Office of Transport and Traffic Policy and Planning

From the People of Japan

UNDP

Life Cycle Analysis

LCA

of EV Manufacturing, Use and Recycling in Selected ASEAN Countries (Indonesia, Malaysia, Thailand and Vietnam) to Support EV Climate Credit Program

MINI REPORT

Supporting NDC Target through Incentivizing the Use of Electric Vehicles

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CONTENT

List of Figures

List of Tables

1 Introduction

1.1 Rationale

With fast electric vehicles (EV) technology development around the world, transition from internal combustion engines (ICE) to EV at commercial scale has been realized in many parts of the world (IEA 2024a) as battery price has been continuously declining (except the COVID-19 period for supply chain disruption) to justify total cost of ownership between ICE and EV. Given EV technology maturity in China, Europe and United States accounting over 90% of EV population, emerging economies like India and Southeast Asia have been adopting EV into vehicle fleet especially as a measure to reduce Greenhouse Gas Emissions (GHGs) in transport sector in response to global warming. For instance, Vinfast, Vietnam EV company has made significant progress after getting almost 65 thousand orders from international markets. (VinFast 2022, Kane 2022). As of 2022, growing number of EVs (including Hybrid EV, Plug-in EV and Battery EV) have been registered in many ASEAN countries, e.g. 218,000 in Thailand, 25,300 in Indonesia, 14,000 in Philippines, 4,300 in Vietnam (Utama, Merdekawati, and Yurnaidi – The Jakarta Post 2023) with several advantages and benefits over conventional vehicles in terms of local pollution in large cities, potential to use renewable electricity and fossil fuel independence (IEA 2024b).

However, impact of EV on greenhouse gas emissions should be thoroughly assessed from whole value chain starting from vehicle production, vehicle usage and vehicle scrappage in order to inclusively justify benefit of EV over ICE. The fuel (energy) life cycle and the vehicle cycle, as shown in Figure 1 (Toyota Motor Corporation and Mizuho Information & Research Institute 2004), need to be analyzed for automotive GHG emissions, which requires many parameters, data and assumptions.

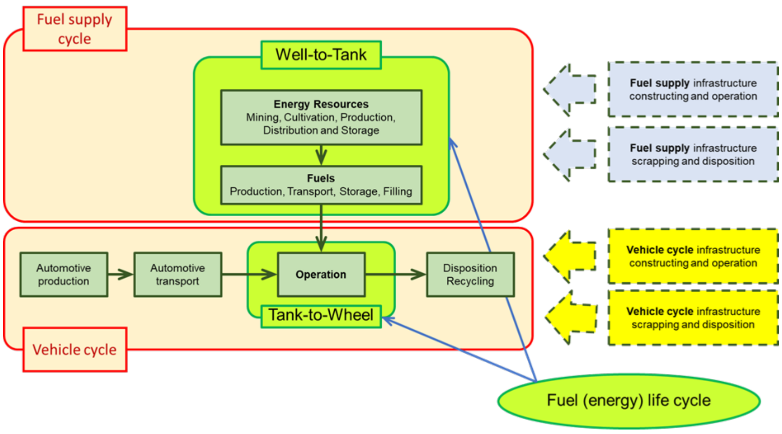


Figure 1 Schematic diagram of automotive life cycle

Source: Toyota Motor Corporation and Mizuho Information & Research Institute 2004

For vehicle use phase, while EV technology has higher energy efficiency converting electricity to propel vehicle than conventional ICE vehicles converting chemical energy in fuel to propel vehicle (tank-to-wheel), the entire energy consumption in the fuel (energy) life cycle need to account for source of energy (well-to-tank), namely fossil fuel for ICE and electricity produced from various sources in ASEAN member states with different portions of sources and GHG emission factors. In addition to well-to-wheel analysis of vehicle use phase, the vehicle cycle also produces GHG emissions from the production process and recycling process (Qiao, Zhao, Liu, et al. 2019) such as materials mining, car manufacturing and waste implications of scrapped automobiles. As power generation in ASEAN countries do not yet have substantial share of renewables, EV deployment in vehicle fleet may not fully contribute to GHG emission reduction from WTW (well-to-wheel) fuel/energy life-cycle assessment (LCA), as well as related emissions of EV and batteries manufacturing (Suehiro, and Purwanto 2019, and 2020). Therefore, this work aims to quantify GHG emissions from both fuel (energy) and vehicle cycles of automotive value chain.

1.2 Objectives and Methodology

This work aims to conduct life-cycle assessment (LCA), which covers all potential impacts from the mining and processing of the materials, vehicle and battery fabrication, vehicle use, and waste impacts from the scrapped vehicles and batteries, to investigate the potential for global warming mitigation and the environmental effects of electric vehicles in ASEAN. The LCA will be applied for popular models of xEVs (including Battery Electric Vehicle: BEV, Plug-in Electric Vehicle: PHEV and Hybrid Electric Vehicle: HEV) in comparison with international combustion engine (ICE) vehicle for Thailand (TH) and 3 other ASEAN member states, namely Indonesia (ID), Malaysia (MA) and Vietnam (VN).

Following the life cycle assessment shown in Figure 1, three phases that comprise the scope of LCA are

- the Cradle-to-Gate (CTG) phase of vehicle production and transportation to showroom,
- the Well-to-Wheel (WTW) phase of vehicle usage phase, and
- the Grave-to-Cradle (GTC) phase of vehicle disposal and recycling phase.

The scope of LCA can be modified as shown in Figure 2 (Qiao, Zhao, Liu, et al. 2019).

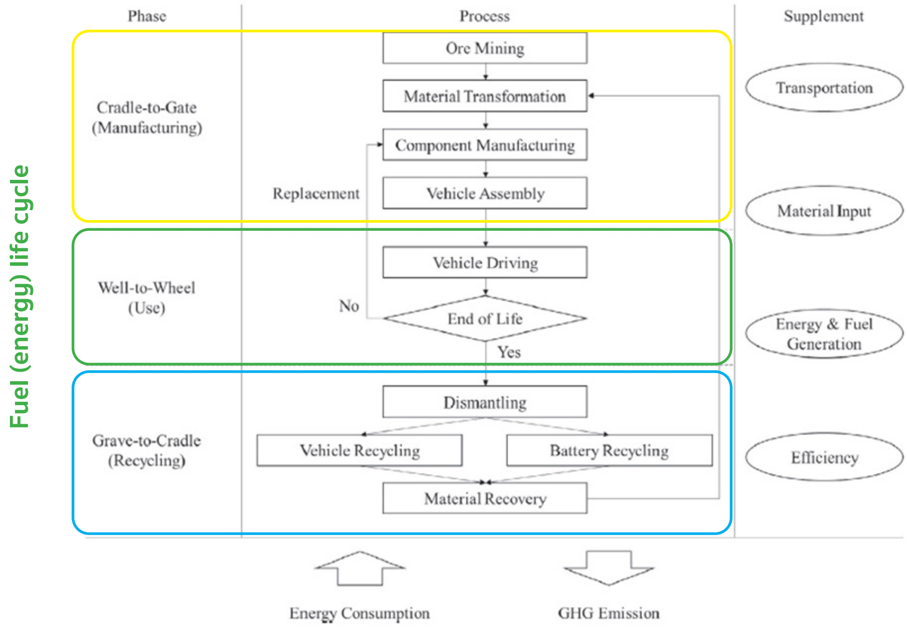


Figure 2 Life cycle scope of EV in this study

Source: Qiao, Zhao, Liu, et al. 2019

Regarding to Life Cycle Assessment which compose both fuel (energy) life cycle and vehicle life cycle, the vehicle usage is included in the analysis. The vehicle lifetime, Vehicle Kilometer of Travel (VKT), Emission Factors (EF), and Fuel Economy (FE) or often called Fuel Consumption (FC) should be considered. The final analysis results will be provided in kilometers (per travel distance) and vehicle unit. The emissions sources for the fuel (energy) life cycle are divided into two categories: tank-to-wheel and well-to-tank as shown in Figure 2; whereas, the vehicle life cycle—which comprises the vehicle production (Cradle-to-Gate, CTG)—will be conducted additionally to cover whole value chain, namely the vehicle assembly, component manufacturing, and raw material processing, as well as the vehicle end-of-life (Grave-to-Cradle, GTC).

1.2.1 Tank-to-Wheel Greenhouse Gas Emissions in Fuel (energy) Life Cycle

In this study, the tank-to-wheel greenhouse gas (TTW GHGs) emissions are estimated according to the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2019). For fuel combustion of road transport, the emissions factors are selected according to the Technology and Environmental Database as shown in Figure 3.

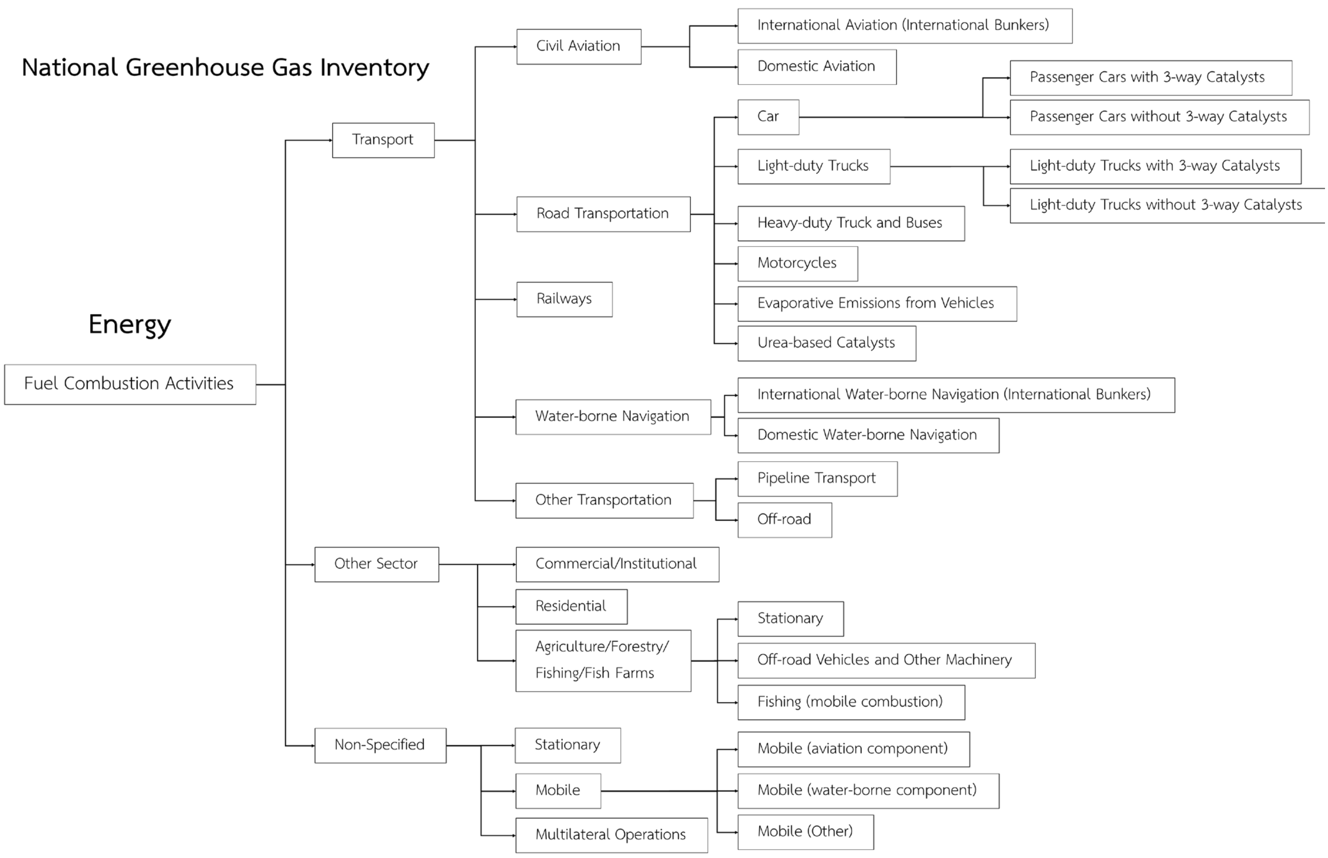


Figure 3 IPCC Activity and Source Structure in the Energy Sector
Source: IPCC 2019

The TTW GHG emissions are defined from the fundamental of combustion reaction. Carbon dioxide (CO2) is the primary greenhouse gas released during combustion. However, nitrous oxide (N2O) and methane (CH4) emissions also have an impact on the effects of global warming. Tier 2 of GHG emissions calculation is selected in this study to collect TTW GHG emissions for fossil fuel. The emissions levels are assumed according to current emissions standards for new vehicles and the share of vintage vehicles in the considered region as shown in Table 1. Since the global warming potentials of the TTW GHG emissions from the combustion of fossil fuels, namely CO2, CH4, and N2O, differ, these potentials can be multiplied by the global warming potentials (GWP) to get equivalent CO2 (CO2eq) units., as shown in Table 2. As most private passenger vehicle in ASEAN countries use gasoline fuel, Tank-to-Wheel emission factor of car (4-wheelers) is assumed, as shown in Table 3. The Tank-to-Wheeler emission of electric vehicle is conventionally neglected.

Table 1 Selected vehicle models to represent TTW GHG emissions

Type of Vehicles	Chosen Vehicle Models
Gasoline passenger car (For all gasoline combustion)	European cars moderate control gasoline

TTW GHG = tank-to-wheel greenhouse gas.
Source: IPCC 2019

Table 2 Global Warming Potentials of GHG emissions from combustion process

	CO_2	CH_4	N_2O
GWP (kg in CO2eq/kg of considered emissions)	1	28	265

kg = kilogramme, GHG = greenhouse gas, GWP = global warming potentials,
Source: IPCC 2014

Table 3 Tank-to-Wheel emission factor of car (4-wheelers) using gasoline fuel

Vehicle Types	$kgCO_{2eq}$/liter
Passenger car	2.1886

Source: IPCC 2019, including CO_2, CH_4, and N_2O

1.2.2 Well-to-Tank Greenhouse Gas Emissions in Fuel (energy) Life Cycle

The upstream GHG emissions in the fuel (energy) life cycle inside the vehicle use-phase are defined by the Well-to-Tank (WTT) GHG emissions. The WTT GHG emissions of electric vehicles (BEV and PHEV) are calculated from the grid electricity of various countries in ASEAN due to the different primary sources of power generation in different countries. On the other hand, the fossil fuel processes that include oil and gas production (oil extraction and drilling), oil and gas transportation (from the well to refinery plant), crude oil refinery process, and commercial fuel transportation (from refinery plant to fuel storage to fuel retail station) are responsible for the upstream greenhouse gas emissions of conventional vehicles with internal combustion engines (ICE, including ICE, HEV and PHEV). The well-to-tank emissions of fossil fuel and biofuel used in this study are shown in Table 4 (Thai LCI database 2023, Permpool N, and Gheewala SH 2017, and Silalertruksa and Gheewala 2011) for Thailand, and Table 5 (ERIA, 2022b) for Indonesia, Malaysia, and Vietnam.

Table 4 Well-to-Tank emission factors of fossil fuel and biofuel

Fuel	Well-to-Tank emission factor ($kgCO_{2eq}$/liter, $kgCO_{2eq}$/kgCNG)
Gasoline	0.2977
Diesel	0.3062
LPG	0.8582
CNG	0.6164
Biodiesel (FAME)	1.1780
Ethanol	0.6803

Source: Thai LCI database, Permpool and Gheewala (2017), Silalertruksa and Gheewala (2011)

Table 5 Well-to-Tank emission factor of gasoline fuel of Indonesia, Malaysia, and Vietnam

kgC_{O2}/liter	Crude oil mining				Refinery				
	Domestic	Import	Ratio	Results	Domestic	Import	Ratio	Results	Total WTT
Indonesia	0.489	0.287	29%	0.430	0.173	0.405	54%	0.298	0.729
Malaysia	0.412	0.258	24%	0.375	0.112	0.418	56%	0.283	0.658
Vietnam	0.283	0.220	43%	0.256	0.016	0.494	26%	0.140	0.396

Source: ERIA, 2022b

The selected ASEAN countries' grid electricity GHG emission factors are gathered from existing policies as shown in Table 6. The usage grid emission factors are collected from each national data, i.e., countries ministry of energy (MOE), or national power development plan.

Table 6 Reference for grid emission factor of ASEAN countries

	$kgCO_{2,eq}$/kWh	Sources
Indonesia (ID)	0.894	Refer to the Indonesian State Electricity Company (Perusahaan Listrik Negara, PLN)
Malaysia (MY)	0.657	Calculate from Global Environment Facility shown the GEF-7 Malaysia National Dialogue
Thailand (TH)	0.386	Thailand Power Development Plan 2018 (PDP2018-2037)
Vietnam (VN)	0.658	Vietnam's Eight National Power Development Plan (PDP8)

Source: Philippines Department of Energy, Thailand Power Development Plan 2018 rev.1, Vietnam's Eight National Power Development Plan (PDP8)

1.2.3 Full Life Cycle GHG Emission Calculation

Within the scope of this study, the whole life cycle calculation—which can be calculated using equations [1] - [3]—combines the GHG emissions from the Cradle-to-Gate and Grave-to-Cradle phases. (Qiao, Zhao, Liu, et al. 2019), as follows:

$$E_{LC} = \left(E_A + \sum_i E_{M,i}\right) + E_D + \left(E_{VR} + E_{BR} + \sum_i E_{MR,i}\right) - E_S$$

where E_{LC} is the entire life cycle GHG emissions, E_A is the GHG emissions of component and vehicle assembly, $E_{M,i}$ is the GHG emissions of the production and transformation of material i, E_D is the GHG emissions of vehicle driving (WTT and TTW Greenhouse Gas emissions), E_{VR} and E_{BR} are the GHG emissions of vehicle and battery recycling, $E_{MR,i}$ is the GHG emissions for recovering material i, and E_S is the reduction of GHG emissions when primary materials is replaced by recovered materials. Note the GHG emissions of vehicle driving (E_D) is calculated from equation [2]:

$$E_D = \sum_j \left(MA \times FC_j \times {EF_j}/{EFC_j}\right)$$

where MA is the life-time mileage (km), FC_j is the consumption of fuel (or energy) j (energy unit per driven distance), EF_j is the life cycle GHG emissions factor of fuel (or energy) j, and the EFC_j is the efficiency of fuel (or energy) conversion/transmission, i.e., the line loss of electricity. Finaly, the GHG emission reduction when primary materials are replaced by recovered materials E_S, which can be calculated through equation [3]:

$$E_S = \sum_i \left(M_{MR,i} \times \sum_j \left(EC_{MR,i,j} \times EF_j\right)\right)$$

where $M_{MR,i}$ is the mass of recovered materials i, $EC_{MR,i,j}$ is the consumption of fuel (or energy) j for primary materials i, and EF_j is previously defined.

1.2.4 Vehicle Models

For the purpose of accurately depicting various passenger car categories in each ASEAN country's automotive market, the most popular models of electric cars (xEV), which cover HEV, PHEV, and BEV, are selected, as well as best-selling internal combustion engine (ICE) car. Through this approach, the selected ICE and xEV vehicles can represent the most popular class rather than the manufacturer's specialty models like luxurious EV or hyper power EV.

For the current status, the popular models of BEV, PHEV, HEV, and ICE vehicles have been selected from 2023 automotive markets for Indonesia, Malaysia, Thailand and Vietnam. The passenger cars chosen for analysis are detailed in Table 7, respectively.

Table 7 Selected passenger cars model from ASEAN automotive markets of four countries

Countries	ICE	HEV	PHEV	BEV	Note
Indonesia	Toyota Avanza	Toyota Kijang Innova Zenix	Toyota Rav4 PHEV	Hyundai Ioniq 5	Small MPV/ SUV
Malaysia	Perodua Bezza	Honda City	Volvo XC 60	Neta V	B-segment / A-Segment/ SUV
Thailand	Toyota Yaris ATIV	Toyota Corolla Cross	MG HS PHEV	BYD Dolphin	B-segment
Vietnam	Mitsubishi Xpander	Toyota Kijang Innova Zenix	Kia Sorento PHEV	Vinfast VF 6	B-segment – crossover/ SUV

Note: The estimated useful lifespan for passenger cars is 20 years.

Assumption & Input Data Collection

2

The data required to analyse the whole life cycle greenhouse gas emissions of passenger cars across four countries—Indonesia, Malaysia, Thailand, and Vietnam—was gathered in this chapter

2.1 Estimation of Vehicle Kilometer of Travel (VKT)

The vehicle kilometer of travel (VKT) is the distance travelled by each considered vehicle. Each vehicle type's total fuel and energy consumption will be governed by the VKT. The VKT values in this study were collected from some member countries The collected VKT are shown in Table 8.

Table 8 Vehicle Kilometer of Travel

VKT	Passenger Cars
Indonesia	18,480
Malaysia	22,715
Thailand	20,230
Vietnam	13,723

VKT = vehicle kilometer of travel

Source: (Allyana & Anwar, 2020; Deendarlianto et al., 2020; ERIA, 2022a; EPPO, 2019)

2.2 Estimation of Fuel Consumption (FC)

As fuel consumption (FC) may not be regularly updated, certain assumptions must be made from the engineering aspects. For instance, the FC needs to be identified according on technical parameters such engine age, fuel ratio (gas or liquid with biofuel blending), and engine type (spark-ignition vs. compression-ignition). The vehicles in this study were therefore simplified into spark-ignition engine, hybrid electric vehicle (HEV), Plug in hybrid electric vehicle (PHEV), and Battery electric vehicle (BEV). Gas fuels were neglected in this work, whereas biofuels were assumed to be blended with mean-average blended ratios (different from market blended ratios). In this study, the fuel consumption of passenger cars with various fuel/technology are shown in Table 9.

Table 9 Assumption of Fuel Consumption

Countries	Fuel Consumption of Passenger Cars				
	Gasoline (l/100km)	HEV (l/100km)	PHEV		BEV (kWh/100km)
			Gasoline (l/100km)	Electricity (kWh/100km)	
Indonesia	10.99	7.72	3.86	13.62	10.73
Malaysia*	7.86	5.52	2.63	9.74	16.18
Thailand*	7.86	5.52	2.63	9.74	16.18
Vietnam	8.02	5.63	2.69	9.94	14.74

Notes: Fuel consumption is in the unit of litres/100 kilometers for gasoline, and kilowatt hour/100 kilometers for consumed electricity of EV (BEV, PHEVs).
*Thailand data is used where data from member countries are not available
BEV = battery electric vehicle, HEV = hybrid electric vehicle, PHEV = plug in hybrid electric vehicle
Source: ERIA (2022)

2.3 Input Data for Vehicle Life Cycle Analysis

As abovementioned, Greenhouse Gas (GHG) analysis for the Cradle-to-Gate (CTG) and Grave-to-Cradle (GTC) requires vehicle materials information of chosen models as shown in Table 7.

2.3.1 Vehicle information and materials shares

For passenger cars (ICE, HEV, PHEV, and BEV), the materials fractions were collected from literature, including Qiao et al. 2009, and Burnham 2012. Most of the selected models are in the sedan B-segment (small economic car), which are similar to the literature (Qiao, Zhao, Liu, et al. 2019). However, some specific models are in the MPV (Multi-Purpose Vehicle) type, such as the small MPV for Vietnam and the medium MPV for Indonesia, where the materials portion is based on Argonne data. (Burnham 2012). The information of selected MPVs were assumed similar to the SUVs in Burnham 2012. The collected vehicle information and vehicle materials composition of car segment are shown in Table 10 - Table 13.

Table 10 Specification of selected 4-wheeler vehicle model (cars) for Indonesia

Countries	Indonesia			
Sedan	**ICE vehicle**	**HEV**	**PHEV**	**BEV**
Model name	Toyota INNOVA	Toyota Kijang Innova Zenix	Toyota Rav4 PHEV	Hyundai Ioniq 5 Standard
Battery warranty time	-	8 years	8 years	10 years or 100,000 km
Weight (kg)	2,270	1,595	2,005	1,905
Weight (without battery, kg)	2,270	1,574	1,870	1,495
Reference	Burnham 2012	Burnham 2012	Burnham 2012	Burnham 2012
Steel	63.10%	66.67%	67.40%	67.10%
Cast iron	11.40%	6.31%	5.80%	2.60%
Wrought aluminum	1.80%	1.70%	1.70%	0.90%
Cast aluminum	4.90%	5.11%	4.80%	5.80%
Copper/Brass	1.60%	3.90%	3.90%	4.40%
Glass	3.10%	3.20%	3.30%	3.80%
Plastic	9.80%	9.01%	9.00%	10.40%
Rubber	2.70%	2.20%	2.20%	2.30%
Others	1.60%	1.90%	1.90%	2.70%
Type		Li-ion	Li-ion	Li-ion
Battery capacity (kWh)		1.6	18.1	58.0
Battery weight (kg)		21.03	134.83	410.00

Source: Indonesia: https://www.focus2move.com/indonesia-best-selling-cars/, https://www.statista.com/statistics/1414822/indonesia-best-selling-electric-vehicle-models/, Indonesia: https://whatsindonesia.blogspot.com/2023/07/5-top-brands-hybrid-cars-sales-in-indonesia-on-year-2023.html, https://www.toyota.astra.co.id/product/rav4-phev, https://otomotif.kompas.com/read/2022/11/24/191200515/bahas-baterai-kijang-innova-zenix-hybrid-dapat-garansi-8-tahun

Table 11 Specification of selected 4-wheeler vehicle model (cars) for Malaysia

Countries	Malaysia			
Sedan	**ICE vehicle**	**HEV**	**PHEV**	**BEV**
Model name	Perodua Bezza 1.3	Honda City	Volvo XC 60	Tesla Model Y
Battery warranty time	-	8 years	8 years	8 years or 192,000 km
Weight (kg)	925	1,250	2,250	1,911
Weight (without battery, kg)	925	1,231	2,109	1,384
Reference	Qiao 2019	Qiao 2019	Qiao 2019	Qiao 2019
Steel	62.90%	65.70%	67.40%	65.50%
Cast iron	10.30%	5.80%	5.80%	2.00%
Wrought aluminum	1.90%	1.80%	1.70%	1.50%
Cast aluminum	4.50%	5.10%	4.80%	5.70%
Copper/Brass	1.90%	4.30%	3.90%	5.80%
Glass	3.00%	2.90%	3.30%	3.10%
Plastic	11.36%	10.50%	9.00%	11.90%
Rubber	2.20%	1.70%	2.20%	1.70%
Others	2.00%	2.20%	1.90%	2.80%
Type		Li-ion	Li-ion	Li-ion
Battery capacity (kWh)		1.3	19.0	75.0
Battery weight (kg)		18.97	141.03	527.24

Source: Malaysia: https://m.newpages.com.my/en/company/777469/news/126021/Malaysia--039;s-top-10-best-selling-cars-in-2023.html, https://www.wapcar.my/new-cars/best-and-a-segment-and-b-segment-and-ev, https://data.gov.my/dashboard/car-popularity, https://www.carsome.my/news/item/hybrid-cars-malaysia, https://www.carbase.my/honda/city/gn2-gn3/e:hev-rs-2022, https://www.volvocars.com/my/cars/xc60-hybrid/specifications/, https://www.honda.com.my/model/city/spec

Table 12 Specification of selected 4-wheeler vehicle model (cars) for Thailand

Countries	Thailand			
Sedan	**ICE vehicle**	**HEV**	**PHEV**	**BEV**
Model name	Toyota Yaris Ativ	Toyota Corolla Cross	MG HS PHEV	BYD Dolphin
Battery warranty time	-	8 years	8 years	8 years or 160,000 km
Weight (kg)	1,045	1,430	1,775	1,512
Weight (without battery, kg)	1,045	1,414	1,651	1,192
Reference	Qiao 2019	Qiao 2019	Qiao 2019	Qiao 2019
Steel	62.90%	66.67%	67.40%	65.50%
Cast iron	10.30%	6.31%	5.80%	2.00%
Wrought aluminum	1.90%	1.70%	1.70%	1.50%
Cast aluminum	4.50%	5.11%	4.80%	5.70%
Copper/Brass	1.90%	3.90%	3.90%	5.80%
Glass	3.00%	3.20%	3.30%	3.10%
Plastic	11.36%	9.01%	9.00%	11.90%
Rubber	2.20%	2.20%	2.20%	1.70%
Others	2.00%	1.90%	1.90%	2.80%
Type		Li-ion	Li-ion	Li-ion
Battery capacity (kWh)		0.9	16.6	45.0
Battery weight (kg)		16.21	124.48	319.86

Source: Thailand: https://www.headlightmag.com/2024-01-10-sales-report-2023/, https://carnewschina.com/2024/01/09/byd-is-bestselling-ev-brand-in-thailand-in-2023-neta-is-runner-up/, https://www.checkraka.com/car/article/110563, https://www.carsome.co.th/news/item/top-hybrid-cars, https://www.pptvhd36.com/automotive/news/220538, https://www.iseecars.com/car/toyota-corolla-cross-hybrid-specs, https://www.mgcars.com/th/mg-models/new-mg-hs-phev/spec

Table 13 Specification of selected 4-wheeler vehicle model (cars) for Vietnam

Countries	Vietnam			
Sedan	**ICE vehicle**	**HEV**	**PHEV**	**BEV**
Model name	Mitsubishi Xpander	Toyota Kijang Innova Zenix	Kia Sorento PHEV	Vinfast VF 6
Battery warranty time	-	8 years	8 years	8 years or 160,000 km
Weight (kg)	1,245	1,595	2,090	1,550
Weight (without battery, kg)	1,245	1,574	1,985	1,129
Reference	Burnham 2012	Burnham 2012	Qiao 2019	Qiao 2019
Steel	63.10%	66.67%	67.40%	65.50%
Cast iron	11.40%	6.31%	5.80%	2.00%
Wrought aluminum	1.80%	1.70%	1.70%	1.50%
Cast aluminum	4.90%	5.11%	4.80%	5.70%
Copper/Brass	1.60%	3.90%	3.90%	5.80%
Glass	3.10%	3.20%	3.30%	3.10%
Plastic	9.80%	9.01%	9.00%	11.90%
Rubber	2.70%	2.20%	2.20%	1.70%
Others	1.60%	1.90%	1.90%	2.80%
Type		Li-ion	Li-ion	Li-ion
Battery capacity (kWh)		1.6	13.8	59.6
Battery weight (kg)		21.03	105.17	421.03

Source: Vietnam: https://www.vietnam.vn/en/infographic-10-xe-ban-chay-nua-dau-2023-vinfast-chiem-nhieu-vi-tri-hon-ford-va-hyundai/, https://www.statista.com/statistics/1366989/vinfast-electric-car-sales-in-vietnam-by-model/, https://vov.vn/o-to-xe-may/o-to/xe-hybrid-dang-dan-duoc-nguoi-viet-ua-chuong-post1108821.vov, https://vov.vn/o-to-xe-may/o-to/xe-hybrid-dang-dan-duoc-nguoi-viet-ua-chuong-post1108821.vov, https://www.toyota.com.my/en/models/zenix/toyota-innova-zenix-2-0v.html#specifications, https://kiaviet-nam.com.vn/chi-tiet-san-pham/sorento-plug-in-hybrid/thong-so-ky-thuat, https://otomotif.kompas.com/read/2022/11/24/191200515/bahas-baterai-kijang-innova-zenix-hybrid-dapat-garansi-8-tahun

2.3.2 Emission Factors for Vehicle Life Cycles

For materials mining and processing, the data were collected from Sullivan, Burnham, and Wang, 2010 with the updated information from Burnham 2012 (vehicle specification), Iyer and Kelly, 2022 (production inventory of advanced battery chemistries). The production of battery information was collected from Quan, et al., 2022. The vehicle assembly data was gathered from Vinoles-Cebolla et al., 2015. Table 14 shows emission factors during materials mining, processing and vehicle assembly in unit of $kgCO2_{eq}$/ton of materials.

Table 14 Emission factors in vehicle before the use phase (Cradle-to-Gate)

Cradle-to-Gate	Emission factor ($kgCO_{2eq}$/ton)
Materials	
• Steel	4,060.4
• Cast iron	1,690.0
• Wrought aluminium	10,533.7
• Cast aluminium	9,850.5
• Copper/Brass	3,030.8
• Glass	930.0
• Plastic	2,901.4
• Rubber	3,169.0
Battery production	8,874.7
Vehicle assembly	905.3

Source: Sullivan, Burnham, and Wang, 2010, Quan, et al., 2022, Vinoles-Cebolla et al., 2015

After the use phase, the car had been placed into scrappage, with some of its materials and its battery componentry assumed to be recycled. The rest materials were subjected crushing for disposal. The GHG emission during materials recycle and battery refurbished were also considered. While material mining and preparation can reduce greenhouse gas emissions, recycling itself requires energy input. Table 15 shows GWP of vehicle after its End-of-Life. The data were collected from Schneider et al., 2023, and Koroma, et al, 2022.

Table 15 Global warming impacts after vehicle use phase (Grave-to-Cradle)

Grave-to-Cradle		Global warming impact (kgCO2eq/kg of materials)
Materials recovery	%recovery	
• Steel & iron	88.70%	1.85
• Aluminium	97.00%	0.97
• Copper	96.00%	0.96
Vehicle crushing		0.1
Battery recycling		
• Battery refurbished		3.66
• Avoid primary materials of Li-ion battery production		-7.33

2.4 Battery Replacement

Throughout the vehicle use phase, the deteriorating battery for the HEV, PHEV, and BEV needs to be replaced, which impacts on global warming with greenhouse gas emissions from the production of batteries, as shown in Table 14. The vehicle usage lifetime of EV car (20 years) was assumed to undergo battery replacement for 2 times (at 8th & 16th years for passenger cars).

3 Results and Discussion

3.1 Result Findings

The activities/processes taken into consideration during the vehicle life cycle can be divided into three phases: the processes/activities prior to the use phase (Cradle-to-Gate), the vehicle usage phase (known as well-to-wheel), and the End-of-Life (Grave-to-Cradle) phase, that occurs place after the vehicle usage phase. These processes or actions can be summarized as follows.

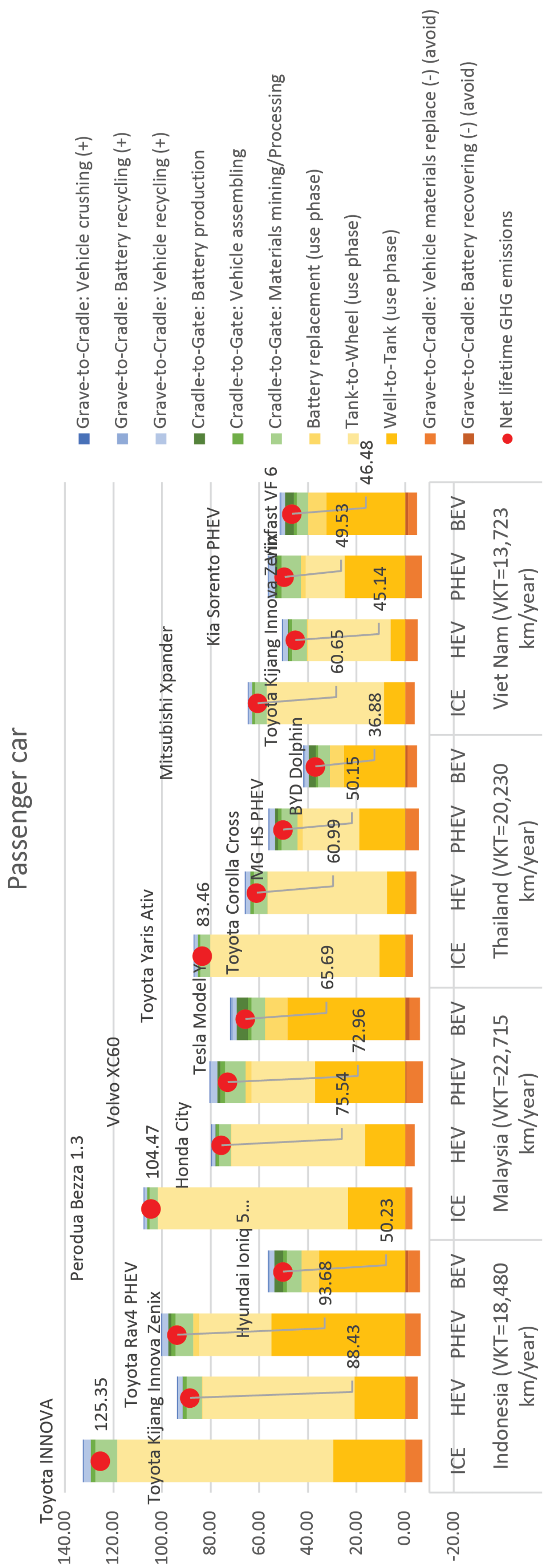
Before the use phase, the process of the vehicle production is the first phase which is cradle-to-gate. The vehicle specification from Table 10 - Table 13 which covers ICE, HEV, PHEV, and BEV, can be calculated with the emission factors in the vehicle before the use phase (Cradle-to-Gate) which is shown in Table 14 for materials mining and processing, vehicle assembling, and battery production.

During the vehicle use phase, the GHG emissions are estimated from Well-to-Tank (WTT) and Tank-to-Wheel (TTW) with required input data, including VKT from Table 8, fuel consumption from Table 9, emission factors from Table 3 and Table 4, as well as vehicle battery replacement discussed in Section 3.4. The emissions in this phase should be estimated for the whole of the lifetime in the use phase.

For End-of-Life phase which is grave-to-cradle, the calculation on vehicle materials recycling, battery recycling, vehicle crushing, replacement of primary materials and battery recovering use data collected in Table 15.

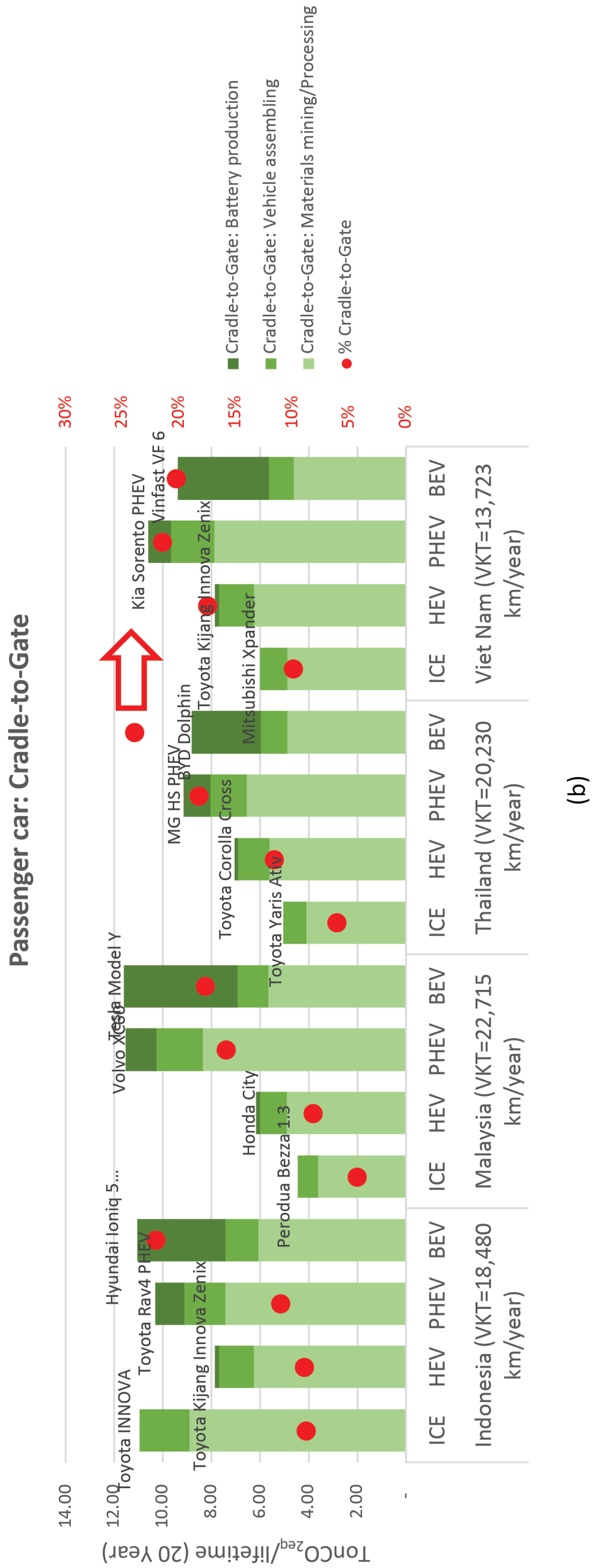
The estimated findings of the Life Cycle Assessment (LCA) of ASEAN passenger cars are shown in Figure 4 (20-year life time). The findings show that the vehicle usage phase accounts for the majority of GHG emissions compared to the vehicle production and end-of-life phases. This main portion of GHG emissions primarily comes from tank-to-wheel and well-to-tank processes. Moreover, GHG emissions during the usage stage are related to vehicle kilometers traveled (VKT), fuel consumption, driving behaviour, etc. The usage phase is divided into 3 portions: well-to-tank phase, tank-to-wheel phase, and battery replacement. Well-to-tank emission is mainly related to PHEV and BEV, which results from the emission factors of the primary energy sources of the electricity. Tank-to-wheel emissions is mainly related to ICE and HEV, which results from the internal combustion engine of the vehicle. Tank-to-wheel from combusting fossil fuel in ICE vehicle is accounted for 80-85% of total GHG emissions. The second significant contributor to the GHG emissions of the passenger cars is the cradle-to-gate phase (materials mining/processing). These emissions arise from the process of the primary materials, which use high energy consumption for the process.

Moreover, cradle-to-gate contributes to total GHG emission in the range of 5-24%, BEV mostly emits more GHG than ICE vehicles, as shown in Figure 4(a) and Figure 4(b), according to battery production. For Grave-to-Cradle, GHG saving demand from avoiding new materials production in vehicle (and battery for EV) always offset GHG emission from energy consumption during scrappage, as shown Figure 4(c). Also, Figure 5 shows the GHG intensity in units of kgCO2eq/km, which calculates emissions per driving distance.

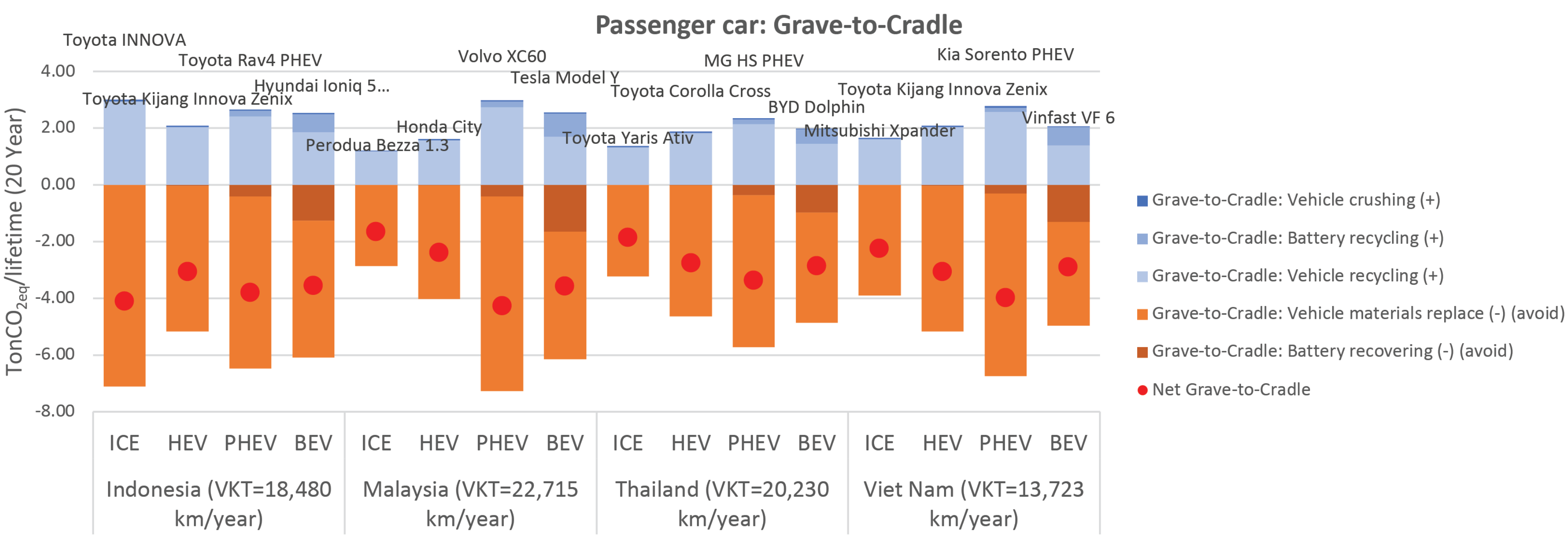


Passenger car
TonCO2eq/lifetime (20 Year)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
-20.00
Toyota INNOVA
125.35
Toyota Kijang Innova Zenix
88.43
Toyota Rav4 PHEV
93.68
Hyundai Ioniq 5...
Perodua Bezza 1.3
50.23
104.47
Honda City
Volvo XC60
75.54
72.96
Tesla Model Y
65.69
Toyota Yaris Ativ
83.46
Toyota Corolla Cross
MG HS PHEV
60.99
BYD Dolphin
50.15
Mitsubishi Xpander
36.88
Toyota Kijang Innova Zenix
60.65
Kia Sorento PHEV
45.14
49.53
Vinfast VF 6
46.48
ICE
HEV
PHEV
BEV
Indonesia (VKT=18,480 km/year)
Malaysia (VKT=22,715 km/year)
Thailand (VKT=20,230 km/year)
Viet Nam (VKT=13,723 km/year)
Grave-to-Cradle: Vehicle crushing (+)
Grave-to-Cradle: Battery recycling (+)
Grave-to-Cradle: Vehicle recycling (+)
Cradle-to-Gate: Battery production
Cradle-to-Gate: Vehicle assembling
Cradle-to-Gate: Materials mining/Processing
Battery replacement (use phase)
Tank-to-Wheel (use phase)
Well-to-Tank (use phase)
Grave-to-Cradle: Vehicle materials replace (-) (avoid)
Grave-to-Cradle: Battery recovering (-) (avoid)
Net lifetime GHG emissions

(a)

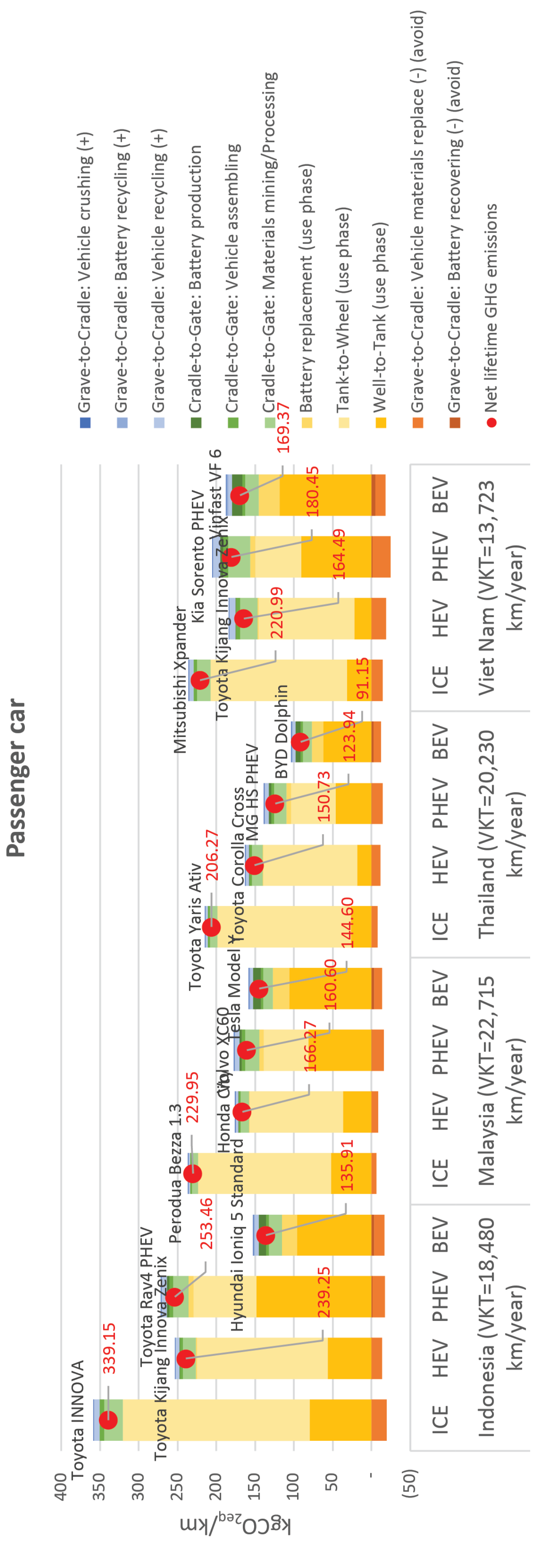

Passenger car: Cradle-to-Gate
Cradle-to-Gate: Battery production
Cradle-to-Gate: Vehicle assembling
Cradle-to-Gate: Materials mining/Processing
% Cradle-to-Gate
TonCO2eq/lifetime (20 Year)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
-
30%
25%
20%
15%
10%
5%
0%
Toyota INNOVA
Toyota Kijang Innova Zenix
Toyota Rav4 PHEV
Hyundai Ioniq 5...
Perodua Bezza 1.3
Honda City
Volvo XC60
Tesla Model Y
Toyota Yaris Ativ
Toyota Corolla Cross
MG HS PHEV
BYD Dolphin
Mitsubishi Xpander
Toyota Kijang Innova Zenix
Kia Sorento PHEV
Vinfast VF 6
ICE
HEV
PHEV
BEV
Indonesia (VKT=18,480 km/year)
Malaysia (VKT=22,715 km/year)
Thailand (VKT=20,230 km/year)
Viet Nam (VKT=13,723 km/year)

(b)

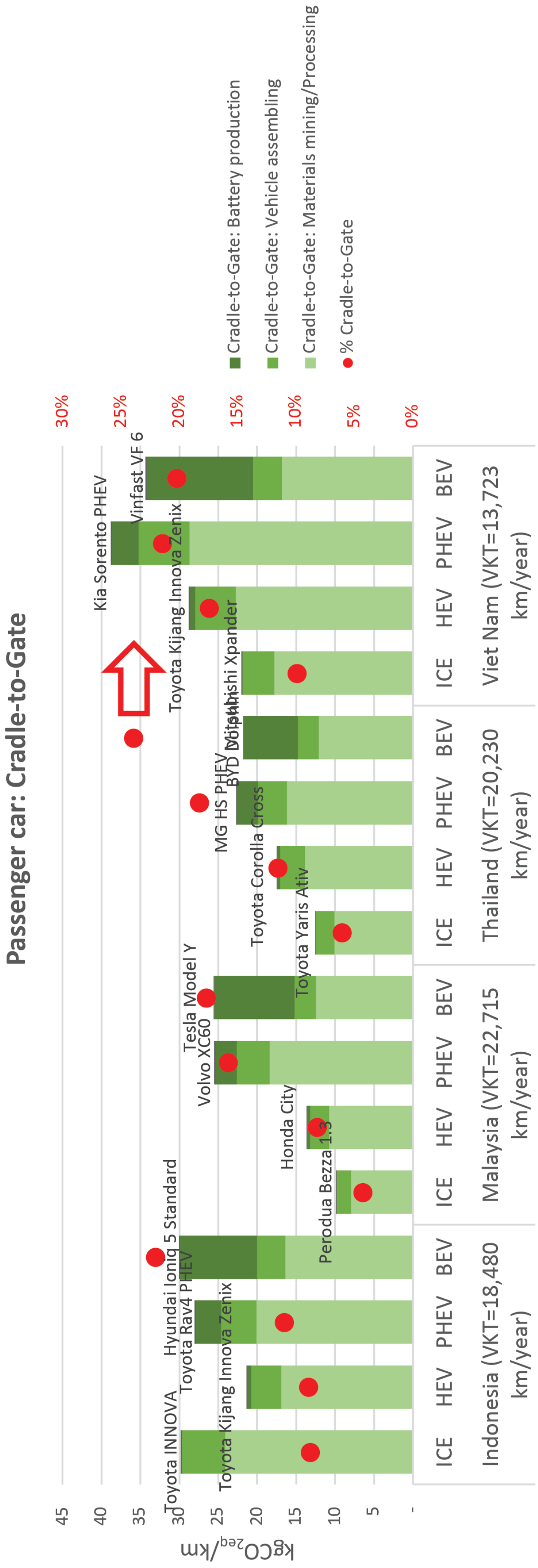


(c)

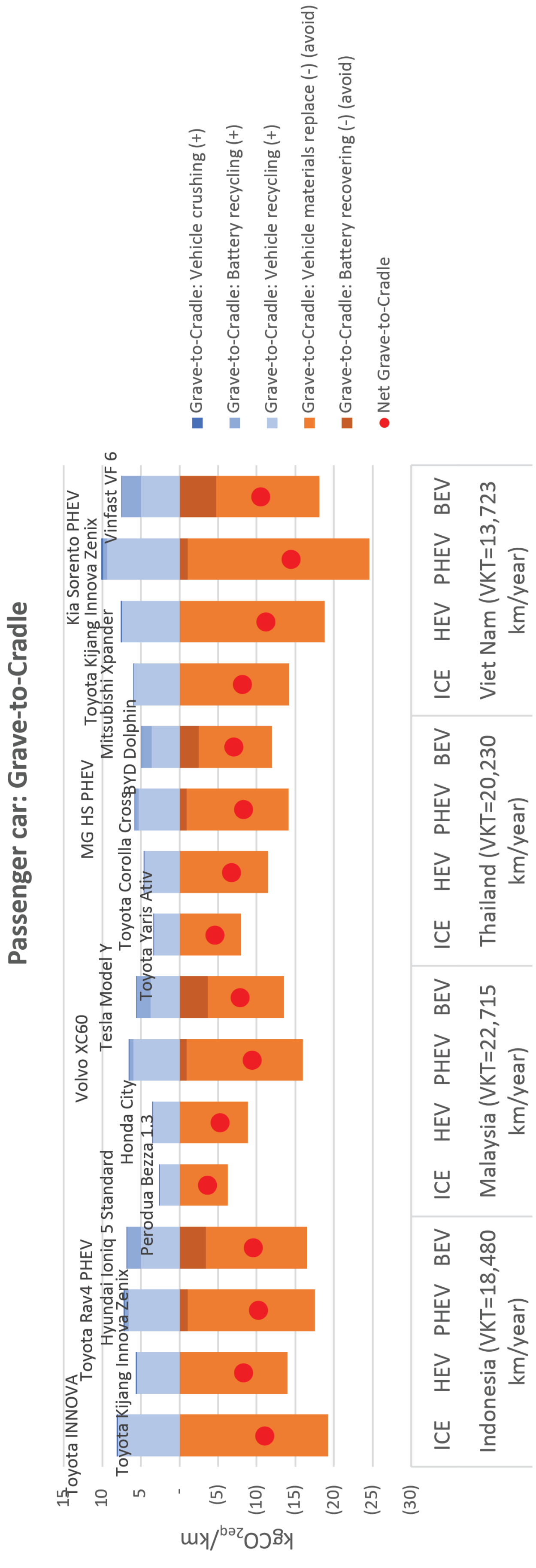
Figure 4 Lifetime analysis (20-Year) of global warming impact comparing between ICE, HEV, PHEV, and BEV (Four wheelers): (a) complete, (b) Cradle-to-Gate, and (c) Grave-to-Cradle


Passenger car
kgCO2eq/km
400
350
300
250
200
150
100
50
-
(50)
Toyota INNOVA
Toyota Kijang Innova Zenix
Toyota Rav4 PHEV
Hyundai Ioniq 5 Standard
Perodua Bezza 1.3
Honda City
Volvo XC60
Tesla Model Y
Toyota Yaris Ativ
Toyota Corolla Cross
MG HS PHEV
BYD Dolphin
Mitsubishi Xpander
Toyota Kijang Innova Zenix
Kia Sorento PHEV
Vinfast VF 6
339.15
253.46
239.25
229.95
135.91
166.27
160.60
206.27
144.60
150.73
123.94
91.15
220.99
164.49
180.45
169.37
ICE HEV PHEV BEV
Indonesia (VKT=18,480 km/year)
ICE HEV PHEV BEV
Malaysia (VKT=22,715 km/year)
ICE HEV PHEV BEV
Thailand (VKT=20,230 km/year)
ICE HEV PHEV BEV
Viet Nam (VKT=13,723 km/year)
Grave-to-Cradle: Vehicle crushing (+)
Grave-to-Cradle: Battery recycling (+)
Grave-to-Cradle: Vehicle recycling (+)
Cradle-to-Gate: Battery production
Cradle-to-Gate: Vehicle assembling
Cradle-to-Gate: Materials mining/Processing
Battery replacement (use phase)
Tank-to-Wheel (use phase)
Well-to-Tank (use phase)
Grave-to-Cradle: Vehicle materials replace (-) (avoid)
Grave-to-Cradle: Battery recovering (-) (avoid)
Net lifetime GHG emissions

(a)


Passenger car: Cradle-to-Gate
kgCO2eq/km
45
40
35
30
25
20
15
10
5
-
30%
25%
20%
15%
10%
5%
0%
Cradle-to-Gate: Battery production
Cradle-to-Gate: Vehicle assembling
Cradle-to-Gate: Materials mining/Processing
% Cradle-to-Gate
Toyota INNOVA
Toyota Kijang Innova Zenix
Toyota Rav4 PHEV
Hyundai Ioniq 5 Standard
Perodua Bezza 1.3
Honda City
Volvo XC60
Tesla Model Y
Toyota Yaris Ativ
Toyota Corolla Cross
MG HS PHEV
BYD Dolphin
Mitsubishi Xpander
Toyota Kijang Innova Zenix
Kia Sorento PHEV
Vinfast VF 6
ICE
HEV
PHEV
BEV
Indonesia (VKT=18,480 km/year)
Malaysia (VKT=22,715 km/year)
Thailand (VKT=20,230 km/year)
Viet Nam (VKT=13,723 km/year)

(b)



Passenger car: Grave-to-Cradle
kgCO2eq/km
15
10
5
-
(5)
(10)
(15)
(20)
(25)
(30)
Toyota INNOVA
Toyota Kijang Innova Zenix
Toyota Rav4 PHEV
Hyundai Ioniq 5 Standard
Perodua Bezza 1.3
Honda City
Volvo XC60
Tesla Model Y
Toyota Yaris Ativ
Toyota Corolla Cross
MG HS PHEV
BYD Dolphin
Mitsubishi Xpander
Toyota Kijang Innova Zenix
Kia Sorento PHEV
Vinfast VF 6
ICE
HEV
PHEV
BEV
Indonesia (VKT=18,480 km/year)
Malaysia (VKT=22,715 km/year)
Thailand (VKT=20,230 km/year)
Viet Nam (VKT=13,723 km/year)
Grave-to-Cradle: Vehicle crushing (+)
Grave-to-Cradle: Battery recycling (+)
Grave-to-Cradle: Vehicle recycling (+)
Grave-to-Cradle: Vehicle materials replace (-) (avoid)
Grave-to-Cradle: Battery recovering (-) (avoid)
Net Grave-to-Cradle

(c)

3.2 Discussion

For four countries in ASEAN (Indonesia, Malaysia, Thailand, and Vietnam), a full life cycle analysis covering vehicle production, usage, and scrappage on popular models of ICE, HEV, PHEV, and BEV for passenger cars was carried out with key messages as follows. Note that the assessment is based on commercially available and most popular vehicle models in each country, which may differ in vehicle class and usage.

- In all countries, the GHG emissions from ICE vehicles are higher than those from HEV, PHEV, and BEV passenger cars.
- The least emissions vehicle is a BEV when considered the whole of a lifetime.
- The vehicle uses phase accounts for the majority of overall GHG emissions in all vehicle types. ICE and HEV are dominated by tank-to-wheel; whereas, PHEV and BEV are dominated by well-to-tank.
- The emission factors of electricity play important role in well-to-tank emissions for both PHEVs and BEV.
- VKT and fuel consumption of the vehicles are the main parameters that contribute to the GHG emissions in vehicle use phase.
- EV with better energy conversion efficiency can help reduce GHG emission for road transport sector.
- Materials mining/Processing (cradle-to-gate) is ranked 2nd for contribution to the emissions for all vehicle types.
- In general, cradle-to-gate accounts for 5-24% of the life cycle assessment.
- Vehicle recycling (grave-to-cradle) is ranked 3rd for contribution to the emissions for all vehicle types. This is due to the energy input for the recycling process.

Of course, the results would depend on assumptions used in the LCA calculations, which may change if the following policies have been deployed Share of renewable energy in power sector.

- Fuel economy standard.
- Battery management/recycle policy.
- Battery improvement for capacity and lifespan
- Weight reduction of EV

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4

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