Chapter 4

CO_2 Emissions from Producing Mineral Resources by Mobility Electrification

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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.

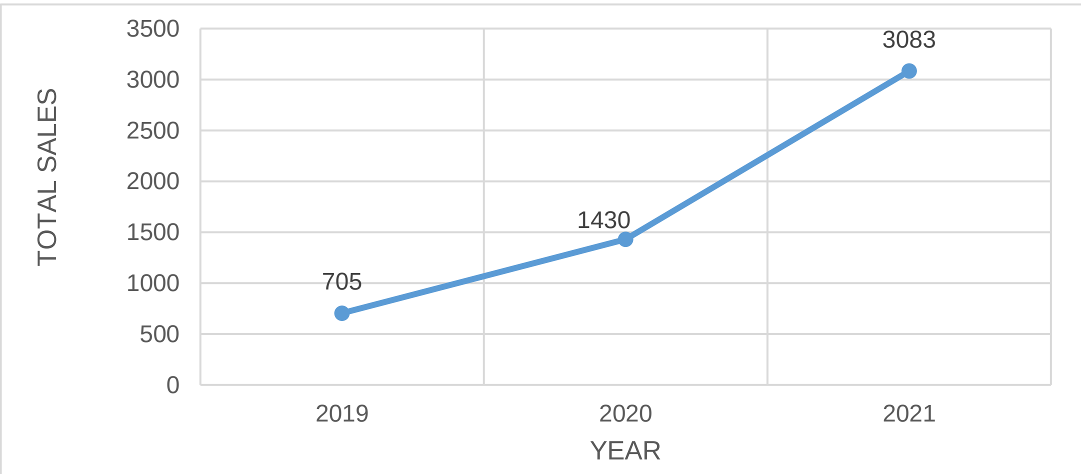
Table 4.3: Electric Vehicle Sales Projection, Indonesia

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).

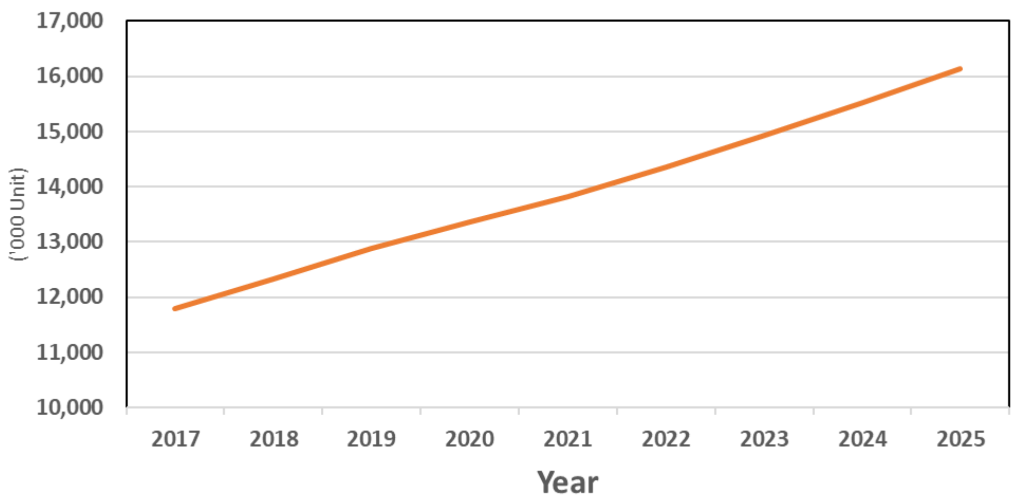
1.1.2. Malaysia

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).

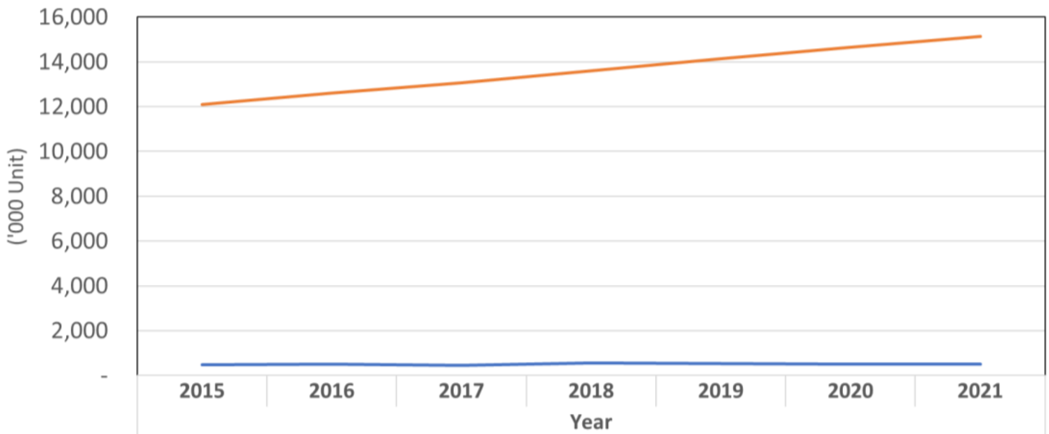
Under the Low Carbon Mobility Blueprint, targets of 5% HEVs and 5% EVs were envisaged by 2030. The national target to set up 9,000 AC charging points and 1,000 DC charging points has been set to be achieved by 2025. The e-motorcycle share is targeted at 15% by 2030 (Ministry of Environment and Water,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

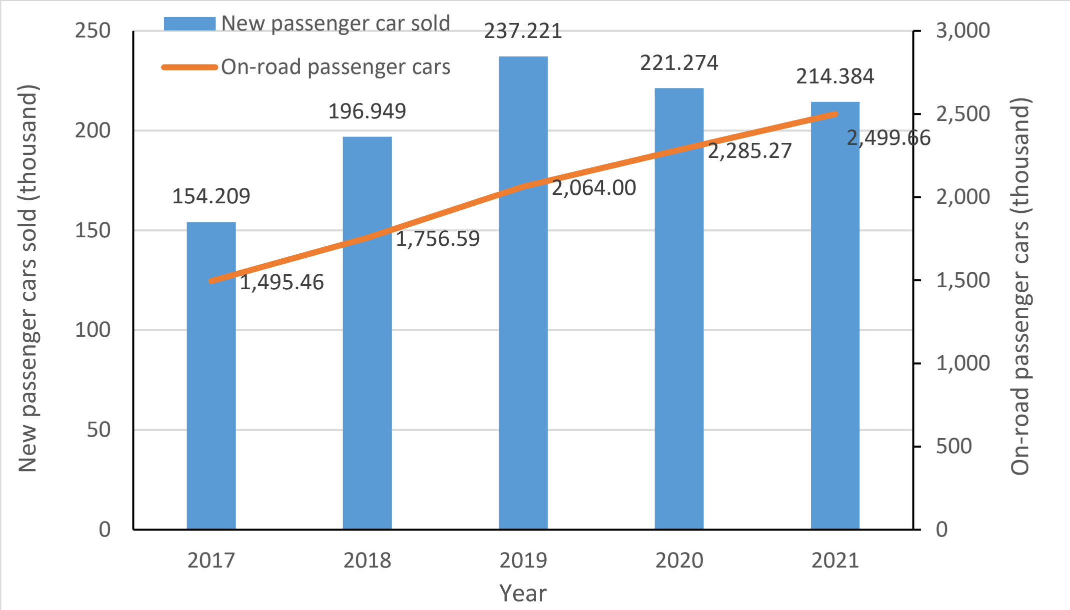
Sources: Ministry of Environment and Water (2021); McD Motorcycles Data, https://www.motorcyclesdata.com/2022/02/01/malaysia-motorcycles (accessed 19 April 2022).

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).

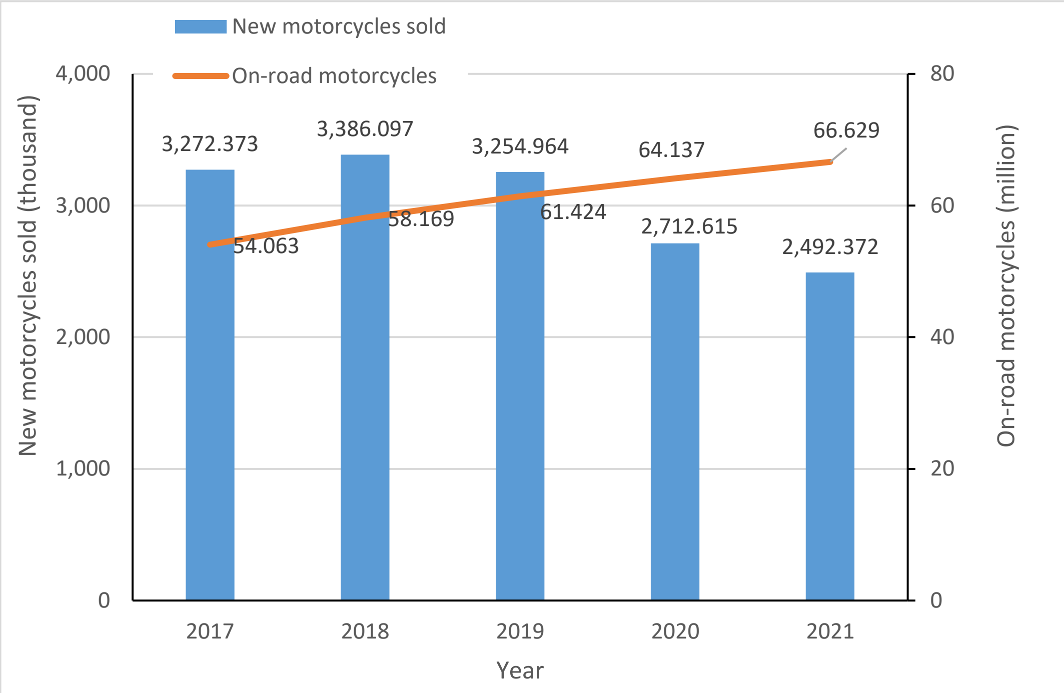
For the distance that passenger cars travel per day, the available study shows the values of 42 kilometres(km)/day/vehicle in Ha Noi, and 33.4 km/day/vehicle in Ho Chi Minh city (Oanh, 2015). The average is calculated to be about 37.7 km/day/vehicle.

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).

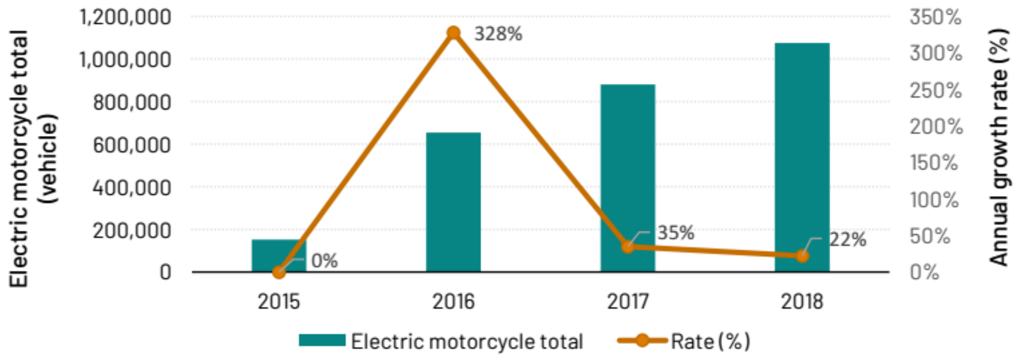
For the distance that motorcycles travel per day, the available study shows the values of 20.3 km/day/vehicle in Ha Noi, and 19.4 km/day/vehicle in Ho Chi Minh city (Oanh, 2015). The average is calculated to be about 19.85 km/day/vehicle.

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

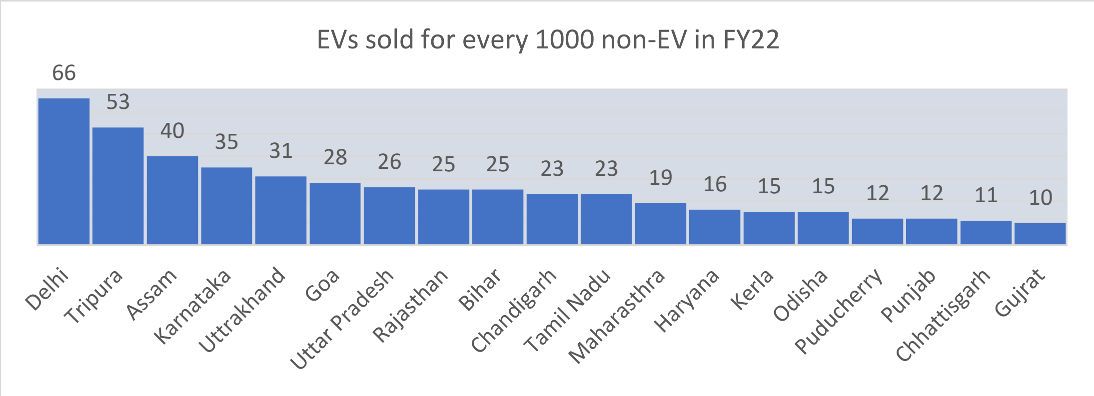
Vehicle Type	Sales	% Share in EVs Sales
Two-Wheeler	1,36,468	49.4%
Three-Wheeler	1,26,716	45.87%
Four-Wheeler	10,469	3.79%
Goods Vehicle	971	0.35%
Total	2,76,265	100%

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).

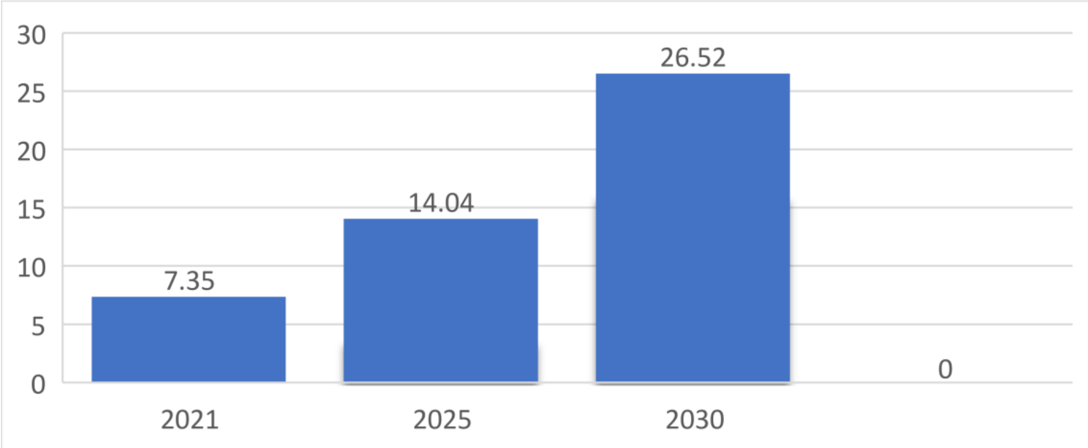
Table 4.10 provides the details of state-wise EV sales in the top 10 states for 3 consecutive years 2019–20, 2020–21, and 2021–22, respectively. For 3 consecutive years Uttar Pradesh leads the sales of EVs in India but its share in total EV sales in India has decreased from 33.4% to 21%, whilst Haryana 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).

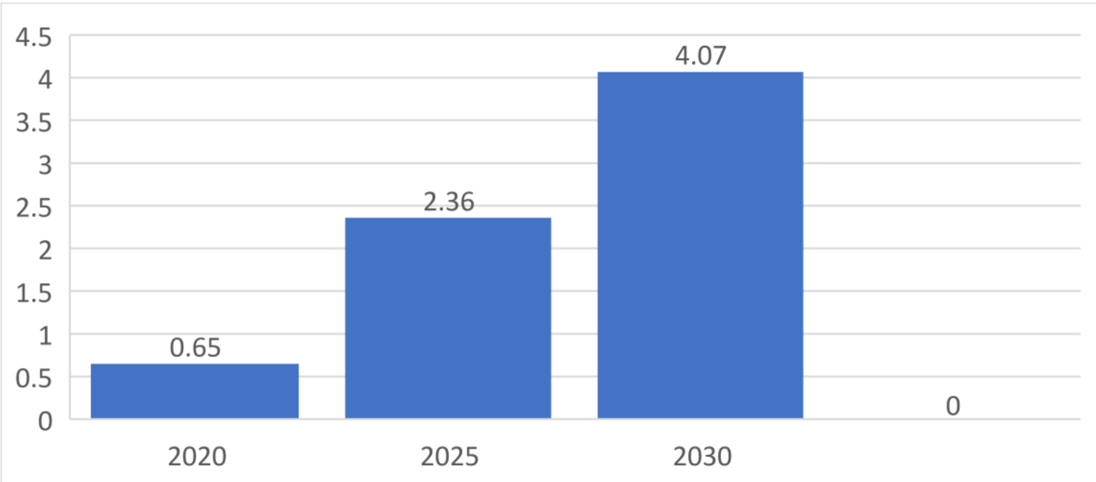
Figure 4.8. Projection of Electric Two-Wheelers in India (in millions)



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).

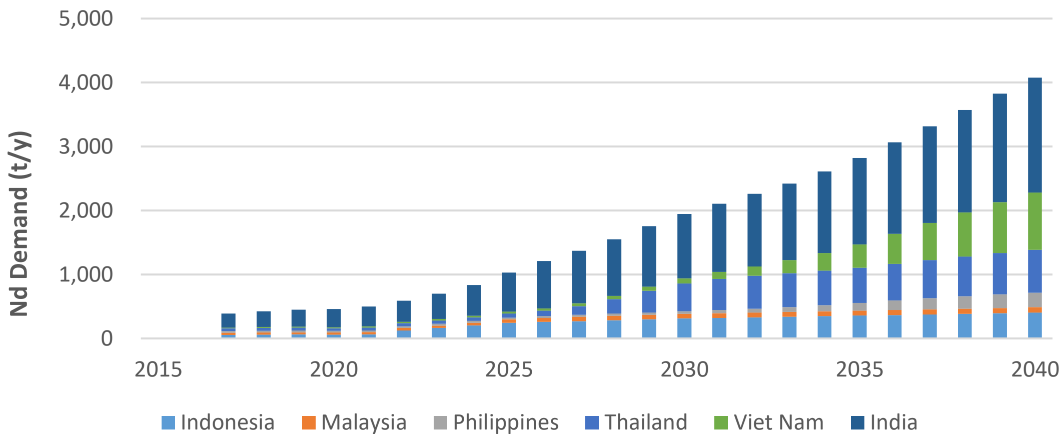
2. Mineral Resource Demand and CO_2 Emissions by Mobility Electrification

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.

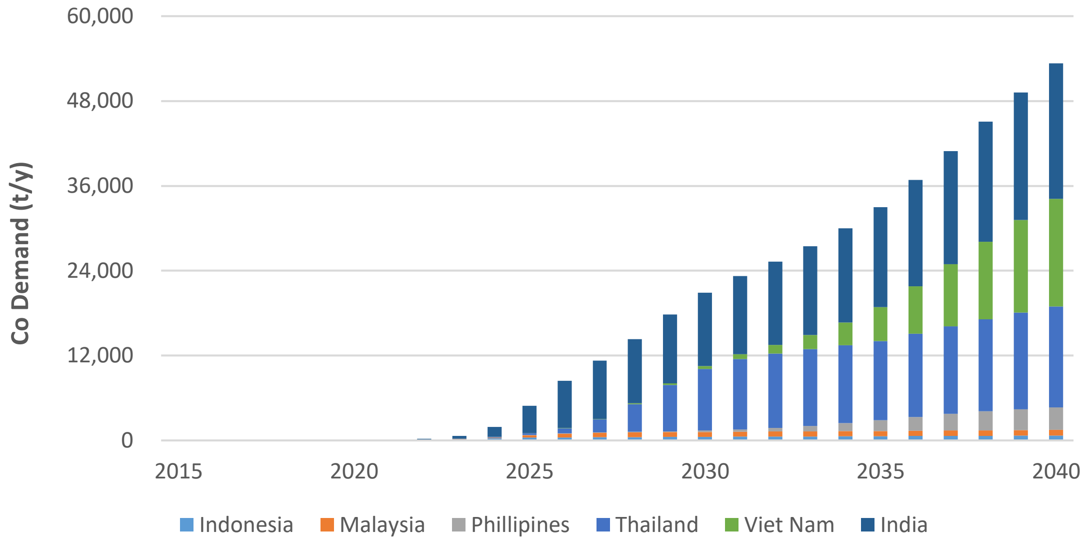
2.1. Demand for and Waste of Mineral Resources

Figure 4.10. Neodymium Demand Forecast



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

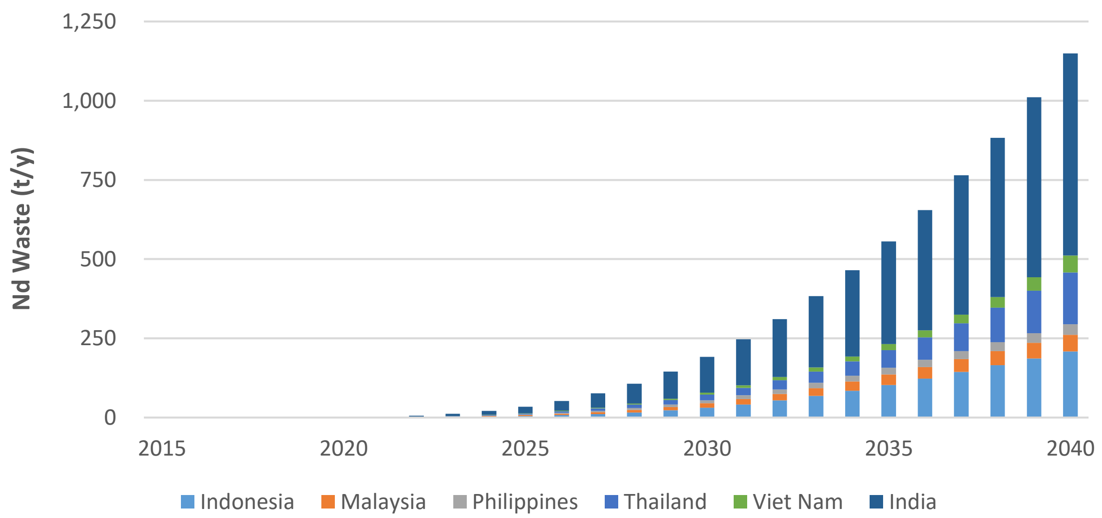
Figure 4.11. Cobalt Demand Forecast



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

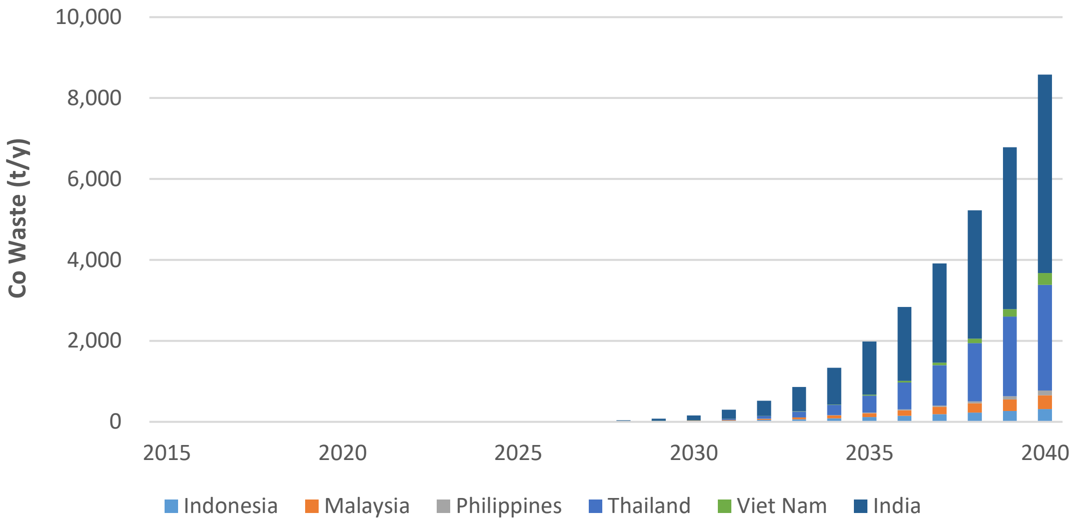
Based on Figures 4.10 and 4.11, the demand of Nd is predicted to be 4,075 t/y in 2040. India, Viet Nam, and Thailand cover 82.51% of all Nd demand in EAS countries, and India is predicted to have the largest demand of Nd in future. Moreover, the demand of Co is predicted to be 53,324 t/y in 2040 and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

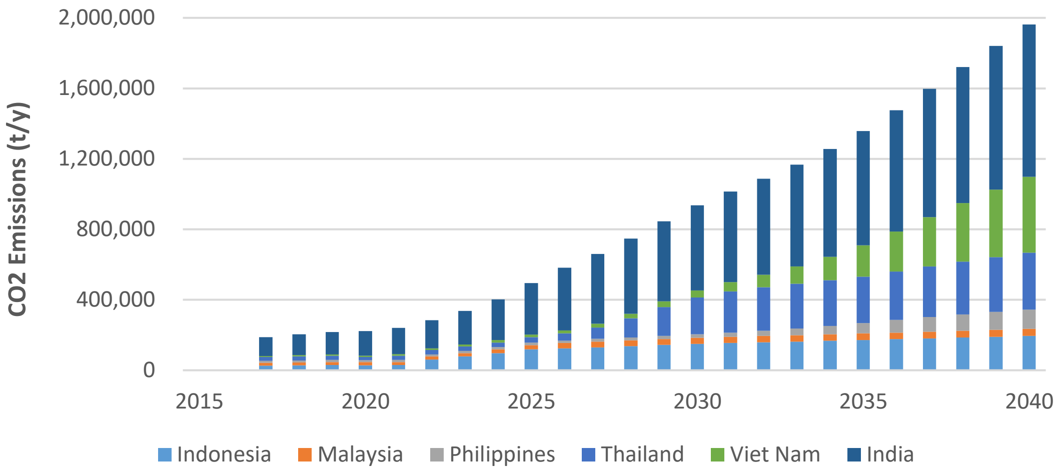
From the result of Figures 4.12 and 4.13, the total waste of neodymium is predicted to be 1,149 t/y in 2040. India, Indonesia, and Thailand generate 87.89% of all Nd waste/disposal in EAS countries. Moreover, the total waste of cobalt is predicted to be 8,583 t/y in 2040 with India and Thailand predicted 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.

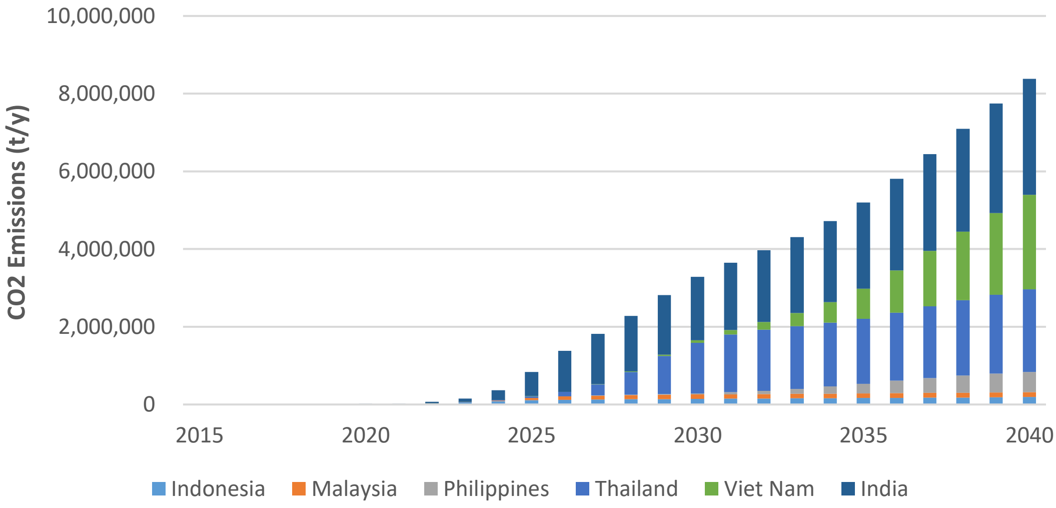
Figures 4.14 and 4.15 show the CO_2 emissions from neodymium magnets and lithium-ion battery cells production from virgin materials until 2040 as required for the demand shown in Figures 4.10 and 4.11. Each figure shows the total CO_2 emissions in Indonesia, Malaysia, Philippines, Thailand, Viet Nam,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



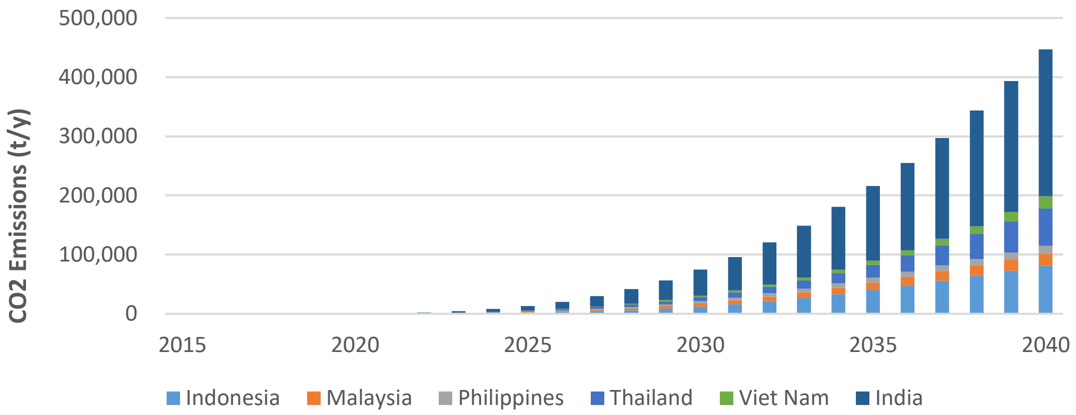
t/y = ton/year.
Source: Authors.

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.

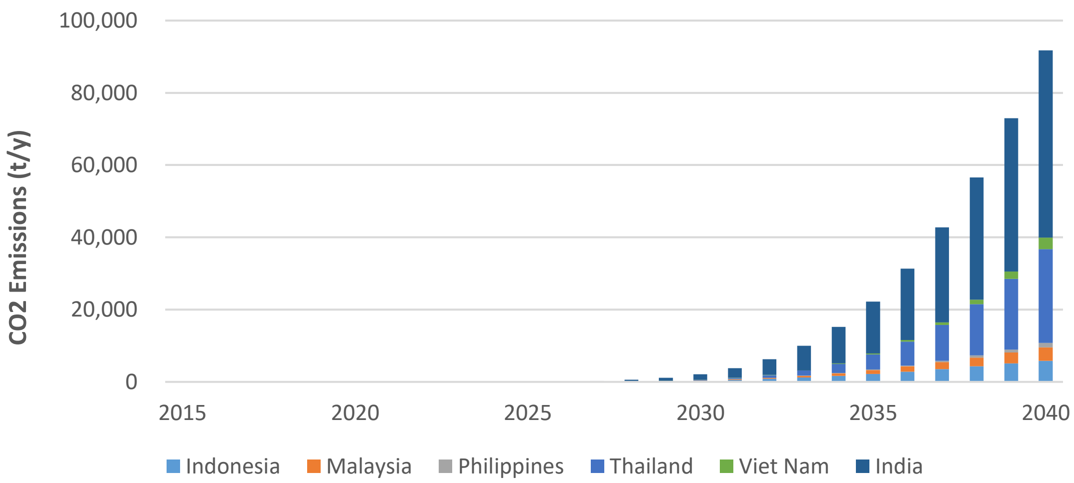
From the result of Figures 4.16 and 4.17, we predicted the total reduction of CO_2 emissions using a 100% recycle rate for neodymium magnets and lithium-ion battery cells will be 446,856 t/y and 91,759 t/y in 2040. India and Thailand cover 69.77% of CO_2 emissions reduction from neodymium magnet production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

References

ASEANStatsDataPortal. https://data.aseanstats.org/indicator/ASE.TRP.ROD.B.006 (accessed 16 May 2022).

BPS Indonesia (2022), *Vehicle Population*. https://www.bps.go.id/indicator/17/57/2/perkembangan-jumlah-kendaraan-bermotor-menurut-jenis.html.

Cabinet Secretariat of the Republic of Indonesia (2021), 'COP26: President Jokowi Says Indonesia is Committed to Tackling Climate Change'. https://setkab.go.id/en/cop26-president-jokowi-says-indonesia-is-committed-to-tackling-climate-change/.

Chan, K.H., J. Anawati, M. Malik, and G. Azimi (2021), 'Closed-Loop Recycling of Lithium, Cobalt, Nickel, and Manganese from Waste Lithium-Ion Batteries of Electric Vehicles', ACS *Sustainable Chemistry and Engineering*, 9(12), pp.4398–410. https://doi.org/10.1021/acssuschemeng.0c06869.

Department of Climate Change (2021a), Announcement No 116.BDKH-TTBVTOD, dated 26 Feb 2021 on Emission Factors for Vietnamese Electrical Grid in 2019.

______ (2021b), Announcement No 1316.BDKH-TTBVTOD, dated 31 Dec 2021 on Emission Factors for Vietnamese Electrical Grid in 2020.

Desiderio, L. (2022), 'New EV Dev't Law to Lure Hi-tech Investment', *The Philippine Star*, 9 May. https://www.philstar.com/business/2022/05/09/2179641/new-ev-development-law-lure-hi-tech-investment.

Economic Research Institute for ASEAN and East Asia (ERIA) (2020), *Assessing the Readiness for Industry 4.0 and the Circular Economy*. Jakarta: ERIA.

Epic Cycles. https://epiccycles.ca/choose-right-battery-electric-bike/ (accessed 14 June 2022).

GAIKINDO (2022), Indonesian Automobile Industry Data Wholesales. https://www.gaikindo.or.id/indonesian-automobile-industry-data/.

Geducos, A.C. (2022), 'New Laws Regulating Use of Electric, Vintage Vehicles Now in Effect', *Manila Bulletin*, 30 April. https://mb.com.ph/2022/04/30/new-laws-regulating-use-of-electric-vintage-vehicles-now-in-effect/.

Honda Motorcycle Products (2022), https://www.honda.com.vn/xe-may/san-pham/wave-alpha-110cc.

Hongyue J. et al. (2018), 'Life Cycle Assessment of Neodymium-Iron-Boron Magnet-to-Magnet Recycling for Electric Vehicle Motors', *Environmental Science & Technology*, 52(6), pp.3796–802. DOI: 10.1021/acs.est.7b05442.

Indonesian Ministry of Industry (2020), Minister of Industry Regulation No. 28 Year 2020 on Battery based Electric Vehicles.

______ (2020) Minister of Industry Regulation No. 27 Year 2020 on Specification, Roadmap, Local Content Measurement Methods for Battery Based Electric Vehicles.

Indonesian State Electricity Company (2020), Roadmap of EV Infrastructure Development 2020–2024. https://gatrik.esdm.go.id/assets/uploads/download_index/files/ab04d-road-map-pengembangan-infrastruktur-kendaraan-listrik-pln-.pdf

Intergovernmental Panel on Climate Change (IPCC) (2006), *2006 IPCC Guidelines for National Greenhouse Gas Inventories.*

LEAP (2022), https://leap.sei.org/.

Le, A. T. (2021), Study of Electric Mobility Development in Viet Nam, Report for NDC Transport Initiative for Asia (NDC-TIA).

McD Motorcycles Data. https://www.motorcyclesdata.com/2022/02/01/malaysia-motorcycles/ (accessed 19 April 2022).

Ministry of Environment and Water, Malaysia (2021). *Low Carbon Mobility Blueprint 2021–2030: Decarbonising Land Transportation*. Kuala Lumpur: Ministry of Environment and Water.

Malaysian Automotive Association (MAA), http://www.maa.org.my/statistics.html (accessed on 18 May 2022).

Morimoto, S., K. Sanematsu, K. Ozaki, A. Ozawa, and Y. Seo (2019), 'Methodological Study of Evaluating the Traceability of Neodymium Based on the Global Substance Flow Analysis and Monte Carlo Simulation', *Resource Policy,* 63, 101448. DOI: 10.1016/j.resourpol.2019.101448

Morimoto, S., Y. Cheng, N. Mizukoshi, and K. Tahara (2020), 'Methodological Study of Evaluating Future Lightweight Vehicle Scenarios and CO2 Reduction Based on Life Cycle Assessment', *Sustainability,* 12(14), 5713. DOI:10.3390/su12145713

Oanh, N.T.K. (2015), 'Comparative Assessment of Traffic fleets in Asian Cities for Emission Inventory and Analysis of Co-benefit from Faster Vehicle Technology Intrusion', Conference Paper, 04/2015. DOI: 10.13140/RG.2.1.4691.3040

Philippine Board of Investments (PBOI) (2021), 'The Future of E-Mobility: Opportunities for Manufacturing Investments in the Value Chain (Summit Presentation)', 9th Philippine Electric Vehicle Summit, Manila, 23–24 September. https://www.evap.com.ph/summit

Philippine Department of Energy (PDOE) (2021), *Philippine Energy Plan 2020–2040.* https://www.doe.gov.ph/sites/default/files/pdf/pep/PEP_2020-2040_signed_01102022.pdf

Philippine Land Transportation Office (PLTO) (2022), *Annual Reports.* https://lto.gov.ph/transparency-seal/annual-reports.html

President of The Republic of Indonesia (2019), Presidential Regulation No. 55 Year 2019 on the Acceleration Program for Battery Based Electric Vehicles for Road Transport.

Siqin X., J. Ji, and X. Ma (2020), 'Environmental and Economic Evaluation of Remanufacturing Lithium-ion Batteries from Electric Vehicles', *Waste Management*, 102, 579–586. DOI:10.1016/j.wasman.2019.11.013.

The Prime Minister of Government (2021), Decision No. 1658/QD-TTg to Ratify the National Green Growth Strategy for the 2021–2030 Period, Vision Towards 2050.

United Nations (2015), Paris Agreement. https://unfccc.int/sites/default/files/english_paris_agreement.pdf (accessed 5 August 2016).

United States Geological Survey (USGS) (2021), *Mineral Commodity Summaries 2021.* https://doi.org/10.3133/mcs2021.

Vietnam Automobile Manufacturers' Association (VAMA) (2022), *Sales Report.* http://vama.org.vn/vn/bao-cao-ban-hang.html

Vietnam Association of Motorcycle Manufacturers (VAMM) (2022), *Sales Data.* https://vamm.vn/sales-data/.

Vietnam Register (2022), 'Information about Fuel Consumption of Passenger Cars'. http://203.162.20.156/vaq/Tieuthu_Nlieu/List_Tieuthu_nlieu.asp.

Vietnam Star (2022), 'VinFast Plans to Build 3,000 Charging Stations for Electric Vehicles in HCMC', https://vietnamstar.net/vinfast-plans-to-build-3000-charging-stations-for-electric-vehicles-in-hcmc/.

Yang, Y. et al. (2016), 'REE Recovery from End-of-Life NdFeB Permanent Magnet Scrap: A Critical Review', *Journal of Sustainable Metallurgy*, 3, pp.122–49. DOI 10.1007/s40831-016-0090-4.