ERIA Research Project 2022 No.16

Analysis of Future Mobility Fuel Scenarios Considering the Sustainable Use of Biofuels and Other Alternative Vehicle Fuels in East Asia Summit Countries – Phase II

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ERIA Research Project Report FY2022 No. 16
Published in November 2022

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List of Abbreviations and Acronyms

AEDP	Alternative Energy Development Plan
AIST	National Institute of Advanced Industrial Science and Technology
ASEAN	Association of Southeast Asian Nations
BEV	battery electric vehicle
CME	coconut methyl ester
Co	cobalt
CPO	crude palm oil
E0	unblended
E10	10% ethanol blend
E20	20% ethanol blend
EAS	East Asia Summit
ERIA	Economic Research Institute for ASEAN and East Asia
EV	electric vehicle
FAO	Food and Agriculture Organization of the United Nations
FCEV	fuel cell electric vehicle
FE	fuel economy
GDP	gross domestic product
GHG	greenhouse gas
GWP	global warming potential
HEV	hybrid electric vehicle
IPCC	Intergovernmental Panel on Climate Change
L	litre
LCA	life cycle analysis
MEMR	Ministry of Energy and Mineral Resources
MJ	megajoule
MPOB	Malaysian Palm Oil Board
Nd	neodymium
PHEV	plug-in hybrid electric vehicle

PNS	Philippine National Standards
REO	rare earth oxide
RON	research octane number
SDGs	Sustainable Development Goals
TOE	tons of oil equivalent
TTW	tank-to-wheel
t/y	ton per year
US	United States
VKT	vehicle kilometre of travel
WTT	wheel-to-tank
xEV	electrified vehicle

Executive Summary

Reducing greenhouse gas (GHG) emissions in the transport sector is now attracting attention worldwide, especially after the Paris Agreement in 2015. To meet this target, East Asia Summit (EAS) countries have been making great efforts to introduce biofuels on a large scale considering the potential of their resources. Meanwhile, the introduction of electrified vehicles (xEVs) is now expanding rapidly, which can be another efficient option to reduce GHG emissions in the transport sector. Therefore, creating a future mobility fuel scenario with the balance of biofuel vehicles and xEVs is necessary.

In this regard, this project aims to analyse the future scenario of EAS mobility, which highly contributes to the Sustainable Development Goals (SDGs) (7, 12, and 13) in consideration of the balance between transport CO_2 reduction, biofuel use, and mineral resources demand. The outcome will contribute to the EAS Energy Research Road Map (Pillar 3: Climate Change Mitigation and Environmental Protection corresponding to the Association of Southeast Asian Nations (ASEAN) Plan of Action for Energy Cooperation 2016–2025, 3.5 Programme Area No.5: Renewable Energy, and 3.6 Programme Area No.6: Regional Energy Policy and Planning).

In financial year (FY) 2020, existing biofuel policies and implementation plans were updated from selected EAS countries as a foundation to accommodate emerging electric vehicle trends during mobility energy transition. As the result, the information on biofuel policies and implementation mechanism, as well as potential CO_2 reduction, are collected. Moreover, the progress of sustainability assessment of biofuels in the East Asia region were evaluated with examples of some of the participating countries using the sustainability indicators proposed by the earlier ERIA project on 'Sustainable Biomass Utilisation Vision in East Asia'.

Following FY2020 progress, this report provides evaluation results of 'well-to-tank' CO_2 emissions from producing biofuels, 'tank-to-wheel' CO_2 emissions from using biofuels, and demand and CO_2 emissions from producing mineral resources considering mobility electrification.

First, national policy and future projection of biofuels were clarified in Malaysia, Philippines, Viet Nam, and Thailand. The well-to-tank GHG emissions from biofuels in the various countries in the region are summarised. Despite some variations in the emissions values from the different feedstock and countries, these are all lower than their fossil fuel counterparts (i.e. 2.92 kilogrammes per litre gasoline as compared to ethanol and 83.8 grammes of CO_2 equivalent per megajoule of diesel as compared to biodiesel). In the case of palm biodiesel production, the cultivation of oil palm has a significant contribution followed by biodiesel production and crude palm oil production. Crude palm oil production gains benefits from many by-products such as fibre, shell, empty fruit bunches, and biogas from palm oil mill effluent that can be used for energy. In the case of ethanol, the agriculture stage is once again quite a high contributor for both cassava and sugarcane molasses. However, for the case of cassava, ethanol production particularly distillation and dehydration, have a very high contribution to GHG emissions due to the use of fossil fuels. However, in the case of sugarcane molasses the use of biomass-based by-products such as bagasse and biogas from vinasse as energy sources reduces the contribution of the ethanol production to GHG emissions. The transportation of feedstock and intermediates has a relatively modest contribution for all the biofuels.

Second, a bottom-up energy demand model for transport sector was constructed, focusing on car and motorcycle, in six countries: Indonesia, Malaysia, Philippines, Thailand, Viet Nam, and India. Tank-to wheel-GHG emissions were estimated using the Low Emissions Analysis Platform system with input data on population, gross domestic product, vehicle history and projection, vehicle kilometre of travel and fuel economy.

In particular, the tank-to-wheel greenhouse gas emissions in this study are calculated according to the Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories. For fuel combustion in road transportation, the emissions factors are selected according to the available Technology and Environmental Database. The tank-to-wheel greenhouse gas emissions from fossil fuel combustion in road transportation comprise CO_2, CH_4, and N_2O. These emissions are converted into the CO_2-equivalent unit by multiplied with the global warming potentials.

Third, long-term mineral resource demand associated with automobile electrification was estimated in EAS countries. In addition, CO_2 emissions from producing mineral resources and the potential for recycling in these countries were assessed by determining the amount of waste of these mineral resources and the effectiveness of introducing a circular economy under these conditions was evaluated.

In conclusion, the demand for neodymium is predicted to be a minimum of 4,075 tons per year (t/y) in 2040. If the recycle rate is 100%, secondary resources can cover 28.2% of total neodymium demand in EAS countries. The total demand for cobalt is predicted to be 53,324 t/y in 2040. If the recycle rate is 100%, secondary resources can cover 16.1% of cobalt demand in EAS countries.

Moreover, the total CO_2 emissions produced from neodymium magnet and lithium-ion battery cell production will be 1.9 metric tons per year neodymium magnet production and 8.4 metric tons per year for lithium-ion battery cell production in 2040. If the recycle rate is 100%, secondary resources can reduce CO_2 emissions 446,856 t/y for neodymium magnet production and 91,759 t/y for lithium-ion battery cell production in 2040.

For further studies, a case study of mobility scenario considering the balance between CO_2 reduction and potential of biofuels and/or mineral resources will be conducted. This will bring more uniformity to the overall sustainability assessment of biofuels for the region. Furthermore, the synergies as well as multi-benefits between biofuel implementation and mobility electrification will be more clarified. At last, the sustainable mobility scenarios for EAS countries will be created considering the achievement of the SDGs.

Chapter 1

Introduction

1. Background and Objectives of the Research

Reducing greenhouse gas (GHG) emissions in the transport sector is now attracting attention worldwide, especially after the Paris Agreement in 2015. To meet this target, East Asia Summit (EAS) countries have been making great efforts to introduce biofuels on a large scale considering the potential of their resources. Meanwhile, the introduction of electrified vehicles (xEVs) is now expanding rapidly, which can be another efficient option to reduce GHG emissions in the transport sector. Therefore, creating a future mobility fuel scenario with the balance of biofuel vehicles and xEVs is necessary.

The National Institute of Advanced Industrial Science and Technology (AIST) in Japan has been studying future mobility scenarios of EAS countries since 2014. In this AIST and Economic Research Institute for ASEAN and East Asia (ERIA) project, the scenarios for India, Indonesia, and Thailand were examined considering the potential of biofuels and xEVs and the constitution of power generation. As the result, well-to-wheel CO_2 emissions were estimated for several scenarios by creating energy mix models.

However, in the previous project, the sustainability of biofuels and xEVs has not yet been taken into consideration. Diffusion of xEVs can contribute to the reduction of CO_2 emissions but may increase the demand for mineral resources induced by motors and batteries.

In this regard, this project aims at analysing the future scenario of EAS mobility, which highly contributes to the Sustainable Development Goals (SDGs) (7, 12, and 13) in consideration of the balance between transport CO2 reduction, biofuel use, and mineral resources demand. The outcome will contribute to the EAS energy research road map (Pillar 3: Climate Change Mitigation and Environmental Protection corresponding to the ASEAN Plan of Action for Energy Cooperation 2016–2025, 3.5 Programme Area No.5: Renewable Energy, and 3.6 Programme Area No.6: Regional Energy Policy and Planning).

2. Study Method

The topics and method of each study are as follows. The target of EAS countries are India, Thailand, Indonesia, Philippines, Malaysia, and Viet Nam.

(1) Evaluation of the potential for biofuels and its sustainability including fuels from unconventional resources.

1st year	➢ Collate the existing research on biofuels sustainability assessment in EAS countries. ➢ Review the most updated biofuel sustainability standards. ➢ Identify needs for updating research.
2nd year	➢ Collect additional information/data for updating research as identified in the first year. ➢ Collect the existing research which assesses the potential of biofuels from residual waste (and agricultural waste, etc.) ➢ Conduct additional assessment for updating research results.
3rd year	➢ Interpret research results after scientific validation. ➢ Prepare policy brief to address policy concerns and needs vis-à-vis biofuels sustainability in EAS countries.

(2) Assessment of well-to-wheel CO_2 reduction considering the sustainability of biofuels and mineral resources.

1st year	➢ Updating with current biofuel policy of the countries to assess well-to-wheel CO_2 reduction. ➢ Evaluate the relationship between demand of xEVs and consumption of mineral resources (cobalt, nickel, and rare earths) using AIST original database of critical raw materials.
2nd year	➢ Estimate the well-to-wheel CO_2 reduction by biofuels and xEVs in EAS countries. ➢ Material flow analysis of mineral resources considering supply chain between ore, alloy, device (batteries and motors) and xEVs. ➢ Forecast the demand of xEVs and CO_2 emissions by mineral resources until 2050 in EAS countries considering the production capacity of mineral resources.
3rd year	➢ Scenario analysis of various biofuel policy in term of CO_2 reduction. ➢ Case study of mobility scenario considering the balance between CO_2 reduction and potential of biofuels/mineral resources.

3. Policy Recommendations

(1) Mobility scenario and strategy of EAS countries.

(2) Reduction of transport energy consumption and CO_2 emissions in EAS countries.

(3) Implementation of sustainable transport energy which highly contributes to SDGs.

4. Timeline/Schedule

Timeline of fiscal year 2021–2022:

December 2021 1st working group meeting

May 2022 2nd working group meeting

June 2022 Submission of report

September 2022 Publication of report

Timeline of the total project: September 2021–June 2023

Chapter 2

Well-to-Tank CO_2 Emissions from Biofuels in East Asia Summit Countries

1. Introduction

1.1. Background

Unlike fossil fuels, the upstream part of the life cycle of biofuels, or the so-called 'well-to-tank' is more significant than the downstream part or 'tank-to-wheel', especially for the case of greenhouse gas (GHG) emissions. As biofuels are derived from different agricultural feedstock and through several different processing pathways, these need to be carefully considered to establish the well-to-tank GHG emissions. In addition to the variation in feedstock and production pathways, there may also be additional differences due to country-specific issues.

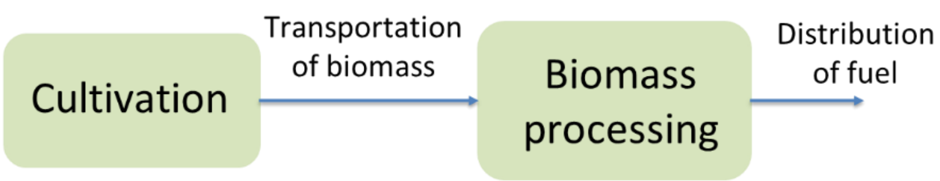
1.2. Objective and Scope

The well-to-tank GHG emissions of various biofuels in the participating East Asia Summit countries are summarised in this chapter. The current utilisation of biofuels and the planned use are also included.

1.3. Methodology

The life cycle approach is used for calculating the well to tank GHG emissions. The generic framework is shown in Figure 2.1. The well-to-tank GHG emissions will include feedstock cultivation, transportation of biomass to the biomass processing facilities, and biofuel production.

Figure 2.1. Generic System Boundary of Biofuel



Source: Authors.

For the current and planned utilisation of biofuels, government data from the various countries have been collated.

2. Well-to-Tank CO_2 Emissions from Biofuels in East Asia Summit Countries

2.1. Malaysia

2.1.1. Biofuels Plan

Malaysia has rolled out numerous energy policies since the 1970s and has gradually changed its policy direction to embrace sustainable development. This is evidenced in the 12th Malaysia Plan (2021–2025) (12 MP) where Theme 3 emphasised 'Advancing Sustainability' through green growth as well as enhancing energy sustainability and transforming the water sector (12th Malaysian Plan, 2021). Under the plan, green growth towards a low carbon nation will be augmented by managing energy in a holistic and sustainable way. The circular economy will be promoted to reduce waste generation, pollution, GHG emissions, and dependency on natural resources to expand the green economy and attain a low carbon future. The government has committed to driving sustainability and inclusivity as outlined in the 12 MP, with a commitment to achieve net-zero GHG emissions by 2050 at the earliest.

In-line with the 12 MP, the National Agricommodity Policy 2021–2030 promotes biofuel as a source of clean energy. Ten indicators and targets were identified to drive development of palm biodiesel over the next 10 years. Seven strategies were prioritised for implementation. The landscape of palm oil-based and oil palm biomass-based renewable energy will cover palm biodiesel, renewable hydrocarbon fuel (hydrotreated vegetable oil and sustainable aviation fuel) and biogas from palm oil mills. The B30 (30% palm biodiesel and 70% diesel) biodiesel programme is planned for implementation by 2030. However, the rollout could start earlier if sufficient technical data have been acquired. Beyond the B30 biodiesel programme, renewable hydrocarbon fuel or hydrotreated vegetable oil could be introduced in the future.

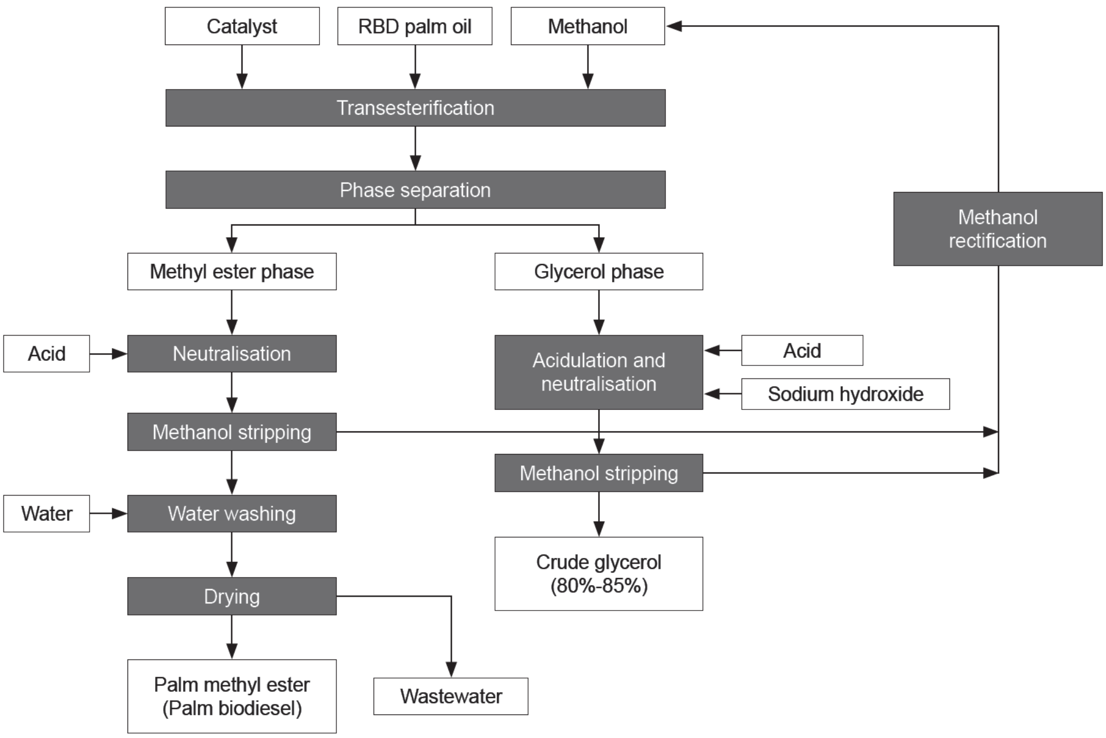
Since the introduction of the National Biofuel Policy 2006, Malaysia implemented the biodiesel programme in 2010. The production of palm biodiesel has increased over the years from 173,000 tonnes in 2010 to 1,423,000 tonnes in 2019. Biodiesel production decreased in 2020 to 906,000 tonnes due to an unfavourable market situation and the COVID-19 pandemic.

The implementation of the biodiesel programme in Malaysia started in 2011 with B5 (5% palm biodiesel and 95% diesel) and the blend ratio was increased to B7 in 2014 and B10 in 2019. The projected demand of biodiesel for the B10 programme is 534,000 tonnes of biodiesel per year. Apart from the automotive sector, B7 also has been mandated for industrial and/or commercial fleet usage starting in 2019 with anticipated demand of 227,000 tonnes of biodiesel per year. The B20 programme for the transport sector was introduced in 2020 by phases and the anticipated delayed rollout due to the COVID-19 pandemic. The nationwide B20 implementation is expected in 2025. The projected demand of palm biodiesel usage for biodiesel mandate in Malaysia is shown in Figure 2.2. The B30 programme is expected to rollout in 2030 with biodiesel usage of 1.6 million tonnes per year.

2.1.2. Well-to-Tank GHG Emissions from Palm Biodiesel in Malaysia

A gate-to-gate life cycle analysis (LCA) for the production of palm biodiesel was performed (Yung, Subramaniam, and Yusoff, 2021). The study was carried out based on actual operation data (primary data) obtained from six commercial palm biodiesel plants in Malaysia from 2015–2017. The study was conducted with a specific aim to evaluate the environmental performance of the production of palm biodiesel on various impact categories that focus specifically on the activities in the biodiesel plant. It was also aimed to provide an up-to-date information on the palm biodiesel production in Malaysia. Most of the feedstock used in the production of palm biodiesel for the local mandate is crude palm oil and refined palm oil. Thus, the LCA study was focused on the production of palm biodiesel based on refined palm oil as the primary feedstock. The process flow of the production of palm biodiesel is shown in Figure 2.2.

Figure 2.2. Process Flow Chart for the Production of Palm Biodiesel



RBD = refined, bleached, and deodorised.
Source: Yung, Subramaniam, and Yusoff (2021).

The methodology used for the LCA study was in accordance with ISO 14040 and ISO 14044. The impact assessment was performed using SimaPro software version 8.5.

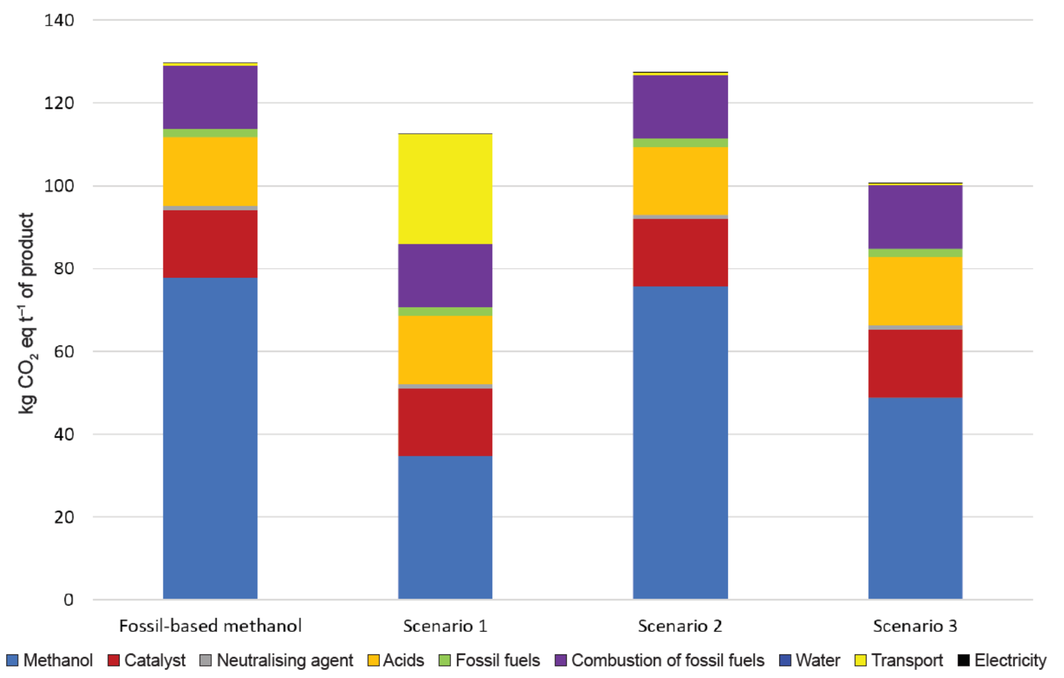
The inventory table was presented as per tonne of palm biodiesel produced as shown in Table 2.1. Based on the LCA conducted for commercial palm biodiesel production, methanol, transesterification catalyst, and acids are the main contributors to the adverse environmental impacts. Replacement of fossil-based methanol with biomethanol can lower the overall adverse environmental impact (Figure 2.3). However, not all the biomethanol sources would have a positive contribution to the environmental impacts. The impact assessment showed that the replacement of fossil-based methanol with biomethanol produced from biogas is the most preferred option with 22% reduction in global warming impact and saving up to 63% fossil resources. This study also shows that allocation based on mass value does not reflect the actual differences of both products, palm biodiesel and crude glycerol. Since the amount of crude glycerol used as fuel substitute is insignificant, allocation based on energy content was found unsuitable. The study concluded that allocation based on economic value can be more appropriate and relevant as both products are traded commercially in the open market at different prices.

Table 2.1. Inventory Data of Palm Biodiesel Production

Item	Unit	Amount
Input		
Refined, bleached, and deodorised (RBD) palm oil	tonne	0.9406
RBD palm stearin	tonne	0.0380
Palm fatty acid distillate (PFAD)	tonne	0.0166
Total feed material	tonne	0.9952
Methanol	kilogramme	108.8932
Sodium methoxide 30% (neutralizing agent)	kilogramme	9.4371
Hydrochloric acid	kilogramme	9.5788
Citric acid	kilogramme	0.8725
Acetic acid	kilogramme	0.1396
Sodium hydroxide (neutralising agent)	kilogramme	0.7853
Electricity	kilowatt hour	37.1409
Boiler fuel		
Natural gas	cubic metre	6.0749
Diesel	kilogramme	0.0081
Fuel Oil	kilogramme	0.1348
Water	litre	603.1306
Average distance from palm oil refineries to biodiesel plant	kilometre	9.2864
Transfer of feed oil to biodiesel plant	tonne kilometre	9.2418
Output		
Palm biodiesel	tonne	1.0000
Crude glycerol	kilogramme	127.4327

Note: Weighed average data calculated from five palm biodiesel producers for 2015 to 2017.
RBD = refined, bleached, and deodorised.
Source: Yung, Subramaniam, and Yusoff (2021).

Figure 2.3. Global Warming Effect from the Production of 1 Tonne of Palm Biodiesel



Note: Scenario 1: Replacement of fossil-based methanol with biomethanol produced from biomass in Switzerland; Scenario 2: Replacement of fossil-based methanol with biomethanol produced from biomass in Malaysia; Scenario 3: Replacement of fossil-based methanol with biomethanol produced from biogas in Malaysia.

Source: Yung, Subramaniam, and Yusoff (2021).

The GHG emissions computation in Table 2.2 is based on refined vegetable oils. Generally, the GHG emissions for the production of biodiesel from vegetable oils (palm oil, rapeseed oil, and soybean oil) using the transesterification process are similar as it uses the same amount of energy and chemicals.

Table 2.2. GHG Emissions Computation Based on Refined Palm Oil, Rapeseed Oil, and Soybean Oil

GHG Emissions	Refined Palm Oil (Malaysian Palm Oil Board, 2011)	Refined Rapeseed Oil	Refined Soybean Oil
Tonne CO_2eq/tonne oil	1.11 (without biogas capture) 0.63 (with biogas capture)	1.35	1.70

Sources: Choo et al. (2011); Mortimer et al. (2010).

The GHG emissions data for refined palm oil were published in 2011 using attributional LCA methodology. Palm biodiesel produced from palm oil sourced from mills with and without biogas capture emits 21.20 and 33.19 g CO_2 eq for every megajoule (MJ) of fuel, respectively. Currently, 28% of palm oil produced in Malaysia is with biogas capturing. The summary of the data on GHG emissions of the entire palm oil supply chain (from FFB to palm biodiesel) is shown in Table 2.3.

Table 2.3. GHG Emissions from the Entire Palm Oil Supply Chain (from FFB to palm biodiesel)

Production	**GHG Emissions (kg CO_2 equivalent)**	
1 tonne fresh fruit bunch (FFB)	119	
	Without biogas capture	**With biogas capture at 85% efficiency**
1 tonne crude palm oil (CPO)	971	506
1 tonne refined palm oil (RPO)	1,113	626
1 MJ of palm biodiesel	**GHG Emissions (g CO_2 equivalent)**	
	33.19	21.20

GHG = greenhouse gas, kg = kilogrammes, g = grammes.
Source: Choo et al. (2011).

By comparing the GHG emissions from utilising 1 MJ of fossil diesel in the transport sector with the GHG emissions from utilising 1 MJ of palm biodiesel, the emissions savings potential was estimated in Table 2.4. Compared to the typical GHG emissions from fossil diesel of 83.8 gCO_2 per MJ of fuel, the emissions savings of palm biodiesel produced from palm oil with and without methane capture are 74.7% and 60.4%, respectively. The GHG emissions savings of palm biodiesel based on national level (28% biogas capturing) would be 64.4%. The high palm biodiesel blending of as much as 30% can provide 18 to 22% more GHG emissions savings when used in automotive diesel applications.

Table 2.4. Estimated GHG Emissions Savings per MJ of Palm Biodiesel Produced

	GHG Emissions (g CO_2 equivalent)	
	Without biogas capture	**With biogas capture at 85% efficiency**
One MJ of palm biodiesel (Choo et al., 2011)	33.19	21.20
One MJ of fossil diesel (ISCC, 2016)	83.8	
	GHG savings potential (%) compared to fossil diesel used in transport sector	
Palm biodiesel (B100)	60.39	74.70
B7	4.22	5.23
B10	6.04	7.47
B20	12.08	14.94
B30	18.12	22.41

GHG = greenhouse gas, MJ = megajoule.
Sources: ISCC (2016); Choo et al. (2011).

2.2. Philippines

As part of the energy sector, the significant contribution of biofuels in the Philippines' energy mix is to develop and utilise indigenous renewable and sustainably sourced clean energy sources, thereby primarily reducing the country's dependence on imported fossil-based fuels.

The National Biofuels Board led the formulation of the Joint Administrative Order (JAO) No. 2008-1, Series of 2008 or the 'Guidelines Governing the Biofuel Feedstocks Production, and Biofuels and Biofuel Blends Production, Distribution and Sale under Republic Act No. 9367' to principally address the increasing unease on 'food versus fuel', which may be encountered in pursuing the progress of the Philippines' biofuels industry.

As defined in the Biofuels Act, feedstock refers to organic sources such as but not limited to the following: molasses, sugarcane, coconut, cassava, jatropha, sweet sorghum, oil palm, and other biomass that can be used to produce biofuels. For bioethanol, molasses and sugarcane are the current feedstock used for production. Out of the 13 accredited bioethanol producers, 10 are using 100% molasses as feedstock, whilst the remaining are using both molasses and sugarcane. Whilst for biodiesel production, coconut oil (CNO) is the currently used feedstock. Ten out of the 13 accredited biodiesel producers use 100% RBD CNO as feedstock with the remaining using both RBD and crude CNO.

The Philippine Sugar Regulatory Administration and the Philippine Coconut Authority are the concerned national government agencies that authorise local bioethanol and biodiesel producers to utilise locally-sourced feedstock in the production of biofuels to be sold to oil company customers for blending with gasoline and diesel, respectively.

For the biodiesel or the coconut methyl ester (CME) production, the raw materials needed are coconut oil (feedstock), alcohol and catalyst (base) which shall undergo transesterification reaction through mixing. Afterwards, the crude CME shall be separated from the glycerol (by-product), formed during the transesterification process. The crude CME shall then be washed with an ample amount of water before it is filtered to remove impurities and excess methanol (for recovery). To obtain the Philippine National Standards (PNS)-grade CME, the washed CME is dried for removal of traces of moisture. Prior to distribution to pump stations, the PNS-grade CME is blended at 2% with diesel fuel.

Whilst for bioethanol production, feedstock such as sugarcane and/or molasses is processed through fermentation producing hydrous ethanol with carbon dioxide and organic sludge water as by-products. Subsequently, to achieve the PNS-grade bioethanol of 99.3%, the produced hydrous ethanol is distilled and dehydrated. Prior to distribution to pump stations, the PNS-grade bioethanol is blended at 10% with gasoline fuel.

2.3. Indonesia

2.3.1. Biofuels Plan

The basic underlying policy of biofuel development in Indonesia is the Government Regulation No. 79/2014 which states that the contribution of new and renewable energy to the national energy mix must reach 23% by 2025. Further, the government has also committed to the Paris Agreement that Indonesia will, by 2030, reduce 29% of its GHG emissions below that of the business-as-usual (BAU) case. As a part of the 23% target, the Ministry of Energy and Mineral Resources (MEMR) has targeted that the contribution of bioenergy (solid biomass, biogas, and liquid biofuels) should reach 8%–9 % by 2025.

Indonesia started to become a net petroleum oil and fuels importing country in 2004 and the production and utilisation of biodiesel and bioethanol started in 2006. Then, through Decree No. 32/2008 of the MEMR, the government mandatorily set that by January 2015, the utilisation of liquid biofuels must reach B5 to B10 (depending on the field of applications) for biodiesel and E5 for bioethanol. However, the implementation of this biofuel programme went up and down due to the lack of a fixed incentive policy. The government took care of the programme only when the increase of international petroleum prices caused a large deficit in the national oil and gas trade balance.

In mid-2015, based on the initial and intensive discussions with the palm oil industry association, the government put a levy of US$50 per ton of exported palm oil and established the Indonesia Oil Palm Plantations Fund Management Agency to collect the levy and use it to subsidise palm oil biodiesel, amongst others. At about the same time, MEMR Decree No. 12/2015 mandatorily set that the utilisation of biodiesel must reach B20 by 2016 and B30 by 2020. The availability of a palm oil biodiesel subsidy from the fund management agency has benefited the biodiesel programme and helped fulfil the targets set by the MEMR Decree. On the other hand, the MEMR Decree No. 12/15 set mandates that the utilisation of bioethanol must reach E2 by 2016 and E5 by 2020, lack of similarly effective incentive policy (and agency) for gasoline-blending biofuel has made, since 2015, practically no bioethanol has entered the automotive fuel market. In turn, this standstill status of the bioethanol fuel programme has been a major cause of practically stagnant development of the Indonesian bioethanol industry. At present, even if the whole domestic bioethanol capacity, regardless of quality, is devoted to blending into gasoline, nation-wide it will not be enough even for an E1 gasohol programme.

In response to the successful development and large-scale trials of technologies to produce bio-hydrocarbon gasoline or bio-gasoline (G100), bio-hydrocarbon or green diesel (D100), as well as jet biofuel (J100) from palm and palm kernel oil, the MEMR has targeted the production of, through co-processing in petroleum refineries as well as a newly built stand-alone plant, 1.4 million cubic metres (m^3) of bio-hydrocarbon diesel and 0.5 million m^3 of bio-hydrocarbon gasoline by 2025 (Bioenergy Directorate, MEMR of Indonesia, 2021).

Recently, the government announced a plan to enforce a carbon tax on fossil fuel. Hopefully, this will provide a new source of funding for incentivising biofuel and other renewable energy development and utilisation programmes.

The target of biofuel implementation in Indonesia is shown in Table 2.5.

Table 2.5. Official Usage Targets of Biofuel (million m^3)

Biofuel	2021	2025	2030	2035
Biodiesel	9.2	9.6	10.5	11.5
Bio-hydrocarbon (green) diesel, D100	-	1.4	1.4	1.4
Bio-hydrocarbon (or bio-) gasoline, G100	-	0.6	2.1	2.1
Total	9.2	11.6	14.0	15.0

Note: As yet no target for bioethanol has been fixed.
Source: Bioenergy Directorate, Indonesian MEMR (2021).

2.3.2. Well-to-Tank GHG Emissions of Biofuels in Indonesia

The well-to-wheel (WTW) GHG emissions of liquid fuels consists of two parts: the well-to-(vehicle fuel)-tank (or WTT) part and the (vehicle fuel) tank-to-wheel (or TTW) part. GHG emissions from fossil fuels are small in the WTT part and large in the TTW part. In contrast, the GHG emissions of biofuels usually are dominantly large in the WTT part and small in the TTW part.

Traction Energy Asia (2019) reported that GHG emissions from plantations are still the largest contributor to emissions from biodiesel in Indonesia, accounting for over 80% of GHG emissions across the biodiesel supply chain. It is reported that the differentiating factor for total GHG emissions produced through land use change lies in the type of land, namely mineral or peat. Palm biodiesel based on mineral land plantations have well-to-gate GHG emissions of 0.7–1.09 kg CO_2 eq/L biodiesel, which is far below the 3.14 kg CO_2 eq/L WTW

GHG emissions of fossil diesel. In contrast, palm biodiesel based on plantations entailing land use change from peat have well-to-gate GHG emissions of 2.54–22.85 kg CO_2 eq/L biodiesel. The report also pointed out that methane capture can halve the emissions from the palm oil mills.

2.4. Viet Nam

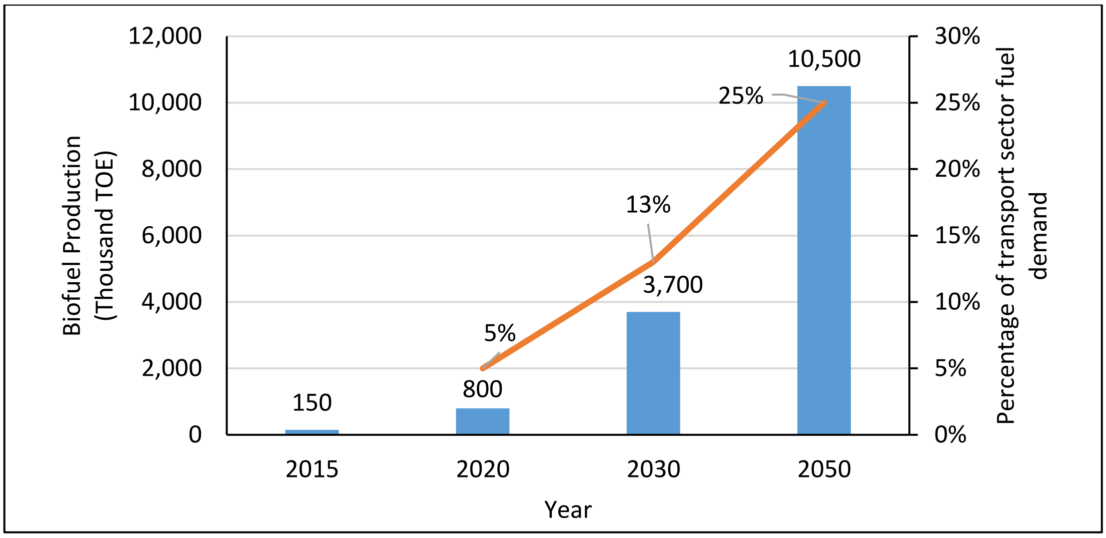
2.4.1. Biofuels Plan

In October 2021, the government issued Decision 1658/QD-TTg approving the National Green Growth Strategy 2021–2030, vision to 2050 (The Prime Minister of Government, 2021). Its overall objective is to contribute to the restructuring of the economy in conjunction with renewing the growth model, to achieve economic prosperity, environmental sustainability, and social equality; strive towards a green and carbon neutral economy; and contribute to the realisation of the goal to reduce global warming. In term of GHG emissions reduction, the specific target is to reduce emissions per gross domestic product (GDP) by at least 15% by 2030 and at least 30% by 2050 compared to 2014. In terms of greenifying economic sectors, the key specific targets until 2030 are to reduce the primary energy consumption per unit of GDP by 1.0%–1.5% annually on average for the 2021–2030 period, to achieve the proportion of 15%–20% of renewable energy in the total primary energy supply; and until 2050 the primary energy consumption per unit of GDP reduces by 1.0% annually on average for each 10-year period; the proportion of renewable energy in the total primary energy supply reaches 25%–30%. In order to promote sustainable transportation, the share of buses that use clean energy is expected to reach at least 15% of total operating buses in special-class cities and 10% of total new buses in class-1 cities by 2030; and the share of clean energy buses in total new buses in special-class cities and class-1 cities is expected to reach 100% and at least 40% respectively by 2050.

The targets for biofuel implementation are mentioned in the following policy documents:

- Decision 177/2007/QD-TTg issued on 20 November 2007 approving the scheme on development of biofuels up to 2015, with a vision to 2025, that states the output of ethanol and vegetable oil will reach 250,000 tons (enough for blending 5 million tons of E5 and B5), satisfying 1% of the whole country's fuel demand by 2015, and reach 1.8 million tons, satisfying about 5% of the whole country's fuel demand by 2025 (The Prime Minister of Government, 2007).
- Decision No. 2068/QĐ-TTg issued on 25 November 2015 approving Viet Nam’s Renewable Energy Development Strategy up to 2030 with an outlook to 2050 that expects to produce biofuels from approximately 150,000 tons of oil equivalent (TOE) in 2015 to about 800,000 TOE, i.e. 5% of the transport sector’s fuel demand in 2020; 3.7 million TOE, i.e. 13% of transport sector’s fuel demand in 2030; and 10.5 million TOE, i.e. 25% of the transport sector’s fuel demand in 2050 (Fig 2.4) (The Prime Minister of Government, 2015).

Figure 2.4. Biofuel Production and Consumption Expected, Viet Nam

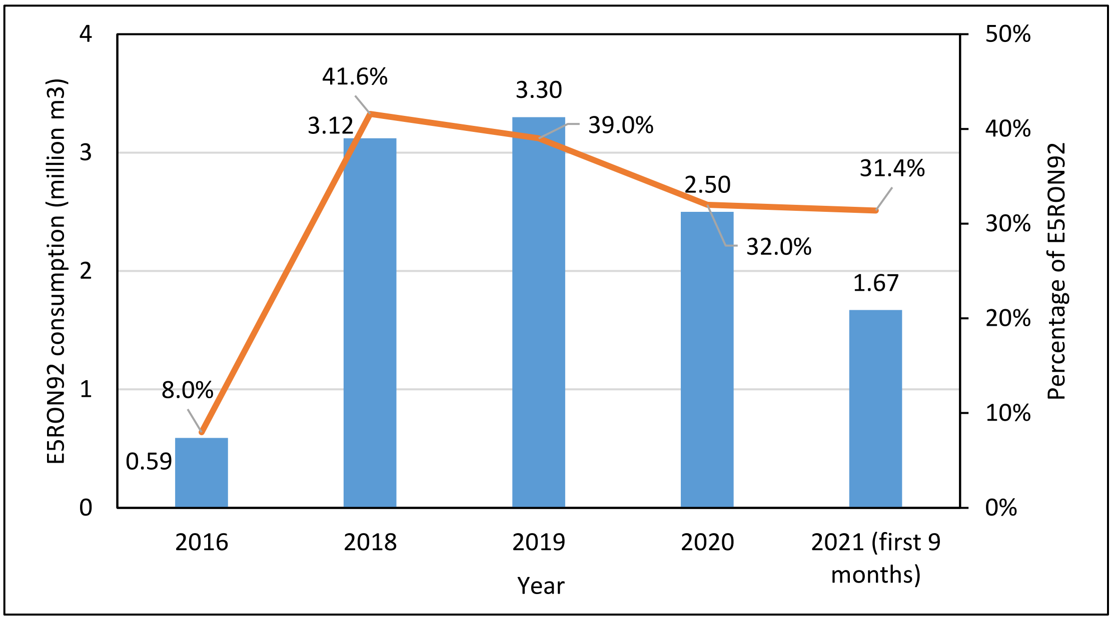


TOE = tons of oil equivalent.
Source: The Prime Minister of Government (2015).

- Decision 53/2012/QD-TTg issued on 22 November 2012 approving the road map to commercialise 5% ethanol blend (E5) in seven big cities (Hanoi, Ho Chi Minh City, Hai Phong, Danang, Can Tho, Quang Ngai, and Ba Ria-Vung Tau) beginning in December 2014 and nationwide from December 2015. This decision also set a target for 10% ethanol blend (E10) commercialisation in the seven cities beginning in December 2016, and nationwide from December 2017 (The Prime Minister of Government, 2012).
- Government Office's Announcement No.255/TB-VPCP dated 6 June 2018 states that as of 1 January 2018 only production of E5RON92 (a blend of 5% of ethanol and 95% of gasoline by volume, octane number (RON) of the blend is 92 minimum) and gasoline RON95 would be allowed (Government Office, 2017). After the release of Announcement No.255/TB-VPCP, E5RON92 consumption increased rapidly in 2018, up to 3.12 million m^3 accounting for 42% of total gasoline consumption.

After the release of Announcement No.255/TB-VPCP, E5RON92 consumption increased up to 3.12 million m^3, accounting for 42% of total gasoline consumption in 2018. In 2019 and 2020, E5RON92 consumption was about 3.3 and 2.5 million m^3, accounting for approximately 39% and 32% of total gasoline consumption, respectively. In the first 9 months of 2021, E5RON92 consumption was about 1.67 million m^3, approximately 31.4% of total gasoline consumption (Figure 2.5) (Vietnamnet, 2019; VOV traffic, 2020; Tuoitre Online, 2021).

Figure 2.5. E5RON92 Consumption, Viet Nam



Sources: Vietnamnet (2019); VOV traffic (2020); Tuoitre Online (2021).

It is seen that E5RON92 fuel consumption in 2020 was 2.5 million m^3, corresponding to 125 thousand m^3 of ethanol consumption or about 0.1 million ton of ethanol, equivalent to about 64.5 thousand TOE. This biofuel consumption achieves just about 8% of the biofuel production and consumption target mentioned in the Decision No. 2068/QĐ-TTg.

So far, there are some suggestions to increase the percentage of ethanol in blend (such as E10), and/or substitute E5 RON95 to gasoline RON95, but the plan has not been announced. Besides, the mandate to biodiesel blend use has not been issued due to the lack of domestic feedstock for biodiesel production.

2.4.2. Well-to-Tank GHG Emissions of Biofuels in Viet Nam

Some main properties of gasoline, diesel, and biofuels are provided in Table 2.6.

Table 2.6. Some Main Properties of Gasoline, Diesel, and Biofuels, Viet Nam

Fuel	Density	Unit	Heating Value	Unit	Tank-to-Wheel	Unit	Well-to-Tank	Unit
Gasoline	0.73 (Reported)	kg/L	43.96 (Energy Conservation Research and Development Center)	MJ/kg	69,300 (2006 IPCC Guidelines)	kg CO_2/TJ fuel	NA	
Diesel	0.85 (Viet Nam Standards, 5689:2018)	kg/L	42.7 (Energy Conservation Research and Development Center)	MJ/kg	74,100 (2006 IPCC Guidelines)	kg CO_2/TJ fuel	NA	
Ethanol	0.79 (Reported)	kg/L	27 (2006 IPCC Guidelines)	MJ/kg		kg CO_2/kg fuel	58.36 (FAO, 2018)	gCO_2/MJ fuel
Biodiesel	0.86–0.90 (Viet Nam Standards, 7717:2007)	kg/L	35.7 (Estimated from Nguyen and Pham, 2015)	MJ/kg	NA		NA	

kg/L = kilogramme per litre, MJ/kg = megajoule per kilogramme, kg CO_2/TJ = kilogramme of carbon dioxide per terajoule, gCO_2/MJ = gramme of carbon dioxide per megajoule, NA = not available.

Source: Various, indicated in the bracket

For biodiesel, there is a study that shows the global warming potential (GWP) of Jatropha biodiesel of 12.3 g CO_2 eq/1 MJ fuel based on the conditions in Viet Nam (Khang, 2019). It means that the GWP of Jatropha biodiesel reduces by 86.56% compared to fossil diesel. The reason for this is the large amount of CO_2 absorbed in biomass growth.

2.5. Thailand

2.5.1. Biofuels Plan

Thailand's Department of Alternative Energy Development and Efficiency (DEDE) has proposed an Alternative Energy Development Plan (AEDP), which provides alternative energy targets for many kinds of alternative energy, including biofuels. The AEDP 2018 target is to increase the share of renewable energy either in the form of electricity, heat, and biofuels to be 30% of final energy consumption in 2037. Biofuels contribute about 3% of the total final energy consumption. The details of the target and actual consumption are presented in Table 2.7.

Table 2.7. Biofuel Targets of AEDP 2018 and Consumption 2019–2021, Thailand

	Unit	AEDP 2018 (2037 target)	2019	2020	2021
1. Ethanol	million litres/day	7.50	4.45	4.10	3.71
2. Biodiesel	million litres/day	8.00	4.90	5.11	4.58

AEDP = Alternative Energy Development Plan.
Sources: DEDE (2018, 2022).

Ethanol is produced from cassava, sugarcane molasses as well as some directly from sugarcane juice. The current installed capacity for ethanol production is 6 million litres per day; the breakdown by feedstock is shown in Table 2.8. Biodiesel, on the other hand, is produced from palm oil. There are 13 factories producing biodiesel in Thailand with a combined capacity of about 8.5 million litres per day, with the capacities varying between 30,000 litres per day to 1,800,000 litres per day (Krungsri Research, 2021b).

Table 2.8. Ethanol Installed Capacity, Thailand (April 2021)

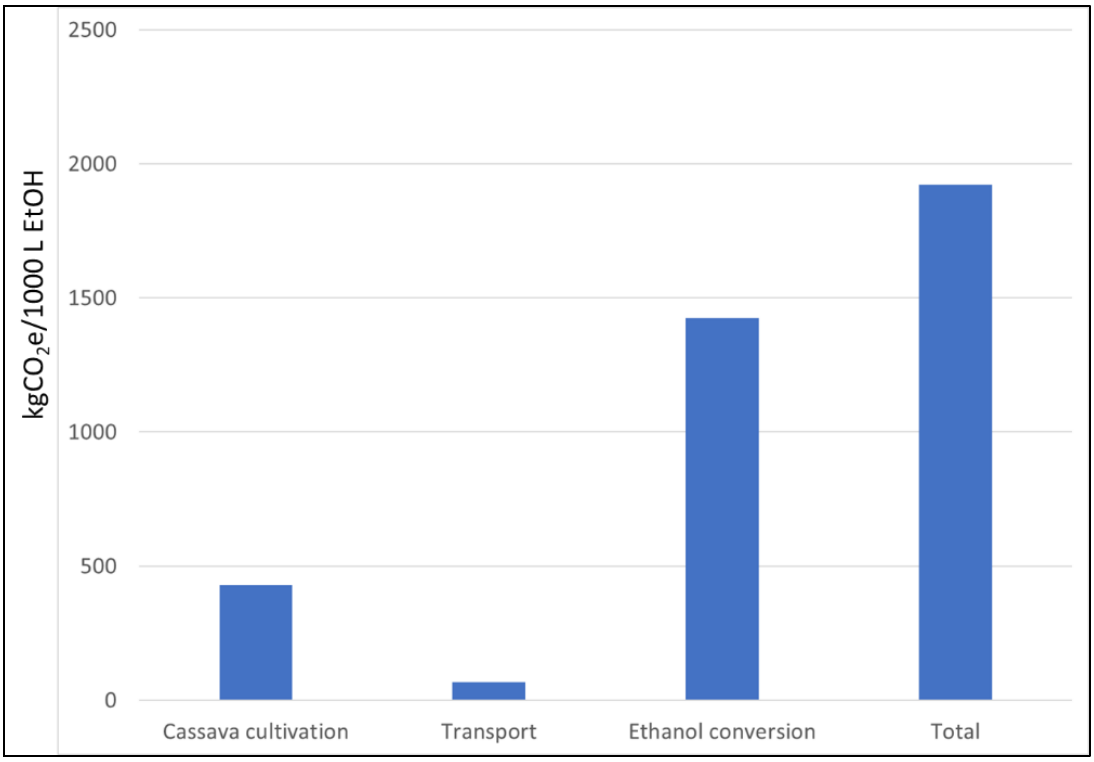
Feedstock	No. of Plants	Installed Capacity (million litres/day)
Molasses	10	2.60
Cassava	10	2.09
Cassava and molasses	5	1.05
Cane juice	1	0.23
Total	**26**	**5.97**

Source: Krungsri Research (2021a).

2.5.2. Well-to-Tank GHG Emissions of Biofuels in Thailand

The well-to-tank stages for ethanol production from cassava includes cassava cultivation, transport, and ethanol conversion (Figure 2.6). Ethanol conversion contributes the biggest share of GHG emissions at 74% followed by cassava cultivation at 22%. The contribution of transportation is relatively modest. The distillation and dehydration process in ethanol conversion requires a substantial amount of energy, which in the case of cassava is largely fossil-fuel based. Cassava cultivation has a large contribution due to the fertilisers and agricultural machinery.

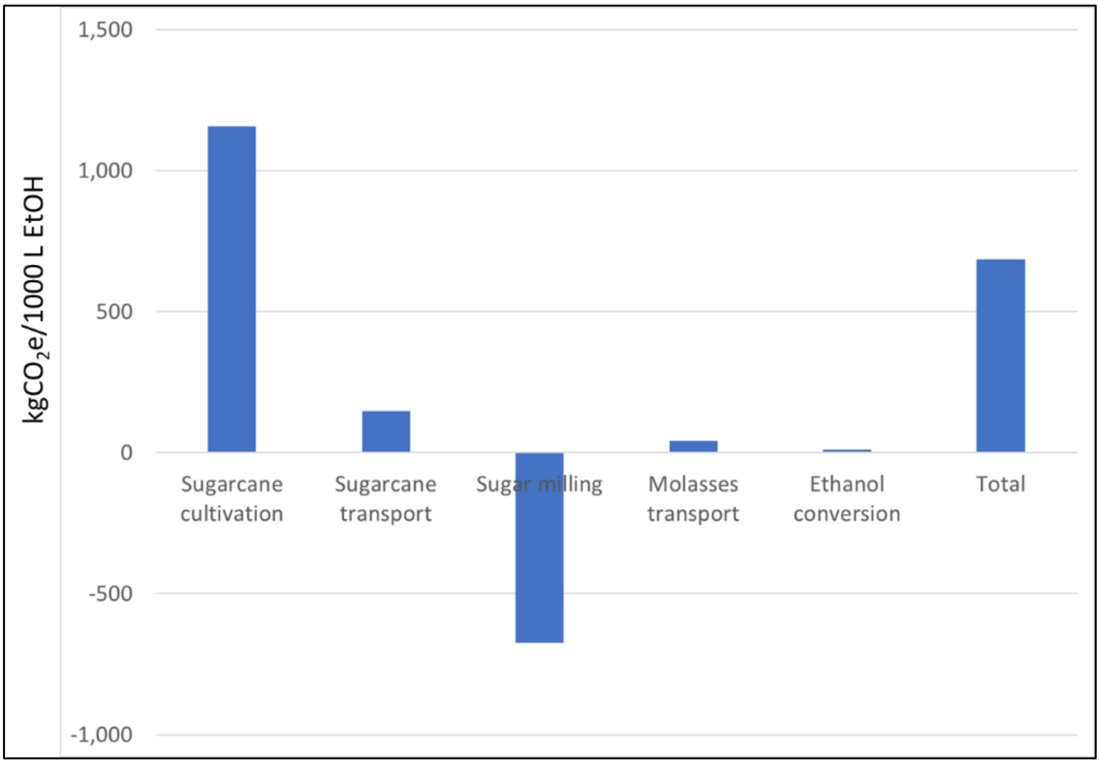
Figure 2.6. GHG Emissions from Production of Cassava Ethanol, Thailand



Source: Silalertruksa and Gheewala (2009).

For the case of ethanol production from sugarcane molasses, the life cycle stages include sugarcane cultivation, sugarcane transport, sugar milling, molasses transport, and ethanol conversion (Figure 2.7). The largest contributor is sugarcane cultivation due to the application of chemical fertilisers and the use of agricultural machinery. Here, unlike the case of cassava ethanol, the contribution of ethanol conversion to the overall GHG emissions is relatively modest despite the high requirement of energy for distillation and dehydration due the use of renewable fuels which are by-products of sugar milling (bagasse) and ethanol production (biogas from wastewater treatment). Sugar milling has a 'negative' contribution because of the production of bagasse which is used for steam and electricity production in excess of the requirement of the sugar mill itself. Transport of both sugarcane and molasses has a modest contribution to GHG emissions.

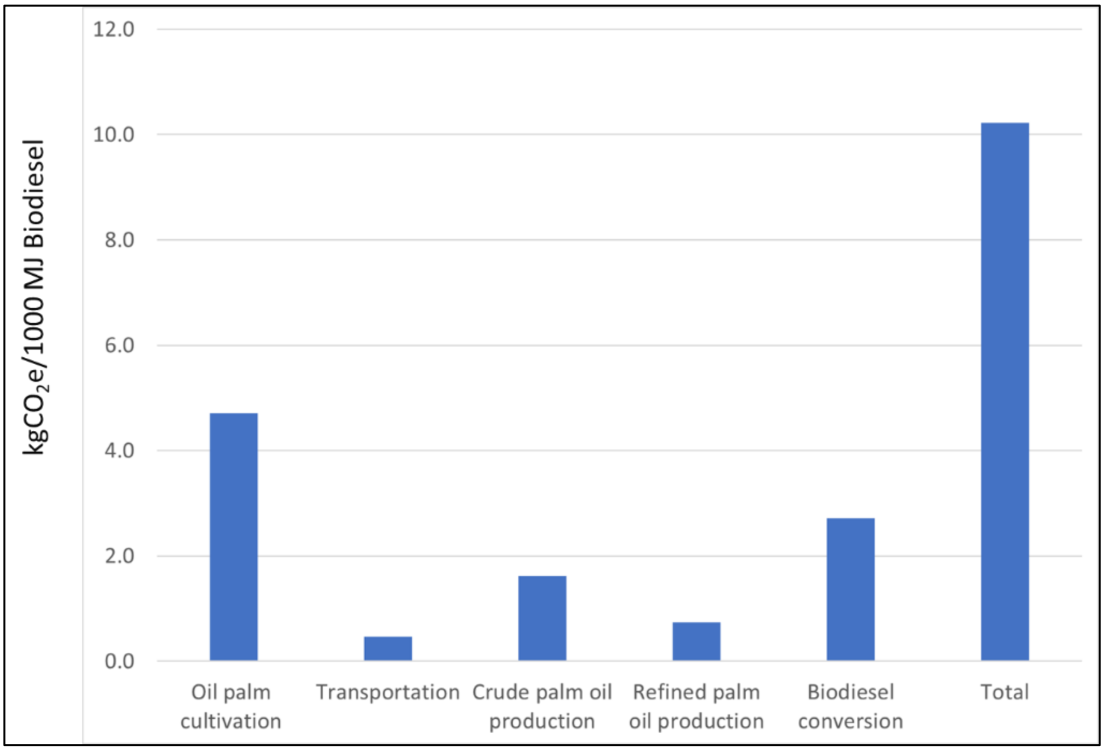
Figure 2.7. GHG Emissions from Production of Molasses Ethanol, Thailand



Source: Silalertruksa and Gheewala (2009).

Biodiesel production from palm oil includes oil palm cultivation, transport, crude palm oil production (palm mill), refining of crude palm oil, and biodiesel production (Figure 2.8). The largest contributor to GHG emissions is oil palm cultivation at about 46%. This is followed by biodiesel production at about 27% and crude palm oil production at 16%. The contribution of transport is nominal.

Figure 2.8. GHG Emissions from Production of Palm Biodiesel, Thailand



Source: Permpool, Ghani, and Gheewala (2020).

3. Discussion

3.1. Biofuel Plans in Selected East Asia Summit Countries

The countries in the region have been promoting biofuels for over a decade via various government regulations. In line with the 12th Malaysia Plan (2021–2025), the National Agricommodity Policy 2021–2030 promotes biofuel as a source of clean energy. Malaysia implemented a biodiesel programme in 2010; the production of palm biodiesel increasing over the years from 173,000 tonnes in 2010 to 1,423,000 tonnes in 2019. Malaysia started in 2011 with B5 and blends, B7 in 2014, and B10 in 2019. By 2025, nationwide implementation of B20 is expected and B30 in 2030. In the Philippines, sugarcane molasses and sugarcane juice are the primary feedstock for bioethanol production and coconut oil for biodiesel. Following the Biofuels Act, ethanol is blended with gasoline at 10% and biodiesel with diesel at 2%. The Ministry of Energy and Mineral Resources in Indonesia targeted to have B5–B10 (depending on the field of applications) for biodiesel and E5 for bioethanol. The target for biodiesel blends was set at B20 by 2016 and B30 by 2020. For bioethanol, the target was E2 by 2016 and E5 by 2020. Viet Nam's Renewable Energy Development Strategy up to 2030 with an outlook to 2050 expects to produce approximately 150,000 TOE biofuels in 2015, about 800,000 TOE, i.e. 5% of the transport sector's fuel demand in 2020; 3.7 million TOE, i.e. 13% of transport sector's fuel demand in 2030; and 10.5 million TOE, i.e. 25% of the transport sector's fuel demand in 2050. The AEDP has a target of 7.5 million litres/day of ethanol from sugarcane molasses, cassava and sugarcane juice, and 8 million litres/day of biodiesel from palm oil.

3.2. Well-to-Tank GHG Emissions from Biofuels

The well-to-tank GHG emissions from biofuels in the various countries in the region are summarised in Table 2.9. Despite some variations in the emissions values from the different feedstock and countries, these are all lower than their fossil fuel counterparts (i.e. 2.92 kg/L gasoline as compared to ethanol and 83.8 gCO_2 eq/MJ diesel as compared to biodiesel).

Table 2.9. Well-to-Tank GHG Emissions from Biofuels

Country	Biofuel	GHG Emissions
Malaysia	Palm biodiesel	33.19 gCO_2 eq/MJ (without biogas capture) 21.20 gCO_2 eq/MJ (with 85% biogas capture)
Indonesia	Palm biodiesel	0.7–1.09 kgCO_2 eq/L
Viet Nam	Bioethanol	58.36 gCO_2 eq/MJ (approx. 1.24 kg kgCO_2 eq/L)
Thailand	Palm biodiesel Cassava ethanol Molasses ethanol	10.2 gCO_2 eq/MJ 1.9 kgCO_2 eq/L 0.685 kgCO_2 eq/L

gCO_2 eq/MJ = grammes of CO_2 equivalent per megajoule of energy, kgCO_2 eq/L = kilogramme of CO_2 equivalent per litre.
Source: Authors.

In the case of palm biodiesel production, the cultivation of oil palm is one of the most significant contributors to GHG emissions followed by biodiesel production (particularly from the production of methanol used in transesterification), and crude palm oil production. Crude palm oil production gains benefits from many by-products such as fibre, shell, empty fruit bunches, and biogas from palm oil mill effluent that can be used for energy. In the case of ethanol, the agriculture stage is once again quite a high contributor for both cassava and sugarcane molasses. However, for the case of cassava, ethanol production particularly distillation and dehydration, has a very high contribution to GHG emissions due to the use of fossil fuels. However, in the case of sugarcane molasses the use of biomass-based by-products such as bagasse and biogas from vinasse as energy sources reduces the contribution of the ethanol production to GHG emissions. Transportation of feedstock and intermediates has a relatively modest contribution for all the biofuels.

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Chapter 3

Tank-to-Wheel CO_2 Emissions from Biofuels in East Asia Summit Countries

1. Introduction

1.1. Background

With an increasing trend of electric vehicle (EV) technology disrupting conventional internal combustion engine (ICE) technology, the future scenario of vehicle mix will change according to policy drive, technology readiness, and cost competitiveness. With recent carbon neutral commitment in the United Nations Climate Change Conference (COP26), the transport sector also holds responsibility in reducing net greenhouse gas emissions (GHG) from balancing the mix of EV and ICE with carbon-neutral biofuel blend.

1.2. Objective and Scope

The objective of this chapter is to establish the business-as-usual (BAU) landscape of the current vehicle ecosystem in select Association of Southeast Asian Nations (ASEAN) Member States (Indonesia, Malaysia, Philippines, Thailand, and Viet Nam) and India, with projection of vehicle growth in the future. Once the BAU landscape is established, a scenario analysis can be conducted with assumption of EV and biofuel mix in the future. Finally, energy consumption and GHG emissions can be analysed as a result of collective efforts on EV and biofuel in the transport sector.

1.3. Methodology

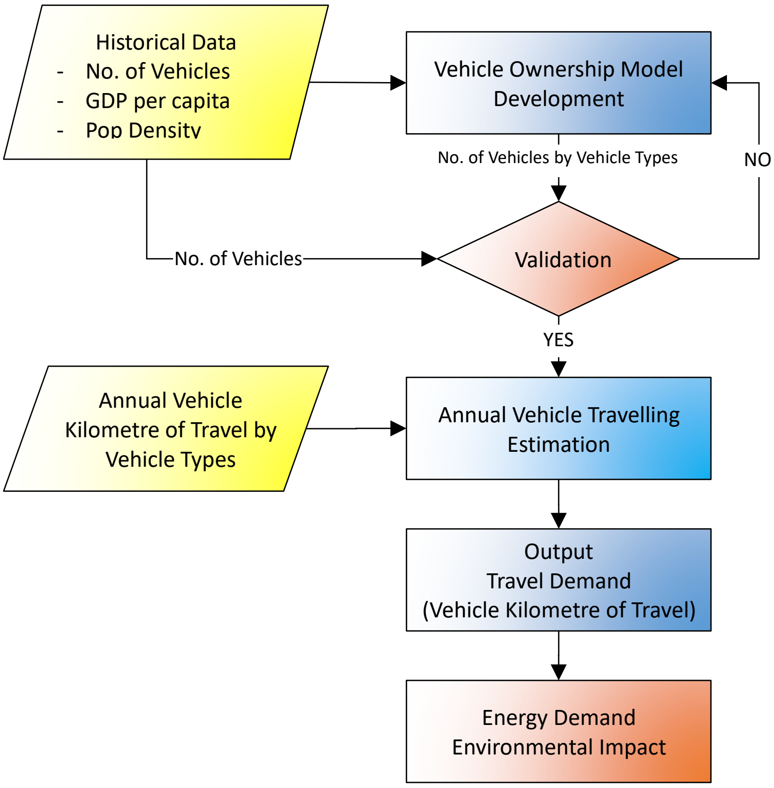
In order to analyse the energy use pattern in the transport sector with capability to predict energy demand with resulting emissions, a bottom-up approach, rather than a top-down approach, is undertaken due to its capability in accounting for the flow of energy based on a simple engineering relationship (Table 3.1) (UNFCC, 2005). Inputs of traveling demand, fuel consumption, and vehicle numbers from various types into the bottom-up model can yield the estimation of energy demand, as schematically shown in Figure 3.1 (LEAP, 2022). Amongst many others, the Low Emissions Analysis Platform (LEAP) system (LEAP, 2022) will be utilised to construct the energy demand model in this study.

Table 3.1. Differences between Top-down and Bottom-up Approach in Energy Model

Top-down	Bottom-up
Use aggregated economic data	Use detailed data on fuels, technologies, and policies
Assess costs/benefits through impact on output, income, GDP	Assess costs/benefits of individual technologies and policies
Implicitly capture administrative, implementation, and other costs	Can explicitly include administration and programme costs
Assume efficient markets, and no 'efficiency gap'	Do not assume efficient markets, overcoming market barriers can offer cost-effective energy savings
Capture intersectoral feedbacks and interactions	Capture interactions amongst projects and policies
Commonly used to assess impact of carbon taxes and fiscal policies	Commonly used to assess costs and benefits of projects and programmes
Not well suited for examining technology-specific policies.	

GDP = gross domestic product.
Source: UNFCC (2005).

Figure 3.1. Flow of Bottom-up Energy Demand Model

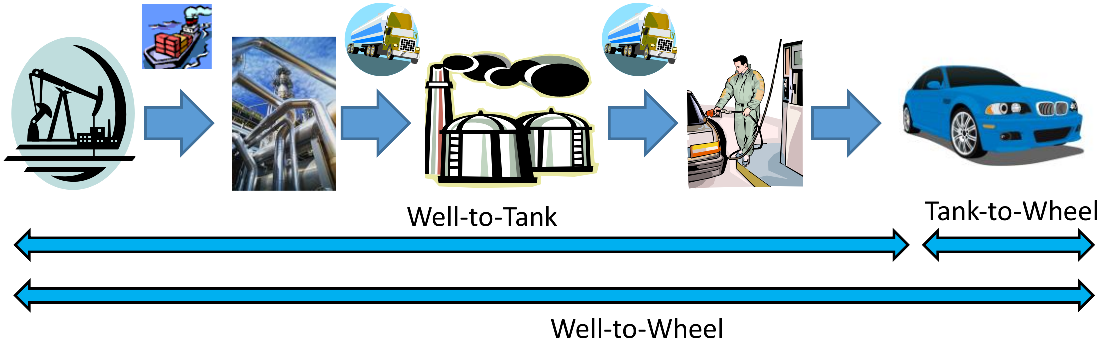


				Energy demand module			
Sector	Sub-sector	End-use	Device	Energy intensity			Energy demand
Transport sector	Transport mode	Modal split	Vehicle kilometre of travel	Type of fuel used	Fuel economy of vehicle		Scenario analysis
(vehicle)	(%)	(%)	(kilometre)	(%)	(GJ per veh-km)		(GJ or ktoe)

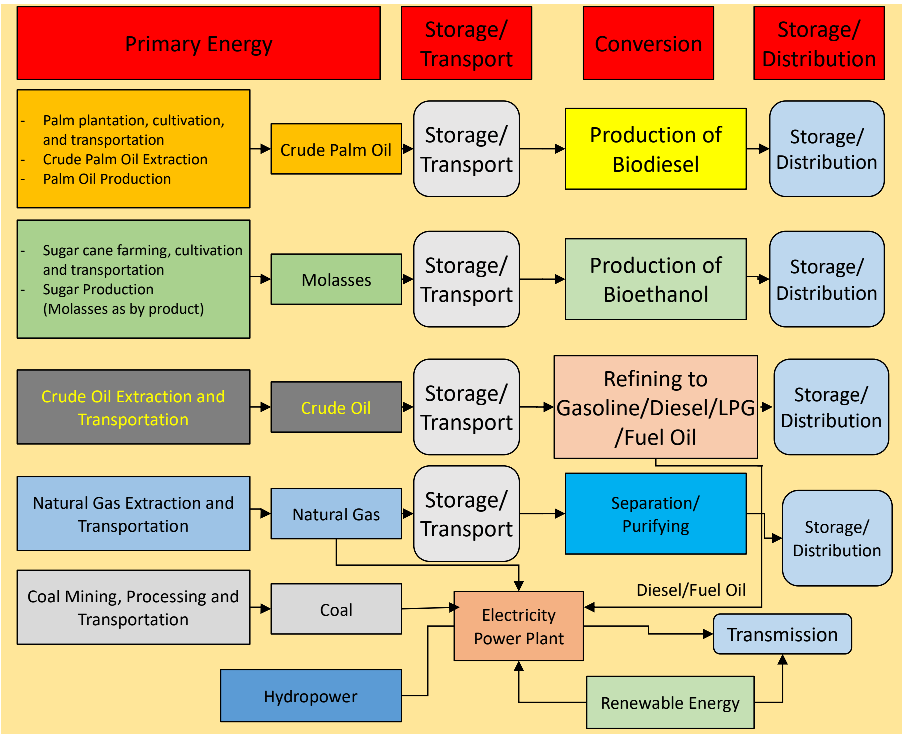
GJ = gigajoule, ktoe = kilotonne of oil equivalent.
Source: LEAP (2022).

Figure 3.2. Schematic Concept of Life Cycle Inventory

(a) Concept of 'Well-to-Tank', 'Tank-to-Wheel', and 'Well-to-Wheel'



(b) Detail Example on Various Transportation Fuels



Source: Pongthanaisawan (2012).

A bottom-up engineering energy demand model is composed of the main variables such as:

- number of vehicles
- fuel economy, and
- vehicle kilometre of travel (VKT)

For model calibration, it will be benchmarked against historic data of energy consumption. For the GHG module, well-to-wheel analysis (taking results from Chapter 2 into account) of fossil, biofuel, and electricity generation will be reviewed with an emphasis on gathering secondary data on biofuel (both ethanol and biodiesel), as well as national inventory data on electricity generation for EVs (Figure 3.2) (Pongthanaisawan, 2012). With careful calibration on both energy consumption and GHG emissions, the final model with a database will be utilised to investigate various effects from energy policy.

2. Energy Demand Model

2.1. Model Setup

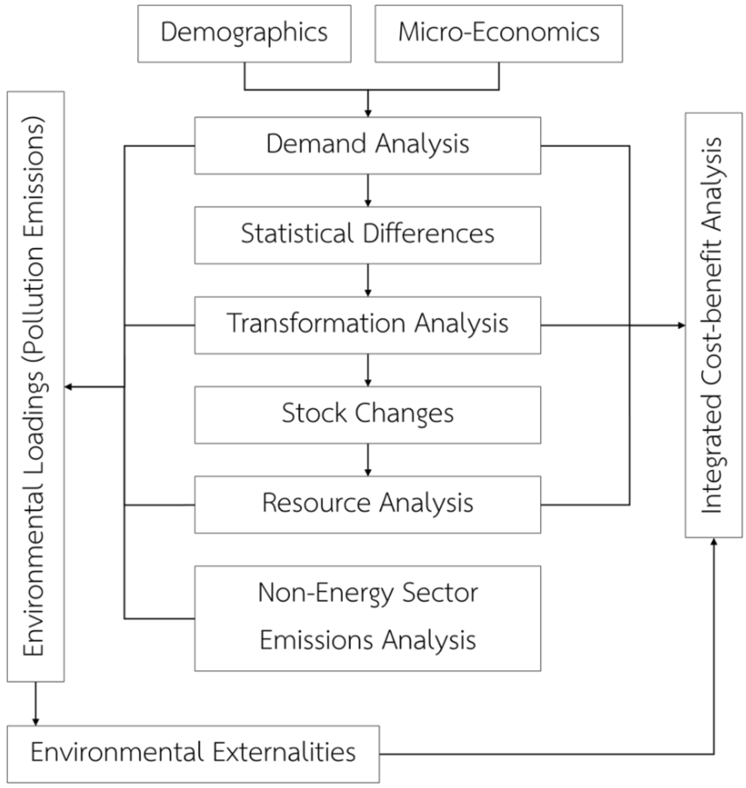
The choice of a bottom-up energy model approach in the present study is the LEAP system (LEAP, 2022), developed by the Stockholm Environment Institute. LEAP modeling capabilities are highlighted in Table 3.2, with the calculation flows shown in Figure 3.3.

Table 3.2. Key Characteristics of LEAP

Aspect	Characteristics
Energy Demand	✓ Hierarchical accounting of energy demand (activity levels x energy intensities) ✓ Choice of methodologies ✓ Optional modelling of stock turnover
Energy Conversion	✓ Simulation of any energy conversion sector (electric generation, transmission and distribution, combined heat and power, oil refining, charcoal making, coal mining, oil extraction, ethanol production, etc.) ✓ Electric system dispatch based on electric load-duration curves ✓ Exogenous and endogenous modelling of capacity expansion
Energy Resources	✓ Tracks requirements, production, sufficiency, imports and exports ✓ Optional land-area based accounting for biomass and renewable resources
Costs	✓ All system costs: capital, operations and maintenance, fuel, costs of saving energy, environmental externalities
Environment	✓ All emissions and direct impacts of energy system. ✓ Non-energy sector sources and sinks.

Source: LEAP (2022).

Figure 3.3. LEAP Calculation Flows



Source: LEAP (2022).

As mentioned earlier, important assumptions or variables for the energy demand model are:

1. estimation of the number of vehicles (NV)
2. estimation of the distances travelled by each vehicle (VKT)
3. estimation of the fuel economy of each vehicle (FE)

In this study, the energy demand and CO_2 emissions are calculated for five ASEAN countries, i.e. Indonesia, Malaysia, Philippines, Thailand, and Viet Nam, and India from the current situation to 2040. Noted that these three variables are not regularly updated so certain assumptions must be made from the engineering aspects, such as type of engine (spark-ignition vs compression-ignition), engine age, and fuel ratio used (liquid with biofuel blended or gas). The projections of energy demand and CO_2 emissions of considered vehicles are calculated in the road transportation model via the Low Emission Analysis Platform (LEAP). LEAP is a widely used commercial software tool for energy policy analysis and climate change mitigation assessment developed at the Stockholm Environment Institute. The energy demand is determined according on the bottom-up approach as the followed equation. Hence, the influential energy consumed branches in different vehicle technologies, fuels, and vehicles segments can be indicated. Beside the TTW CO_2 emissions, GHG emissions can also analysed by multiplying the energy consumption results with the emissions factor of concordance vehicle technologies, fuels, as well as vehicle segments.

$$ED = \sum_{i,j} NV_{i,j} \cdot FC_{i,j} \cdot VKT_i$$

where *i* means the considered vehicle (segment or technology), *j* is type of fuel or energy used, *NV* is the number of vehicles, *FC* is fuel consumption (fuel unit/km, where fuel unit must correspond to the unit of energy demand, i.e. fuel physical unit or energy unit), and *VKT* is the vehicle kilometre of travel (km).

Two vehicle types are considered: passenger cars and motorcycles. The various technology and fuel used are simplified into gasoline vehicles (fuelled with gasohol fuel at averaged ethanol fraction), diesel vehicles (only for passenger cars, fuelled with diesel fuel with averaged biodiesel fraction), and electric vehicles for every considered country.

2.2. Estimation of the Number of Vehicles (NV)

For passenger cars and motorcycles, the vehicle numbers can be estimated by realising the past data and trend of vehicle growth in a mathematical model, often called 'Vehicle Ownership Model', which can be defined in an S-curve logistic function (Button, Ngoe, and Hine, 1993; Chollacoop et al., 2003; Chollacoop et al., 2011; Dargay, Gately, and Sommer, 2007; Nagai et al., 2003). The relationship of vehicle numbers which are described by vehicle ownership (vehicle number per 1,000 people) and household economic situation are modelled in logarithmic form with saturation level. An example of such function (Laoonual, Chindaprasert, and Pongthanaisawan, 2008) is:

$$ln\left(\frac{S - VO}{VO}\right) = a + b \ln GDPpCap + c \ln PopDen$$

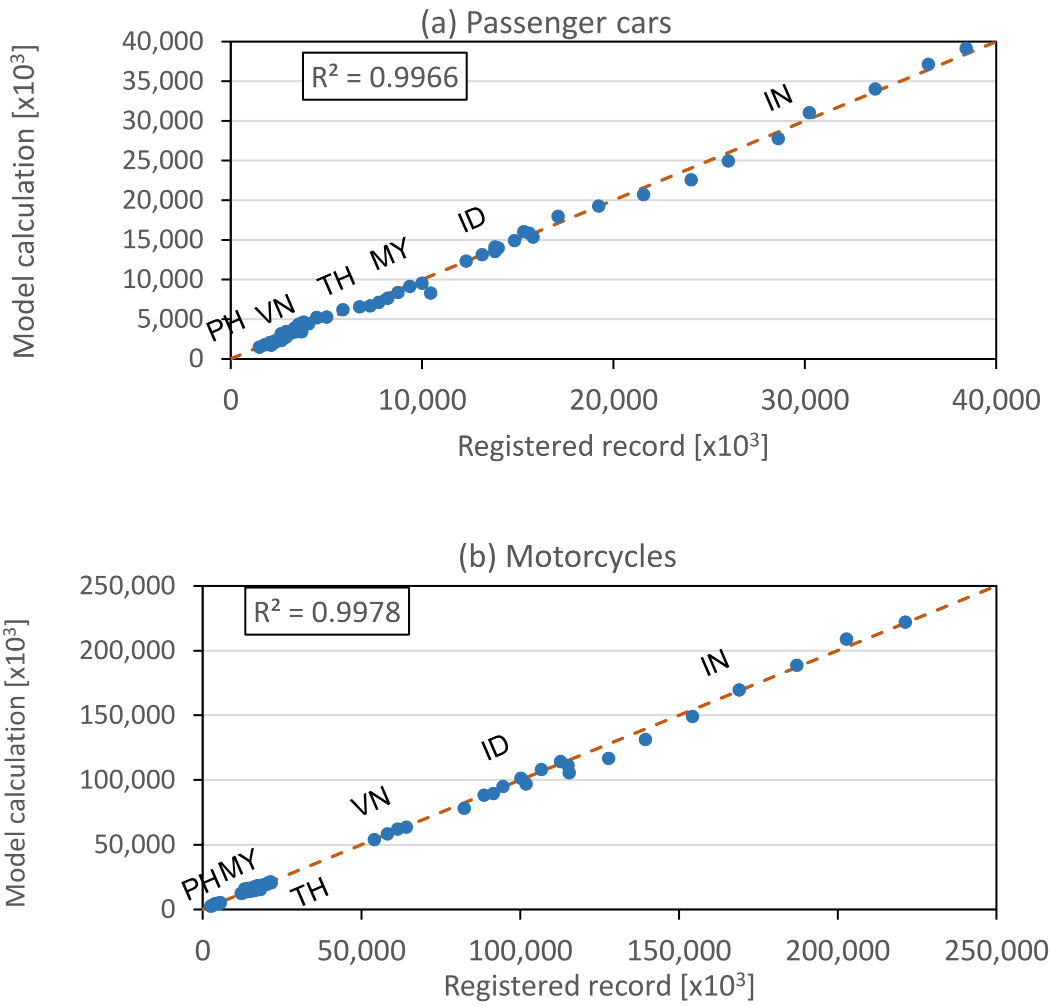
where

VO	= vehicle occupancy (number of vehicle/1,000 population)
S	= saturation level of VO (number of vehicle/1,000 population)
GDPpCap	= GDP per capita ($US/person or B/person)
PopDen	= population density (person/sq km)
a, b, and c	= coefficient from curve fitting with historical data

In this study the numbers of passenger cars and motorcycles from six considered countries (Indonesia, Malaysia, Philippines, Thailand, Viet Nam, and India) are fitted with historical records provided to working group members. The model calculated results are validated with historical registered record for passenger cars and motorcycles as shown in Figure 3.4. The models of vehicle numbers are shown in Table 3.3 for passenger cars and Table 3.4 for motorcycles. Noted that the GDP (at constant price) represents the household economic situation in each country (World Bank, 2022a). The population data are collected from the

World Bank (World Bank, 2022b). However, the Thailand data are collected from the Bank of Thailand (Bank of Thailand, 2022).

Figure 3.4. Validation of Vehicle Numbers for Five ASEAN Countries and India for (a) Passenger Cars and (b) Motorcycles



ID = Indonesia, IN = India, MY = Malaysia, PH = Philippines, TH = Thailand, VN = Viet Nam.
Source: Authors.

Table 3.3. Models of Passenger Car Numbers

Country	Abbr.	Vehicle ownership model (VO)	R^2
Indonesia	ID	$ln\left(\frac{VO}{812-VO}\right) = -14.4341 + 1.4378 \cdot ln(GDPpCap)$	0.97
Malaysia	MY	$ln\left(\frac{VO}{812-VO}\right) = 0.6636 \pm 0.0558 \cdot ln(GDPpCap)$	0.99
Philippines	PH	$ln\left(\frac{VO}{812-VO}\right) = -7.4109 + 0.5178 \cdot ln(GDPpCap)$	0.94
Thailand	TH	$ln\left(\frac{VO}{812-VO}\right) = -31.3784 + 2.4819 \cdot ln(GDPpCap)$	0.95
Viet Nam	VN	$ln\left(\frac{VO}{812-VO}\right) = -26.2333 + 2.8790 \cdot ln(GDPpCap)$	0.99
India	IN	$ln\left(\frac{VO}{812-VO}\right) = -14.7426 + 1.5071 \cdot ln(GDPpCap)$	0.99

*All countries' GDP are in US dollars, except Thailand's GDP is in Thai baht.
Source: Authors.

Table 3.4. Models of Motorcycle Numbers

Country	Abbr.	Vehicle ownership model (VO)	R^2
Indonesia	ID	$ln\left(\frac{VO}{600-VO}\right) = -30.8405 + 3.8369 \cdot ln(GDPpCap)$	0.96
Malaysia	MY	$ln\left(\frac{VO}{600-VO}\right) = -21.0808 + 2.3701 \cdot ln(GDPpCap)$	0.82
Philippines	PH	$ln\left(\frac{VO}{600-VO}\right) = -14.8897 + 1.5192 \cdot ln(GDPpCap)$	0.94
Thailand	TH	$ln\left(\frac{VO}{600-VO}\right) = -10.6937 + 0.8968 \cdot ln(GDPpCap)$	0.81
Viet Nam	VN	$ln\left(\frac{VO}{750-VO}\right) = -42.3103 + 5.6086 \cdot ln(GDPpCap)$	0.99
India	IN	$ln\left(\frac{VO}{600-VO}\right) = -15.8026 + 1.9490 \cdot ln(GDPpCap)$	0.81

*All countries' GDP are in US dollars, except Thailand's GDP is in Thai baht.
Source: Authors.

The saturation levels of the S-curve logistic function are shown in the formulas, 812 for passenger cars and 600 for motorcycles, while Viet Nam's motorcycles have 750 saturation level higher than other countries, according to the specific situation in Viet Nam. In the vehicle stock model, the new vehicles (vehicle sales) were calculated from simplified percent of new vehicle numbers by total on-road vehicle numbers, which are shown in Table 3.5 for various East Asia Summit countries.

Table 3.5. Percent of New Vehicle Numbers by On-Road Vehicle Numbers

	Cars	Motorcycles
Indonesia	5.75%	5.84%
Malaysia	3.67%	3.69%
Philippines	10.64%	19.68%
Thailand	5.85%–3.26%	9.76%–6.35%
Viet Nam	10.26%	5.03%
India	8.77%	9.3%

Source: Calculated from historical vehicle numbers (sale and on-road), except for Thailand where the value is calculated from sales projection of Thai's National EV Policy Committee and projection of vehicle ownership models (2022–2035).

2.3. Estimation of Vehicle Kilometre of Travel

The second variable, vehicle kilometre of travel (VKT), is the distance travelled by each considered vehicle. The VKT will govern how much fuel or energy is consumed for each vehicle type within a unit distance. The VKT values in this study were collected from some member countries but Thailand's data are not available and are presumed (Table 3.6).

Table 3.6. Vehicle Kilometre of Travel

VKT	Cars	Motorcycles
Indonesia	12,723	10,800
Malaysia*	20,230	17,820
Philippines*	20,230	17,820
Thailand*	20,230	17,820
Viet Nam	13,723	7,225
India*	20,230	17,820

Note: *Thailand data is used where data from member countries are not available.
VKT = vehicle kilometre of travel.
Source: Authors.

2.4. Estimation of Fuel Economy

The last collected variable is the fuel economy (FE) of each vehicle type. Together with VKT, the FE will directly give total fuel or energy needed. As aforementioned, all three variables (NV, VKT, and FE) are not regularly updated so certain assumptions must be made from the engineering aspects. Likewise, the FE must be specified according to engineering parameters, such as type of engine (spark-ignition vs compression-ignition), engine age, and fuel ratio used (liquid with biofuel blended or gas). The vehicles in this study were therefore simplified into spark-ignition engine, diesel (compression-ignition) engine, electrified vehicle (plug-in hybrid electric vehicle [PHEV], and battery electric vehicle [BEV]). Gas fuels were neglected in this work, whilst biofuels were assumed to be blended with mean blended ratios (different from practical blended ratios, i.e. gasohol E10, gasohol E85, biodiesel B7, biodiesel B30, but calculated from consumption of various fuels, e.g. if gasohol E10 and gasohol 20% ethanol blend (E20) are consumed with similar quantity – the mean blended ratio will equal to E15). In this study, the fuel/technology of considered vehicles is composed of:

- Passenger cars: gasoline, diesel, PHEV, BEV
- Motorcycles: gasoline, and electric motorcycles (eMC)

Where gasoline is fuelled by gasoline and ethanol fuels, diesel is fuelled by diesel and biodiesel fuels. The share of PHEV fuel usage between gasoline (gasoline and ethanol) and electricity are 68.25% and 31.75%, respectively, estimated from the United States' fuel economy database (US-EPA, 2022). The fuel economy of passenger cars and motorcycles with various fuel/technology are shown in Table 3.7.

Table 3.7. Assumption of Fuel Economy

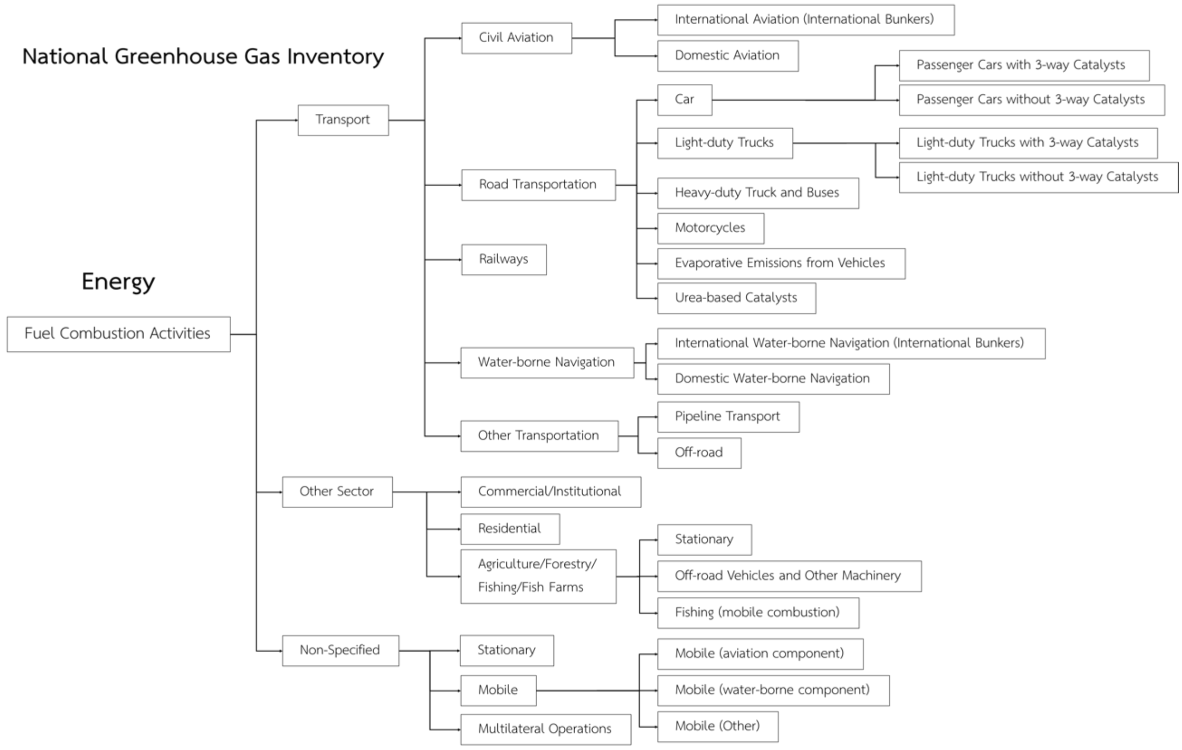
	Passenger Cars					Motorcycles	
	Gasoline	Diesel	PHEV		BEV	Gasoline	eMC
			Gasoline	Electricity			
Indonesia	10.99	9.71	5.25	48.31	10.73	3.60	2.88
Malaysia*	7.86	8.08	3.75	34.55	16.18	2.44	3.49
Philippines	12.62	10.53	6.02	55.47	16.18	2.44	3.49
Thailand*	7.86	8.08	3.75	34.55	16.18	2.44	3.49
Viet Nam	8.02	7.52	3.83	35.25	14.74	1.90	2.00
India*	7.86	8.08	3.75	34.55	16.18	2.44	3.49

Notes: Fuel economy is in the unit of litres/100 kilometres for gasoline and diesel, and kilowatt hour/100 kilometres for consumed electricity of EVs (PHEVs, BEVs, and eMCs). *Thailand data is used where data from member countries are not available.
PHEV = plug-in hybrid electric vehicle, BEV = battery electric vehicle, eMC = electric motorcycle.
Source: Authors.

2.5. Tank-to-Wheel Greenhouse Gas Emissions

The tank-to-wheel greenhouse gas (TTW GHG) emissions are calculated according to the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) in this study. For fuel combustion in road transportation, the emissions factors are selected according to the Technology and Environmental Database as shown in Figure 3.5.

Figure 3.5. Activity and Source Structure in the Energy Sector



Source: IPCC (2006).

The TTW GHG emissions are defined from the fundamentals of combustion reaction. In the combustion process, the complete combustion products are mainly CO_2 and water (H_2O). CO_2 is the major greenhouse gas emissions. In addition, the other emissions also affect the global warming impacts, two major species are methane (CH_4) and nitrous oxide (N_2O). Tier 2 is selected in this study to collect TTW GHG emissions for considered 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 3.8.

Table 3.8. Chosen Vehicle Models to Represent TTW GHG Emissions

Type of Vehicle	Chosen Vehicle Model
Gasoline passenger cars (for all gasoline combustion including HEV and PHEV)	European cars moderate control gasoline
Diesel passenger cars	European cars moderate control diesel
Gasoline motorcycles	European motorcycles >50 cc 4 stroke Uncontrolled gasoline

HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle, TTW GHG = tank-to-wheel greenhouse gas.
Source: IPCC (2006).

As above mentioned, the TTW GHG emissions for fossil fuel combustion in road transportation comprise CO_2, CH_4, and N_2O. These emissions are converted into the CO_2-equivalent unit by multiplied with the global warming potentials (GWP) as shown in Table 3.9.

Table 3.9. Global Warming Potentials of GHG Emissions from Combustion Process

	CO_2	CH_4	N_2O
GWP (kg in $CO_{2,eq}$/kg of considered emissions)	1	25	296

kg = kilogramme, GHG = greenhouse gas, GWP = global warming potentials.
Source: IPCC (2006).

Besides fossil fuel combustion, biofuels are considered as carbon neutral fuels. It means that the CO_2 produced during biofuel combustion is equivalent to the CO_2 quantity absorbed in the photosynthesis process of biofuel plantation.

2.6. Projection of Socioeconomic Variables

The bottom-up model was developed according on socioeconomic variables. In this study, the number of vehicles were defined as S-curve logistic function of two socioeconomic variables, e.g. the gross domestic product (GDP) and population defined in this section.

2.6.1. Gross Domestic Product

The GDP information was collected at the 2015 constant prices in US dollar (World Bank, 2022a) with an exception for Thailand. The data are available to year 2020. Thailand’s GDP is collected from the Bank of Thailand (Bank of Thailand, 2022) in baht at 2002 constant prices. The current GDP value and growth rate are shown in Table 3.10.

Table 3.10. Projection of Gross Domestic Product

	Current Value (billion)	Currency Unit	Growth Rate
Indonesia	1,027.60	US dollar	2.98%
Malaysia	344.10	US dollar	2.97%
Philippines	358.29	US dollar	3.18%
Thailand	10,266.61	Thai baht	3.96%
Viet Nam	258.51	US dollar	5.43%
India	2,500.13	US dollar	4.84%

Sources: World Bank (2022a); Bank of Thailand (2022).

2.6.2. Population (Capita, Cap)

Similar to GDP information, the population of considered countries is collected from the World Bank (World Bank, 2022b) with an exception for Thailand. Thailand's population was collected from the Bank of Thailand (Bank of Thailand, 2022). The current populations and growth rates are shown in Table 3.11.

Table 3.11. Population Projection by Country

	Current Value (million)	Growth Rate
Indonesia	273.52	1.15%
Malaysia	32.37	1.34%
Philippines	109.12	1.42%
Thailand	69.80	0.68%
Viet Nam	97.34	0.99%
India	1,366.42	1.07%

Sources: World Bank (2022a); Bank of Thailand (2022).

3. Scenario Analysis

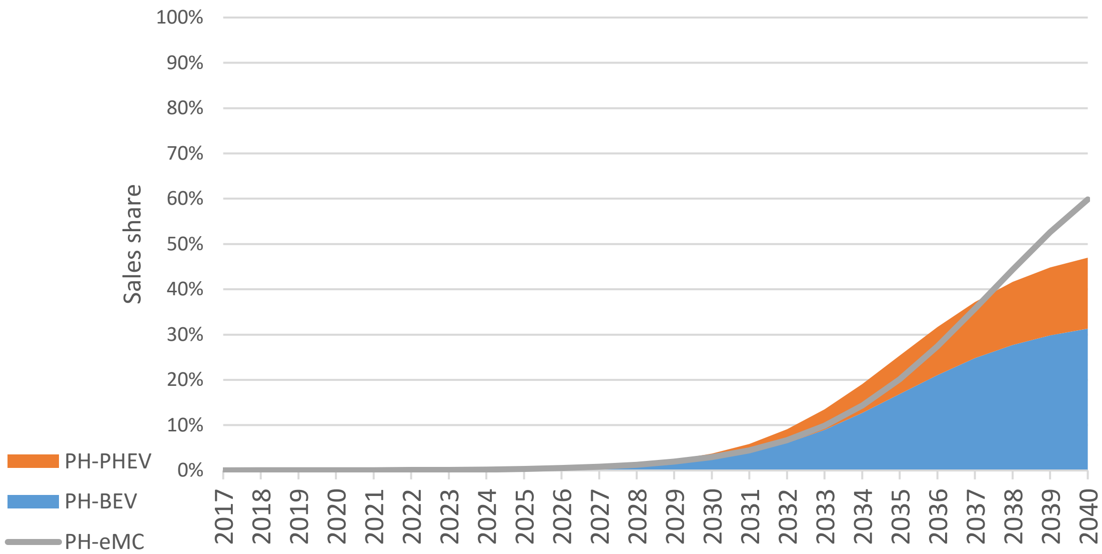
3.1. Scenario Definition

As mentioned above, road transportation was modelled as NV (passenger cars and motorcycles) with additional information of VKT and FE. The road transportation model was calculated between 2022–2040 according to a limit of EV projection. The BAU scenario was developed to be the baseline projection if there will not be any electric vehicle promotion or biofuel support. The share of ICE-to-EV was defined to be unchanged from the current situation, as well as the biofuel fraction. Otherwise, the EV scenario and biofuel scenario were developed to project the impacts of each energy strategies. The definition of EV- and biofuel scenarios are shown in comparing the BAU scenario in this section.

3.1.1. Electric Vehicle Scenario

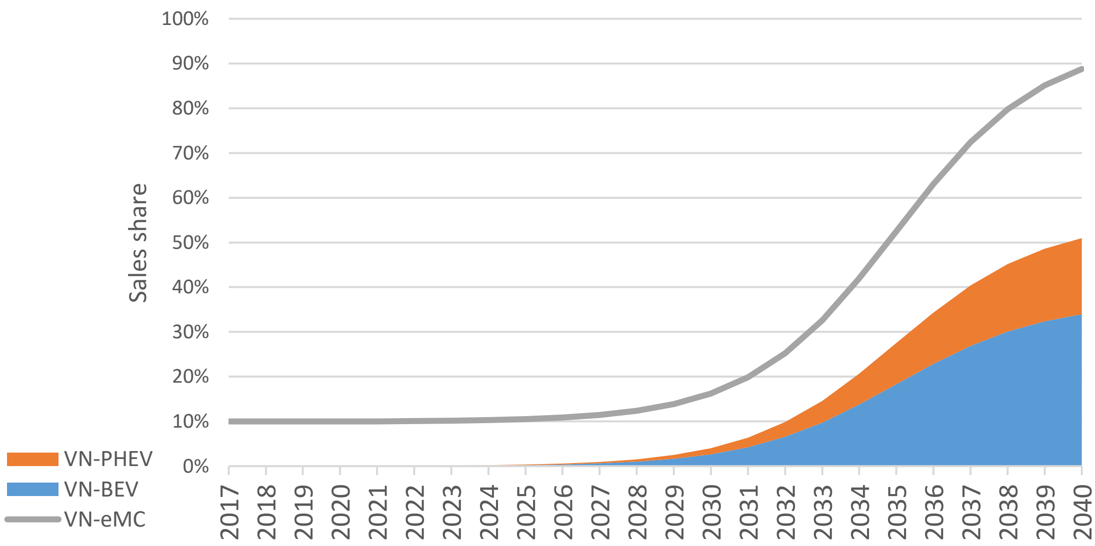
The EV scenario is defined so that EVs can penetrate the automotive market. The potentials of EV penetration in considered countries were collected according to information shared by the working group members who composed national targets, government plans, projection of the industrial sector, etc. However, the EV share for the Philippines and Viet Nam is defined according to the EV projection from Bloomberg New Energy Finance (BNEF, 2021) as shown in Figure 3.6 and Figure 3.7, respectively. The EV share (and EV sale numbers for Indonesia and Thailand) within the total vehicle sales are shown in Table 3.12.

Figure 3.6. Projection of Electric Vehicle Sales Share, Philippines (passenger cars and motorcycles)



BEV = battery electric vehicle, PHEV = plug-in hybrid electric vehicle, eMC = electric motorcycle, PH = Philippines.
Source: BNEF (2021).

Figure 3.7. Projection of Electric Vehicle Sales Share, Viet Nam (passenger cars and motorcycles)



BEV = battery electric vehicle, PHEV = plug-in hybrid electric vehicle, eMC = electric motorcycle, VN = Viet Nam.
Source: BNEF (2021).

Table 3.12. Electric Vehicle Penetration in Five Selected ASEAN Countries and India

		Business-as-Usual Scenario		EV Scenario	
	Projection year	Passenger cars	Motorcycles	Passenger cars	Motorcycles
Indonesia (number)	2022	0	0	750	5,000
	2025	0	0	10,598	1,760,000
	2030	0	0	NA (assume constant share)	2,450,000
Malaysia (%)	2022	0.00%	0.00%	0.00%	0.00%
	2030	0.00%	0.00%	10.00%	15.00%
Philippines* (%)	2022	0.02%	0.04%	0.02%	0.04%
	2030	0.02%	0.04%	17.00%	8.00%
	2040	0.02%	0.04%	47.00%	55.00%
Thailand (number)	2022	0	0	30,000	40,000
	2025	0	0	225,000	360,000
	2030	0	0	440,000	650,000
	2035	0	0	1,154,000	1,800,000
Viet Nam* (%)	2022	0.00%	12.00%	0.00%	12.00%
	2030	0.00%	12.00%	5.00%	45.00%
	2040	0.00%	12.00%	51.00%	95.00%
India (%)	2021	0.00%	2.39%	0.00%	2.39%
	2022	0.00%	2.39%	1.00%	2.39%
	2030	0.00%	2.39%	12.00%	2.39%

Sources: *BNEF (2021); authors.

3.1.2. Biofuel Scenario

Biofuel has a potential to replace some portion of fossil fuel in the automotive energy consumption. The carbon neutrality feature, which means the CO_2 produced in the use phase is equal to that absorbed during the biofuel crop cultivation, is the most advantageous on applying biofuel to each energy consumed sector. In the road transport sector, two biofuels play a major role in replacing both conventional fuels, i.e. gasoline and diesel. The maximum blended fractions of ethanol and biodiesel are limited with some technical issues and also the available quantities of biofuel raw materials in each country or region. In fact, biofuels are blended at various fractions in the retail fuel stations, such as 7% biodiesel blend (B7), B10, and B20 for biodiesel blending in diesel fuel and 10% ethanol blend (E10), E20, and E85 for ethanol blending in gasoline fuel (called gasohol fuel). However, the averaged blended fraction is defined as all the biofuel quantity (from various retail fuel types, i.e. B7, B10, and B20 for biodiesel and E10, E20, and E85 for ethanol) divided by the total retail fuel consumption (gasoline kind and diesel kind). The average blended fractions are assumed from national targets, government plans, projection of available supply projection, industrial sector projection, etc. The ethanol blended fraction (in gasohol fuel) is assumed to be similar for both passenger cars and motorcycles. The average blended fraction of ethanol and biodiesel are shown for the biofuel scenario, in comparison to the BAU scenario (Table 3.13).

Table 3.13. Target of Biofuel Blended Fractions in Gasoline and Diesel Fuels

		Business-as-Usual Scenario		Biofuel Scenario	
	Projection year	Ethanol (%)	Biodiesel (%)	Ethanol (%)	Biodiesel (%)
Indonesia	2022	0.0%	30.0%	0.0%	30.0%
	2024	0.0%	30.0%	0.0%	40.0%
Malaysia	2022	0.0%	10.0%	0.0%	10.0%
	2025	0.0%	10.0%	0.0%	20.0%
	2030	0.0%	10.0%	0.0%	30.0%
Philippines	2022	10.0%	2.0%	10.0%	2.0%
	2026	10.0%	2.0%	10.0%	4.0%
	2030	10.0%	2.0%	10.0%	7.0%
	2040	10.0%	2.0%	15.0%	7.0%
Thailand	2022	14.2%	9.4%	14.2%	9.4%
	2037	14.2%	9.4%	20.0%	15.0%
Viet Nam	2022	5.0%	0.0%	5.0%	0.0%
	2030	5.0%	0.0%	13.0%	0.0%
	2050	5.0%	0.0%	25.0%	0.0%
India	2022	10.0%	0.1%	10.0%	0.1%
	2030	10.0%	0.1%	20.0%	5.0%

Source: Authors.

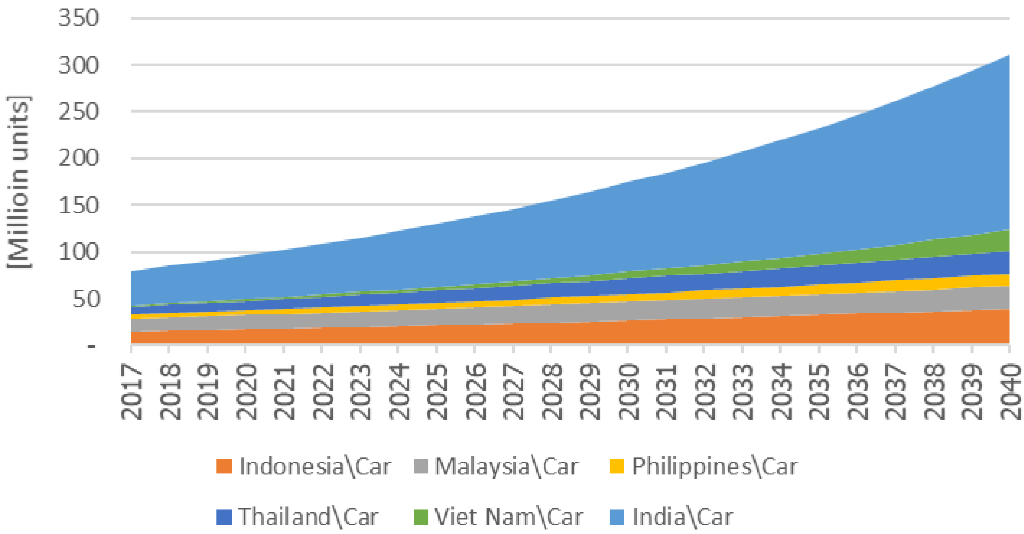
3.2. Perspective of Private Passenger Transport

As mentioned above, the energy demand and TTW GHG emissions are calculated using a bottom-up approach. The number of vehicle models will be projected from the current to the final year of model calculation (2040). The energy demand can be calculated by the assumption of fuel consumption and vehicle kilometre of travel (VKT). Finally, the TTW GHG emissions that relate to the quantity of fuel/energy consumption can be calculated using the Technology and Environmental Database and global warming potentials (GWPs). In this section the projection of vehicle numbers, energy demand, and TTW GHG emissions from the 'BAU scenario' will be shown first in Section 3.2, followed by impacts of 'EV penetration scenario' and 'biofuel promotion scenario' in Section 3.3.

3.2.1. Business-as-Usual: Projection of Vehicle Numbers

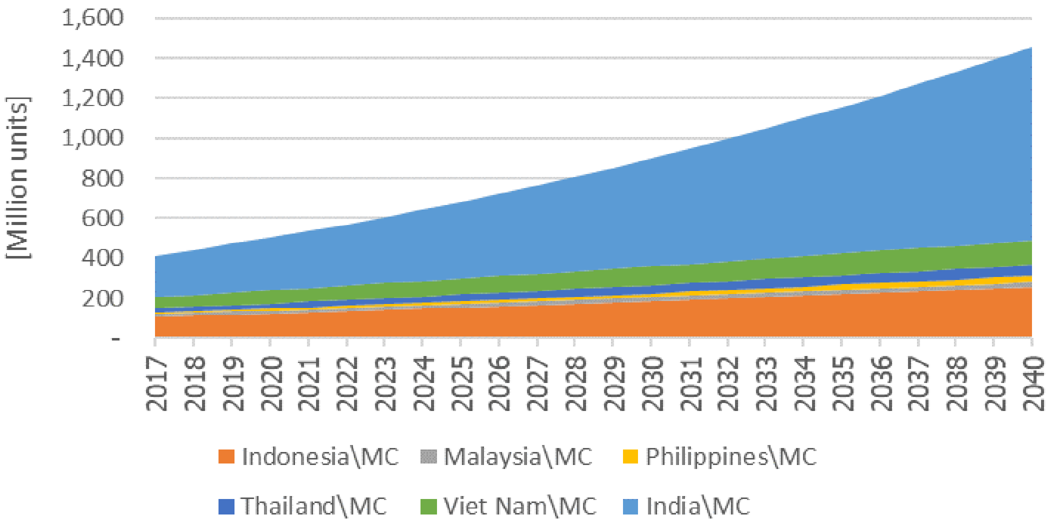
From various socioeconomic activities in the five ASEAN countries and India, the number of passenger cars, as well as motorcycles can be projected from the current year to the final projection year, as shown in Figure 3.8 and Figure 3.9, respectively. The results show that India will have the highest vehicle numbers for both passenger cars and motorcycles. For motorcycles, the three leading countries with high volumes are India, Indonesia, and Viet Nam.

Figure 3.8. Number of Passenger Cars in BAU Scenario



BAU = business-as-usual.
Source: Authors.

Figure 3.9. Number of Motorcycles in BAU Scenario

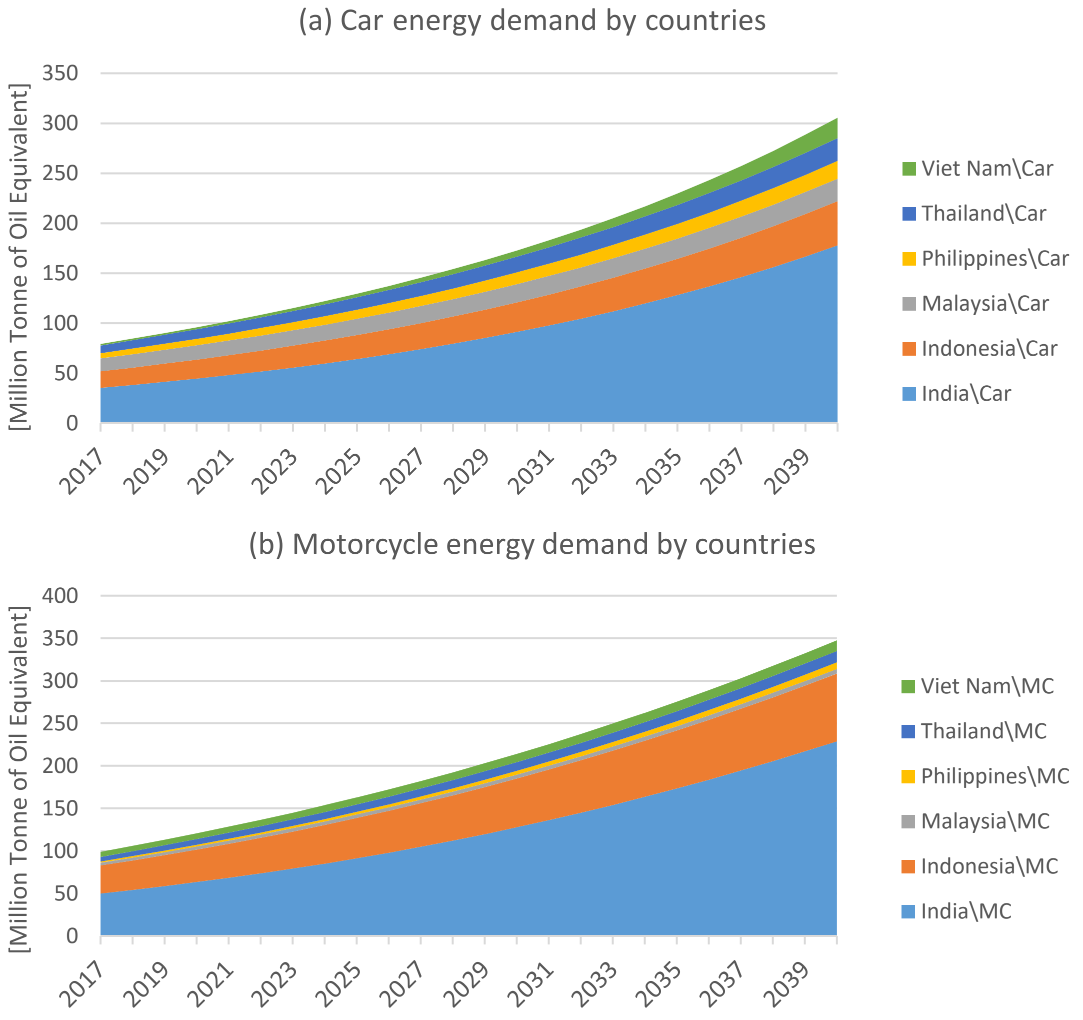


BAU = business-as-usual, MC = motorcycle.
Source: Authors.

3.2.2. Business-as-Usual: Projection of Energy Demand and Tank-to-Wheel Greenhouse Gas Emissions

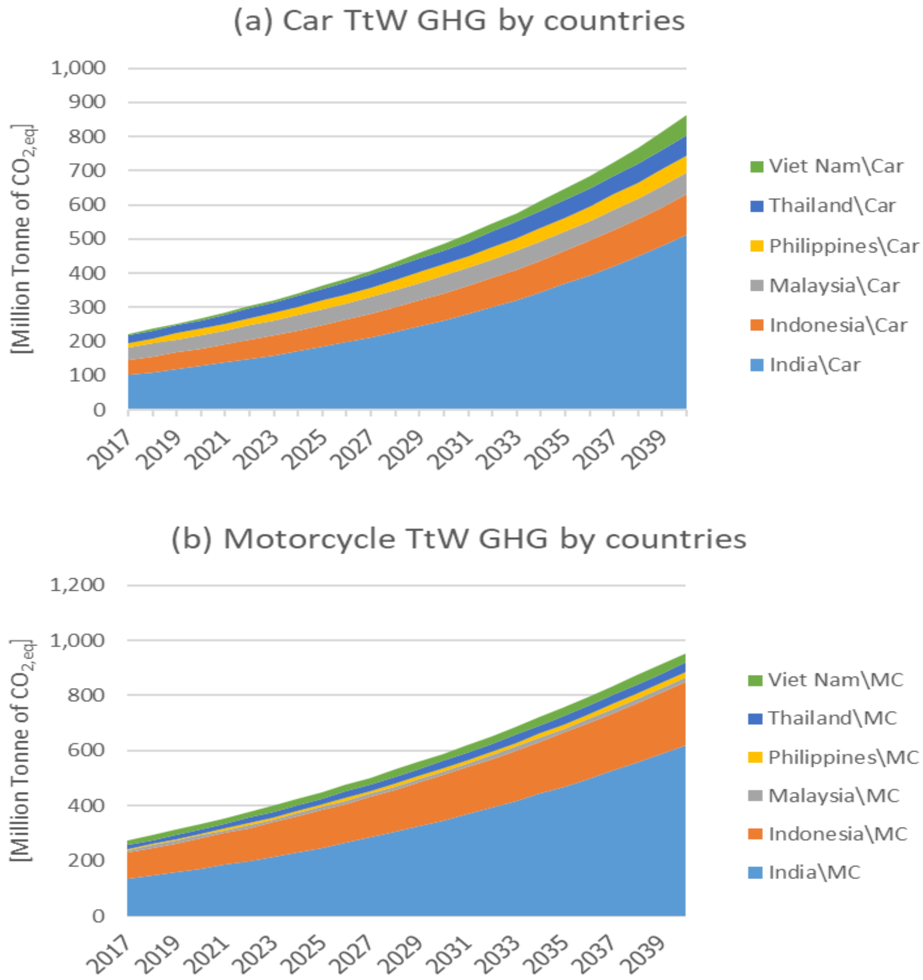
Proportional to the vehicle number, India will also require the highest energy demand for road transportation, followed by Indonesia. Besides, the other countries will require similar levels of energy demand, as shown in Figure 3.10 The same trend can be indicated for the projection of TTW GHG emission by countries, as shown in Figure 3.11. It is worth noting that although motorcycles consume less energy per unit compared to cars, many more units of motorcycles collectively results in higher energy consumption and hence TTW GHG emissions in the six countries. This observation is evidence for policy implications in the motorcycle sector.

Figure 3.10. Projection of Energy Demand by Country in BAU Scenario.



BAU = business-as-usual.
Source: Authors.

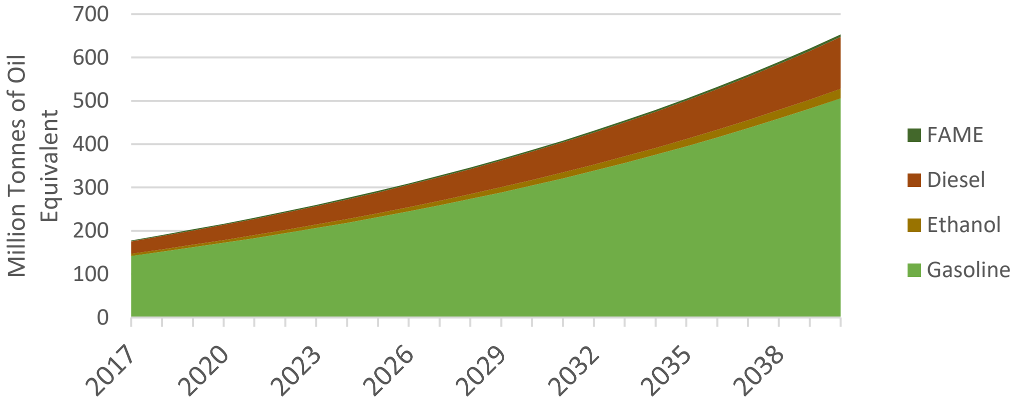
Figure 3.11. Projection of TTW GHG Emissions by Country in BAU Scenario



BAU = business-as-usual, TTW GHG = tank-to-wheel greenhouse gas.
Source: Authors.

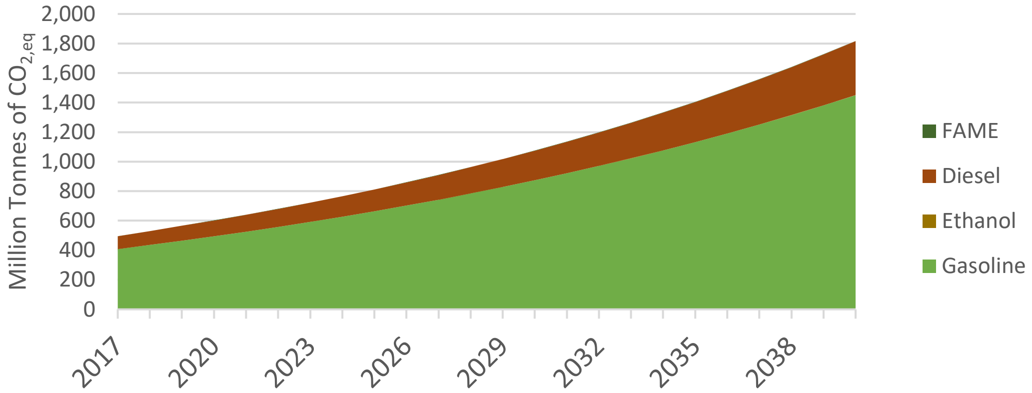
Investigations into the fuel type used in road transportation (cars and motorcycles) show that gasoline vehicles dominate light duty passenger vehicles in the five ASEAN countries and India. Gasoline and ethanol share the biggest portion in both energy demand projection with highest potentials of producing TTW GHG emissions up to 2040. The projection of energy demand and TTW GHG emissions with fuel variants are showed in Figure 3.12 and Figure 3.13, respectively. For Figure 3.13, ethanol and biodiesel, which are globally accepted as TTW carbon neutral fuels, are not presented in the graph.

Figure 3.12. Projection of Energy Demand by Fuel in BAU Scenario



BAU = Business-as-Usual, FAME = Faster Adoption and Manufacturing of Hybrid & Electric Vehicles.
Source: Authors.

Figure 3.13. Projection of TTW GHG Emissions by Fuel in BAU Scenario



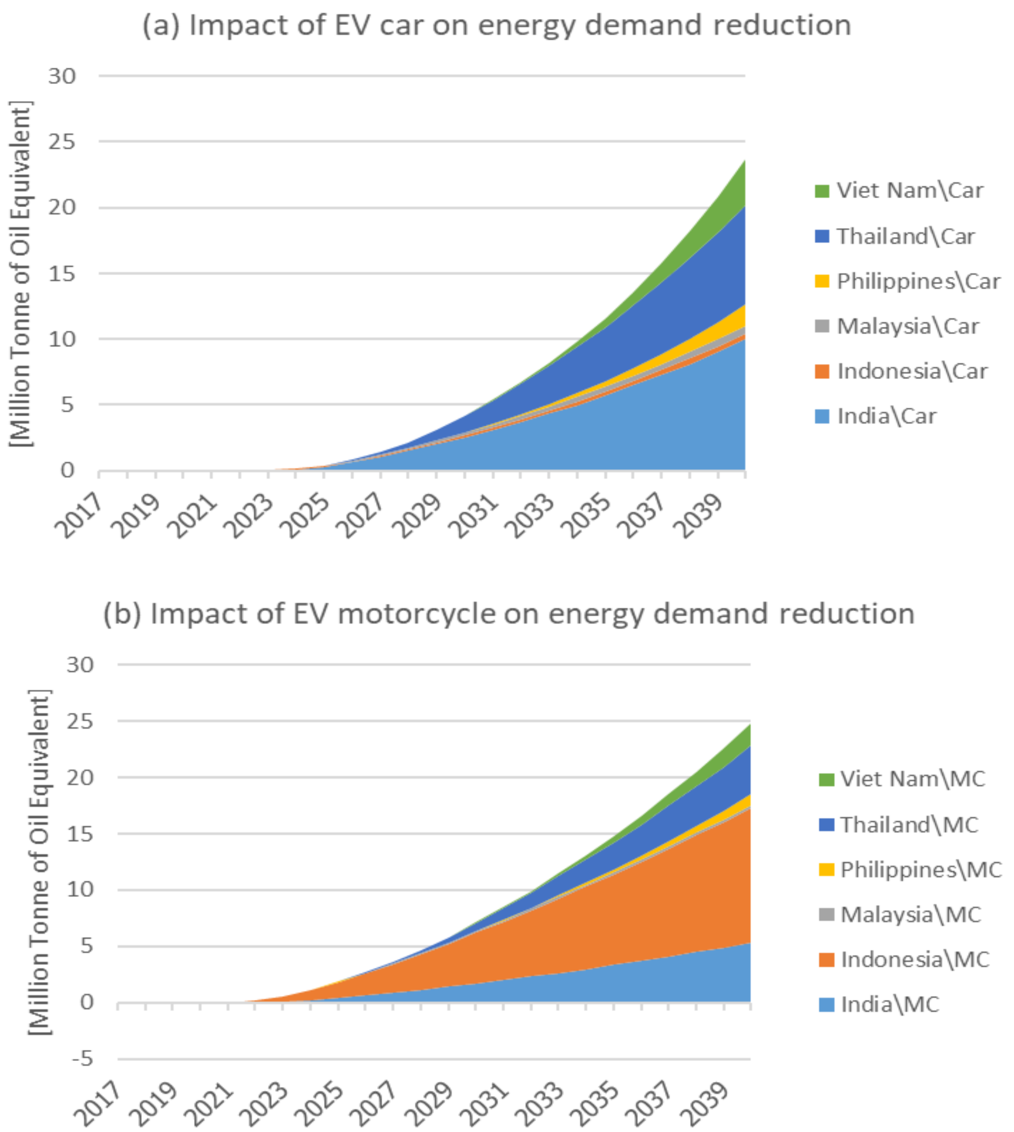
FAME = Faster Adoption and Manufacturing of Hybrid & Electric Vehicles, TTW GHG = tank-to-wheel greenhouse gas.
Source: Authors.

3.3. Impact of Electric Vehicles and Biofuel Scenario

3.3.1. Impact of Electric Vehicle Penetration (EV Scenario)

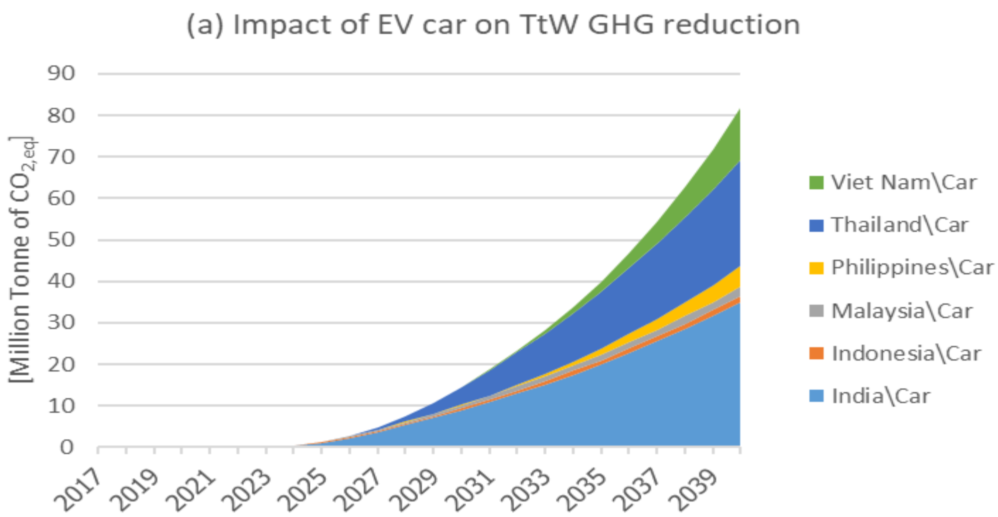
In this section, the impact of EV penetration will be shown for both energy demand and TTW GHG emissions projection in comparison with the BAU scenario. The results indicate that EVs can help reduce energy demand with their better energy efficiency in powertrain, as shown in **Error! Not a valid bookmark self-reference.**. The co-benefit of better energy efficiency, as well as zero-tailpipe (zero TTW GHG emissions), can be illustrated by reduced TTW GHG emissions shown in Figure 3.15. Again, it is interesting to see that the motorcycle segment has similar potential to reduce energy consumption and TTW GHG emissions as the car segment. Hence, policy direction to decarbonise the transport sector in motorcycles could be as effective as in car segment.

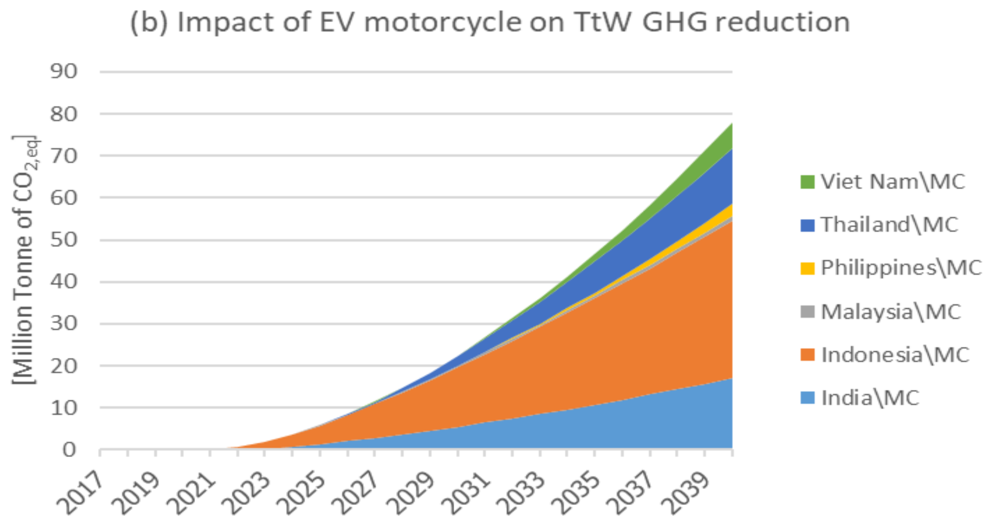
Figure 3.14. Impact of Electric Vehicle Penetration on Energy Demand Reduction



Source: Authors.

Figure 3.15. Impact of Electric Vehicle Penetration on Reduction of TTW GHG Emissions



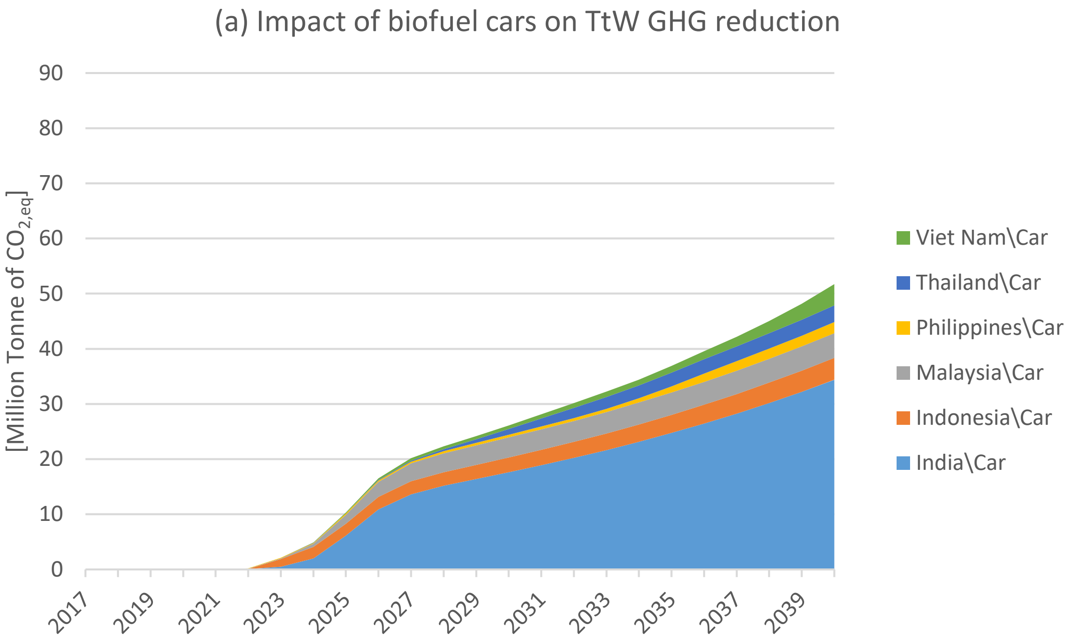


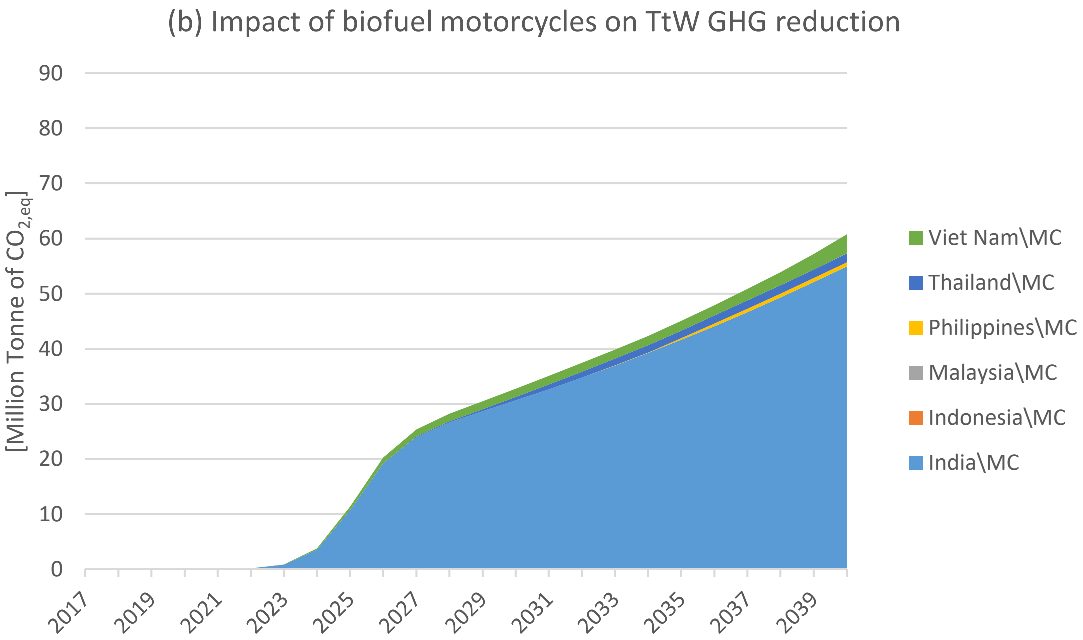
TTW GHG = tank-to-wheel greenhouse gas.
Source: Authors.

3.3.2. Impact of Biofuel Promotion (Biofuel Scenario)

Unlike the EV scenario, the biofuel proportion in gasoline and diesel fuel cannot significantly help reduce energy consumption due to the use of internal combustion engine (ICE) powertrains for biofuel. However, biofuel can help reduce TTW GHG emissions as it is a carbon neutral fuel. The impacts of biofuel promotion on TTW GHG emissions are compared with the BAU scenario (Figure 3.16).

Figure 3.16. Impact of Biofuel Promotion on Reduction of TTW GHG Emissions





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

4. Discussion

This chapter attempts to construct a bottom-up energy demand model for the transport sector, focusing on cars and motorcycles in Malaysia, Philippines, Thailand, Viet Nam, and India using the well-respected Low Emissions Analysis Platform (LEAP) system with input data on population, GDP, vehicle history and projection, vehicle kilometres travelled (VKT), and fuel economy. The best available assumption must be made when data are not available to construct models for scenario analysis on EVs and biofuel.

With relatively robust vehicle ownership model, the BAU setting for energy consumption and WTT GHG emissions can be set as a baseline for investigation into the impact from EVs and biofuel policy. With best available projection of EVs and biofuel, the impact of energy consumption and TTW GHG emissions can be quantitatively illustrated. Further refinement of model assumption, as well as data input, could help improve the accuracy of the present model. However, the present model highlights the importance of the motorcycle segment, which has potential to reduce energy consumption and TTW GHG emissions as much as the car segment collectively in these six countries. Policies to support decarbonisation of the road transport sector by motorcycles must be equally treated as policies for the car segment.

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Chapter 4

CO_2 Emissions from Producing Mineral Resources by Mobility Electrification in East Asia Summit Countries

1. Introduction

The introduction of hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), electric vehicles (BEVs), and fuel cell vehicles (FCVs), hereinafter described as xEVs and biofuels in East Asia Summit (EAS) countries is advancing rapidly. For instance, the Indian automobile market has registered over 638,000 electric vehicle (EV) units since 2011–2012. There were more than 1,000 electric cars registered in Viet Nam at the end of 2020, which consist of 99% HEV/PHEVs and 1% BEVs. There were 32,264 HEVs/PHEVs and 2,999 BEVs registered in Thailand in 2020.

The electrification of automobiles will greatly contribute to CO_2 reduction and complement the introduction of renewable energy programmes. This suggests that EAS countries will continue to promote the electrification of automobiles to achieve the ambitious targets set out in the Paris Agreement (UN, 2015).

However, the electrification of cars requires significant increases in battery requirements, including the development of high-efficiency motors and lithium-ion batteries. High-efficiency motors use neodymium magnets, which are high-performance permanent magnets designed to maintain their efficacy; however, they require several rare earth elements including neodymium (Nd) and dysprosium (Dy), which preserve the thermotolerance of these magnets. This implies that it is becoming increasingly necessary to secure long-term access to these rare-earth elements (Morimoto et al., 2019). Similarly, critical raw materials such as lithium, nickel, and cobalt (Co) are also all required for lithium-ion batteries (Chan et al., 2021). Therefore, the electrification of automobiles relies on the sustainability of these mineral resources and promotes the idea of creating a circular economy that recycles these resources.

Circular economies are designed to improve resource efficiency and minimise the amount of resources needed and their waste by improving both the production system and product design of these items. This prolongs the lifespan of these products and promotes their reuse, remanufacture, repair, and recycling. Currently, EAS countries only consume ‘cradle-to-grave’ products, i.e. those that are produced, designed, and discarded. Therefore, there is a need to shift the consumption of mineral resources to a 'cradle-to-cradle' model rather than the cradle-to-grave model mentioned above (ERIA, 2020).

Following the fiscal year (FY) 2020 report, this study estimates the long-term mineral resource demand associated with automobile electrification in EAS countries. In addition, the CO_2 emissions from producing lithium-ion batteries and rare earth magnets were estimated to evaluate ‘well to tank’ CO_2 emissions of xEVs. Finally, this study aims to assess the potential for recycling in these countries by determining the amount of waste of these mineral resources and evaluate the CO_2 reduction of introducing a circular economy under these conditions.

1.1. Background

The past trends and the future projection of mobility electrification for each EAS country (Indonesia, Malaysia, Philippines, Viet Nam, and India) are as follows.

1.1.1. Indonesia

In 2021, at the United Nations Climate Change Conference (COP26) World Leaders Summit in Glasgow, Scotland, the President of Indonesia, Joko Widodo, affirmed that Indonesia will continue to contribute to the progress of mitigating climate change. The president also stated the development of an electric car ecosystem and utilisation of clean energy such as solar power energy, biofuels etc. will continue to achieve a carbon net sink by 2030 (Cabinet Secretariat of the Republic of Indonesia, 2021).

Referring to the commitment of the Indonesian government, several strategic moves have been implemented to accelerate the ecosystem for electric vehicles in Indonesia. In 2019, the Indonesian President signed the Presidential Regulation No. 55 regarding the acceleration of battery electric vehicles programmes for road transportation, followed by the Regulations of the Ministry of Industry Numbers 27 and 28 about the development roadmap, components, and production of electric vehicles (MOI Indonesia, 2020).

Vehicle population and sales projection

Based on Indonesia’s Central Agency on Statistics (BPS), the vehicle population in Indonesia continues to increase and reached more than 136 million units at the end of 2020 of which the majority are motorcycles (Table 4.1) (BPS Indonesia, 2022). In 15 years, the volume of four-wheeled and multi-wheeled motor vehicles production in Indonesia is projected by the Ministry of Industry to be 1.5 million to 4 million units, whilst motorcycles are predicted to be produced at a rate of 8 million to 15 million units with 30% of units produced for both to be low carbon emissions vehicle type or electric vehicles by 2035 (Table 4.2) (MOI Indonesia, 2020).

Table 4.1. Vehicle Population, Indonesia

Vehicle Type	2015	2016	2017	2018	2019	2020
Passenger cars	12,304,221	13,142,958	13,968,202	14,830,698	15,592,419	15,797,746
Buses	196,309	204,512	213,359	222,872	231,569	233,261
Utility/ Cargo	4,145,857	4,326,731	4,540,902	4,797,254	5,021,888	5,083,405
Motorcycles	88,656,931	94,531,510	100,200,245	106,657,952	112,771,136	115,023,039
Total	105,303,318	112,205,711	118,922,708	126,508,776	133,617,012	136,137,451

Source: BPS Indonesia (2022).

Table 4.2. Vehicle Sales Projection, Indonesia

Item			2020	2025	2030	2035
Motor Vehicles	Production	Total (unit)	1,500,000	2,000,000	3,000,000	4,000,000
		Percentage LCEV (%)	10	20	25	30
		Percentage LCGC (%)	25	20	20	20
	Sales	Total (unit)	1,250,000	1,690,000	2,100,000	2,500,000
	Export	Total (unit)	250,000	310,000	900,000	1,500,000
Motorcycles	Production	Total (unit)	8,000,000	10,000,000	12,500,000	15,000,000
		Percentage Electric Motorcycle (%)	10	20	25	30
	Sales	Total (unit)	7,500,000	9,000,000	11,000,000	13,000,000
	Export	Total (unit)	500,000	1,000,000	1,500,000	2,000,000

LCEV = low carbon emissions vehicle, LCGC = low cost green car.

Source: MOI Indonesia (2020).

The Indonesian State Electricity Company or PLN derived a forecast based on MOI numbers for the years between 2020 to 2025 (Table 4.3). It should be noted that the 'wholesale' numbers are domestic sales, whilst the remainder are exported. The PLN estimates that 78.9% of domestic sales will be passenger cars. Amongst these passenger cars sales, FCEV and HEV sales per year will grow from 0.07% to 1.0% from 2020 to 2025. During the same period the sales of PHEVs and BEVs is estimated to grow from 0.06% to 1.5%. Thus, it is estimated by 2025, total xEV sales (combined FCEVs, HEVs, BEVs, PHEVs) will reach 42,250 units.

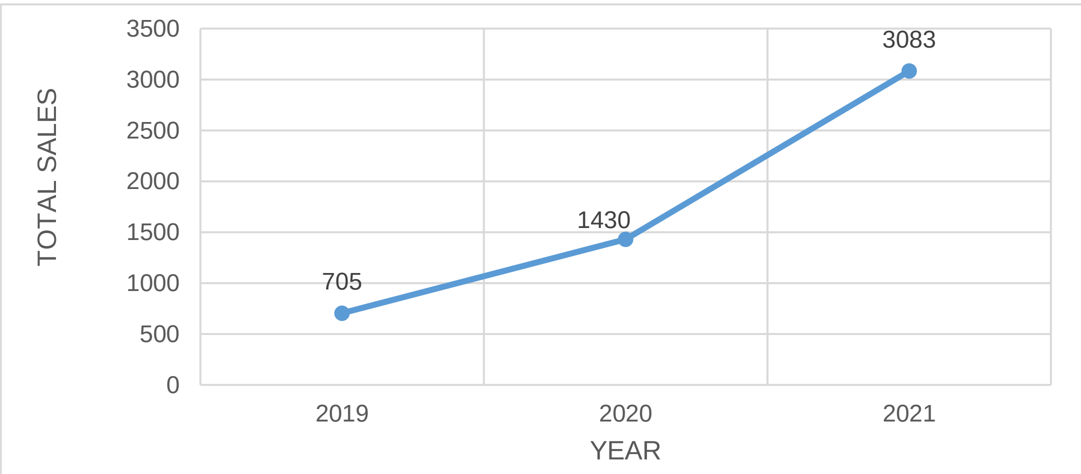
Table 4.3: Electric Vehicle Sales Projection, Indonesia

Parameter	2020	2021	2022	2023	2024	2025
Total	1,500,000	1,600,000	1,700,000	1,800,000	1,900,000	2,000,000
Wholesale	1,250,000	1,338,000	1,426,000	1,514,000	1,602,000	1,690,000
% Passenger cars	78.9%	78.9%	78.9%	78.9%	78.9%	78.9%
Passenger cars	986,124	1,055,547	1,124,971	1,194,394	1,263,817	1,333,240
Sub-total sedans and non-sedans	647,077	734,257	790,684	846,230	900,896	952,992
Energy saving cars	310,423	315,938	321,456	326,968	332,483	337,998
% FCEVs, HEVs from wholesale	0.07%	0.10%	0.40%	0.70%	0.90%	1.0%
% PHEVs, BEVs from wholesale	0.06%	0.30%	0.50%	0.70%	1.00%	1.5%
% xEVs	0.13%	0.4%	0.90%	1.40%	1.90%	2.50%
FCEVs, HEVs	875	1,338	5,704	10,598	14,418	16,900
PHEVs, BEVs	750	4,014	7,130	10,598	16,020	25,350
Total wholesale xEVs	1,625	5,352	12,834	21,196	30,438	42,250
Passenger cars ICE	984,499	1,050,195	1,112,137	1,173,198	1,233,379	1,290,990

BEV = battery electric vehicle, FCEV = fuel cell vehicle, HEV = hybrid electric vehicle, ICE = internal combustion engine, PHEV = plug-in hybrid electric vehicle, xEV = all electric vehicles.
Source: PLN (2020).

Data obtained from the Association of Indonesia Automotive Industries (GAIKINDO) show that actual sales from 2020 to 2021 are below sales predictions for EVs by the MOI and the PLN. This might be attributed to the slump in all vehicle sales in Indonesia in 2020 and 2021 partially due to the novel coronavirus disease (COVID-19) pandemic. Nevertheless, the historical data show around 100% sales growth each year for BEVs and HEVs (Figure 4.1 and Table 4.4). By early 2022, it can be seen that the majority or 75.9% of the sales were HEVs. This is followed by 23.2% being BEVs and 0.9% PHEVs (GAIKINDO, 2022).

Figure 4.1. Electric Vehicle Wholesale Numbers by Year, Indonesia



Source: GAIKINDO (2022).

Table 4.4. Electric Vehicle Wholesale Numbers, Indonesia

	2019	2020	2021	Jan–Feb 2022	Type total
BEV	-	319	798	45	1,162
PHEV	20	6	35	2	43
HEV	685	1,105	2,250	441	3,795
Total	705	1,430	3,083	488	

BEV = battery electric vehicle, PHEV = plug-in hybrid electric vehicle, HEV = hybrid electric vehicle.
Source: GAIKINDO (2022).

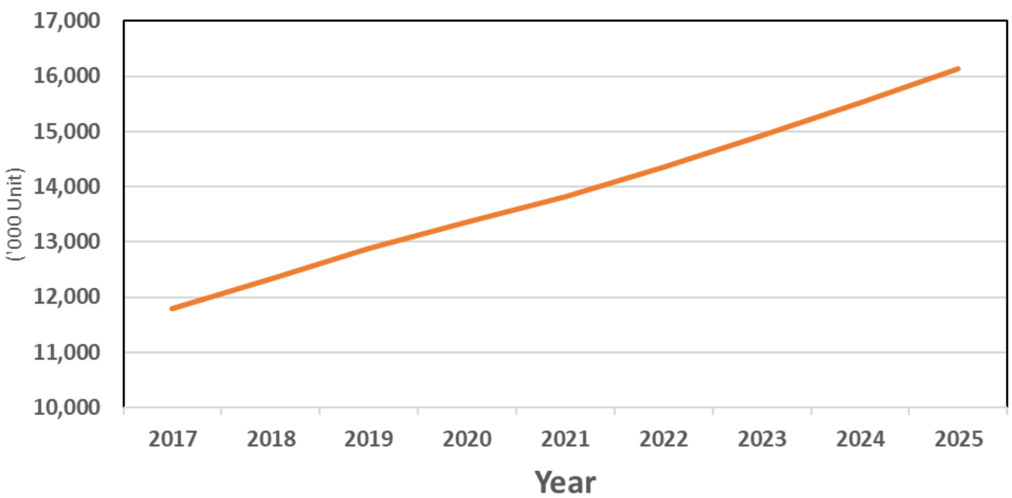
1.1.2. Malaysia

According to the Road Transport Department of Malaysia, the total number of accumulated registered vehicles in 2018 was 29,745,187 units (Ministry of Environment and Water, 2021). Passenger cars and motorcycles accounted for 45% share each and 4.4% of goods vehicles. The annual increase of new passenger cars is around 500,000 units (MAA, 2021). The total number of passenger cars from 2017 to 2025 (projected) is shown in Figure 4.2.

The Malaysian motorcycle market is one of the smaller in the ASEAN region, with around 500,000 in annual sales. The total number of registered motorcycles in Malaysia in 2021 was recorded at 15.137 million units (Figure 4.3).

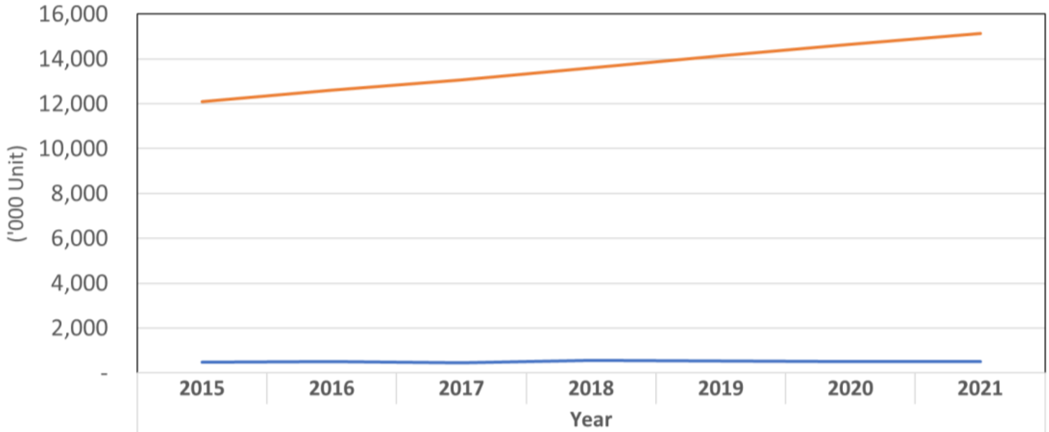
Under the Low Carbon Mobility Blueprint, targets of 5% HEVs and 5% EVs were envisaged by 2030. The national target to set up 9,000 AC charging points and 1,000 DC charging points has been set to be achieved by 2025. The e-motorcycle share is targeted at 15% by 2030 (Ministry of Environment and Water, 2021).

Figure 4.2. On-Road Passenger Cars in Malaysia (2017–2025 projection)



Sources: MAA, http://www.maa.org.my/statistics.html (accessed 18 May 2022); Ministry of Environment and Water (2021); MAA Press Statement (2021).

Figure 4.3. New and On-Road Motorcycles in Malaysia (2015–2021O



	2015	2016	2017	2018	2019	2020	2021
New	465.20	504.82	455.59	552.50	538.00	499.98	492.10
On-road	12,094.47	12,599.29	13,054.87	13,607.37	14,145.37	14,645.34	15,137.45

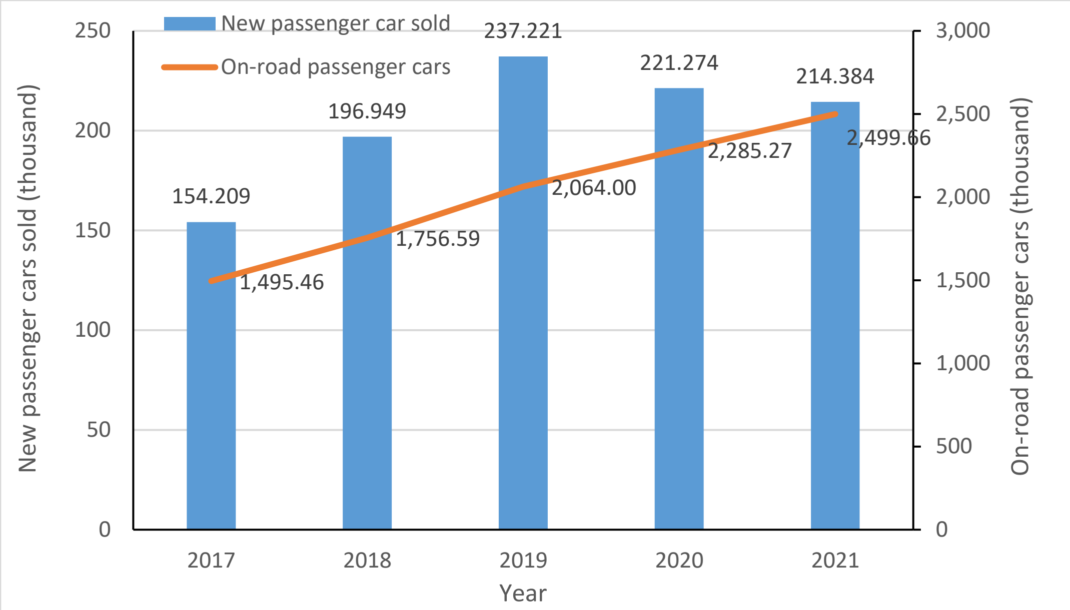
Sources: Ministry of Environment and Water (2021); McD Motorcycles Data, https://www.motorcyclesdata.com/2022/02/01/malaysia-motorcycles (accessed 19 April 2022).

1.1.3. Viet Nam

Passenger Cars

Based on the Sale Report of the Vietnam Automobile Manufacturers' Association (VAMA), new passenger car sales have been about 200,000 units per year in recent years (VAMA, 2022). The number of on-road passenger cars (assumed to be the same as the number of registered passenger cars) increases year by year. In the 5 years from 2017 to 2021, this number increased by about 40%, from 1.5 million units to 2.5 million units (Figure 4.4) (ASEANStatsDataPortal).

Figure 4.4. New Passenger Cars Sold and On-Road Passenger Cars, Viet Nam



Source: VAMA (2022).

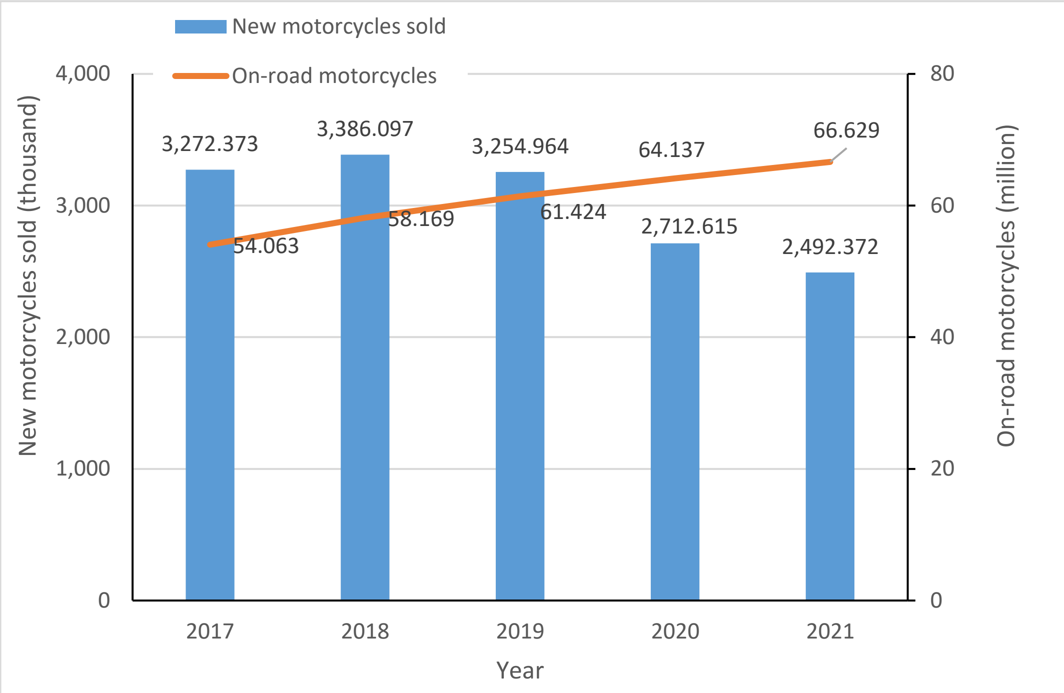
For the distance that passenger cars travel per day, the available study shows the values of 42 kilometres(km)/day/vehicle in Ha Noi, and 33.4 km/day/vehicle in Ho Chi Minh city (Oanh, 2015). The average is calculated to be about 37.7 km/day/vehicle.

For fuel consumption, it is estimated that the average gasoline consumption is about 8.02 litres/100 km, and diesel consumption is about 7.52 litres/100 km based on the published data (Vietnam Register, 2022).

Motorcycles

As reported in the sales data of the Vietnam Association of Motorcycle Manufacturers (VAMM), the number of new motorcycles sold has reduced in recent years (Figure 4.5) (VAMM Sales Report, 2022). It is assumed that the number of on-road motorcycles is the same as the number of registered motorcycles, and the number of on-road motorcycles from 2019 onwards is the sum of the on-road motorcycles in the previous year and new motorcycles sold in the mentioned year. The total number of on-road motorcycles increased about 23.2%, from 54 million units to 66.6 million units in the 5 years from 2017 to 2021.

Figure 4.5. New Motorcycles Sold and On-Road Motorcycles, Viet Nam



Source: VAMM (2022).

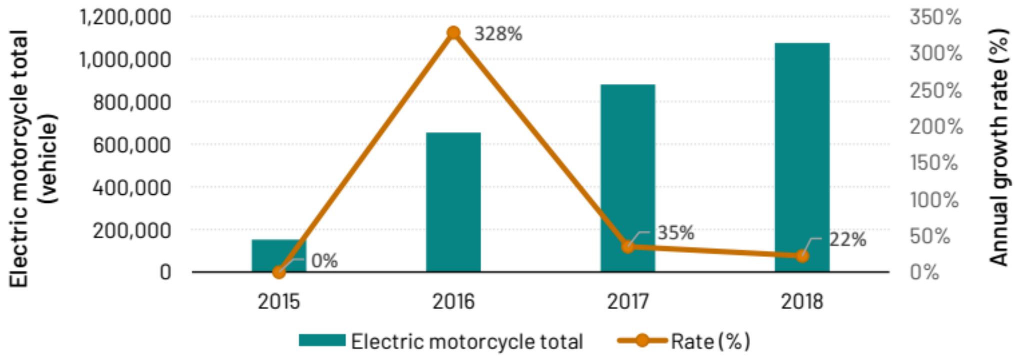
For the distance that motorcycles travel per day, the available study shows the values of 20.3 km/day/vehicle in Ha Noi, and 19.4 km/day/vehicle in Ho Chi Minh city (Oanh, 2015). The average is calculated to be about 19.85 km/day/vehicle.

Fuel consumption is about 1.9 litres/100km in the case of a Honda Wave Alpha 110cc motorcycle that is popularly used and selected as a representative (Honda Motorcycle Products, 2022).

Electric Vehicles

The electric vehicle market is dominated by electric bikes and electric motorcycles. The number of total electric motorcycles increased quite quickly, from nearly 200,000 units in 2015 to more than 1 million units in 2018 with a boom year in 2016 at a growth rate of more than 300% (Figure 4.6) (Le, 2021). The electricity consumption is about 2 kWh/100 km as introduced in the technical data of a normal electric motorcycle model produced by Vinfast.

Figure 4.6. Electric Motorcycles in Viet Nam, 2015–2018



Source: Le (2021).

There are still very few electric passenger cars in Viet Nam. However, there is a sign that electric cars will become more popular soon. Currently, Vinfast – a Vietnamese automotive manufacturer – is a leader in electric vehicle production in Viet Nam. Since December 2021, Vinfast has handed over nearly 1,000 units of VF e34 model electric passenger cars to customers within a few thousand pre-ordered units. The electricity consumption of the VF e34 model is about 14.74 kilowatt hours (kWh)/100 km. VinFast plans to have over 2,000 charging stations set up nationwide (over 40,000 charging ports for cars and motorcycles). To date about 500 charging stations have been installed. Recently, they have also aimed to build 150,000 charging ports with about 3,000 charging stations at locations such as apartments, parking lots, bus stations, rest stops on highways, highways, and commercial centres in Ho Chi Minh city (Vietnam Star, 2022). Based on an announcement by the Department of Climate Change, the emissions factors for the Vietnamese electrical grid in 2019 and 2020 are 0.8458 and 0.8041 tCO_2/megawatt hour, respectively (Department of Climate Change, 2021a and 2021b).

At the national level, it can be seen that the policies for EV development in Viet Nam are just at the stage of setting orientation; the strategy and roadmap for EV development have been not specified yet. At the city level, most cities have not set specific targets, incentives, or roadmaps for EV adoption, whereas some cities already operate public electric bus systems. Ha Noi has seven e-bus routes now and also has a target that 5% of motorcycles will be e-motorcycles by 2030. Nha Trang city in Khanh Hoa province on the south central coast of Viet Nam, expects to have 200 e-buses in operation by 2025. The first e-bus route in Ho Chi Minh city has been launched recently.

1.1.4. Philippines

Number of Vehicles

Vehicle owners in the Philippines register their chosen modes of transportation with the Philippine Land Transportation Office (PLTO). For passenger cars including sedans, utility vehicles, and sport utility vehicles, the number of new passenger cars reached 343,293 units in 2021 with a total of 4,046,383 units of passenger car stock renewals. Covering the same period, motorcycles (with and without sidecars), tricycles, and non-conventional motorcycles contributed around 2,108,565 new units and a whopping 5,962,256 units of on-road motorcycles were renewed (PLTO, 2022).

In terms of industry development, continuous growth for motor vehicles was experienced during 2006–2019 but with a significant increase in both sales and production in 2017 because of the anticipation on higher excise taxes beginning in 2018. Correspondingly, figures plummeted the following year because of overproduction and oversales. Whilst in 2020, both sales and production plunged due to mobility and financial restrictions experienced during the pandemic (PBOI, 2021).

Electric Vehicles

Republic Act (RA) No. 11697 otherwise known as the Electric Vehicle Industry Development Act, which offers a policy framework for the Philippines' local EV industry (Desiderio, 2022), was enacted on 15 April 2022. The formulation of the Comprehensive Roadmap for the Electric Vehicle Industry will significantly hasten the local EV industry's 'development, commercialisation, and utilisation' by laying plans into actions to be headed by the Philippine Department of Energy through the programme's local thrust and implementation particularly on the accreditation of charging stations. The Philippine Department of Trade and Industry serves as the regulatory arm for registration of EVs and establishment of measures for demand creation through the country's local manufacturers (Geducos, 2022). Through the Electric Vehicle Industry Development Act, national government agencies are provided with a holistic plan for local campaigns of the EV industry to attract potential investors (Desiderio, 2022).

The PLTO regulates the registration of EVs which can be used for public transport, depending on their class types. For 2010–2020, the PLTO registered about 12,965 units of EVs with annual registrations (new and renewal) steadily increasing from 2014 (PLTO, 2022). However, the Philippine Board of Investments (2021) informed that there might be potential underestimation compared to the actual number of EVs due to some unregistered EVs on the road.

A dominant population of the EV distribution in the Philippines belong to e-tricycles, e-motorcycles, and e-jeepneys, which can be attributed to the Filipinos' commute between short distances as well as the government's public utility vehicle modernisation programme. On the other hand, the market for personal use of EVs is small as it only caters to the extreme upper class of society (PBOI, 2021).

According to the Philippine Energy Plan 2020–2040, as of 2019, the penetration rate of EVs for road transportation (to include motorcycles, cars, jeepneys, etc.) was at 5% in the business-as-usual scenario. Whilst under the clean energy scenario, the penetration rate for EVs is targeted at 10% by 2040, the majority of which is comprised of e-motorcycles, which is equivalent to about 5% in aggregate energy savings from oil and electricity (PDOE, 2021).

For the next decade, the Philippines is anticipating an adoption of about 6.6 million units until 2030 to be largely composed by two-wheelers. Around 3.3 million EVs are projected to be manufactured in the country (PBOI, 2021).

Despite the unprecedented onset of COVID-19 since 2020 that adversely affected the local and global economy, the Philippines' EV market continues to be motivated through the promotion and commercialisation of EVs given its environmental impact, advanced technology, and minimal maintenance expenses compared with conventional vehicles (PDOE, 2021).

1.1.5. India

The adoption of electric vehicles is being rapidly promoted by the Indian government as part of its efforts to incentivise new age technology and meet its commitment made at the COP26 to reduce its carbon emissions to net-zero status by 2070. By 2030, India plans to have 30% of private cars, 70% of commercial vehicles, and 80% of two- and three-wheeler electric vehicles (EVs) in India. To accomplish this, both the central and state governments are providing a variety of incentives to buyers and manufacturers.

Table 4.5 shows the production of different categories of motor vehicles for the last decade. In 2019-20, the production of two-wheelers was highest amongst other vehicles. About 26 million vehicles were produced in India out of which 21 million were two-wheelers followed by passenger vehicles and three-wheelers.

Table 4.5. Production of Motor Vehicles in India: 2015–16 to 2019–20

Type of Vehicle	2015–16	2016–17	2017–18	2018–19	2019–20
Passenger Vehicles	3,465,045	3,801,670	4,020,267	4,028,471	3,434,013
Commercial Vehicles	786,692	810,253	895,448	1,112,405	752,022
Three-Wheelers	934,104	783,721	1,022,181	1,268,833	1,133,858
Two-Wheelers	18,830,227	19,933,739	23,154,838	24,499,777	21,036,294
Quadricycles	-	1,584	1,713	5,388	6,095
Total	24,016,068	25,330,967	29,094,447	30,914,874	26,362,282

Notes: Passenger vehicles include passenger cars, utility vehicles, and vans. Commercial vehicles include medium and heavy commercial vehicles.
Sources: Government of India (2021), Road Transport Yearbook 2017-18 and 2018-19. https://morth.nic.in/sites/default/files/RTYB-2017-18-2018-19.pdf

The highest number of vehicles registered[1] in 2019 was from the two-wheeler category. Out of a total 295,772 registered vehicles 221,270 were two-wheelers (Table 4.6). In 2019, 38,433 of the vehicles that were registered were cars, jeeps, and taxis, and 13,766 were goods vehicles. Table 4.6 shows that the production of two-wheelers and registered two-wheeler vehicles dominates the Indian domestic market.

Table 4.6. Registered Vehicles with Different Category Wise, India

Year	Total Vehicles	Two-wheelers	Cars, Jeeps, Taxis	Buses	Goods Vehicles	Other Vehicles
2010	122,746	91,598	17,109	1,527	6,432	11,080
2011	141,866	101,865	19,231	1,604	7,064	12,202
2012	159,491	115,419	21,568	1,677	7,658	13,169
2013	176,044	127,830	24,056	1,814	8,307	14,037
2014	190,704	139,410	25,998	1,887	8,698	14,712
2015	210,023	154,298	28,611	1,971	9,344	15,799
2016	230,031	168,975	30,242	1,757	10,516	18,541
2017	253,311	187,091	33,688	1,864	12,256	18,411
2018	272,587	202,755	36,453	1,943	12,773	18,663
2019	295,772	221,270	38,433	2,049	13,766	20,254

Note: 'Other vehicles' include tractors, trailers, three-wheelers (passenger vehicles)/light motor vehicles, and other miscellaneous vehicles which are not classified separately.
Sources: Government of India (2021), Road Transport Yearbook 2017-18 and 2018-19. https://morth.nic.in/sites/default/files/RTYB-2017-18-2018-19.pdf

[1] Motor vehicle registration is the compulsory or voluntary registration of a motor vehicle with a government authority. The purpose of motor vehicle registration is to create a link between a vehicle and its owner or user.

Table 4.7. Electric Vehicle Sales from 2011 to 2022, India

Financial Year	Sales	% Share of EVs in Overall Vehicle Sales
2011–12	7,536	0.05
2012–13	4,106	0.03
2013–14	3,035	0.02
2014–15	2,415	0.01
2015–16	18,037	0.01
2016–17	56,626	0.29
2017–18	96,773	0.45
2018–19	146,597	0.65
2019–20	168,311	0.77
2020–21	133,831	0.87
2021–22	276,265	2.16

Source: Centre for Energy Finance, Council on Energy, Environment and Water (CEEW). https://cef.ceew.in/intelligence/tool/electric-mobility (accessed 13 May 2022).

The share of sales of electric vehicles (EV) in overall vehicle sales has been increasing over the years in India. Table 4.7 shows the sales of EVs from 2012 to 2022. The share of EVs in overall vehicle sales has increased from 0.05% to 2.16% from 2012 to 2022. A total of 276,265 electric vehicles were sold in fiscal year 2021–22, which is 2.16 % of overall vehicle sales.[2]

Table 4.8. Electric Vehicle Type Sales for Last 5 Years, India

Financial Year	Two-Wheeler	Three-Wheeler	Four-Wheeler	Goods Vehicle
2017–18	1,897	92,395	1,362	933
2018–19	25,393	118,944	1,632	517
2019–20	24,839	140,683	2,727	50
2020–21	40,837	88,378	4,588	28
2021–22	136,468	126,716	10,469	971

Source: Centre for Energy Finance, Council on Energy, Environment and Water (CEEW); India https://cef.ceew.in/intelligence/tool/electric-mobility (accessed 12 May 2022).

[2] Overall vehicle sales include the sales of electric as well as non-electric vehicles.

Category-wise sales of EVs has been increasing in the past years. Table 4.8 shows the sales of different types of electric vehicle from 2017–18 to 2021–22. Sales of three-wheelers dominated the EV market in India from 2017–18 to 2020–21. Sales of two-wheelers have increased three times from 2020-21 taking the highest share in total EVs sales. Sales of three-wheelers fell from 2019-20 to 2020-21 due the unavoidable conditions of the pandemic in India. Sales again shot up in 2021-22 to 126,716 EVs in the category of three-wheelers. Four-wheeler sales also increased more than double in 2021-22.

Table 4.9. Sales Share of Electric Vehicles in Financial Year 2021-22 with Vehicle Type, India

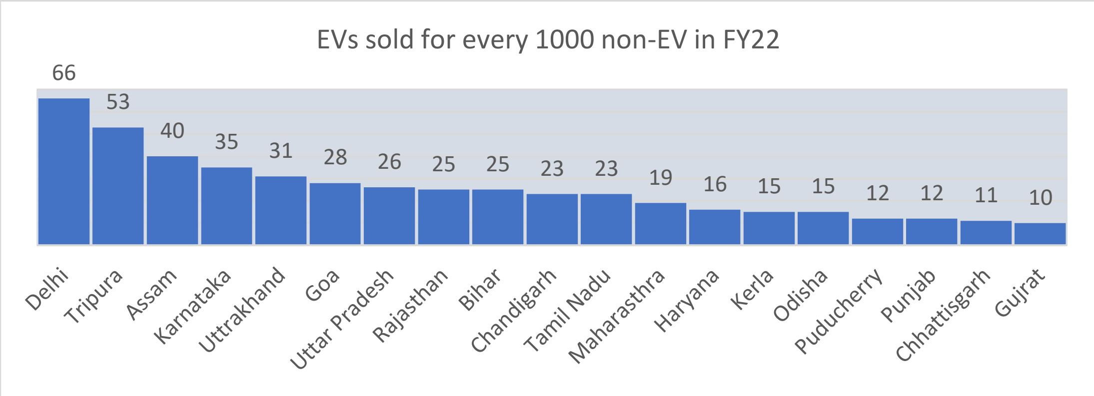
Vehicle Type	Sales	% Share in EVs Sales
Two-Wheeler	1,36,468	49.4%
Three-Wheeler	1,26,716	45.87%
Four-Wheeler	10,469	3.79%
Goods Vehicle	971	0.35%
Total	2,76,265	100%

Source: Centre for Energy Finance, Council on Energy, Environment and Water (CEEW). https://cef.ceew.in/intelligence/tool/electric-mobility (accessed 12 May 2022).

Table 4.9 represents the share of different category EV sales in total EV sales in financial year 2021-22. Two-wheeler sales are almost 50% of total EVs sales followed by three-wheelers, four-wheelers, and goods vehicles with a share of 45%, 3,79% and 0.35%, respectively.

Delhi tops in the sales of EVs per 1,000 non-EV sales. A total of 66 EVs are being sold in Delhi for every 1,000 non-EV (Figure 4.7). It is followed by Tripura, Assam, Karnataka, Uttarakhand, Goa, and Uttar Pradesh with the least sold EVs per 1,000 non-EVs in Gujrat for financial year 2022.

Figure 4.7. Electric Vehicles Sold per 1,000 Non-Electric Vehicles in Indian States



Source: Centre for Energy Finance, Council on Energy, Environment and Water (CEEW); India https://cef.ceew.in/intelligence/tool/electric-mobility (accessed 12 May 2022).

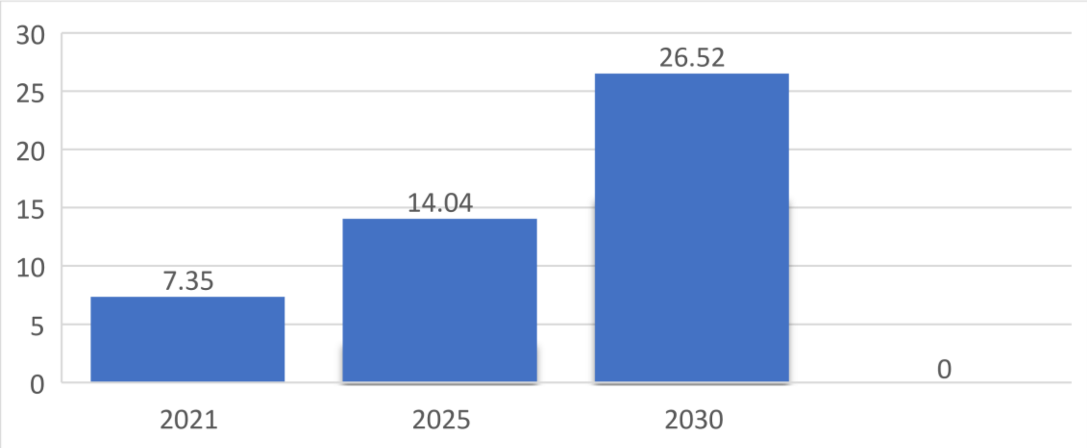
Table 4.10 provides the details of state-wise EV sales in the top 10 states for 3 consecutive years 2019–20, 2020–21, and 2021–22, respectively. For 3 consecutive years Uttar Pradesh leads the sales of EVs in India but its share in total EV sales in India has decreased from 33.4% to 21%, whilst Haryana was last of the top 10 list with a share of around 2% in 2019–20 and 2020–21. Haryana didn't make the list of top 10 states in EV sales in 2021–22. Uttar Pradesh is followed by Karnataka, Maharashtra, Tamil Nadu, and New Delhi with a share of 10.77%, 10.17%, 8.77% and 8.08%, respectively in 2021–22.

Table 4.10. Electric Vehicle Sales of Top 10 States, India

State	Sales	Share*	State	Sales	Share*	State	Sales	Share*
	2019–20			2020–2021			2021–22	
Uttar Pradesh	56221	33.41	**Uttar Pradesh**	31584	23.6	**Uttar Pradesh**	57840	20.94
Delhi	23687	14.07	**Bihar**	13290	9.93	**Karnataka**	29743	10.77
West Bengal	15039	8.94	**Karnataka**	12863	9.61	**Maharashtra**	28093	10.17
Bihar	14263	8.47	**Tamil Nadu**	11937	8.92	**Tamil Nadu**	24241	8.77
Assam	12018	7.14	**Delhi**	11809	8.82	**Delhi**	22326	8.08
Maharashtra	7400	4.4	**Maharashtra**	9417	7.04	**Rajasthan**	20944	7.58
Karnataka	7187	4.27	**Assam**	8959	6.69	**Bihar**	19331	7
Rajasthan	5920	3.52	**West Bengal**	8203	6.13	**Assam**	13271	4.8
Uttarakhand	5470	3.25	**Rajasthan**	8189	6.12	**Gujrat**	10019	3.63
Haryana	4674	2.78	**Haryana**	3027	2.26	**Kerala**	8540	3.09

*Share of states in India's total EV sales %.¥
Source: Accelerated e-Mobility Revolution for India's Transport (e-AMRIT). https://e-amrit.niti.gov.in/electricity-cost-for-charging (accessed 13 May 2022).

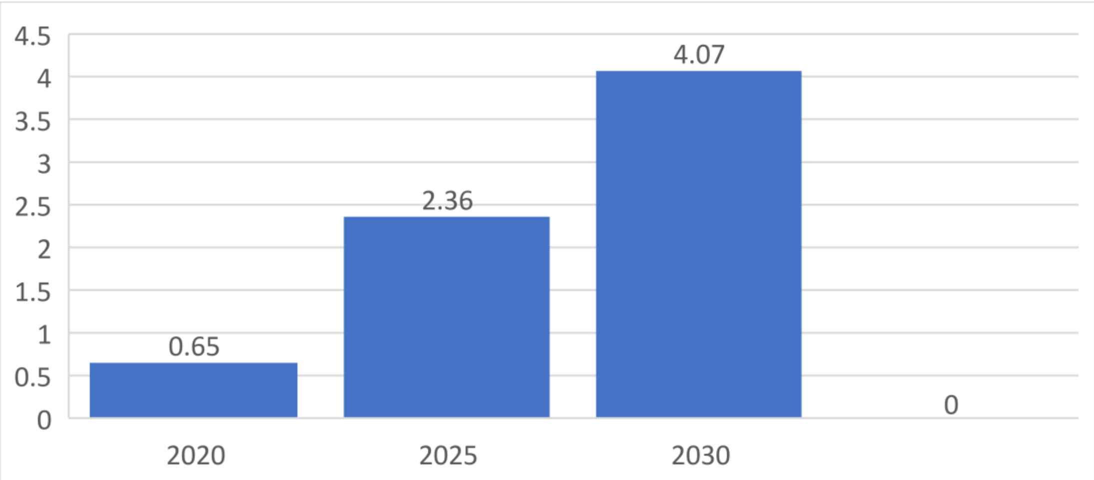
Figure 4.8. Projection of Electric Two-Wheelers in India (in millions)



Source: Statista. https://www.statista.com/statistics/1029838/india-projected-electric-two-wheeler-market-size/ (accessed 11 May 2022).

The number of electric two-wheelers across India was projected to cross the 14 million units in 2025 and 26 million units mark in 2030 as shown in Figure 4.8. The current value of goods and services tax on electric vehicles is just 12%, as opposed to 28% plus taxes on petrol, diesel, and even hybrid vehicles.

Figure 4.9. Projection of Three-Wheelers and Auto Rickshaws in India (in millions)



Source: Statista. https://www.statista.com/statistics/1029864/india-projected-electric-three-wheeler-and-auto-rickshaw-market-size/ (accessed 11 May 2022).

Figure 4.9 shows that the projected number of electric three-wheeler vehicles and auto rickshaws across India was expected to be more than 2 million units in 2025 and 4 million units in 2030. Since 2006, numerous government policies both at the national and state level have been designed to promote electric three-wheelers in the country.

Different states in India have different electricity costs for charging as shown in Table 4.11. The highest cost is encountered in Meghalaya, which is R10.09/kWh. Gujrat charges are the least amongst all states, which is in the range of R4/kWh to R4.1/kWh. Karnataka and Kerala electricity costs are R5/kWh. Many states have a band of electricity charges for charging EVs; these states are Himachal Pradesh, Gujrat, Madhya Pradesh, Maharashtra, Uttar Pradesh, Tamil Nadu, Odisha, Jharkhand, Bihar, and Assam. In these states the charging cost varies in each state with a given range of charges.

Table 4.11. Electricity Costs for Charging in Indian States (in rupees)

State	Tariff	State	Tariff
Himachal Pradesh	4.7 to 5/kWh	**Kerala**	5/kWh
Punjab	5.4/kWh	**Tamil Nadu**	5 to 8.05/kWh
Uttarakhand	5.5/kWh	**Andhra Pradesh**	6.7/kWh
Rajasthan	6/kWh	**Telangana**	6/kWh
Gujrat	4 to 4.1/kWh	**Odisha**	4.20 to 5.70/kWh
Madhya Pradesh	5.9 to 6/kWh	**Chhattisgarh**	5//kWh
Maharashtra	4.05 to 4.24/kWh	**Jharkhand**	6 to 6.25 to5/kWh
Karnataka	5/kWh	**Bihar**	6.3 to 7.4/kWh
Uttar Pradesh	5.9 to 7.7/kWh	**Assam**	5.25 to 6.75/kWh
Meghalaya	10.09/kWh	**Haryana**	6.2/kWh

kWh = kilowatt hour.
Source: Accelerated e-Mobility Revolution for India's Transport (e-AMRIT). https://e-amrit.niti.gov.in/electricity-cost-for-charging (accessed 13 May 2022).

Table 4.12 shows the top five original equipment manufacturers (OEM) in the market of two-wheeler, three-wheeler, and four-wheeler electric vehicles. Hero electric leads the sales of two-wheelers followed by Okinawa. YC Electric Vehicle tops the sales of three-wheelers with significant lead from the second best seller of three-wheelers. Tata Motor leads the sales of EV of four-wheelers with an annual sale of 9,045 four-wheelers EVs in FY22. Mahindra Electric has secured the place in the top five OEMs for the sale in three-wheeler and four-wheeler EVs.

Table 4.12. Top OEMs of Electric Vehicles (2021 to 31 January 2022)

Top OEMs for Two-Wheelers	Two-Wheelers	Top OEMs for Three-Wheelers	Three-Wheelers	Top OEMs for Four-Wheelers	Four-Wheelers
Hero Electric	40,528	YC Electric Vehicle	11,937	Tata Motor	9,045
Okinawa	29,274	Saera Electric Auto	5,913	MG Motor	1,890
Ather Energy	14,514	Mahindra Electric	5,581	Mahindra Electric	179
Ampere Vehicles	11,946	Champion Poly Plast	5,523	Hyundai	104
Pure Energy	10,546	Dilli Electric Auto	4,463	Audi AG	46

OEM = original equipment manufacturer.
Source: Centre for Energy Finance, Council on Energy, Environment and Water (CEEW). https://cef.ceew.in/intelligence/tool/electric-mobility (accessed 13 May 2022).

Under the Faster Adoption and Manufacturing of Hybrid & Electric Vehicles (FAME) India scheme phase II, the Department of Heavy Industries has also approved 2,636 charging stations in 62 cities all over 24 states/union territories. Table 4.13 shows the state-by-state distribution of charging stations in India.

Table 4.13. Approved Charging Stations across Indian States

State/Union Territory	Charging Stations	State/Union Territory	Charging Stations	State/Union Territory	Charging Stations
Andhra Pradesh	266	Haryana	50	Meghalaya	40
Delhi	72	Himachal Pradesh	10	Odisha	18
Assam	25	Pondicherry	10	Rajasthan	205
Bihar	37	Karnataka	172	Telangana	138
Chhattisgarh	25	Kerala	131	Chandigarh	70
Port Blair	10	Madhya Pradesh	159	J&K	25
Gujrat	228	Maharashtra	317	West Bengal	141
Sikkim	29	Tamil Nadu	256	Uttar Pradesh	207
Uttarakhand	10				

Source: Accelerated e-Mobility Revolution for India's Transport (e-AMRIT). https://e-amrit.niti.gov.in/electricity-cost-for-charging (accessed 13 May 2022).

1.2. Objective and Scope

This project analyses future scenarios for EAS mobility, which may strongly contribute to the regional Sustainable Development Goals (SDGs) (7, 12, and 13) and provide a balance between transport CO_2 reduction, biofuel use, and the demands on mineral resources. In this chapter, the demand for Nd and Co were forecast and the amount of waste resulting from the promotion of automobile electrification in EAS countries were also estimated. Moreover, CO_2 emissions caused by producing lithium-ion batteries and rare earth magnets were estimated. The CO_2 reduction by the material recycling of Nd and Co were also examined as well as the recycling potential of these critical materials.

1.3. Methodology

This section explains a method for predicting the demands of Nd and Co needed for vehicle electrification including four-wheelers and two-wheelers in EAS countries and estimating the amount of waste after the promotion of electrified automobiles. The section also describes the method for CO_2 emissions calculation from the production of neodymium magnets and lithium-ion battery cells for vehicles electrification and analysis of CO_2 emissions reduction by implementing 100% recycling of neodymium magnets and lithium-ion batteries.

First, the number of vehicles sales in EAS countries was estimated by the trend of vehicle growth in a mathematical model, often called 'Vehicle Ownership Model', which can be modeled as the S-Curve logistic function of gross domestic product per capita and population density. Then, the model was investigated and validated by the Low Emissions Analysis Platform (LEAP) system software (the details are described in chapter 3). The share/percentage of electric vehicle sales to whole vehicle sales was estimated by considering the input data from the working members of this ERIA report regarding vehicle electrification policy combined with the data of EV share from the Bloomberg projection for EAS countries. The number of discarded vehicles was estimated using the Weibull distribution, when assuming a car's life span to be 14.4 years (Morimoto et al., 2020).

The demand and disposal of Nd and Co were calculated by integrating the data on the amount (contained rate) of Nd and Co in these automobiles with the number of automobiles that were sold and disposed during these projections. The contained rate of Nd per vehicle for four-wheelers and two-wheelers is based on the research paper of Yang et al. 2016. Then, Co contained per vehicle for four-wheelers was estimated based on the Green Business Report data and for two-wheelers from an expert's interview, the Joint Research Centre report, combined with Epic Cycle data.

The calculation of CO_2 emissions from the production of neodymium magnets and lithium-ion battery cells for four-wheeler and two-wheeler vehicles were determined by the amount of neodymium magnets (kg/vehicle) based on the research paper of Yang et al. 2016 and the amount of lithium-ion battery cell (kg/vehicle) based on interviews with several companies in Japan. Then, this value was multiplied by the vehicle sales and disposal vehicles in EAS countries to decide how many neodymium magnets and lithium-ion battery cells are needed. The total CO_2 emissions, as well as the amount of CO_2 reduction by recycling (considering

100% recycling of disposal material) neodymium magnets and lithium-ion battery cells were estimated by the data of CO_2 emissions per item (Hongyue et al., 2018) (Siqin, Ji, and Ma, 2020).

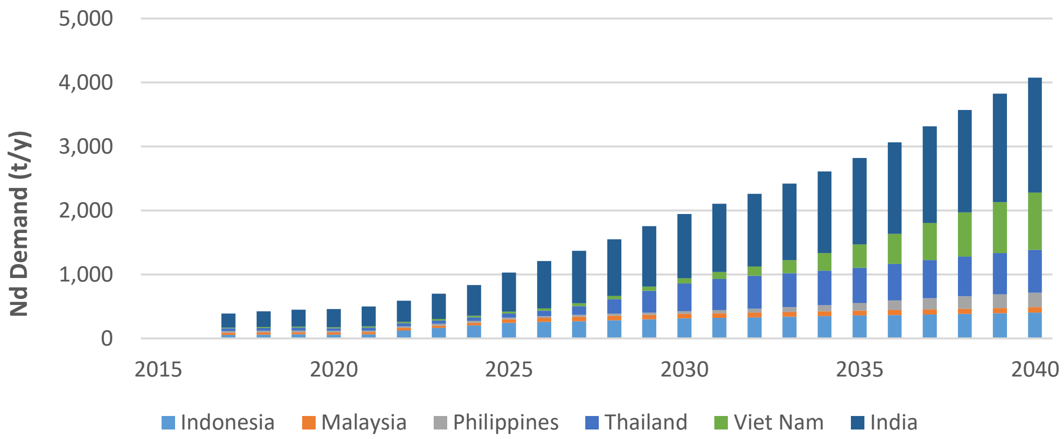
2. Mineral Resource Demand and CO_2 Emissions by Mobility Electrification

This study explains the result of our forecast about the demand and waste of Nd and Co by implementing the mobility electrification of vehicles (four-wheelers and two-wheelers) in EAS countries using the prediction method described in Section 1.3.

Figure 4.10 and 4.11 shows the demand of Nd and Co that are used in neodymium magnets and lithium-ion battery cells until 2040. Each figure shows the total demand of Nd and Co in Indonesia, Malaysia, Philippines, Thailand, Viet Nam, and India.

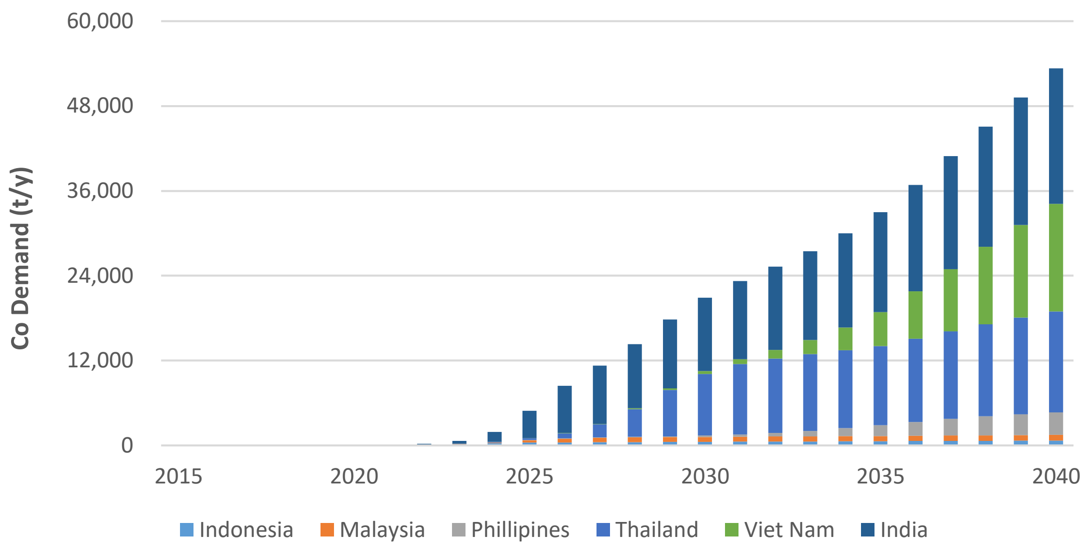
2.1. Demand for and Waste of Mineral Resources

Figure 4.10. Neodymium Demand Forecast



Nd = neodymium, t/y = ton/year.
Source: Authors.

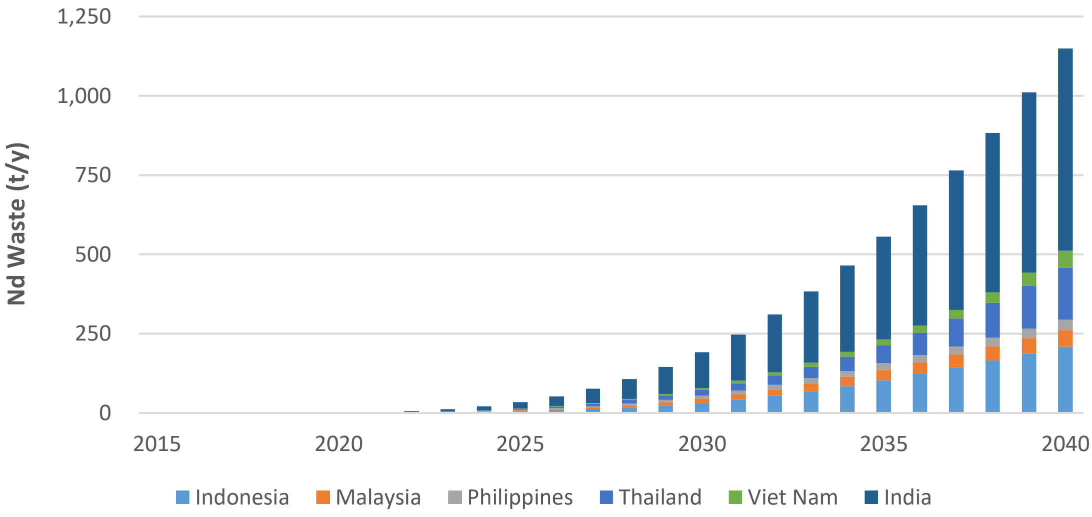
Figure 4.11. Cobalt Demand Forecast



Co = cobalt, t/y = ton/year.
Source: Authors.

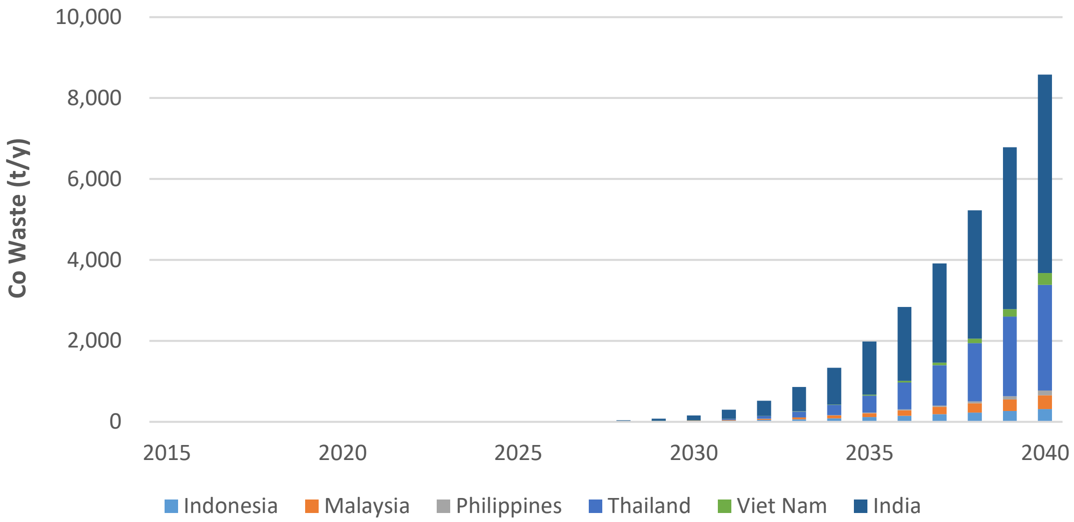
Based on Figures 4.10 and 4.11, the demand of Nd is predicted to be 4,075 t/y in 2040. India, Viet Nam, and Thailand cover 82.51% of all Nd demand in EAS countries, and India is predicted to have the largest demand of Nd in future. Moreover, the demand of Co is predicted to be 53,324 t/y in 2040 and India, Viet Nam, and Thailand also cover 91.26% of all the demand in EAS countries.

Figure 4.12. Neodymium Waste Forecast



Nd = neodymium, t/y = ton/year.
Source: Authors.

Figure 4.13. Cobalt Waste Forecast



Co = cobalt, t/y = ton/year.
Source: Authors.

Figures 4.12 and 4.13 show the waste/disposal forecast of Nd and Co contained in disposal of neodymium magnets and lithium-ion battery cells until 2040. Each figure shows the total waste of Nd and Co in Indonesia, Malaysia, Philippines, Thailand, Viet Nam, and India.

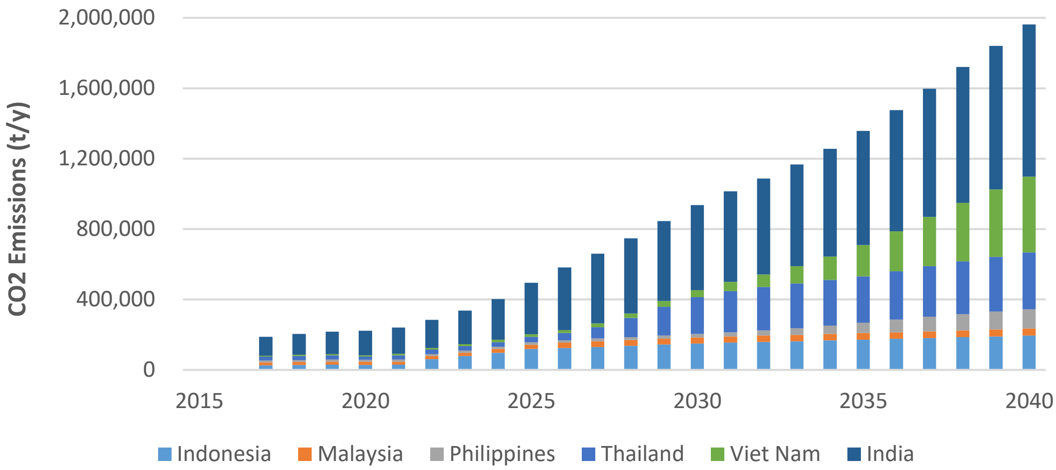
From the result of Figures 4.12 and 4.13, the total waste of neodymium is predicted to be 1,149 t/y in 2040. India, Indonesia, and Thailand generate 87.89% of all Nd waste/disposal in EAS countries. Moreover, the total waste of cobalt is predicted to be 8,583 t/y in 2040 with India and Thailand predicted to generate 87.56% of all Co from lithium-ion battery cells disposal in EAS countries. From the figures it is shown the total secondary resource can cover 28.2% of neodymium demand and 16.1% of cobalt demand by applying the assumption of 100% recycling rate.

2.2. CO_2 Emissions

Mobility electrification will increase the demand and production of neodymium magnets and lithium-ion battery cells. With the methodology described in Section 1.3, we have analysed the CO_2 emissions from the production of neodymium magnets and lithium-ion battery cells used for electric four-wheelers and electric two-wheelers in EAS countries until 2040.

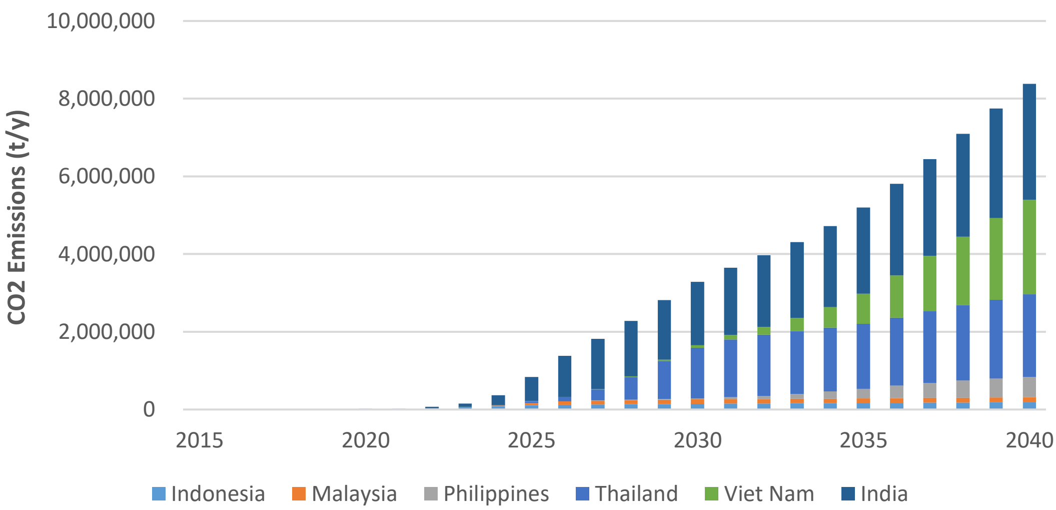
Figures 4.14 and 4.15 show the CO_2 emissions from neodymium magnets and lithium-ion battery cells production from virgin materials until 2040 as required for the demand shown in Figures 4.10 and 4.11. Each figure shows the total CO_2 emissions in Indonesia, Malaysia, Philippines, Thailand, Viet Nam, and India.

Figure 4.14. CO_2 Emissions Forecast from Neodymium Magnet Production



t/y = ton/year.
Source: Authors.

Figure 4.15. CO_2 Emissions Forecast from Lithium-ion Battery Cell Production



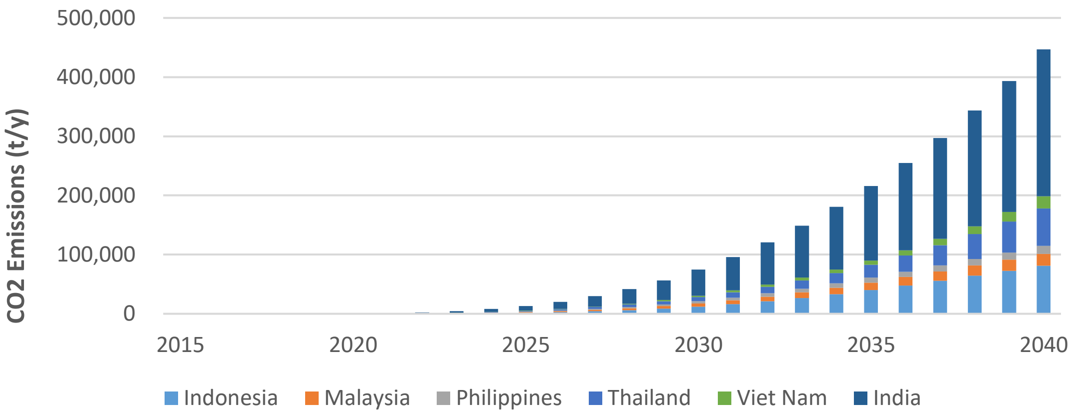
t/y = ton/year.
Source: Authors.

From the results in Figures 4.14 and 4.15, the total CO_2 emissions from the production of neodymium magnets and lithium-ion battery cells are predicted to be 1.9 metric tons (Mt)/y and 8.4 Mt/y in 2040. India, Thailand, and Viet Nam cover around 82.51% of CO_2 emissions from neodymium magnet production and 90.02% of CO_2 emissions from lithium-ion battery cell production in EAS countries because of the high demand of neodymium magnets and lithium-ion battery cells.

Considering a 100% recycle rate of neodymium magnets and lithium-ion battery cells, CO_2 emissions will decrease due to the reduction of virgin materials in the production of neodymium magnets and lithium-ion battery cells. Figures 4.16 and 4.17 show the amount of CO_2 emissions reduction from neodymium magnet and lithium-ion battery cell production by using recycled materials until 2040. Each figure shows the total amount of CO_2 emissions reduction in Indonesia, Malaysia, Philippines, Thailand, Viet Nam, and India.

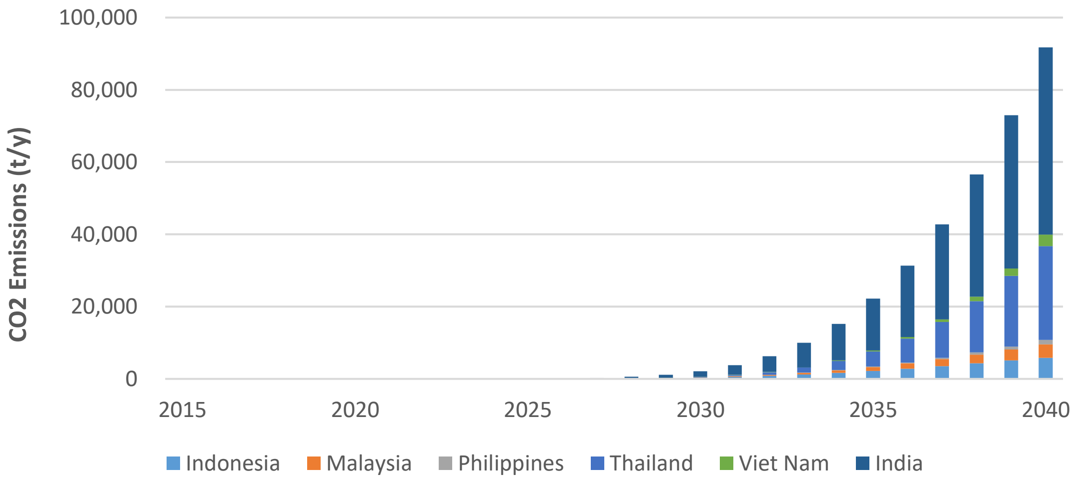
From the result of Figures 4.16 and 4.17, we predicted the total reduction of CO_2 emissions using a 100% recycle rate for neodymium magnets and lithium-ion battery cells will be 446,856 t/y and 91,759 t/y in 2040. India and Thailand cover 69.77% of CO_2 emissions reduction from neodymium magnet production and 84.72% of CO_2 emissions reduction from lithium-ion battery cell production in EAS countries.

Figure 4.16. CO_2 Emissions Reduction Forecast from Neodymium Magnet Production



t/y = ton/year.
Source: Authors.

Figure 4.17. CO_2 Emissions Reduction Forecast from Lithium-ion Battery Cells Production



t/y = ton/year.
Source: Authors.

3. Discussion

This chapter describes the results of the estimation for the long-term mineral resource demand and CO_2 emissions associated with automobile electrification in EAS countries. In addition, this chapter describes the results of the assessment of the potential for recycling in these countries by determining the amount of waste of these mineral resources and the possibility to reduce CO_2 emissions by using materials from the recycling process.

In conclusion, the demand for neodymium is predicted to be a minimum of 4,075 t/y in 2040. If the recycle rate is 100%, secondary resources can cover 28.2% of total Nd demand in EAS countries. The total demand for cobalt is predicted to be 53,324 t/y in 2040. If the recycle rate is 100%, secondary resources can cover 16.1% of cobalt demand in EAS countries.

However, considering that production of neodymium was 43,200 rare earth oxide (REO) tons/year and cobalt was 140,000 tons/year in 2020 (USGS, 2021), it is predicted it will be difficult for world supply to meet the target of EAS mobility electrification regarding the large increase of demand in China, the European Union, and United States.

Therefore, it is necessary to consider the balance between biofuels and mobility electrification based on the potential of secondary resources and the circular economy.

Moreover, in 2040 the total CO_2 emissions from the production of neodymium magnets will be 1.9 Mt/y and from lithium-ion battery cells will be 8.4 Mt/y. If the recycle rate is 100%, secondary resources can reduce CO_2 emissions by 446,856 t/y for neodymium magnet production and 91,759 t/y for lithium-ion battery cell production in 2040.

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Chapter 5
Conclusion

1. Introduction

The National Institute of Advanced Industrial Science and Technology (AIST) has been studying future mobility scenarios of East Asia Summit (EAS) countries since 2014. In the past AIST–Economic Research Institute for ASEAN and East Asia (ERIA) project, the scenarios for India, Indonesia, and Thailand were examined considering the potential of biofuels and electrified vehicles (xEVs). As the result, well-to-wheel CO_2 emissions were estimated for several scenarios by creating energy mix model.

However, in the previous project, the sustainability of biofuels and xEVs has not yet been taken into consideration. Diffusion of xEVs can contribute to CO_2 reduction, but may affect mineral resource demand induced by motors and batteries. Therefore, the aim of this project is to analyse future scenarios of EAS mobility which contribute to the Sustainable Development Goals 7, 12, and 13 in consideration of the balance between transport CO_2 reduction, biofuel use, and mineral resources demand. The outcome will contribute to the EAS Energy Research Road Map (Pillar 3: Climate Change Mitigation and Environmental Protection) corresponding to the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016–2025 3.5 Programme Area No.5: Renewable Energy and 3.6 Programme Area No.6: Regional Energy Policy and Planning).

In fiscal year 2020, the first phase of this project was conducted. Biofuel policies and strategies, as well as existing research on biofuels sustainability were assessed for the EAS countries (India, Thailand, Malaysia, Viet Nam, Indonesia, and Philippines). Moreover, a database was created to evaluate well-to-wheel CO_2 reduction and mineral resource demand based on the biofuel implementation and mobility electrification.

In this fiscal year 2021, working group meetings were conducted in December 2021 and April 2021. As the result, 'well-to-tank' greenhouse gas GHG (WTT GHG) emissions for producing biofuels, 'tank to wheel' GHG emissions for using biofuels, and demand and GHG emissions for producing mineral resources considering mobility electrification were evaluated. This chapter describes the conclusion and progress of each study (chapters).

2. Well-to-Tank CO_2 Emissions from Biofuels in East Asia Summit Countries

National policy and future projection of biofuels were clarified in Malaysia, Philippines, Viet Nam, and Thailand. The well-to-tank (WTT) GHG emissions from biofuels in the various countries in the region are summarised. Despite some variations in the emissions values from the different feedstock and countries, these are all lower than their fossil fuel counterparts (i.e. 2.92 kilogramme/litre gasoline as compared to ethanol and 83.8 gCO_2 eq/MJ diesel as compared to biodiesel). In the case of palm biodiesel production, the cultivation of oil palm has a significant contribution followed by biodiesel production and crude palm oil production. Crude palm oil production gains benefits from many by-products such as fibre, shell, empty fruit bunches, and biogas from palm oil mill effluent that can be used for energy. In the case of ethanol, the agriculture stage is once again quite a high contributor for both cassava and sugarcane molasses.

However, for the case of cassava, ethanol production, particularly distillation and dehydration, has a very high contribution to GHG emissions due to the use of fossil fuels. However, in the case of sugarcane molasses the use of biomass-based by-products such as bagasse and biogas from vinasse as energy sources reduce the contribution of ethanol production to GHG emissions. Transportation of feedstock and intermediates has a relatively modest contribution for all the biofuels.

3. Tank-to-Wheel CO_2 Emissions from Biofuels in East Asia Summit Countries

In this chapter, bottom-up energy demand model for transport sector was constructed, focusing on cars and motorcycles in six countries: Indonesia, Malaysia, Philippines, Thailand, Viet Nam, and India. Tank-to-wheel GHG emissions were estimated using the Low Emissions Analysis Platform (LEAP) system with input data on population, gross domestic product, vehicle history and projection, vehicle kilometre of travel (VKT), and fuel economy.

In particular, the tank-to-wheel greenhouse gas (TTW GHG) emissions are calculated according to the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) in this study. For fuel combustion in road transportation, the emissions factors are selected according to the Technology and Environmental Database. The TTW GHG emissions from fossil fuel combustion in road transportation comprise CO_2, CH_4, and N2O. These emissions are converted into the CO_2-equivalent unit by multiplied with the global warming potentials (GWP).

With relatively robust vehicle ownership model, the business-as-usual setting for energy consumption and WTT GHG emissions can be set as a baseline for investigation into impact from electric vehicle (EV) and biofuel policy. With best available projections of EV and biofuel, impact of energy consumption and TTW GHG emissions can be quantitatively illustrated. Of course, further refinement of model assumption, as well as data input, could help improve accuracy of the present model. However, the present model can evidently highlight important of motorcycle segment, which has potential to reduce energy consumption and TTW GHG emissions as much as car segment collectively in these six countries. Policies to support the decarbonisation of the road transportation sector by motorcycles must be equally treated as policies for the car segment.

4. CO_2 Emissions from Producing Mineral Resources by Mobility Electrification in East Asia Summit Countries

The long-term mineral resource demand associated with automobile electrification was estimated in EAS countries. In addition, CO_2 emissions from producing mineral resources and the potential for recycling in these countries were assessed by determining the amount of waste of these mineral resources and the effectiveness of introducing a circular economy under these conditions was evaluated.

In conclusion, the demand for neodymium is predicted to be a minimum of 4,075 t/y in 2040. If the recycle rate is 100%, secondary resources can cover 28.2% of total Nd demand in EAS countries. The total demand for cobalt is predicted to be 53,324 t/y in 2040. If the recycle rate is 100%, secondary resources can cover 16.1% of cobalt demand in EAS countries. However, considering that production of neodymium was 43,200 REO tons/year and cobalt was 140,000 tons/year in 2020 (USGS, 2021), it is predicted to be difficult that world supply can meet the target of EAS mobility electrification regarding the large increase of demand in China, the European Union, and the United States. Therefore, it is necessary to consider the balance between biofuels and mobility electrification based on the potential of secondary resources and circular economy.

Moreover, the total CO_2 emissions produced from neodymium magnets and lithium-ion battery cells production will be 1.9 Mt/y for neodymium magnets production and 8.4 Mt/y for lithium-ion battery cells production in 2040. If the recycle rate is 100%, secondary resources can reduce CO_2 emissions 446,856 t/y for neodymium magnets production and 91,759 t/y for lithium-ion battery cells production in 2040.

5. Conclusion and Future Aspects

Following the FY2020 project results, this study assessed the WTT GHG emissions from producing biofuels, TTW GHG emissions from using biofuels, and GHG emissions from producing mineral resources considering mobility electrification in EAS countries (India, Thailand, Malaysia, Viet Nam, Indonesia, and Philippines).

In conclusion, the synergies between biofuel implementation and mobility electrification were clarified, which highly contribute to the SDGs. National policies and future projections of biofuels were clarified in EAS countries and well-to-tank GHG emissions were all lower than their fossil fuel counterparts despite some variations in the emissions values from the different feedstock and countries. TTW GHG emissions are calculated according to the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) using the LEAP system. Mobility electrification will contribute to GHG reduction but causes 1.9 Mt/y GHG emissions for neodymium magnet production and 8.4 Mt/y for lithium-ion battery cell production.

For further studies, a case study of mobility scenarios considering the balance between CO_2 reduction and potential of biofuels/mineral resources will be conducted. This will bring more uniformity to the overall sustainability assessment of biofuels for the region. Furthermore, the synergies as well as multi-benefits between biofuel implementation and mobility electrification will be more clarified. Last, the sustainable mobility scenarios for EAS countries will be created considering the achievement of the SDGs.

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