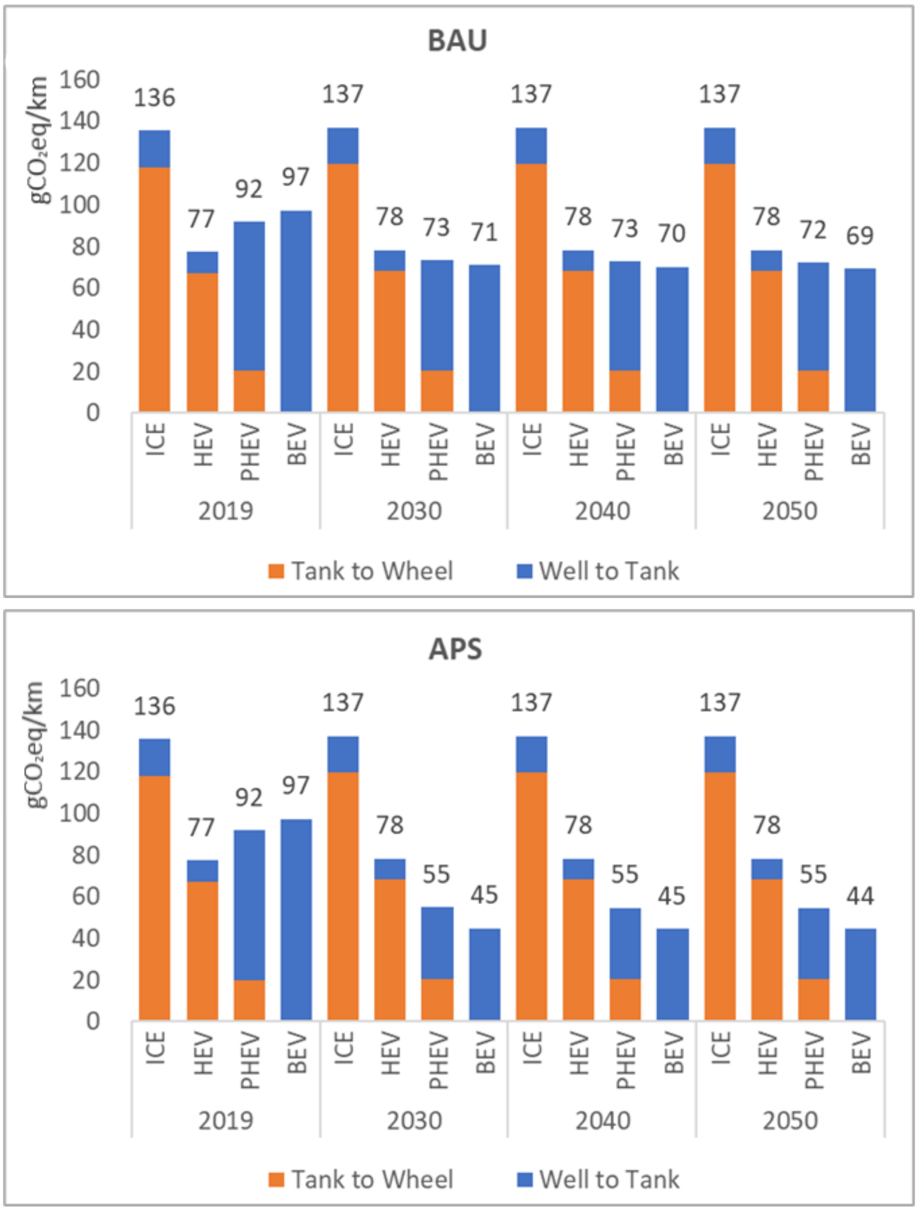
APS = advanced policy scenario, BAU = business-as-usual, BEV = battery electric vehicle, HEV = hybrid electric vehicle, ICE = internal combustion engine, PHEV = plug-in hybrid electric vehicle.

Source: Authors.

3.4. Viet Nam

Figure 2.10 shows the estimation results of the well-to-wheel basis emissions based on BAU and APS generation mix in Viet Nam. The proportion of coal-fired power is relatively high, therefore HEVs is the lowest emitter today. With the introduction of gas-fired power, BEVs will become the lowest emitter after 2030 in both the BAU and the APS.

Figure 2.10. GHG Emissions based on Well-to-Wheel by Powertrain (Viet Nam)



APS = advanced policy scenario, BAU = business-as-usual, BEV = battery electric vehicle, HEV = hybrid electric vehicle, ICE = internal combustion engine, PHEV = plug-in hybrid electric vehicle.

Source: Authors.

3.5. Brunei Darussalam

Figure 2.11 shows the estimation results of the well-to-wheel basis emissions based on BAU and APS generation mix in Brunei Darussalam. Gas-fired power is the mainstream in the country, but the CO_2 intensity of power generation is high due to lower generation efficiency. At present, emissions from HEVs are the lowest. In the BAU, HEVs, PHEVs, and BEVs will be at almost the same level, and slightly lower for BEVs, in 2050. On the other hand, in the APS, BEVs will be the lowest emitter after 2030.

Figure 2.11. GHG Emissions based on Well-to-Wheel by Powertrain (Brunei Darussalam)

APS = advanced policy scenario, BAU = business-as-usual, BEV = battery electric vehicle, HEV = hybrid electric vehicle, ICE = internal combustion engine, PHEV = plug-in hybrid electric vehicle.

Source: Authors.

4. Conclusion

The TTW emissions are almost the same level amongst the studied countries since the fuel efficiencies of automobiles are identical. The emissions are relatively lower in Thailand, where biofuels are introduced. On the other hand, the differences in the WTT emissions amongst the countries are large. The emissions by using liquid fuels do not differ much, meanwhile the emissions by using electricity vary greatly not only amongst countries, but also in terms of the time axis and the scenarios (based on climate change measures).

Namely, the difference in the power generation mix affects the amount of WTW basis emissions. HEVs are the least emitters when the generation mix is dirty, whilst BEVs are the least emitters when it is clean. In the APS where power is cleaner, BEVs become the best option in terms of the WTW basis emissions by 2040 at the latest in all the five countries. It is essential that the automobile electrification progress along with the decarbonisation of the power generation mix.

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