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Reuse of Electric Vehicle Batteries in ASEAN

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Reuse of Electric Vehicle Batteries in ASEAN

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This report was prepared by the working group for the 'Reuse of EV Batteries in ASEAN' under the Economic Research Institute for ASEAN and East Asia (ERIA) energy project. Members of the working group discussed and agreed to utilise certain data and methodologies.

Foreword

In East Asia Summit (EAS) countries, progress has been made in recent years towards electrifying the transport sector. Electric vehicles (EVs) are considered as the important technological options for those EAS countries towards air quality improvement in urban areas, energy security enhancement for shifting away from oil dependence, and climate change mitigation – if these are coupled with low-carbon power generation sources.

In view of the future expansion of EVs on the road, policymakers of the EAS region would have to prepare for establishing systems for reusing waste batteries from EVs. Currently not enough waste batteries from EVs are available in the market but some private companies, especially vehicle manufacturing companies, are undertaking projects, some of which have made a stride into establishing a commercial business. Proper policies need to be established to assist private companies' efforts for lowering costs, at the same time to ensure safety in the use of reused batteries from EVs.

This report has provided future projections of available used EV batteries in ASEAN. Its magnitude is compared with the estimated need for stationary use for variable renewable energy sources. The report has also provided policy implications for ASEAN countries towards facilitating the reuse of batteries from EVs.

I hope the report will provide a good basis for ASEAN countries in the understanding over the magnitude of future available used batteries from EVs and the needs for policymakers in efficient and effective utilisation.

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Valuable insights were obtained from a number of government officials and analysis that were an integral part of implementing this study.

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List of Abbreviations and Acronyms

ASEAN	Association of Southeast Asian Nations
3R	reduce, reuse, recycle
BEV	battery electric vehicle
CO_2	carbon dioxide
EAS	East Asia Summit
ELV	end-of-life vehicle
EPR	extended producer responsibility
ERIA	Economic Research Institute for ASEAN and East Asia
EU	European Union
EV	electric vehicle
FCV	fuel cell vehicle
GW	gigawatt
GWh	gigawatt hour
HEV	hybrid vehicle
ICE	internal combustion engine
IEA	International Energy Agency
IEEJ	The Institute for Energy Economics, Japan
kWh	kilowatt hour
LFP	lithium-ion phosphate battery
LiB	lithium-ion battery
MW	megawatt
NEV	new energy vehicle
PLDV	passenger light-duty vehicle
PHEV	plug-in hybrid vehicle
PV	photovoltaic
R&D	research and development
SNT	Spiers New Technologies
US	United States
VRE	variable renewable energy
WEEE	Waste Electrical and Electronic Equipment

Executive Summary

The main findings from the analysis are summarised below.

Chapter 1

Amongst the Association of Southeast Asian Nations (ASEAN) countries, electric vehicles (EV) are considered an important option for tackling local air pollution and enhancing energy security – away from oil dependence and climate change mitigation. Some countries such as Indonesia and Thailand consider EVs as the important option for developing manufacturing basis. Indonesia has laid out its plan for developing a battery manufacturing industry with the use of local resources, while Thailand aims to become the regional hub for the EV manufacturing industry. Each country's current plan or target is summarised below:

- Brunei Darussalam plans to set EV at 65% of vehicle sales by the year 2035.
- Indonesia has set a target to abandon sales of internal combustion engine (ICE) vehicles by 2040. Indonesia also intends for alternative vehicles to account for 20% of total vehicle production by 2025.
- Malaysia's Ministry of Environment and Water has outlined the electrification of the transport system under the 'Low Carbon Mobility Blueprint 2021–2030'. In the Blueprint, Malaysia aims to increase the share of EV sales in passenger vehicles. The targets are 9% in 2025 and 15% in 2030.
- According to the government's Clean Energy Scenario in the Philippine Energy Plan, the adoption of EV use is expected to reach 10% by the year 2040 in the Philippines.
- The Singapore government has announced plans to phase out petrol and diesel-fuelled vehicles by 2040, and to switch to cleaner fuel vehicles, mainly EVs, and to expand public charging spots from the current 1,600 to 28,000 by 2030.
- The Thai government has announced a new EV roadmap to lead the country to a hub of EVs in ASEAN countries in 5 years. Under the roadmap, it is planned to set a target to produce 250,000 EVs and 3,000 electric public buses by 2025, and to increase EV production to 30% of total annual automotive production or about 750,000 units out of 2.5 million units in Thailand by 2030.
- Viet Nam has no policy or goal relating to the introduction of EVs.

Chapter 2

By 2040, electrified vehicles will supply used batteries of 325 gigawatt hour (GWh) in the reference scenario cumulatively, 778 GWh in the HEV bridge scenario, and 2,166 GWh in the battery electric vehicle (BEV) ambitious scenario. It needs a mechanism for dealing with such a large number of used batteries. For example, one of the methods is said to reuse them as backup battery for variable renewable energy (VRE) power generation.

According to an analysis on ASEAN power systems (focusing on the Indochinese Peninsula and the Malay Peninsula) by the Economic Research Institute for ASEAN and East Asia (ERIA) (2021), it is estimated to need backup batteries of 500–600 GWh when VRE accounts for 40% of the generation mix in 2040. In scenarios where vehicle electrification progress, even if all used batteries can be reused in the power generation sector, a large number of batteries will be left over. Along with promoting vehicle electrification, it will be necessary to consider a wide range of options for reusing and/or recycling batteries.

Chapter 3

Approaches to the reuse of waste EV batteries differ by analysed country and region.

The European Union (EU) tries to ensure transparency in terms of the environmental performance of batteries sold in the market – which will take a step-by-step approach to be achieved up to July 2027. For example, EVs shall have a unique 'battery passport' linked to the information about the characteristics of each battery type and model providing valuable data to recyclers and second-life companies. Batteries will have to comply with maximum carbon thresholds.

In addition, the EU tries to enforce the compliance on the recycled content of batteries. By January 2030, the recycled content thresholds are: 12% cobalt, 85% lead, 4% lithium, and 4% nickel. By 2035, this threshold is required to be increased to 20% cobalt, 85% lead, 10% lithium, and 12% nickel.

In Japan, unique efforts are implemented by respective automobile manufacturers to establish a traceability and/or monitoring system of the health of EV batteries. In addition, the industry group, the Japan Automobile Manufacturers Association, Inc. has also launched a joint collection network. Preparations are under way to increase the amount of reuse of EV batteries in the future. In addition, the Council for Electrified Vehicle Society and the Ministry of Economy, Trade and Industry, composed of electric power companies and automobile manufacturers, formulated 'Providing Information Guideline of In-vehicle Battery Performance' in June 2020, thereby clarifying specific measurement methods.

The Chinese government enacted interim measures for reuse and recycling of new energy vehicle batteries, including (i) the establishment of an extended producer responsibility system, (ii) the establishment of a traceability information system, (iii) the promotion of innovation in market mechanisms and recycling models, and (iv) the establishment of maximising benefits of comprehensive utilisation of resources – reuse as the primary option followed by recycling.

Interim regulations on traceability management were published in accordance with the interim measures. Firstly, the government will build a 'traceability management platform' under which information on all processes of battery production, sales, use, disposal, recycling, reuse, and others will be collected, and the status of implementation of recycling will be monitored. Furthermore, producers of new energy vehicles are also responsible for managing traceability.

The United States (US) has not established regulations at the Federal level, while reuse and recycling regulations for EV lithium-ion batteries operate at the state level. In California, lithium-ion batteries are regarded as hazardous waste due to health and safety concerns, including flammability. In 2019, the Lithium-ion Car Battery Recycling Advisory Group was setup to form policies for the recovery and recycling of automotive lithium-ion batteries from the viewpoint of the importance of circular economy. In Assembly Bill No. 2832, the advisory group is required to submit policy recommendations to the legislature by 1 April 2022 with the purpose of reusing or recycling as close to 100% of the state's lithium-ion batteries as is possible.

Chapter 4

Understanding the health of EV batteries is the key for establishing a value chain of waste batteries. The business practice by 4R Energy shows the interesting illustration that the health of batteries would be monitored from the time of operation in EVs. The company's evaluation and/or classification depending on the quality would provide multiple reuse options from high-quality, middle quality, and relatively low-quality options of which utilisation frequency is only for emergency backup purpose.

The reuse of EV batteries would remain an economically viable option in future despite the observed substantial reduction of EV batteries pack price. From 2016 to 2020, the EV batteries average pack price has been lowered from $273 per kilowatt hour (kWh) in 2016 to $137/kWh in 2020. The IEEJ analysis shows that the new EV batteries' pack price is projected to reach $51/kWh with the assumption of 20% learning rate. Meanwhile, a study by Elementenergy shows that the sales price of reused EV batteries is likely to remain lower in future compared with that of new ones. The estimated sales price of reused EV batteries is likely to be somewhere around $35/kWh.

Caution needs to be paid in the assessment of the future sales price of EV batteries. The sales price should depend on the quality. Currently, 4R Energy's sales price – available from media information – of reused EV batteries at $115/kWh is 16% lower than the global average price of new batteries at $137/kWh, as the former includes applications requiring high performance for reuse in EVs. It has to be also considered that the availability of waste batteries is small currently, but it is expected to increase from 2030 to reflect the higher uptake of EVs.

The environmental benefits of EV batteries reuse would be important from policymaking purposes. A study that compares the environmental benefits of reused EV batteries generate positive performance for (i) energy savings, (ii) mineral resources savings, (iii) greenhouse gas emissions reduction, and (iv) health impacts. Nevertheless, careful planning should be required because reuse of EV batteries does not necessarily generate positive benefits if it is compared with the replacement for grid-connected electricity supply.

It is also important to put the reuse of EV batteries in broader context to genuinely understand the EV's benefits on environment. For example, in terms of the magnitude of CO_2 emissions reduction, the largest contributions in future – under the decarbonised generation mix – would come from operational stage, followed by light-weighting/sharing, which would be followed by the contributions from reuse and/or recycling benefits. Again, policy coordination is essential to plan for obtaining maximum environment benefits from EVs, from generation mix planning, designing, operation, and reuse and/or recycling.

Chapter 5

Approaches to the reuse and recycling of appliances differ by analysed country and region.

The EU has required manufacturers to handle the waste appliances, of which coverage is wide to include (i) temperature exchange equipment; (ii) screens, monitors, and equipment of which screen surface is greater than 100 cm^2; (iii), lamps; (iv) large equipment; (v) small equipment; and (vi) small IT and telecommunications equipment.

Despite its targets for a recycling rate at above 70%, its real implementation in many member governments does not meet the target.

According to the survey results, consumers in the EU would rather repair their devices than replace them; 79% think that manufactures should be legally obliged to facilitate the repair of digital devices or the replacement of their individual parts.

To improve the recycling rate and cope with consumers' preference on 'right to repair', the EU is trying to broaden the scope of the Ecodesign Directive to include non-energy-related products. In other words, in the notion that the products durability should be determined at design phase, the Ecodesign Directive requires manufacturers to design energy consuming products to reduce energy consumption at its life cycle basis. New rules on the Ecodesign Directive are expected to be in place in 2021.

In Japan, for household appliances discarded from households, manufacturers, and others (manufacturers and importers) are required to recycle four items of household appliances under the Home Appliance Recycling Law and the Small Home Appliance Recycling Law. Business operators are required to implement the reduce, reuse, recycle (3R) initiatives for 10 industries and 69 items under the Law for the Promotion of Effective Utilization of Resources.

Japan's recycling rate for air conditioners, cathode-ray tube TVs, flat-panel TVs, refrigerators, and washing machines has improved, and the latest data show that all of them have met the respective target rate of 80%, 55%, 74%, 70%, and 82%. The essence of the relative successful implementation of meeting the target is that the system is coordinated to involve manufacturers, retailers, and designated recycling entities. Consumers bear the cost of recycling, and they can hand over waste appliances to retailers that will send the waste to a designated recycling facility, of which establishment and operation is handled by manufacturing companies.

In the United States, there is no federal law equivalent to the EU Waste Electrical and Electronic Equipment (WEEE) Directive. Twenty-five states including California and others, plus Washington, DC, have enacted and enforced their own recycling laws covering waste electronic equipment such as televisions and computers that are discarded from homes. The first Waste Electronics Recycling Act in the United States was enacted in California in 2003. Recyclable devices vary from state to state, but the big five, namely TVs, desktops, laptops, monitors, and printers are targeted in many states.

For the target entities, households and consumers are targeted in all states, but the coverage of companies and public facilities is different. Regarding programme funds, a method of some form of extended producer responsibility (EPR) has been adopted in states other than California, and manufacturers are collecting and recycling targeted devices that come from general households, small businesses, and the like, free of charge, at their own expense. Conversely, California operates the programme at a rate paid by consumers when they purchase targeted devices.

In China, regarding the recycling of waste electronic equipment, under the Chinese version of WEEE promulgated in 2009, the responsibilities of producers, importers, and the like are defined for 14 items of electrical and electronic equipment, such as adopting effective designs for the comprehensive use of resources and treatment to eliminate hazards from the design stage, and for being responsible for the disclosure of information on toxic and hazardous substances. Also, this establishes funds to assist in the costs necessary for disposal and the collection of such costs from manufacturers, importers, and the like under the concept of EPR. Still further, a qualification permit system has been created for waste electronic equipment processing companies. This defines restrictions on the use of hazardous substances (lead, mercury, cadmium, and other substances) in electrical and electronic equipment in the new Chinese version of the Reduction of Hazardous Substances directive promulgated and enforced in 2016.

In China, waste electrical and electronic products are highly valued as resources, and regular recyclers are buying them from consumers. However, because non-regular vendors that do not bear the cost of preventing environmental pollution and damage to public health buy high-value waste electrical and electronic products at high prices, it is assumed that an overwhelming proportion of waste electrical and electronic products are still collected and processed through non-regular routes.

Chapter 6

It is necessary to consider a wide range of options for reusing and/or recycling batteries. Depending on the quality of the used batteries, they could be utilised as replacement EV batteries or for large-scale grid storage. Other options could include residential storage, backup in factories, and street lighting batteries.

To realise the reuse of EV batteries, the following practices need to be encouraged.

- **Health and safety**: Monitoring mechanisms should be in place to understand the health and safety of EV batteries at the time of operation. This would allow the timing of replacement, and conditions for repurposing as well.
- **Technology**: Research and Development (R&D) should be made to evaluate the performance of waste batteries. The evaluation of used EV batteries is a time-consuming process, as the performance by cell, pack, and module as a whole have to be checked. R&D should be encouraged to develop a system as well as know-how that can shorten the required time for evaluation.
- **Regulatory**: Regulatory requirements for manufacturers and owners should be clearly formulated. It would strengthen the construction of a power battery traceability management platform for new energy vehicles and achieve traceability of the entire life cycle of the power battery.
- **Economic**: R&D should be encouraged to lower the cost of repurposing waste EV batteries. Large-scale implementation such as grid storage using repurposed batteries, and also identification of some small-scale projects – such as battery systems at distributed energy systems or other purposes such as street lighting would need to be implemented simultaneously.
- **Collection System**: It is important to establish a system that needs to be coordinated to involve manufacturers, retailers, and designated recycling entities. Aside from the establishment of traceability, it is important to establish a system that consumers and owners can access to be involved in the value chain of EV battery reuse. Dealers should be able to play the important role for maintenance as well as communication with consumers and owners in this regard.

Introduction

In East Asia Summit (EAS) countries, progress has been made in recent years towards electrifying the transport sector. Electric vehicles (EVs) are considered as important technological options for those EAS countries towards air quality improvement in urban areas, energy security enhancement for shifting away from oil dependence, and climate change mitigation – if these are coupled with low-carbon power generation sources.

Some countries consider EV and battery manufacturing as opportunities for industrial development. Amongst EAS countries, some manufacturers have started investment in or planning for domestic battery, and/or EV production in addition to the formulation of regulations surrounding the EV supply chain. Planning for infrastructure investment (mainly charging stations) has been under consideration by some EAS countries.

Amongst the Association of Southeast Asian Nations (ASEAN) countries, Indonesia, Malaysia, and Thailand have formulated EV production plans, and their plans include battery production as well. For example, Indonesia aims for establishing an integrated production system from the extraction of cobalt (required for cathode) to battery production, while vehicle manufacturers in Thailand have formulated plans to assemble batteries produced in other countries.

Despite the progress on the formulation of plans to manufacture EVs or batteries with the ASEAN countries, no ASEAN member countries have yet to formulate plans or regulations on batteries recycling.

1. Study Method

The study will conduct both quantitative and qualitative analysis as follows.

First, the study will estimate EV demand in ASEAN by 2040. With the assumptions on EV travel distance and lifetime, the study will estimate the supply of used batteries by 2040. Building on this estimate, the study will estimate the capacity of stationary batteries required or variable renewable energy (VRE) by 2040.

Second, the study will conduct research on battery reuse in Europe, the United States (US), Japan, and China in an attempt to gain insights for the formulation of regulations.

Third, the study will gain insights from those countries in Europe, the United States (US), Japan, and China on their respective implementation of regulations for the recycling of appliances with the analysis on (i) how those regulations are implemented, (ii) who bears the costs of recycling, and (iii) how those regulations contributed to appliances recycling.

Fourth, the study will formulate policy recommendations for ASEAN countries to establish regulation on batteries reuse, and to harmonise the regulations amongst member countries.

2. Report Structure

This report is structured to analyse the potential and economic benefits and/or costs of a shift towards EVs in ASEAN as follows.

The introduction presents the study background and objectives as well as the methodologies for this study.

Chapter 1 presents the EV policies in ASEAN countries, including policies, targets, the current status of EV introduction, reuse, and variable renewable energy deployment plans.

Chapter 2 presents the outlook of EV introduction in the ASEAN market, and the availability of reusable capacity in 2040. The analysis compares the result of reusable EV batteries in 2040 with the demand for stationary battery capacity required for flexibility adjustment in ASEAN by 2040.

Chapter 3 presents the policies and plan of reuse of EV batteries in the European Union, Japan, China, and the US, and tries to gain insights for ASEAN countries.

Chapter 4 presents the future trajectory of the cost of reused batteries, in comparison with new ones. The chapter also provides an analysis of environmental implications from the reuse of EV batteries. To gain insights, the chapter also offers a case study of business practices in EV batteries reuse.

Chapter 5 presents the policies implementation on the appliances recycling in the European Union, Japan, China, and the US, and tries to gain insights for the creation of an EV reuse value chain.

Finally, policy implications are drawn from the above analysis.

Chapter 1

Electric Vehicle Policies in ASEAN Countries

This chapter provides an overview of electric vehicle (EV) policies in selected Association of Southeast Asian Nations (ASEAN) countries. The chapter investigates the EV policies and targets, the current status of EV introduction, EV reuse plans, and battery reuse policies.

1. Country Policies

1.1. Brunei Darussalam

- **EV Policy and Target**

The Government of Brunei Darussalam believes that EVs are a powerful means of transportation, as they focus on short-range transportation that can be recharged relatively inexpensively with electricity. Furthermore, according to the Brunei Darussalam National Climate Change Policy, it plans to set EVs at 65% of vehicle sales by the year 2035. To achieve that goal, the government will make policy decisions by controlling EV prices and expanding charging stations, including through excise tax incentives and the like, as well as paying attention to electricity and vehicle license fees. Still further, the Electric Vehicle Joint Task Force, composed of relevant stakeholders, was established in 2019. It is expected to ensure the implementation of EV promotion policies. In addition, pilot projects such as the development of charging stations are currently being implemented through government initiatives.

- **Current Status of EV introduction**

There is no statistically reliable information on the number of EVs introduced into Brunei.

- **EV Battery Production Plan, EV Criteria**

The Government of Brunei Darussalam has not enacted a manufacturing plan for EV batteries and EV standards.

- **EV Manufacturers**

No EV manufacturer has been identified in Brunei.

- **Battery Reuse Plan**

The Government of Brunei Darussalam has not enacted an EV battery reuse plan.

- **Variable Renewable Energy (VRE) Introduction Plan**

According to the National Climate Change Policy, renewable energy will account for more than 30% of the capacity of power generation facilities by 2035, especially through the expansion of solar power. Currently, 1.2 megawatt (MW) solar power plants are operating in Seria, Belait District domestically, accounting for 0.14% of the country’s total power generation.

1.2. Indonesia

- **EV Policy and Target**

To reduce the expected potential increase in oil imports and to nurture the domestic automobile manufacturing industry, Indonesia has set a target to abandon sales of internal combustion engine (ICE) vehicles by 2040. Indonesia also intends for alternative vehicles to account for 20% of total vehicle production by 2025.

As Table 1.1 shows, Indonesia is electrifying transport for both four-wheelers and two-wheelers. In view of the continued Indonesia's reliance on two-wheelers, the country aims to expand the stock of electric bikes from 83,000 in 2020 to 40 million in 2040. The stock of electric cars is planned to expand from 545 in 2020 to 13 million in 2040.

Table 1.1. Indonesia's EV Stock Target

	2020	2030	2040
Electric Cars (four-wheelers)	545	4 million	13 million
Electric Bikes (two-wheelers)	83,000	16 million	40 million

EV = electric vehicle.
Source: Ministry of Industry and Draft of National Energy Grand Strategy.

The Indonesian government announced new local tax rates in March 2021 as shown in Table 1.2.

Table 1.2. Indonesia's Luxury Tax on EVs, Plug-in Hybrids, and Hybrids

	Previous	After March 2021
Battery EVs	0%	0%
Plug-in Hybrid Vehicles	0%	5%
Hybrid Vehicles	2%–12%	6%–12%

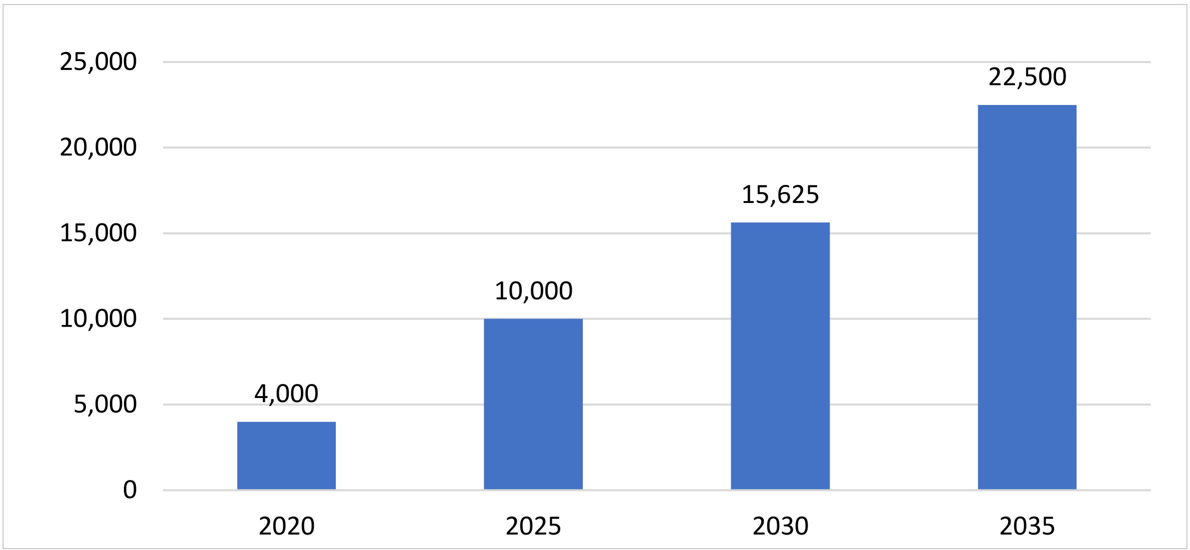
EV = electric vehicle.
Source: Just Auto (2021). Indonesia Offers Tax Incentives to Help Lift EV Sales.
https://www.just-auto.com/news/indonesia-offers-tax-incentives-to-help-lift-ev-sales_id200803.aspx

Indonesia has formulated Presidential Regulation, No. 55 Year 2019 Regarding Acceleration of Battery-Based Electric Vehicle Program for Road Transportation. Aside from promoting EVs for energy security enhancement and environmental purposes, Indonesia's EV policy is to focus on domestic manufacturing. Taking advantage of the essential metals availability domestically, Indonesia aims to become the hub of EVs manufacturing.

For the purpose of providing incentives to increase the sales of domestically produced battery EVs, Indonesia plans to increase the luxury tax on plug-in hybrid and hybrids respectively to 8% and 10%–14% according to the draft regulation of the Ministry of Finance.

Besides, the country has formulated the Ministerial of EMR Regulation No. 13 Year 2020 Regarding Provision of Charging Infrastructure for Battery-based Electric Vehicles. It aims to increase the number of charging stations from 180 in 2020 to 7,146 in 2030. As the country continues to rely on two-wheelers, it aims to expand the number of swap battery stations that can replace drained batteries within a few minutes. This is a convenient method as battery charging takes a few hours at normal charging systems.

Figure 1.1. Roadmap of the Number of Swap Battery Stations in Indonesia



Source: Anditya C. (2020), 'Policy, Plan, and Strategy of EV/EV Reuse in Indonesia', Presented at ERIA Working Group Meeting on Reuse/Recycling of EV Batteries in ASEAN, 10 December.

- **Current Status of EV Introduction**

Indonesia's hybrid electric vehicle/plug-in hybrid electric vehicle HEV/PHEV sales in 2019 was 837, and battery electric vehicles (BEVs) accounted for 20 units in the same year. This represents 0.2% of total sales of vehicles.

Faced with the pandemic, Indonesia's vehicle sales in 2020 nearly halved from the 2019 level to reach 532,027. The number of EV sales is not published at the time of writing, while it is evident that EV sales were affected by the economic downturn.

Table 1.3. Number of HEV/PHEV and BEV Registrations from 2018 to 2020 in Indonesia

Year	HEV/PHEV	BEV	Total of EV	Total Passenger Vehicle Sales
2018				1,151,306
2019	837	20	857	1,030,000
2020				532,027

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

- **EV Battery Production Plan**

On 12 August 2019, Indonesia promulgated Presidential Regulation No. 55 of 2019 on the Acceleration of Battery Electric Vehicle Program for Road Transportation (PR 55/2019).

With the issuance of PR 55/2019, the government plans to become the manufacturing hub of EVs, taking advantage of the domestically available rare metal resources. The government is trying to increase the local content of EV manufacturing and nurture the domestic industry.

- **EV Criteria**

Based on PR 55/2019, an EV is defined as a vehicle moved by an electric motor using electricity power from a battery directly in the vehicle or from outside the vehicle.

PR 55/2019 divides EVs into two main categories:

- two-wheeled and/or three-wheeled EVs, and
- four-wheeled and/or more EVs

The presidential regulation further provides that the Minister of Industry may provide further provision on the specifications of EVs.

- **EV Manufacturers**

There are two types of EV manufacturers acknowledged under PR 55/2019:

- EV manufacturing company (EV industry), and
- EV components manufacturing company (EV components industry).

The domestic EV producers are required to build a domestic manufacturing facility by itself or by cooperating with another manufacturing company. In the event the EV components manufacturing companies are not yet able to produce the main and/or the supporting components of EVs, the EV producers may import the EV components in a completely knocked-down or incompletely knocked-down state.

As Table 1.4 and Table 1.5 shows, the Indonesian government plans to gradually increase local content requirement by considering the ability of the domestic production.

For two and/or three-wheeled EVs:

Table 1.4. Two- and Three-wheeled EVs in Indonesia

Year	Local Content
2019–2023	Minimum 40%
2024–2025	Minimum 60%
2026 and further	Minimum 80%

Source: Government of Indonesia (2019). Presidential Regulation No. 55/2019 on Acceleration of Battery Based Electric Vehicles for Road Transportation.

Table 1.5. Four-wheeled and Other EVs in Indonesia

Year	Local Content
2019–2021	Minimum 35%
2022–2023	Minimum 40%
2024–2029	Minimum 60%
2030 and further	Minimum 80%

Source: Government of Indonesia (2019), Presidential Regulation No. 55/2019 on Acceleration of Battery Based Electric Vehicles for Road Transportation.

- **Battery Reuse Plan**

Article 32 of PR 55/2019 stipulates the Indonesia's general framework of EV batteries reuse and recycling as follows.

- Handling of battery waste from battery-based electric vehicles (BEV) must be carried out by recycling and/or waste management.
- Handling of battery waste is carried out by institutions, the BEV industry, and/or the domestic BEV component industry that has a battery waste management license from a BEV that own licenses in accordance with regulations in the field of waste management.

Despite this general framework promulgated by PR55/2019, other regulations still consider used batteries as hazardous waste.

For example, Government Regulation No.101 Year 2014 regarding Hazardous Waste Management listed all kinds of waste batteries as hazardous waste, and Law No. 32 Year 2009 regarding Environmental Management prohibits the importation of hazardous waste.

Coordination is required before the domestic EV manufacturing starts at full-scale.

In view of the future expansion of used batteries, companies such as PT Indonesia Puqin Recycling Technology plan to invest in a lithium-ion battery waste treatment plant of annual processing capacity of 20,000 tons.

- **VRE Introduction Plan**

The General Plan for National Electricity (called RUKN) is prepared as the national plan for the electricity sector in Indonesia. The latest RUKN is prepared for the time period between 2019 and 2038.

The basic idea of the RUKN is to:

- meet the realistic demand growth, address the lack of electricity supply areas, increase reserve capacity, and to fulfil reserve margin;
- reduce oil share from energy mix;
- use more new and renewable energy sources, and

- utilise clean power generation technology (e.g. super critical, and carbon coal storage technology).

In the RUKN, the government plans to increase the generation share of new and renewable sources from 12.36% in 2019 to 23% in 2025. The progress of increasing renewables (such as hydro, solar, wind, biomass, and other bioenergy) is slower compared with the initial target at 17.5% in 2019.

For the short term, the government has introduced renewable energy goals during the time period between 2020 and 2024. In total, Indonesia aims to increase the renewable capacity to reach 9,051 MW in 2024. This is in line with the RUKN's plan for meeting the 23% share of renewables by 2025.

Of the renewable energy sources, the Indonesian government is promoting solar to invest $12.5 million for the development of 800 points – on top of government buildings and public facilities – throughout the country in 17 provinces. This is expected to expand the capacity up to 1.785 MW. With the additional budget, the Ministry of Energy and Mineral resources expects that solar capacity would expand to 6 MW (German-Indonesian Chamber of Industry and Commerce, 2020).

1.3. Malaysia

- **EV Policy and Target**

Malaysia's Ministry of Environment and Water has outlined the electrification of the transport system under the 'Low Carbon Mobility Blueprint 2021-2030'. The blueprint entails Malaysia's overall strategies related to the transport sector, including fuel economy improvement, EV and low emissions vehicle adoption, greenhouse gas emissions reduction, and modal shifts towards an energy efficient system.

In the blueprint, Malaysia aims to increase the share of EV sales in passenger vehicles. The targets are 9% in 2025 and 15% in 2030 (Table 1.6).

Table 1.6. Target Sales Share of EVs in Malaysia

Year	2025	2030
Passenger vehicles	9%	15%
Motorcycles	8%	15%
Buses	2,500 units	10,000 units

Source: Ministry of Environment and Water (2020).

To facilitate the sales increases, Malaysia plans to expand the number of charging systems to install 7,700 units (AC: 7,000 units, and DC: 700 units) in 2025.

The public sector will lead the EV deployment as part of public procurement. In the time period between 2021–2022, the share of EVs in the public procurement is targeted to account for 10%, and it is targeted to increase to 20% (2023–2025), and 50% (2026–2030). From 2025 to 2030, Malaysia's EV public procurement will be limited to domestic production only.

The blueprint includes the plan for economic incentives for BEVs and PHEVs summarised in Table 1.7.

Table 1.7. Economic Incentives for the Purchase of EVs in Malaysia

	2021–2022	2023–2025	2026–2030
BEV	100% import and excise duty exemption for complete built units (CBUs) – for the sales of maximum 10,000 units.	50% exemption	
PHEV	100% import and excise duty exemption for CBUs – for the sale of maximum 90,000 units.	75% exemption	50% exemption

BEV = battery electric vehicle, EV = electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Ministry of Environment and Water (2020).

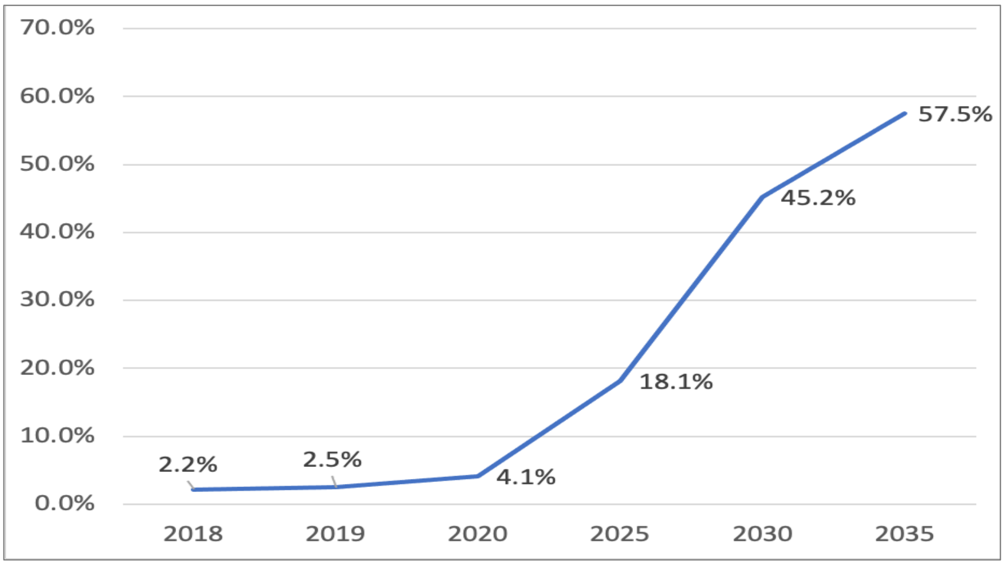
On the charging infrastructure, the Malaysian government has set a target of 7,000 AC charging points and 500 DC charging points to be installed nationwide.

In 2020, the National Automotive Policy 2020 (NAP 2020) was officially launched. The policy aims to develop Malaysia as a leader in the automotive manufacturing industry. NAP 2020 focuses on next-generation vehicles, industrial evolution (IR 4.0), and mobility-as-a-service (Christopher & Ong, 2020).

- **Current Status of EV Introduction**

The share of EVs in passenger vehicle stocks accounts for 4.1% in 2020. It is expected that the stock share will account for 57.5% in 2035.

Figure 1.2. Passenger Vehicles EV Stock Share in Malaysia



EV = electric vehicle.
Source: Ministry of Environment and Water (2020).

- **EV and Battery Production Plan**

The blueprint includes an action plan for EV production as summarised in Table 1.8.

Table 1.8. Action Plan of EV Increases Specified in 'Low Carbon Mobility Blueprint 2021–2030' in Malaysia

	Passenger vehicles	Buses	Motorcycles
Action Plan	• EV public procurement • Promotion of EV taxis • Provision of economic incentives • Development of charging infrastructure • Provision of economic incentives for R&D in EV research and support for domestic production • Comprehensive EV ecosystem development (business environment)	• Establishment of government body for EV procurement • Support for domestic production	• EV public procurement • Promotion of e-motorcycles for delivery business • Standardisation of swap battery for e-motorcycles • Support for domestic production

EV = electric vehicle, R&D = research and development.
Source: Ministry of Environment and Water (2020).

- **Battery Reuse Plan**

The policy for reuse of EV batteries is under formulation.

- **VRE Introduction Plan**

Currently, Malaysia's renewable share in electricity generation accounts for 2%, while the government plans to expand the share to 20% in 2025. Photovoltaic (PV) systems are expected to play an important role in meeting the target. Net metering is implemented in Malaysia, with rooftop PV systems playing an important role. Also, for facilitating large-scale PV introduction, Malaysia has implemented a large-scale solar bidding system of which first bidding took place in 2016, followed by those implemented in 2017 and 2019.

1.4. Philippines

- **EV Policy and Target**

According to the government's Clean Energy Scenario in the Philippine Energy Plan, the adoption of EVs is expected to reach 10% by 2040. To achieve this goal, the government has introduced income tax exemptions for pioneering companies such as EVs, alternative fuel vehicles, charging stations, and the like from 6 years to up to 8 years, as well as exemptions for imports of equipment, spare parts, and consumables, under Executive Order No. 226. Furthermore, Executive Order No. 488 exempts from duty the import tariff rates of components, parts, and accessories required for the assembly of hybrid vehicles, EVs, flexible fuel vehicles, and compressed natural gas vehicles. Still further, EVs' automotive tax exemption, the introduction of a 50% exemption for hybrid vehicles, and the expansion of charging stands will also be addressed.

- **Current Status of EV Introduction**

As of 2019, the total number of e-trikes, e-quads, e-jeeps, and other EVs (e-motorcycles, e-trucks, and e-buses) available in the Philippines was 5002 units. This brings the total number of EVs available to 8,682 units for the years 2020–2021. See Table 1.9 for details.

Table 1.9. Number of Electric Vehicles Registered (2019) and Market Projection (2020–2021) in the Philippines

	No. of Units per Year			Total
	2019	2020	2021	
E-Trikes*	4,318	1,597	1,758	7,673
E-Quads**	71	50	55	176
E-Jeeps	89	70	80	239
Other EVs (e-Motorcycles, e-Truck, and e-Bus)	524	30	37	594
Total	5,002	1,750	1,930	8,682

*Three-wheeled vehicle assisted by motor, **Four-wheeled vehicle assisted by motor,
Source: Philippine Energy Plan.

- **EV Battery Production Plan**

The Philippine government has not enacted a manufacturing plan for EV batteries.

- **EV Criteria**

The Bureau of Philippine Standards of the Department of Trade and Industry has formulated the following as standards related to EVs.

- EV safety specifications
- Fuel cells and road vehicles
- Hybrid vehicles
- Charging systems
- Lithium-ion battery packs, plugs, socket outlets, vehicle connectors, vehicle inlets
- Vehicle grid communication interface

As of 2019, 45 standards have been established.

- **EV Manufacturers**

The Philippine government has attracted 14 EV-related businesses under the Department of Energy's Introduction of Energy Efficient Electric Vehicles (e-trike) Project, with an investment of PhP562 million ($11.3 million) and has created approximately 1,050 direct jobs between 2013 and 2019 (Table 1.10).

Table 1.10. Electric Vehicle Companies in the Philippines

Company Name	Employment
BEMAC Electric Transportation Phils, Inc.	206
Emotors, Inc.	25
Gerweiss Motor, Inc.	43
KEA Industrial Corporation	24
Pangea Phils., Inc.	175
Phil-Etro EV, Inc.	97
PhUV, Inc.	97
PinoyAko Corp.	34
Prozza Hirose Manufacturing Inc.	42
Ropali-Teco Corporation	115
Terramotors Philippines Corp.	27
Tojo Motors Corp.	41
Le’Guider International E-Trike Electronics Assembly Philippines, Inc.	124
Total Jobs Generated	1,050

Source: Philippine Energy Plan.

- **Battery Reuse Plan**

The Philippine government has not enacted an EV battery reuse plan.

- **VRE Introduction Plan**

According to the Philippine government's National Renewable Energy Program, renewable energy generation capacity is expected to reach a total of 25.27 gigawatts (GW) with an additional 15 GW planned by 2030.

1.5. Singapore

- **EV Policy and Target**

In February 2020, the Singapore government announced plans to phase out internal combustion engines (ICE) vehicles by 2040, to switch to cleaner fuel vehicles, mainly EVs, and to expand public charging spots from the current 1,600 to 28,000 by 2030. In order to tackle these challenges, there are several incentives and measures.

Firstly, the Vehicular Emissions Scheme metes out tax rebates and surcharges based on a vehicle's emissions levels. The scheme takes into account the emissions of five pollutants of carbon dioxide (CO_2), hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM) and consists of five bands – A1, A2, B, C1, and C2. Depending on how many pollutant(s) the vehicle emits, the worst performing one will determine which band the vehicle falls under. For instance, bands A1 and B2 are the ones that give the rebate, bands C1 and C2 are the ones that impose the surcharge. Secondly, an early adoption incentive scheme, which offers a 45% rebate on the vehicle's Additional Registration Fee, capped at SGD20,000 per vehicle. Thirdly, the road tax for EVs is less punitive.

In February 2021, the government announced the Green Plan 2030, and showed more ambitious plans to require all newly-registered cars to be cleaner-energy models from 2030, and set aside SGD30 million over the next 5 years for related initiatives. In addition, affordability of EVs by narrowing the cost differential between EVs and ICE vehicles will be increased.

- **Current Status of EV Introduction**

According to the statistics from the Land Transport Agency, as of the end of 2020, the cumulative number of EVs was 1,217 units or 0.2% of all passenger cars in the country. The lowest-priced EV available in Singapore is priced at SGD110,000 to SGD120,000 including the certificate of entitlement, and the purchase cost is one of the key factors of consideration for EV adoption. Additionally, EVs' reliance on charging stations limits long-distance driving today. For instance, vehicle owners who frequently drive to Malaysia could find it difficult to find electrical charging points to charge their car in Malaysia, compared to the widely available petrol stations.

- **EV and Battery Production Plan**

It was recently reported that Hyundai Motors will invest SGD400 million to build an innovation centre in western Singapore. The company aims to manufacture 30,000 units of EVs a year by 2025. Ford Motors closed its plants decades ago, effectively ending car production in Singapore, and

Dyson, a major vacuum cleaner manufacturer, abandoned plans to produce EVs in Singapore as it was considered to be unprofitable.

- **Battery Reuse Plan**

Although it is still in the early stage on the battery reuse, some companies are starting to work on business development. It is reported that the Singapore utilities firm, SP Group and Hyundai Motor Group will jointly develop a new business model for the leasing of EV batteries. The new model, named battery-as-a-service, is said to be the first in Southeast Asia, and will enable EV users to rent the car battery instead of owning it. In addition, the global e-waste recycler, TES announced that it is working with partners to develop energy storage systems that will use retired EV batteries to store electricity for various commercial and residential energy needs.

- **VRE Introduction Plan**

Singapore is working to improve energy security by 'decentralising energy sources' and 'improving energy efficiency' through the introduction of natural gas. Renewable energy sources such as hydro power, geothermal, and wind power are not available due to low potentiality since Singapore has little land and high population density. In solar power, as Singapore itself has limited land space, there are restrictions on its spread.

Singapore's Economic Development Authority and Public Utility Board jointly conducted the demonstration test of large-scale floating solar power generation systems, which was the largest scale in the world.

1.6. Thailand

- **EV Policy and Target**

In March 2020, the Thai government announced a new EV roadmap to lead the country to become a hub of EVs in ASEAN countries in 5 years. Under the roadmap, it is planned to set a target to produce 250,000 EVs and 3,000 electric public buses by 2025, and to increase EV production to 30% of total annual automotive production or about 750,000 units out of 2.5 million units in Thailand by 2030.

Furthermore, the government aims to increase the adoption of EVs including hybrids (HEV) and plug-in hybrids (PHEV), and started promoting the alternative-powertrain vehicle industry in 2017 by launching incentives for automakers and parts suppliers. Table 1.11 summarises the key incentives. During 2018–2019, the Board of Investment approved 26 investment projects with a total worth of $2.584 billion. The approved projects tend to be HEVs (Nissan, Honda, and Toyota) and PHEVs (BMW and Mercedes-Benz). Only three companies (FOMM, EA Mobility, and Takano Auto) invested in BEVs. As of December 2020, the Board of Investment announced additional approved applications, such as Mitsubishi Motor and SAIC Motor-CP Co., Ltd, etc. Tesla EVs are not officially sold in Thailand; however, consumers can buy Tesla EVs from local auto dealers who normally import them from Hong Kong and the United Kingdom.

The Thai government also created technology-push policies to encourage the investment in the EV charging station business in the country such as subsidies for charging stations, setting a temporary selling price for electricity, and building an EV charging consortium. Since 2015, the number of charging stations in Thailand has gradually increased to 647 as of November 2020.

According to IHS Markit, the demand for EVs in Thailand is to grow in the coming years, as the government has announced plans to offer tax waivers, discounts, and partial subsidies for EV buyers under the new roadmap. It is estimated that annual production of EVs in Thailand will increase up to 570,500 units in 2025 and 934,200 units in 2030 respectively.

Table 1.11. Key Incentives for EVs and EV Stations of the Board of Investment in Thailand

Type of Business	Incentives
Manufacture of battery electric vehicles (BEV), hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV)	- 8-year corporate income tax exemption, accounting for 100% of investment (excluding cost of land and working capital) - Exemption of import duty on machinery - Exemption of import duty on raw or essential materials used in manufacturing export products for 1 year, which can be extended as deemed appropriate by the Board
Manufacture of parts for BEVs, HEVs, PHEVs	- Exemption of import duty on machinery - Exemption of import duty on raw or essential materials used in manufacturing export products for one year which can be extended as deemed appropriate by the Board
EV charging stations	- 5-year corporate income tax exemption, accounting for 100% of investment (excluding cost of land and working capital) unless specified in the list of activities eligible for investment promotion that the activity shall be granted corporate income tax exemption without being subject to a corporate income tax exemption cap - Exemption of import duty on machinery - Exemption of import duty on raw or essential materials used in manufacturing export products for one year which can be extended as deemed appropriate by the board

EV = electric vehicle.
Source: Thailand Board of Investment.

- **Current Status of EV Introduction**

After the launch of the EV policies, the number of EV registrations has steadily increased. Table 1.12 shows the number of HEV/PHEV and BEV registrations in Thailand. Between 2018 and 2020, the number of HEV/PHEV registrations has increased steadily (20,334 units in 2018 and 30,676 units in 2019, and 32,264 units in 2020). Similarly, the number of registered BEVs has greatly increased from 325 units in 2018 to 2,999 units in 2020. Meanwhile, it also shows that the number of HEVs and PHEVs outnumber that of BEVs, and the share of EVs in total automotive market has remained sluggish.

Table 1.12. Number of HEV/PHEV and BEV Registrations from 2017 to 2020 in Thailand

Year	HEV/PHEV	BEV	Total EV	ICEV*
2018	20,344	325	20,699	2,994,326
2019	30,676	1,572	32,248	2,931291
2020	32,264	2,999	35,263	2,638,466

BEV = battery electric vehicle, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid vehicle.
Note: * The number of motorcycles is also included.
Source: Thailand Automotive Institute.

- **EV Battery Production Plan**

According to Kasikorn Research Center (K-Research), EVs market share in the next 5 years will increase to one-quarter, or 240,000 units, of the total car sales nationwide. When EV production is approaching its full capacity in 2023, it is expected that at least 260,000 units of EV batteries will be rolled out to serve the demands in Thailand. Moreover, the prospects are bright for export-oriented EV batteries as many automotive companies have planned to produce EVs in Thailand at a large scale for export. Thailand can be a new production base for original equipment manufacturer batteries for export too.

- **Battery Reuse Plan**

The application of battery energy storage systems in Thailand is in its infancy, and there is no official plan and target by the government with regard to battery reuse at present. Meanwhile, EV battery production is growing in Thailand. A leading car maker, Toyota Motor has announced that the battery localisation will be realised by establishing an HEV battery production line in Thailand, and showed the plan for the future regarding the management of used HEV batteries under the project 'Hybrid Battery Life Cycle Management' in the form of rebuild, reuse, and recycle.

- **VRE Introduction Plan**

On the move to reinforce electricity security, the Ministry of Energy has amended its Alternative Energy Development Plan 2018, which covers operations from 2018 to 2037, to comply with the national electricity generating capacity development, increasing the ratio of renewable energy sources to 29.4 GW or 33% of the national electricity generating capacity by 2037.

According to the latest amendment of the Alternative Energy Development Plan 2018, electricity generated from renewable energy sources will be introduced into the national power grid, with solar power at 15.6 GW, biomass at 5.8 GW, wind power at 3.0 GW, hydropower from domestic supply and the Lao People's Democratic Republic at 3.0 GW, and waste to energy at 0.9 GW.

1.7. Viet Nam

- **EV Policy and Target**

There is no policy or goal relating to the introduction of EVs by the Vietnamese government. There is also no tax incentive for the manufacture or introduction of EVs.

- **Current Status of EV Introduction**

There is no statistically reliable information on the number of EVs introduced into Viet Nam.

- **EV Battery Production Plan, EV Criteria**

The Vietnamese government has not enacted a manufacturing plan for EV batteries and EV standards.

- **EV Manufacturers**

Major EV manufacturers in Viet Nam include VinFast of the Vin Group, a start-up company since 2017, which mainly manufactures EVs and electric bikes. The number of units sold by the company in 2020 is estimated to be approximately 30,000 units, including internal combustion engine vehicles. It is expected to reach 45,000 units by 2021. In addition to automotive sales, it is also actively involved in the development of domestic EV charging infrastructure.

- **Battery Reuse Plan**

The Vietnamese government has not enacted an EV battery reuse plan.

- **VRE Introduction Plan**

According to the Vietnamese government's 8th Power Development Plan, renewable energy will account for 29% of the capacity of power generation facilities by 2030.

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Chapter 2

Potential of Electric Vehicle Battery Reuse in ASEAN Countries

1. Introduction

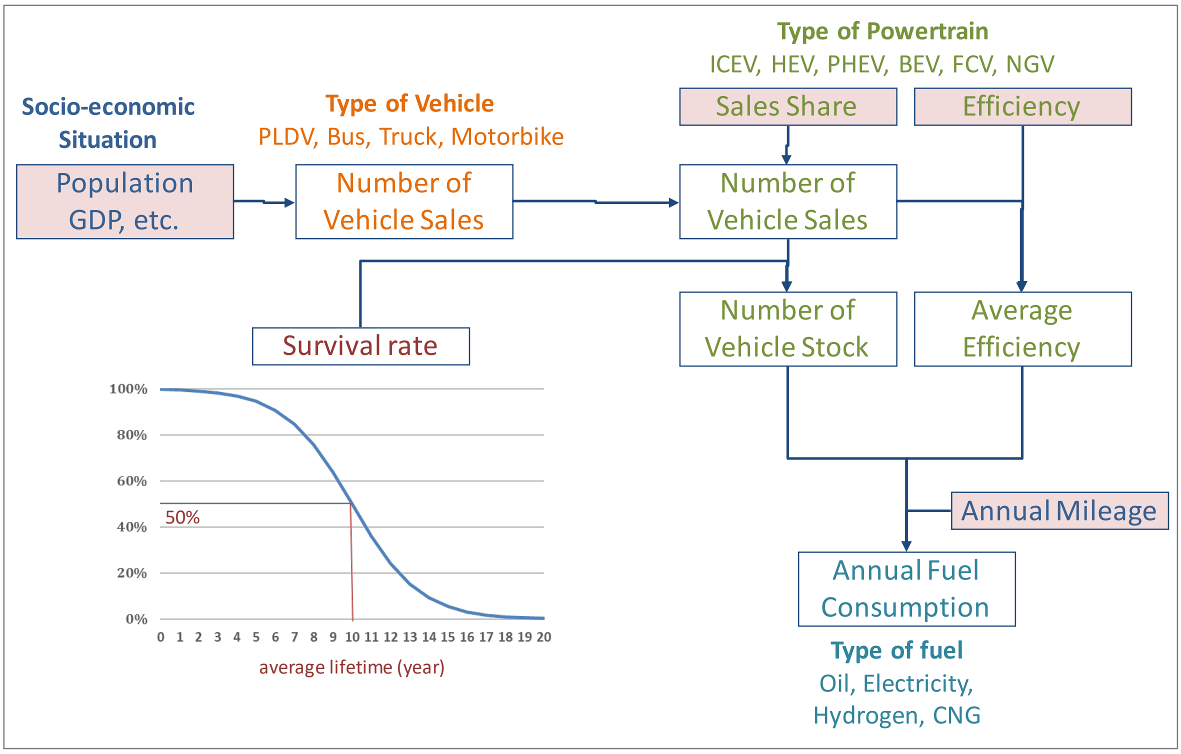
The use of in-vehicle batteries is expected to increase with the electrification of vehicles. Conversely, a large number of used batteries will also be generated. In this chapter, the authors use a quantitative model to analyse how many used batteries are likely to be generated in 10 ASEAN countries.

2. Analytical Methods

2.1. Model

The model developed by Suehiro and Purwanto (2020) is used to estimate the number of used batteries to be generated (Figure 2.1). This model adopts a turnover model. By multiplying powertrain sales volume for each vehicle type x each year by the survival rate, the number of units used can be estimated for each year. This is divided into four models of passenger light-duty vehicles (PLDV), buses, trucks, and motorbikes. It assumes six powertrains (internal combustion engine vehicles, ICEV; hybrid electric vehicles, HEV; plug-in hybrid electric vehicles, PHEV; battery electric vehicles, BEV; fuel cell vehicles, FCV; and natural gas vehicles, NGV). The survival rate uses a logistic curve. The shape of the survival rate curve can be set by assuming the average service life. In the case of PLDV, the average service life is about 15 years. Although this model is intended to estimate fuel and power usage, in this calculation, the survival rate curve is used to estimate the number of battery-installed vehicles that have been discarded.

Figure 2.1. Model Flow



BEV = battery electric vehicle, CNG = compressed natural gas, FCV = fuel cell vehicle, HEV = hybrid electric vehicle, GDP = gross domestic product, NGV = natural gas vehicle, PHEV = plug-in hybrid vehicle, PLDV = passenger light duty vehicle, HDV = heavy duty vehicle (bus + truck).
Source: Suehiro and Purwanto (2020).

The Suehiro and Purwanto (2020) study covers four countries: Indonesia, Thailand, Malaysia, and Viet Nam, so it is necessary to build models for the other six countries. Models with similar structures are used in IEEJ (2020), and for the four countries of the Philippines, Singapore, Brunei, and Myanmar, IEEJ models are used. For the remaining countries of the Lao People's Democratic Republic and Cambodia, models with similar structures were newly constructed for this analysis.

2.2. Installed Battery Settings

The installed battery capacity varies from electric vehicle to electric vehicle. Essentially, HEV driven by the engine is relatively small because it is auxiliary equipped with a battery, and BEV driven by the motor alone without an engine need to be equipped with a large battery. Table 2.1 shows the assumed values of installed battery capacities used in this analysis.

Table 2.1. Battery Capacity of Each Powertrain (kWh)

	HEV	PHEV	BEV
PLDV	1	9	40
HDV	2	18	66
Motor Bike			0.9

BEV = battery electric vehicle, HEV = hybrid electric vehicle, kWh = kilowatt hour, PHEV = plug-in hybrid vehicle, PLDV = passenger light duty vehicle, HDV = heavy duty vehicle (bus + truck).
Source: Authors' analysis.

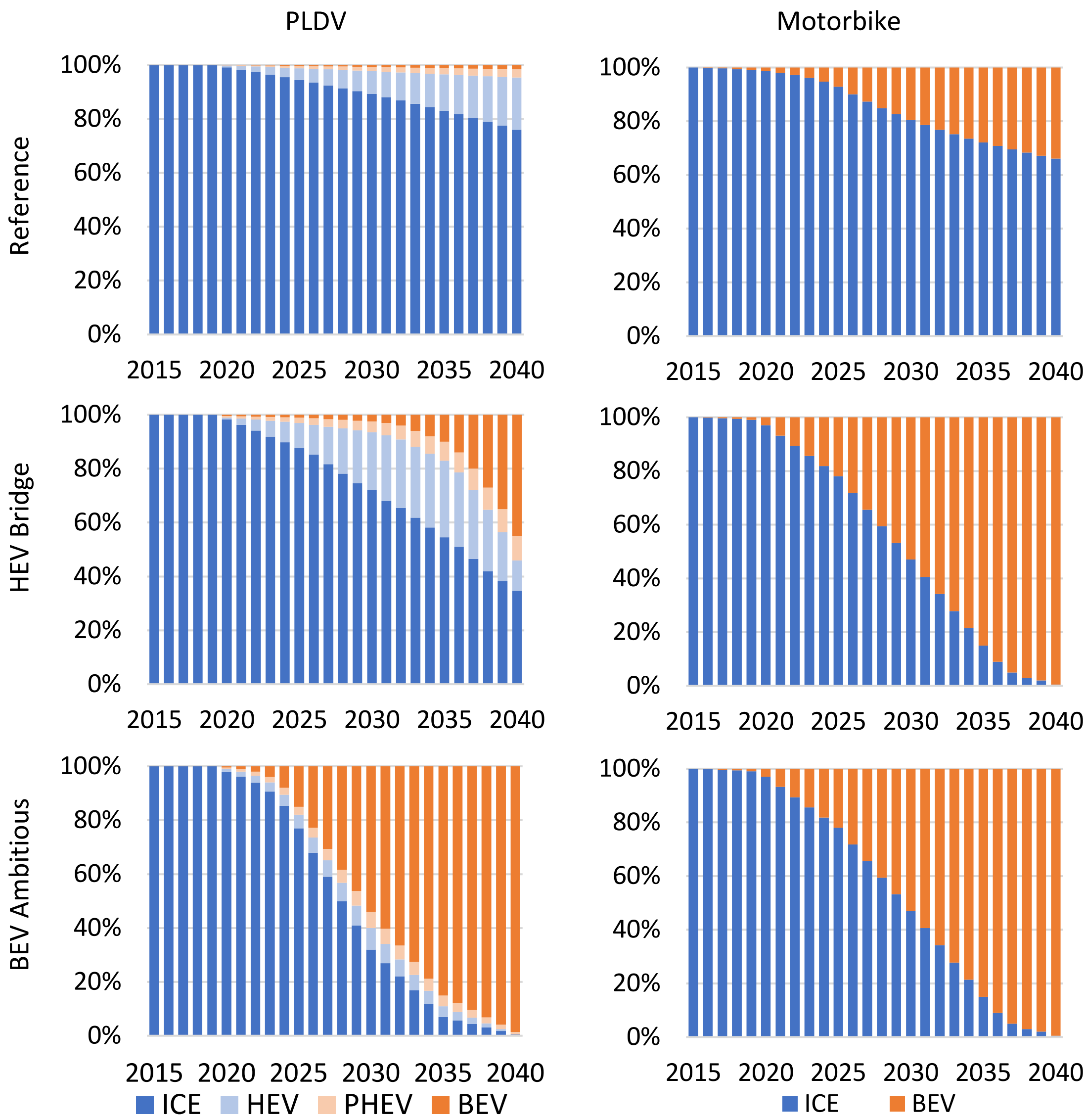
The charging capacity of the battery gradually decreases over the time of use. In the case of automobiles, it is said that the battery must be replaced if its power decreases by approximately 30%. Although the rate of capacity reduction will vary depending on the number of discharges and the environment in which the battery is used (such as temperature and the like), this analysis assumes battery replacement every 5 years. Used batteries are generated when the vehicle body is scrapped. However, even if the vehicle is not scrapped, calculations are made to assume that used batteries are generated every 5 years.

3. Results of Quantitative Analysis

3.1. Setting the Scenario

The number of used batteries to be generated in the future will depend on how popular and well-received electric vehicles become. It is difficult accurately to predict the future. For that reason, this analysis sets three scenarios relating to popularisation (Figure 2.2) and estimates the number of used batteries to be generated. Note that the scenario covers only PLDVs and motorbikes in accordance with Suehiro and Purwanto (2020). HDVs are excluded from the scenario.

Figure 2.2. Powertrain Sales Configuration by Scenario



BEV = battery electric vehicle, HEV = hybrid electric vehicle, ICE = internal combustion engine, PHEV = plug-in hybrid vehicle, PLDV = passenger light duty vehicle.
Source: Authors' analysis.

The reference scenario has the slowest rate of electrification, with a sales share of approximately 30% of electric vehicles as 2040. In PLDVs, high-cost BEVs are rarely popularised, and the mainstream electric vehicles are HEVs. Conversely, electric bikes are likely to become popular because they have a lower cost burden than PLDV BEVs.

The 'BEV ambitious' scenario sets out that BEVs will rapidly penetrate and get almost 100% market share by 2040. This scenario is considered to be similar to the target path for some European countries.

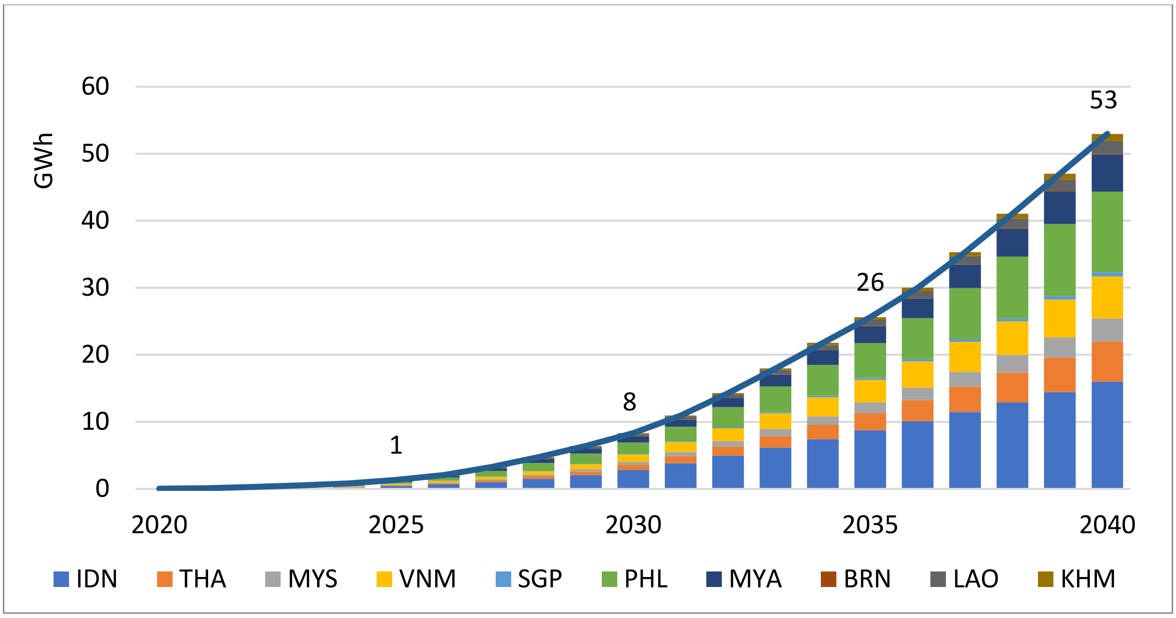
Meanwhile, the 'HEV bridge' scenario is assumed to start with low-cost HEVs, and BEVs are gradually introduced starting after 2030 when the cost of BEVs starts to decline. Electric bike will have a 100% sales share by the year 2040. Since PLDV BEV is more easily popularised, it was assumed to be the same as 'BEV ambitious'.

3.2. Outlook for Used Batteries to be Generated

Based on the above assumptions, the authors estimated the number of used batteries to be generated for the entire ASEAN region by scenario.

In the reference scenario, 8 GWh of used batteries will be generated in 2030 and 53 GWh in 2040 (Figure 2.3). Cumulatively by 2040, it will be 325 GWh (Figure 2.6). Because the electrification of automobiles has not progressed much, most of the batteries supplied are installed in motorcycles. By country, Indonesia and the Philippines account for the majority of motorcycles.

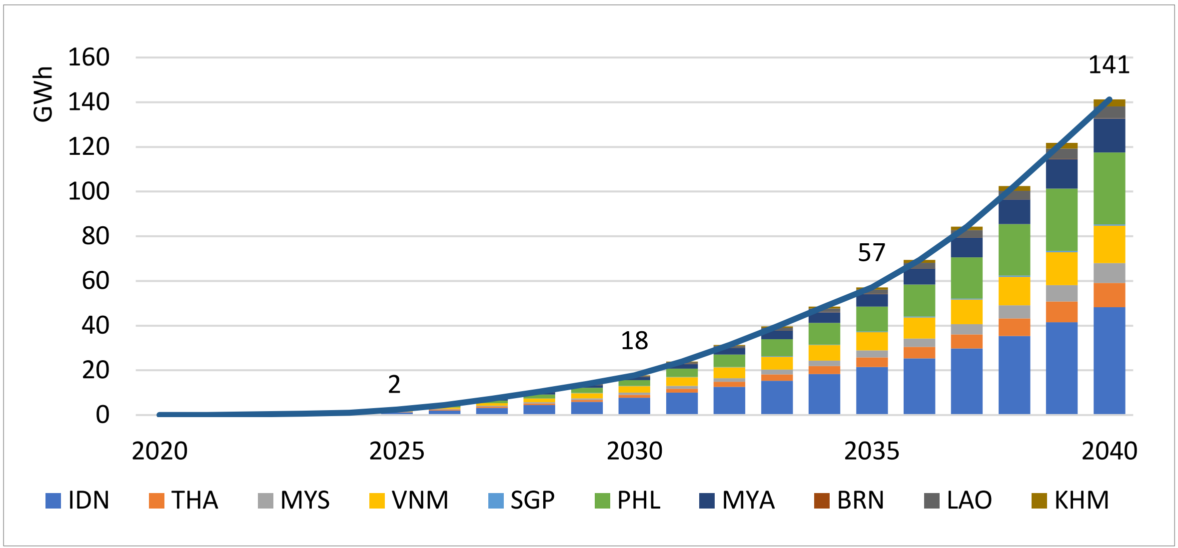
Figure 2.3. Number of Used Batteries to be Generated (Reference)



IDN = Indonesia, THA = Thailand, MYS = Malaysia, VNM = Viet Nam, SGP = Singapore, PHL = Philippines, MYA = Myanmar, BRN = Brunei, LAO = Lao PDR, KHM = Cambodia, GWh = gigawatt hour.
Source: Authors' analysis.

In the HEV Bridge scenario, 18 GWh of used batteries will be generated in 2030 and 141 GWh in 2040 (Figure 2.4). Cumulatively by 2040, it will be 778 GWh, more than double the reference scenario (Figure 2.6). In this scenario, all two-wheeled vehicle sales will be electric motorcycles by 2040, thereby generating a large number of used batteries. Because of the electrification of automobiles focusing on HEVs, the capacity of the installed batteries is small and the number of used batteries supplied is relatively small. By country, Indonesia and the Philippines account for the majority of motorcycles.

Figure 2.4. Number of Used Batteries to be Generated (HEV Bridge)

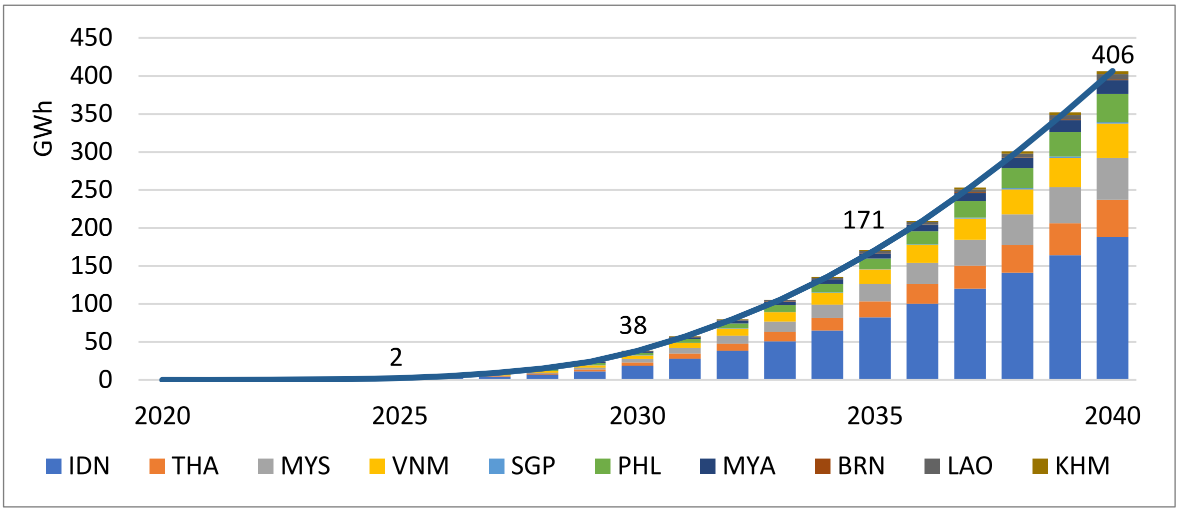


IDN = Indonesia, THA = Thailand, MYS = Malaysia, VNM = Viet Nam, SGP = Singapore, PHL = Philippines, MYA = Myanmar, BRN = Brunei, LAO = Lao PDR, KHM = Cambodia, GWh = gigawatt hour, HEV = hybrid electric vehicle.

Source: Authors' analysis.

In the BEV ambitious scenario, 38 GWh of used batteries will be generated in 2030 and 406 GWh in 2040 (Figure 2.5). Cumulatively by 2040, it will be 2,166 GWh, roughly triple the HEV bridge scenario (Figure 2.6). In this scenario, BEVs with large installed battery capacity will become rapidly widespread, and therefore a large number of used batteries will be supplied. By country, Indonesia accounts for about half of the motor vehicles and motorcycles, while Thailand, Malaysia, Viet Nam, and the Philippines account for the majority of motorcycles.

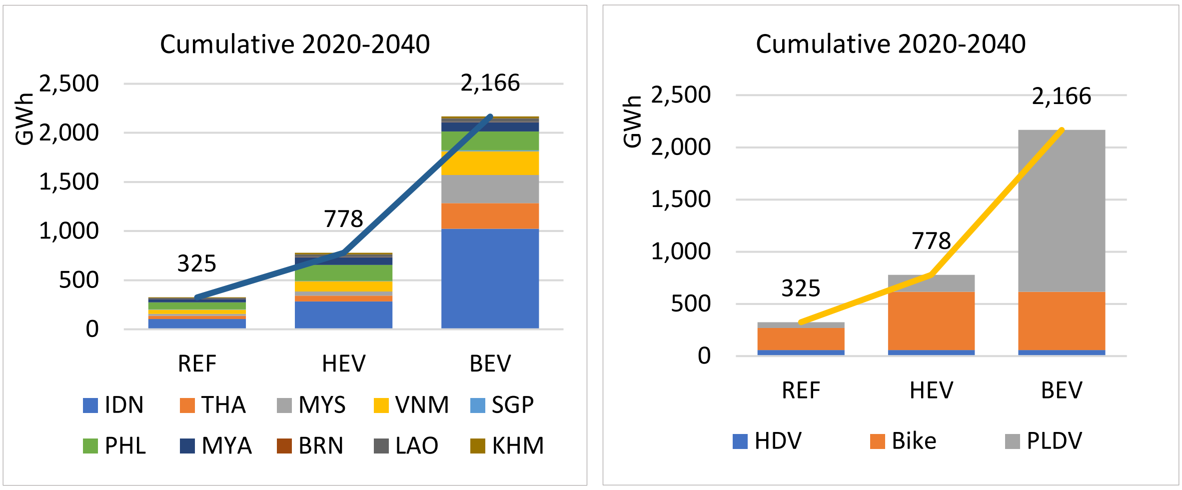
Figure 2.5. Number of Used Batteries to be Generated (BEV Ambitious)



IDN = Indonesia, THA = Thailand, MYS = Malaysia, VNM = Viet Nam, SGP = Singapore, PHL = Philippines, MYA = Myanmar, BRN = Brunei, LAO = Lao PDR, KHM = Cambodia, BEV = battery electric vehicle, GWh = gigawatt hour.

Source: Authors' analysis.

Figure 2.6. Cumulative Number of Used Batteries to be Generated (by Country/Model)

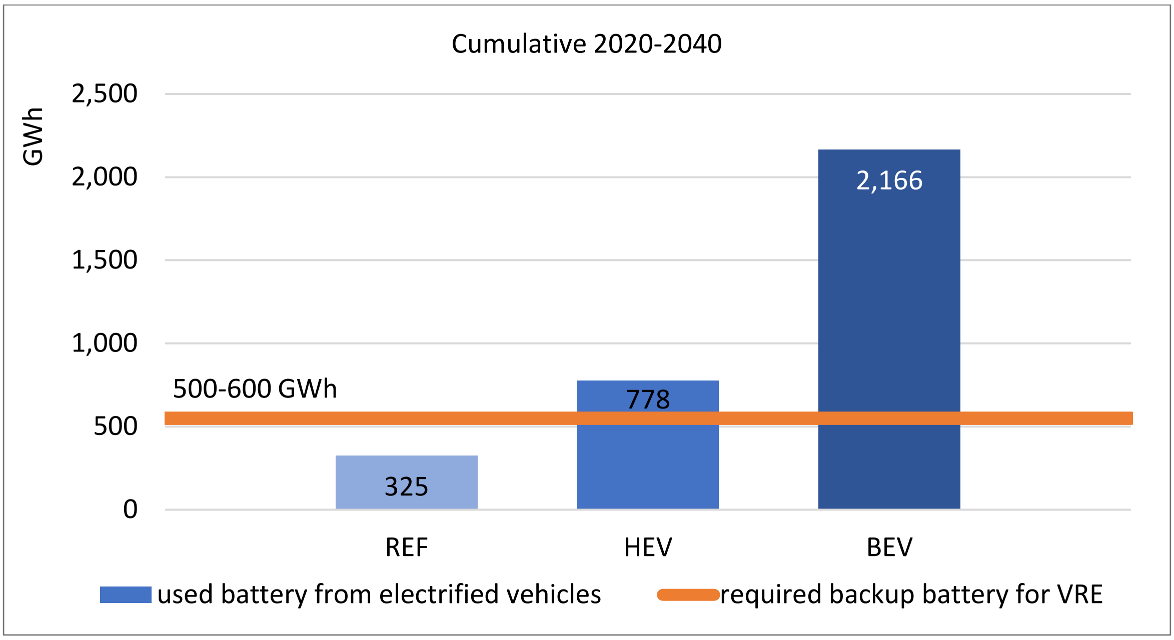


IDN = Indonesia, THA = Thailand, MYS = Malaysia, VNM = Viet Nam, SGP = Singapore, PHL = Philippines, MYA = Myanmar, BRN = Brunei, LAO = Lao PDR, KHM = Cambodia, REF = Reference scenario, HEV = HEV Bridge scenario, BEV = BEV Ambitious scenario, GWh = gigawatt hour, PLDV = passenger light-duty vehicle.
Source: Authors' analysis.

4. Conclusions

By 2040, electrified vehicles will supply used batteries of 325 GWh in the reference scenario cumulatively, 778 GWh in the HEV bridge scenario, and 2,166GWh in the BEV ambitious scenario. A mechanism is needed for dealing with such a large number of used batteries. For example, one of the methods is said to reuse them as backup batteries for variable renewable energy power generation. According to an analysis on ASEAN power systems (focusing on the Indochinese Peninsula and the Malay Peninsula) by Matsuo and Purwanto, (2021), it is estimated to need backup batteries of 500–600 GWh when variable renewable energy accounts for 40% of the generation mix in 2040. In scenarios where vehicle electrification progress, even if all used batteries can be reused in the power generation sector, a large number of batteries will be left over. Along with promoting vehicle electrification, it will be necessary to consider a wide range of options for reusing and/or recycling batteries.

Figure 2.7. Comparing Numbers of Used Batteries with Required Backup Batteries for VRE



REF = reference scenario, HEV = HEV bridge scenario, BEV = BEV ambitious scenario, VRE = variable renewable energy.

Source: Authors' analysis and Matsuo and Purwanto (2021).

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Chapter 3

Electric Vehicle Battery Reuse and Recycling in Europe, United States, Japan, and China

1. Introduction

This chapter presents the electric vehicle (EV) battery reuse and/or recycling policies of the European Union (EU), the United States (US), Japan, and China. These are offered to draw implications for EV battery reuse policymaking in ASEAN countries.

2. Europe

2.1. EU Directive

Since 2006, batteries and waste batteries have been regulated by the EU under the Batteries Directive (2006/66/EC). Nevertheless, changing socio-economic conditions – presented by wider diffusion of lithium-ion battery powered EVs and future considerations for the efficient utilisation of rare materials such as cobalt, lithium and nickel – required the directive to be amended. The coverage of the original directive was not integrated to consider batteries used for appliances and vehicles.

On 10 December 2020, the European Commission published the proposal for the revision of the Batteries Directive 2006/66/EC. The proposal was the first initiative under the EU's Circular Economy Action Plan that aims to achieve economic growth and resources efficiency.

The main points of the proposed amendment include the following (European Commission, 2020).

(1) Batteries on the EU market should become sustainable, high-performing and safe all along their entire life cycle.

This requires producers to minimise the impacts on environment, and the material should be collected in a manner that observes human rights and ecological standards. This also requires the batteries to be repurposed, remanufactured, and recycled.

(2) Mandatory requirements

The Commission proposes the use of responsibly sourced materials, with restricted use of hazardous substances, minimum content of recycled materials, carbon footprint, performance and durability and labelling. The Commission also requires meeting of the collection targets, and recycling targets.

(3) Minimise environmental impact

The proposal aims to establish the battery value chains in order to minimise the environmental impact. In this end, the proposal includes that only stationary and mobile batteries with the carbon footprint label can be sold to the market.

2.2. Current Status

At present, only a limited number of EVs are available for repurposing in the EU. It is pointed out that the number of lithium-ion batteries becoming available annually for remanufacturing, recycling and repurposing will reach 3 million units between 2029 and 2032 (Foster et al., 2014).

In view of the future potential availability of batteries for repurposing, a number of trial cases are implemented in European countries as below.

- **Case 1: Renault**

Renault offers leasing scheme called 'RECHARGE', under which manufacturers retain the ownership of the batteries while consumers purchase the vehicle. The leasing scheme provides consumers with the ability to pay the monthly price of battery usage depending on the travel distance. This scheme allows Renault the control over the timing of repair or replacement of batteries. And in the case of replacement, Renault can decide whether the replaced batteries could be reused, repurposed, or recycled.

- **Case 2: Daimler, The Mobility House, GETEC, and REMONDIS** (Mobility House, 2016).

A battery storage project of 13 megawatt hours (MWh) is implemented in Lünen, Germany. The used EV batteries are repurposed as the option for power grid stability. The project is implemented by Daimler, The Mobility House, GETEC, and REMONDIS. A total of 1,000 battery systems from second-generation EVs are utilised for this purpose.

- **Case 3: 2BCycled Project** (EOL–IS, 2014)

A research project is implemented to evaluate the viability of second life of EV batteries. The project aims to investigate the economic performance of stationary usage of batteries from hybrid vehicles and battery electric vehicles for the residential households that own photovoltaic (PV) systems in the Netherlands.

- **Case 4: Vattenfall, BMW, and Bosch** (Greencar Congress, 2016)

Vattenfall, BMW, and Bosch are testing the second-life EV batteries in Hamburg, Germany. The project has transformed the batteries from 100 EVs into stationary facility that comprises 2600 modules. The storage is intended to be sold to the primary control reserves by Vattenfall.

2.3. Issues and Hurdles

A study implemented by Hill et al. (2019) points out several issues and hurdles for the purpose of developing value chain of battery reuse. As Table 3.1 shows, the study evaluated the EU's performance on the creation of an EV battery value chain. The study identified the constraint on the access to raw materials, meanwhile it is recognised that recycling will play the important role in alleviating the constraint.

The study also identifies the emerging growth of industry related to battery cell manufacturing, reuse, and repurposing.

Table 3.1. Summary of SWOT Analysis for the EV Battery Value Chain in the European Union

EV battery Value Chain	Industry	Infrastructure	Policy
Raw materials	Weak	Intermediate	Strong
Cell component manufacturing	Intermediate	Intermediate	Strong
Cell manufacturing	Intermediate	Intermediate	Intermediate
Battery pack manufacturing	Strong	Strong	Strong
EV manufacturing	Strong	Strong	Strong
Re-use	Intermediate	Intermediate	Weak
Re-purposing	Intermediate	Intermediate	Weak
Recycling	Strong	Strong	Strong

EV = electric vehicle.
Note: Green: key strengths that future policy should continue to reinforce and support; Amber: development areas that should be monitored; and Red: key barriers or constraints that future policy should look to ease.
Source: Hill et al. (2019).

Other hurdles include:

- **Health and safety**: Some concerns are expressed over the use of repurposed EV batteries on the potential of fire safety, and/or environmental impacts.
- **Regulatory**: The transportation of used EV batteries requires regulatory transparency that it should not be classified as hazardous waste.
- **Economic**: Repurposing a battery safely in the manner that meets required standards result in high manufacturing costs, while low-cost alternatives may become suitable for energy storage solutions.
- **Technical**: In relation to health and safety, some technical concerns and reduced lifetime of used batteries offer a big challenge.

2.4. Future Direction

Under the revised EU Batteries Directive various new undertakings will be held to assist the creation of a value chain of used batteries in the EU market. Table 3.2 includes the time schedule specified in the revised directive. The EU tries to ensure transparency in terms of the environmental performance of the batteries sold in the market – which will take a step-by-step approach to be achieved through July 2027. In addition, the EU tries to enforce the compliance on the recycled content of batteries. By January 2030, the recycled content thresholds are 12% cobalt, 85% lead, 4% lithium, and 4% nickel. By 2035, this threshold is required to be increased t0 20% cobalt, 85% lead, 10% lithium, and 12% nickel.

Table 3.2. Overview of the Future Implementation Plan of EV Batteries Reuse and Recycling in the European Union

Time	Implementation
July 2024	A carbon footprint declaration will be required.
January 2026	Each industrial battery and electric vehicle battery with a capacity higher than 2 kWh shall have a unique 'battery passport' linked to the information about the characteristics of each battery type and model providing valuable data to recyclers and second-life companies. An electronic exchange system in the form of an online battery database has also been proposed to complement the passport.
January 2026	These batteries must have a carbon intensity performance class label the details of which are yet to be communicated.
July 2027	Batteries will have to comply with maximum carbon thresholds that have yet to be stated.
January 2030	These batteries will have to comply with minimum recycled content thresholds (12% cobalt, 85% lead, 4% lithium, 4% nickel).
January 2035	These thresholds will be further increased (20% cobalt, 85% lead, 10% lithium, 12% nickel).

EV = electric vehicle, kWh = kilowatt hour.
Source: European Commission (2020).

A study by Abdelbaky et al. (2020) estimates the EU's future potential for EV batteries recycling. The study analysed the usable batteries amount from plug-in passenger and light commercial electric vehicles in the EU for both plug-in hybrid (PHEV) and full battery electric vehicles (BEV).

The study focused on lithium-ion batteries only, and nickel metal hydride batteries, which are more suited for hybrid electric vehicles, are excluded.

Three scenarios developed in this study are:

- **Recycling scenario** – This scenario is characterised by rapid growth of waste batteries for recycling. Under this scenario, high learning curves for EV batteries.
- **Baseline scenario** – This scenario is in line with the most outlook studies, and expert views on exploiting full battery potentials in EV use.
- **Repurpose scenario** – This scenario assumes the longest lifetime and slower growth rate of waste batteries.

All three scenarios project higher availability of waste from EVs after 2030. Annual recycling capacity of 12 gigawatt hour (GWh) (18 kiloton/year), and 138 GWh (150 kiloton/year) are needed for 2030 and 2040, respectively.

3. United States

3.1. Regulations

- **Vehicle Regulations**

Since the 1970s, through the Corporate Average Fuel Economy standards, the federal government has imposed obligations on automobile manufacturers and importers to achieve average fuel consumption standards for passenger cars and small trucks to improve fuel consumption for automobiles. In addition, since 2010, a tax credit of $2,500–$7,500 has been established for each purchase of an electric vehicle. The deduction is based on battery capacity and vehicle weight, and will be phased out after sales of 200,000 units per automobile manufacturer (US Department of Energy, n.d.)

In September 2019, the former Trump administration announced the One National Program Rule, which revoked the exception that allowed California to set its own emissions regulations and centralised standard-setting authority to the federal government. Also in March 2020, the final rules of the Safer Affordable Fuel-Efficient Vehicle Regulations, which provided for a significant relaxation of the Corporate Average Fuel Economy standards set in 2012 during the Obama administration, were announced. However, the Trump administration's policies led to litigation by a coalition of states, including California (Grandoni and Eilperin, 2019). California is also the largest automotive market in the United States, with automobile manufacturers split between federal support (General Motors, Fiat Chrysler Automobiles, Toyota, and others) and state support (Honda, Ford, BMW, VW/Audi, and Volvo) (Shepardson, 2019).

In January 2021, President Biden signed an executive order requesting a review of federal rules and regulations issued under the pre-Trump administration. This also includes the above-mentioned automotive fuel consumption regulations.

- **Vehicle Recycling Regulations**

In the United States, there is no federal law governing the recycling of end-of-life vehicles (ELVs). They are governed by a voluntary system under a market economy. Automotive recycling is promoted by automotive manufacturers and industry associations such as the Automotive Recyclers Association and the like, with more than 95% of ELVs entering recycling routes, 80% of the materials from them is recycled. Whether there is any economic benefit is an important issue for the scrapper to determine whether to recycle, and this trend is significant in the United States. Conversely, since hazardous substances such as heavy metals are handled in the automotive recycling business, strict monitoring is implemented in accordance with environment-related laws and ordinances such as the Resource Conservation and Recovery Act, the Clean Air Act, the Clean Water Act, and others.

- **EV Battery Reuse and Recycling Regulations**

At the federal level, the Federal Mercury-Containing and Rechargeable Battery Management Act (Battery Act) defines the proper disposal of batteries containing hazardous materials such as mercury, cadmium, and lead, but it does not cover lithium-ion batteries. At the federal level, lithium-ion batteries are not clearly considered hazardous waste under the Resource Conservation and Recovery Act. Reuse and recycling regulations for EV lithium-ion batteries operate at the state level, and California, New York, and Minnesota are the only states that prohibit landfill disposal of lithium-ion batteries (Gaines, Ritcha, and Spangenberger, 2018).

In California, lithium-ion batteries are regarded as hazardous waste due to health and safety concerns, including flammability. In 2019, the Lithium-ion Car Battery Recycling Advisory Group was setup to form policies for the recovery and recycling of automotive lithium-ion batteries from the viewpoint of the importance of the circular economy. In Assembly Bill No. 2832, the Advisory Group is required to submit policy recommendations to the legislature by 1 April 2022 with the purpose of reusing or recycling as close to 100% of the state's lithium-ion batteries as is possible (CalEPA n.d).

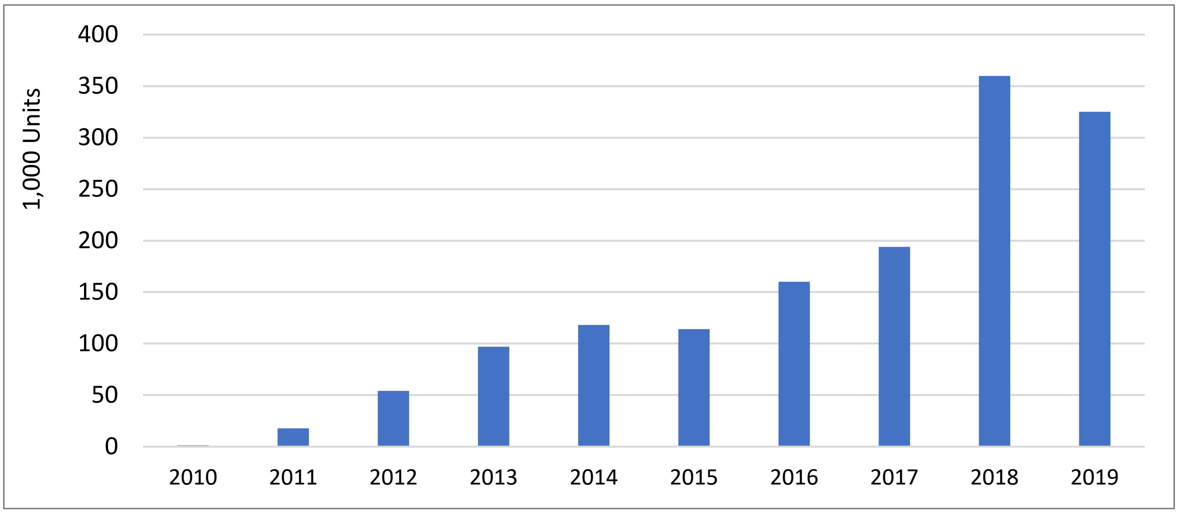
3.2. Current Status

- **EV and EV Battery Industry**

Figure 3.1 shows the change in sales of EVs (PHEVs + BEVs) in the United States. The number of EVs sold in 2019 was 327,000 units, accounting for 2.1% of new car sales. The number of EVs sold in 2020 showed a significant increase of 43% over the previous year worldwide (mainly driven by Europe), while the United States remained at 4% (Shahan, 2021).

The share of EV sales in the United States is low compared to Europe and China. Challenges include inadequate charging infrastructure, consumer preferences for larger cars, and a lack of clear policies.

Figure 3.1. Sales of PHEVs and BEVs in the United States



BEV = battery electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: IEA (2020).

With regard to the EV battery industry, as of 2019, the United States had eight manufacturing plants including Tesla's Giga Factory, with manufacturing capacity ranking second in the world to China (China: 236 GWh, United States: 35 GWh) (BNEF, 2019), but overseas capital in Japan (Panasonic) and the Republic of Korea (LG Chem, SK innovation, and others) is responsible for this.

- **EV Battery Reuse Industry**

Pilot projects such as those shown in Table 3.3 have been implemented in the United States for the reuse of EV batteries.

In 2016, a project implemented by UC Davis with funding from the California Energy Commission achieved a peak cut in power consumption for the UC Davis Robert Mondavi Institute, a winery, a brewery, and a food processing complex. In this project, a 300 kWh energy storage system composed of 18 reused Nissan LEAF battery packs was built inside a transport container to store surplus power of 200 kW PV installed on the rooftop of the facility during the day and to discharge it in the evening, thereby reducing the energy usage of the facility by more than 20% (Feller, 2019; Ambrose, 2020).

In June 2019, EV start-up Rivian, which is working to develop electric pickups, announced plans to convert spent EV batteries into an energy storage system for Puerto Rico's solar microgrid. They build a 135 kW system using battery packs for development vehicles in Adjuntas, a city in Puerto Rico that was damaged by a hurricane in 2017. In normal times, it is used to reduce electricity charges, and in the event of power outages, it serves to supply power to core businesses. According to an announcement by Rivian, Puerto Rico's commercial energy costs are twice as high as the US average, so this is a good start for the project (Krok, 2019).

Table 3.3. Overview of the EV Reuse Pilot Projects in the United States

Lead Entity	Location	Year(s)	Capacity
UC Davis, California Energy Commission, Nissan	Davis, CA	2016	260 kWh (864 LEAF modules, 100 kW PV)
BMW, EVgo	Los Angeles, CA	2018	30 kW, 44 kWh (2 i3 packs)
UC San Diego, BMW, EVgo	San Diego, CA	2014–2017	108 kW, 180 kWh (unspecified number of mini E packs)
General Motors, ABB	San Francisco, CA	2012	25 kW, 50 kWh (5 volt packs, 74 kW PV, 2 kW wind turbines)
Toyota	Yellowstone National Park	2014	85 kWh (208 Camry modules)
Nuvve, University of Delaware, BMW	Newark	2019	200 kW (unspecified number of mini E packs, integrated with V2G in addition)
Rivian	Adjuntas, Puerto Rico	2020 (plan)	135 kW (battery packs from its development vehicles)

CA = California, kW = kilowatt, kWh= kilowatt hour, PV = photovoltaic.
Sources: Krok (2019), Ambrose (2020).

Spiers New Technologies (SNT) is the largest in the United States as an operator for the reuse of EV batteries. Founded in 2014, SNT deploys repair, re-manufacturing, refurbishing, and repurposing (4R) services for EV batteries, providing one-stop life cycle management of EV batteries. Most of the battery packs accepted by SNT come from dealer replacements during the warranty period and testing projects. The accepted battery packs go either through screening and are returned to the EV for replacement during the warranty period, repurposed for other applications, or their materials are recycled. In the first quarter of 2019, 2,000–2,500 battery packs were received per month. SNT is located in Oklahoma City, the geographic centre of the United States, so it can ship to almost any dealer in North America within 24 hours. SNT also built a battery software platform called ALFRED. The system accepts data from various sources, including manufacturers, dealers, and carriers, and collects, manages, and processes battery-related information (Spiers New Technologies; Kelleher Environmental, 2019).

Conversely, California-based start-up companies such as RePurpose Energy, Smartville Energy, ReJoule, and others are also developing unique reuse businesses with California Energy Commission support (Table 3.4).

Table 3.4. Overview of the EV Reuse Start-up Companies in the United States

Company Name	Overview
RePurpose Energy	Led by Professor Jae Wan Park, University of California, Davis Developed a way to shorten the process of testing battery degradation, which traditionally took 1 day, to approximately 1 minute.
Smartville Energy	Spin out from the University of California, San Diego Energy Research Center. Developed a refurbishing process that supports a variety of batteries.
ReJoule	Adopted an approach that optimises the secondary life battery that starts inside the vehicle.

EV = electric vehicle.
Source: Pyper (2020).

- **EV Battery Recycling Industry**

Table 3.5 shows the import dependency, recycling rate, and main import destination of the raw materials contained in lithium-ion batteries (LiB) in the United States. These substances tend to have mining quantities and refining capacity biased towards specific countries, and the United States also relies on imports for more than half of its domestic consumption. Especially for cobalt, mining is done in Congo, refining is highly dependent on China; geopolitical risks are high. The demand for nickel is mostly for stainless steel manufacturing, and the like, but higher quality nickel is needed for EV batteries. Expansion of the supply system is required to keep pace with future demand growth (WEF, 2019).

Table 3.5. Import Dependency, Recycling Rate, and Main Import Destination of Raw Materials Contained in Lithium-ion Batteries in United States

Material	Net Import Reliance, 2020	Recycling Rate, 2020	Main Import Sources, 2016–2019
Cobalt	76%	29%	Cobalt contained in metal, oxide, and salts: Norway, 20%; Canada, 14%; Japan, 13%
Lithium	>50%	-[1)]	Argentina, 55%; Chile, 36%; China, 5%
Nickel	50%	50%	Nickel contained in ferronickel, metal, oxides, and salt: Canada, 42%; Norway, 10%; Finland, 9%
Manganese	100%	-[2)]	Manganese ore: Gabon, 69%; South Africa, 17%; Mexico, 8%
Graphite (Natural)	100%	-[3)]	China, 33%; Mexico, 23%; Canada, 17%

Notes: [1)] One domestic company has recycled lithium metal and lithium-ion batteries since 1992 at its facility in British Columbia, Canada. In 2015, the company began operating the first US recycling facility for lithium-ion vehicle batteries in Lancaster, Ohio. Seven other companies located in Canada and the United States have begun recycling or intend to begin recycling lithium metal and lithium-ion batteries to some degree.
[2)] Manganese was recycled incidentally as a constituent of ferrous and nonferrous scrap; however, scrap recovery specifically for manganese was negligible. Manganese is recovered along with iron from steel slag.
[3)] The abundance of graphite in the world market inhibits increased recycling efforts. Information on the quantity and value of recycled graphite is not available.
Source: USGS (2021).

Table 3.6 shows an example of an EV battery recycling facility located in North America. The centre of EV battery recycling is in China and South Korea, and the recycling capacity of EV batteries in North America is currently limited.

Founded in 1992, Retriev Technologies is one of the largest battery recycling companies in North America, accepting all batteries for domestic, industrial, and EV use and collecting and selling valuable metals. They also have the technology and expertise to recycle all commercially available LiBs, including those for EVs. In February 2021, they announced the signing of a strategic partnership with the Japanese trading company Marubeni (Retriev Technologies; Marubeni, 2021).

Table 3.6. Examples of EV Battery Recycling Facilities Located in North America

Company	TRL level	Country	Technology	Capacity (tonnes)
Lithion	Commercial	Canada	Mechanical	2,500
Li-cycle	Pilot	Canada	Mechanical	7,500
Retriev Technologies	Pilot	United States	Mechanical	4,500

TRL = technology readiness level.
Sources: IEA (2020) created by Pinegar and Smith (2019) and Eduljee and Harrison (2020).

Trends in start-ups are also notable in the recycling sector. Founded in 2016, Canada's LiB recycling company, Li-Cycle, has plans to invest $175 million to build North America's largest LiB recycling plant in New York. The plant's processing capacity will eventually reach 25,000 tonnes, recovering more than 95% of cobalt, nickel, lithium, and other valuable elements. Construction of the facility is scheduled to commence sometime in 2021 (Kumagai, 2021).

Redwood Materials is a start-up company co-founded in 2017 by former Tesla CTO J.B. Straubel to recycle batteries for EVs and home appliances. The company became one of the first five investors in Amazon's $2 billion Climate Pledge Fund (Kumagai, 2021).

The United States Department of Energy is supporting research and development with the goal of increasing the recycling rate of LiB, which currently stands at less than 5%, to 90%. In 2019, the US Department of Energy established ReCell Center, a consortium of labs specialising in the development of safe and cost-effective battery recycling, to provide a $15 million grant over 3 years. Under ReCell, national laboratories, scholars, and industry will work together to develop an innovative approach to building a closed-loop battery industry. This research centre focuses on the longer-term, promising technologies such as direct cathode recycling (Kumagai, 2021; US Department of Energy, 2019).

3.3. Issues and Hurdles

Barriers to recycling and reuse were identified in materials submitted (CalEPA, 2019) at the first meeting of the California Advisory Group, as follows. Challenges include a lack of standardisation for reuse, small scale and a poor economy for recycling. For reuse, it is also a challenge to have different degrees of degradation of individual batteries. For this reason, Tesla is said to be negative towards the reuse for applications where high reliability is required. Instead, it is looking for directions to extract raw materials for recycling (Slattery, Clark, and Scheff, 2019).

Barriers to Recycling

- Recycling not cost-feasible at scale
- Difficult to recover all materials in the battery – currently research and pilot projects to improve methods and increase recovery
- Lack of battery pack standardisation, different chemistries, and cell structure make recycling hand to automate, requires costly manual disassembly
- Battery chemistry likely to change significantly in next decade. Potential changes are low cobalt or cobalt free cathodes (with higher nickel content), which makes recycling even less profitable to recycle since cobalt is the most profitable recovered product
- Collection and subsequent transportation to recycling facility difficult and costly

Barriers to Reuse

- Lack of batteries standardisation; no standard way to test battery life
- Performance inconsistency for batteries that are old and outdated technologies
- Not included in the European Union Batteries Directive, once batteries certified as waste, cannot be put back into circulation without auditable trail of tests

Battery demand in the United States is expected to grow not only from EVs, but also from the perspective of grid management as renewable energy expands. Conversely, the US does not have a domestic battery supply chain. Mineral resources required for LiB production are import-dependent. Japanese and Korean manufacturers are also responsible for domestic battery production. The United States is looking at increasing battery demand, reducing mineral resource import dependency, and creating employment through in-house production in the future, and is considering building a supply chain that includes domestic mineral resource development. Reuse and recycling of EV batteries can also be positioned in this context.

3.4. Future Direction

- **Estimation of Supply and Demand of Second Life Batteries**

Worldwide, the supply of reusable LiB is currently extremely limited, and the gap between supply and demand is expected to remain large in the short to medium term. One estimation shows that energy storage systems in the United States will reach 75 GWh, while reusable EV batteries supply will be less than 5 GWh in 2030 (Melin, 2018).

- **Federal Policy Direction**

The Biden administration intends actively to promote an EV policy and will promote EV replacement by installing more than 500,000 charging stations and offering tax credits for consumers. Furthermore, it is assumed that it will create 1 million new jobs in the automotive industry in the United States (Joe Biden).

In April 2021, an infrastructure investment plan named the American Jobs Plan was announced. In this plan, noting that the size of the US market for EVs is one-third that of the Chinese market, the Biden administration aims to make EVs affordable for all households by investing $174 billion in the EV market, by building a domestic supply chain and creating jobs (White House, 2021).

Regarding battery reuse and recycling, in March 2021, Senator Angus King, a founding member of the bipartisan Climate Solutions Caucus, announced the Battery and Critical Mineral Recycling Act of 2020. The bill calls for the spending of $150 million over the next 5 years to support innovative research on recycling and to establish battery recovery systems across the United States (King, 2020).

Conversely, as mentioned in section 3.1, California is currently considering specific policies related to the reuse and recycling of EV batteries. In the United States, state autonomy is strong, and the specific enforcement of waste and recycling regulations is delegated to state governments. The following section introduces future policy trends in California.

- **State Policy Direction**

The Advisory Group based on Assembly Bill No. 2832 in California has held eight meetings as of the end of March 2021. At its sixth meeting on 14 December 2020, it was indicated that three subgroups for reuse, recycling, and logistics would be established within the Advisory Group as future work plans, and that the review work would be implemented according to the timeline shown in Table 3.7. Phase 1 will discuss the identification of barriers and opportunities, and Phase 2 will discuss the means to address those barriers. California is forging ahead of the federal government and other states to consider reuse and recycle policies for EV batteries. For that reason, it is necessary to keep an eye on future trends in California.

Table 3.7. Proposed Timeline for Discussion in Assembly Bill 2832 Advisory Group

Phase	Goal
Phase I: Identification of barriers and opportunities (January–March 2021)	1. Get a complete understanding of laws as they currently stand. What is allowed and what isn't allowed in California? 2. Based on federal and state laws, what kind of programme do we want to be able to do in California? Do we want reuse and recycling to occur in California? If so, what are the barriers to get that in place? 3. What is the capacity that is required? When do we anticipate the recycling need to be built? Or the potential capacity to get us to 100% reuse and recycling?
Phase II: Options to Address Barriers (March–July 2021)	1. Options to address barriers and incentivise the reuse of batteries with a sufficient state of health 2. Options to address barriers and incentivise recycling that minimises environmental and economic cost while recovering key materials 3. Options to address barriers and facilitate safe and efficient logistics to support the reuse and recycling
Phase III: Compile and Complete Draft of Final Report (July–December 2021)	31 December 2021: Complete draft of final report
Phase IV: Edit and Finalise Final Report (December 2021–March 2022)	1 March 2022: Complete final report

Source: CalEPA (2020).

4. Japan

4.2. Regulations

In Japan, the Act on Recycling, etc. of End-of-Life Vehicles (End-of-Life Vehicles Recycling Law), which came into effect in January 2005, has established a legal system for recycling fluorocarbons, airbags, and shredder dust generated from used vehicles. A system has been established whereby the owner of a vehicle pays a prescribed recycling fee when they purchase a new vehicle, and when they scrap the vehicle, the automobile manufacturer takes back the automobile they manufactured and recycles it directly or through a collection agency or scrapper or the like as shown in Table 3.8. However, batteries for electric vehicles (EVs) are not covered by the End-of-Life Vehicles Recycling Law. A system has been established whereby each automobile manufacturer voluntarily collects them free of charge when scrapping the vehicle in accordance with the Waste Management and Public Cleansing Act (Waste Management Law). However, there are also cases in which batteries removed from EVs by scrappers or the like are resold to third parties.

Table 3.8. Role of Relevant Parties in the End-of-Life Vehicles Recycling Law

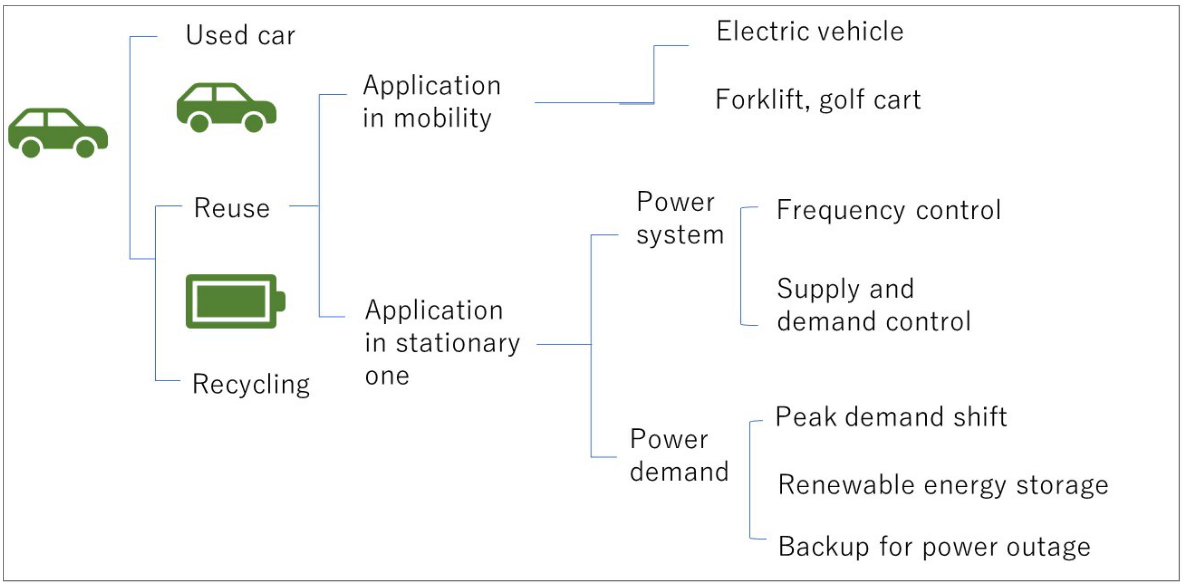
Vehicle Owner (End Owner)	Payment of Recycling Fees and Delivery of Scrapped Cars to Collection Agent Registered with the Municipality
Relevant Vendor • Collection Agent • Scrapper	• Collects scrapped vehicles from end owner and hands them over to the scrapper. • Properly collects scrapped cars according to standards and delivers them to automobile manufacturers.
Automobile Manufacturers	When a vehicle manufactured by the manufacturer is scrapped, shredder dust, airbags, and fluorocarbons generated from the car are collected and recycled.

Source: Author's summary based on Ministry of Environment, Japan.

4.2. Current Status

Regarding the collection of EV batteries, in addition to the unique efforts of automobile manufacturers, the industry group, the Japan Automobile Manufacturers Association, Inc., has also launched a joint collection network. Preparations are under way to increase the amount of reuse of EV batteries in the future. Furthermore, since most of the recovered EV batteries maintain a storage capacity of about 70% compared to new ones, in addition to the technical developments in recycling that remove rare earth raw materials such as cobalt, nickel, lithium, and the like, efforts such as technical verification and demonstration projects to reuse recovered batteries are also underway. Depending on the status of deterioration of recovered batteries, there are cases where the batteries are reused as it is. Some are dismantled, reassembled, and reused. In addition to being reused as an EV battery, other uses are anticipated, such use as a stationary battery, as a power source for adjusting power supply and demand and frequency fluctuations, and as a power storage system combined with variable renewable energy such as solar power generation and the like.

Figure 3.2. Reuse and Recycling of Battery in Japan



Source: The Institute of Energy Economics, Japan (2021).

When judging the application of reuse of EV batteries, it is important to understand the status of deterioration of the batteries. To do so, it is essential to establish a battery-performance evaluation technology. Therefore, companies are working on the development of technologies quickly and accurately to measure the performance of used batteries and to predict the status of their deterioration when reused. In addition, the Council for Electrified Vehicle Society and the Ministry of Economy, Trade and Industry, composed of electric power companies and automobile manufacturers, formulated 'Providing Information Guideline of In-vehicle Battery Performance' in June 2020, thereby clarifying specific measurement methods.

4.3. Issues and Hurdles

Battery deterioration conditions vary greatly depending on cell shape, electrode material, vehicle type, and other factors. Opinions have emerged that standardisation of the battery itself is also necessary from the viewpoint of streamlining performance evaluation. However, for automobile manufacturers, the design of the battery is also something that leads to product differentiation, and the reality is that it is not easy to attain standardisation. Furthermore, standard settings based on deterioration conditions, residual value levels, and the like are also necessary. In addition, ensuring safety during reuse, organising the concept of product responsibility (the responsibility when disassembling batteries into modular units and then reusing them, sharing responsibility between asset holders and battery operators, and the like), and improving logistics efficiency to reduce battery recovery costs are also important issues.

4.4. Future Direction

With a view to attaining carbon neutrality set by the Government of Japan by 2050, the decarbonisation of the power sector is accelerating, and the introduction and expansion of solar and wind power generation, as well as the spread of stationary power storage systems are expected to expand. There is also a great possibility that stationary power storage systems utilising used EV batteries will be introduced. In addition to clearing technical challenges for the introduction and expansion of that, it is also necessary to be cost competitive for new battery-based power storage systems. Continuous efforts by companies to improve the efficiency of battery reuse supply chains and to reduce costs are essential. However, policy support by the government will also be necessary to prevent the illegal disposal of used EV batteries and to aim for a resource-cycling society.

The legal system related to EV batteries is also expected to continue to be studied in the future, but the European Commission (EU) announced a proposal to amend the regulation on batteries in December 2020, adding manufacturers' responsibilities (Extended Producer Responsibility) such as declaring carbon footprints throughout the battery life cycle, the obligation to collect batteries as a measure to promote a recycling society, and the practical application of a battery passport to create a battery database to improve traceability. These are expected to be studied based on these trends.

From the viewpoint of responding to the performance and safety evaluation of reused batteries, in April 2020, Japan took the lead in issuing the world's first international standard on the safety of large stationary battery systems from the International Electrotechnical Commission (METI, 2020a). It is also considering international standardisation such as product standards for reuse for stationary and management system standards and others.

5. China

5.1. Regulations

- **Vehicle Regulations**

China's new energy vehicle (NEV = BEV + PHEV + FCEV) market developed rapidly from the mid-2010s because of preferential and regulatory policies of the central government. For the demand side, the NEV industry has been promoted by subsidisation policies for individuals purchasing an NEV, policies by local governments such as license plate regulations and the like, and for the supply side by NEV regulations and Corporate Average Fuel Consumption regulations (Figure 3.3).

Figure 3.3. Overview of NEV Policies in China

NEV Sales Target: Approx. 20% by 2025

<Supply Side>	<Demand Side>
NEV Regulations Request automobile manufacturers to sell NEV at a certain ratio or higher. Targets are measured with NEV credits; inter-company transactions are possible. Regulation will be strengthened after 2021.	Subsidies The amount provided depends on cruising distance, efficiency, and energy density of the battery pack. Originally scheduled to close in 2020; was extended to 2022 while gradually reducing the payment amount.
CAFC Regulations Request automobile manufacturers to attain corporate average fuel consumption standards. Inter-company credit transactions are possible; NEV credits can be converted.	Local Government Policies More than 29 provinces and cities provide incentives to NEV purchasers for easy access to license plates, exemption from traffic restrictions, and reduced parking fees and others.

CAFC = Corporate Average Fuel Consumption, NEV = new energy vehicle.
Source: Created by IEEJ based on METI (2020b) and IEA (2020).

Subsidies that have played a major role in the popularisation of NEVs are scheduled to end in 2022. The subsidy policy was originally scheduled to close in 2020. However, it was extended to 2022 because of the stagnation in NEV sales in 2019 and it was announced that the payment rate would be reduced by 10% in 2020, 20% in 2021, and 30% in 2022 compared to the previous year (State Council, 2020).

- **Vehicle Recycling Regulations**

When disposing of automobiles, the law on ELV recycling, which came into force in 2001, applies. Although the main purpose of this law was to regulate automobile reassembling plants, in fact, the automobile reassembling market already existed and there was a need for second-hand parts. Therefore, deregulation was implemented in 2011 and 2019, when it became possible to sell to companies with the ability to re-manufacture if the conditions for re-manufacture were met (IEA, 2020).

In 2006, the Automotive Products Recycling Technology Policy, an instructive document, was implemented for the recycling of automobiles. The purpose of this document is to promote the development of automotive product waste collection work by automotive production, sales, and related companies. The recyclable rate target of automobiles is approximately 85% in 2010 (of which 80% or more is for material recycling), approximately 90% in 2012 (of which 80% or more is for material recycling), and approximately 95% in 2017 (of which 85% or more is for material recycling). Conversely, with regard to the actual status of ELV collection, there is a deviation between the number of scrapped vehicles registered for disposal and the number recovered by the collection and scrapper business operators. It is believed that the majority has flowed to unauthorised, illegal vendors. One of the possible reasons for this is the higher ELV purchase prices by illegal vendors due to the illegal sale of the parts (METI, 2011).

- **EV Battery Reuse and Recycling Regulations**

With the popularisation of NEVs, there is an urgent need to consider the handling of discarded batteries that are expected to be emitted in the future. According to Chinese government estimates, by the end of 2017, more than 1.8 million NEV units had been deployed, and they contained approximately 86.9 GWh of batteries, exceeding more than 200,000 tons (24.6 GWh).

With this as a background, in 2018, the Chinese government enacted interim measures for reuse and recycling of NEV batteries (State Council, 2018). Table 3.9 shows the main contents of these measures. Also, LiB and nickel-hydrogen batteries are targeted for power batteries in this measure, and lead batteries are not targeted.

Table 3.9. Main Contents of Interim Measures, MIIT (2018) No. 43

Item	Content
Establishment of an extended producer responsibility system	NEV manufacturers are primarily responsible for recycling batteries.
Execution of product lifecycle management	Affiliates are responsible for all links to design, manufacture, sales, use, maintenance, disposal, recycling, usage, and the like.
Establishment of traceability information systems	Build a platform that links information to the battery code so that related companies can upload information in a timely manner.

Item	Content
Promote innovation in market mechanisms and recycling models	Encourage companies to explore new business models and support scientific and technological research on battery recycling.
Maximise the benefits of comprehensive utilisation of resources	In order to maximise the residual value of spent power batteries, the principle of first reusing and then considering recycling is followed.

NEV = new energy vehicle.
Source: MIIT (2018a).

In the same year, interim regulations on traceability management (MIIT, 2018a; 2018b) were published in accordance with the interim measures. Firstly, the government will build a 'traceability management platform' under which information on all processes of battery production, sales, use, disposal, recycling, reuse, and others will be collected, and the status of implementation of recycling will be monitored. Furthermore, NEV producers are also responsible for managing traceability. Each entity uploads the information shown in Table 3.10 to the platform and associates them with the battery code.

As of the end of February 2019, 393 automobile manufacturers, 44 scrappers, 37 cascade using companies, and 42 recyclers had joined the traceability platform (People's Daily Online, 2019). Furthermore, today, there are no companies that cover the entire value chains for these (ATCRR, 2020).

Table 3.10. Information to Upload to the Traceability Management Platform

Entity	Information
Automobile Manufacturer	Vehicle production, sales, repairs, replacements, battery replacements and disposal
Vehicle recycling and scrappers	Vehicle disposal
Ladder utilisation vendors	Battery ladder utilisation (destination, and others)
Battery recycling vendors	Battery recycling (type and amount and others of renewable resources)

Source: MIIT (2018b).

Also in the same year, a pilot project implementation plan (MIIT (2018) No. 68) for the recycling and use of batteries for NEV batteries was formulated because of the need to explore various recycling models that are technically and economically feasible when implementing the interim measures.

In 2019, a guideline for the installation and operation of recycling facilities for NEV batteries (MIIT, 2019, No. 46) was published. This guideline defines construction requirements, work requirements, safety and environmental requirements for recycling service outlets to be installed by operators producing and cascade-using NEVs. There are two types of recycling service outlets: They are the ‘collection-style’, which is a temporary storage and has a battery storage limit of 5 tonnes, and the ‘concentrated storage-style’, which is larger. In regions with more than 8,000 NEV company vehicles and regions where existing recycling service outlets do not have storage capacity and safety standards, the installation of the concentrated storage-style recycling service outlets is required. Recycling service outlets require the collection, sorting, storage, packaging, and shipping of used batteries, but disassembly of batteries for purposes other than safety inspections is prohibited (Yin, 2091).

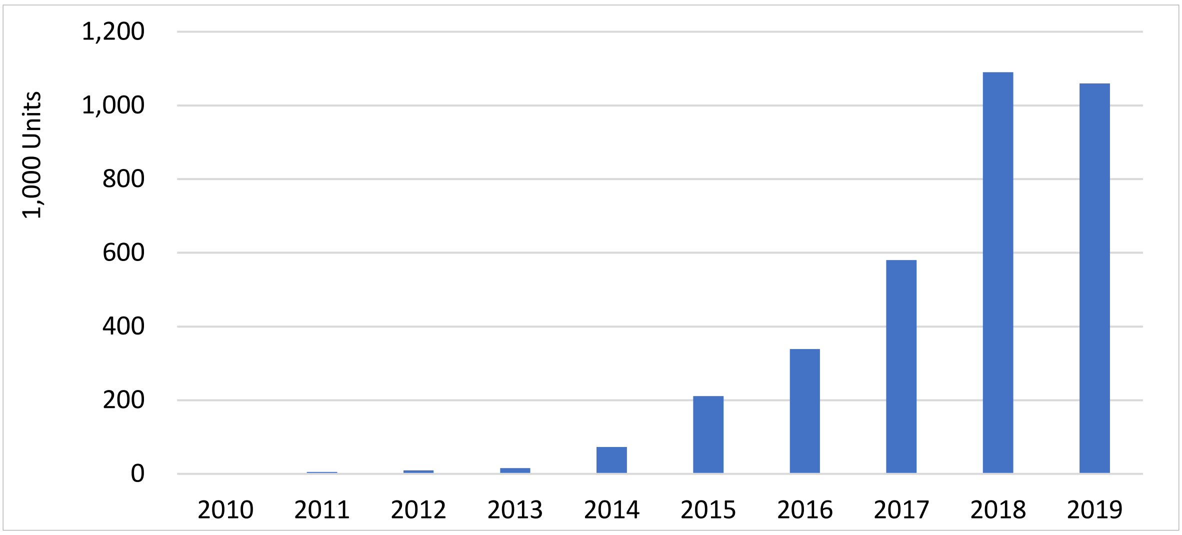
Currently, 45 NEV manufacturers have installed 3,204 recycling service outlets in 31 provinces (cities) across the country (ATCRR, 2020).

5.2. Current Status

- **EV and EV Battery Industry**

Figure 3.4 shows the historical sales of EVs (PHEVs and BEVs) in China. The number of EVs sold in 2019 was 1,060,000 units, accounting for 4.9% of new car sales. The number of EVs sold in 2020 showed a significant increase of +43% over the previous year worldwide (mainly driven by Europe), while China remained at 12% (Shahan, 2021).

Figure 3.4. New Vehicle Sales of PHEVs and BEVs in China



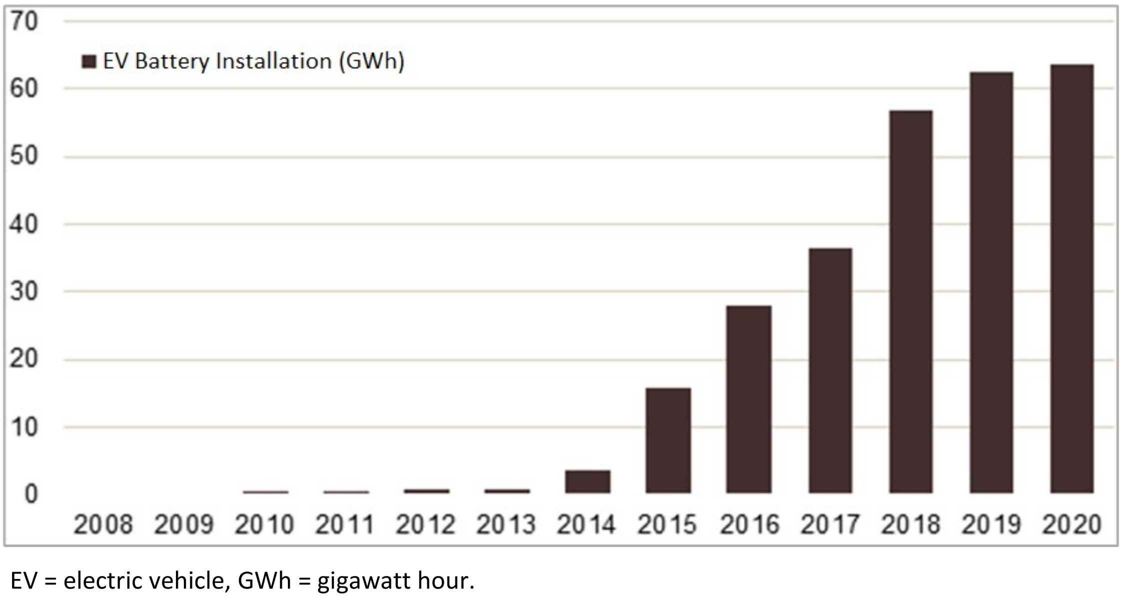
BEV = battery electric vehicle, PHEV = plugin hybrid electric vehicle.
Source: IEEJ created by IEA (2020).

When viewed by manufacturer, the top three NEV companies in China in 2020 were SAIC Motor Corporation Limited, BYD, and Tesla. SAIC Motor Corporation Limited (SAIC-GM-Wuling Automobile, which SAIC Motor Corporation owns the majority of shares and is funded by General Motors in the US) sold well with its small $4,200 EV (Wuling HongGuang Mini EV) launched in July 2020, ranking second after Tesla's model 3 in 2020. It has been pointed out that EV prices will continue to polarise in China, and sales of low-cost vehicles will increase in regional cities and rural areas, and sales of high-end, luxury cars will increase in large cities. In addition, with the move to EVs, China is accelerating its entry from different industries such as Baidu, DiDi, and Alibaba Group (Nikkei, 2021a; EV Sales, 2021; Nikkei, 2021b; Nikkei 2021c).

Regarding EV charging, in addition to normal charging at charging stations and at home, battery replacement services provided by Shanghai NIO Automobile hat incorporate the 'battery as a service' concept are well established in China. Against the backdrop of EVs' extended range and faster charging speeds, such services have become established in China, where private land ownership basically is not permitted, and where many people live in collective housing in urban areas, it can be difficult to charge at home. In August 2020, Shanghai NIO Automobile established an asset management company for EV batteries with four companies, including Contemporary Amperex Technology Co. Limited (CATL), and the newly-founded company will move into the concept of battery subscriptions (EV Smart Blog, 2020).

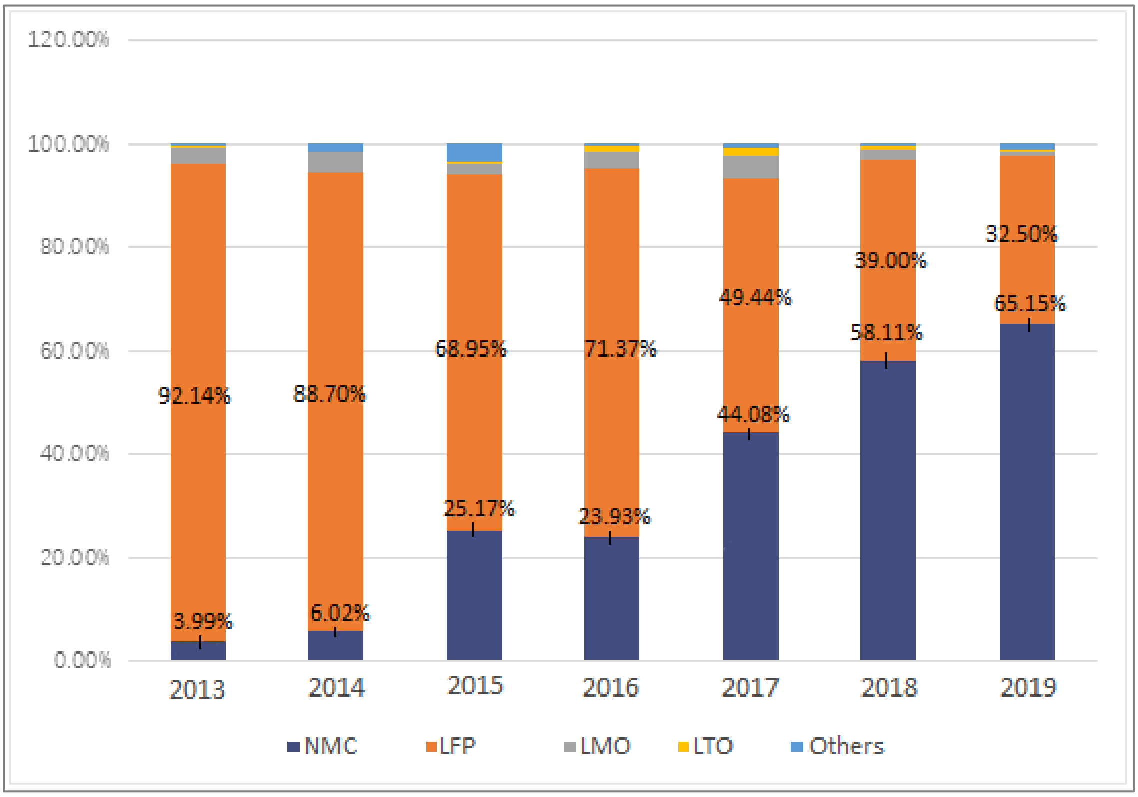
China has major automotive battery manufacturers such as CATL and BYD, and battery loads are increasing in proportion to the growth in EV sales (Figure 3.5). In 2019, the share of battery types (Figure 3.6) was 65% for ternary systems (lithium-nickel-manganese-cobalt-oxide, NMC) and 33% for iron phosphate (lithium-ion phosphate battery, LFP). The shares of NMC tend to increase. However, in recent years, Tesla has adopted LFP as part of the Chinese produced model of the Tesla Model 3, and there has also been a regression trend to LFP, which has an advantage in terms of price. While LFP, which is excellent in terms of safety, is suitable for cascade uses, NMC has a high content of rare metals such as nickel, manganese, and cobalt, and has high recycle value. Conversely, looking at the share of vehicle types (Figure 3.7), passenger cars accounted for 68% and buses for 23% in 2019. Previously, the share of buses with large batteries was large, but in recent years, the share of passenger cars has tended to increase. Battery manufacturers' share of supply is an oligopolistic market with 50.6% for CATL and 73.4% made up by three companies including BYD and Guoxuan High-Tech in 2019 (CAAM, 2020).

Figure 3.5. EV Battery Installation in China



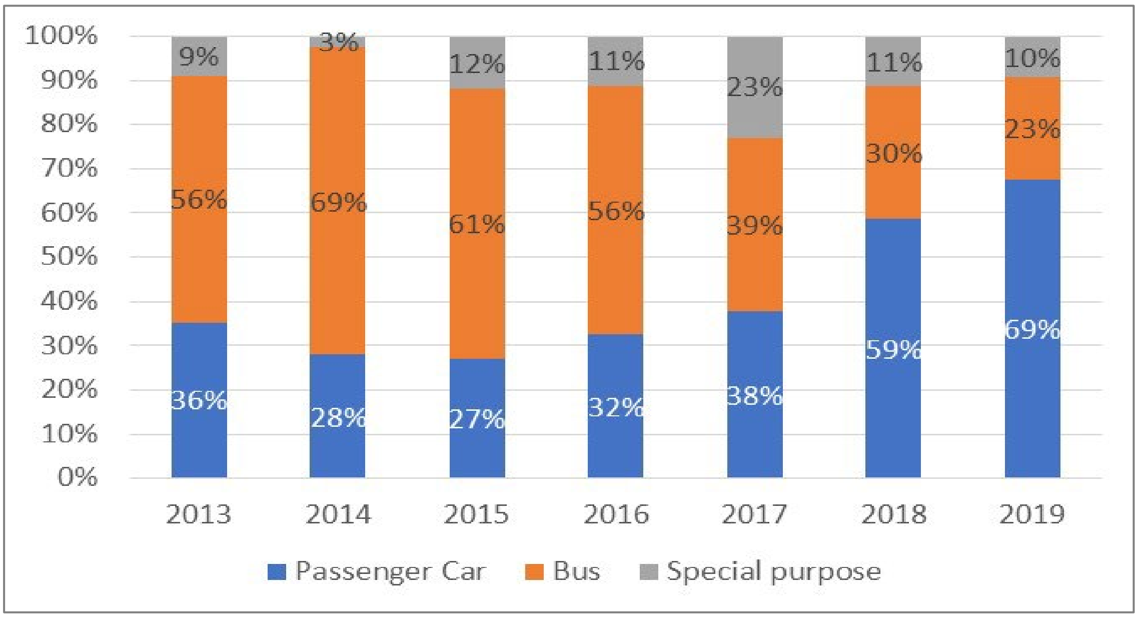
EV = electric vehicle, GWh = gigawatt hour.
Source: ATCRR (2021).

Figure 3.6. EV Battery Installation by Material Ratio in China



EV = electric vehicle, LFP = lithium-ion phosphate battery, LMO = lithium manganese oxide battery, LTO = lithium-titanate battery, NMC = nickel, manganese, and cobalt battery.
Source: CAAM (2020).

Figure 3.7. EV Battery Installation by Model Ratio in China



EV = electric vehicle
Source: CAAM (2020).

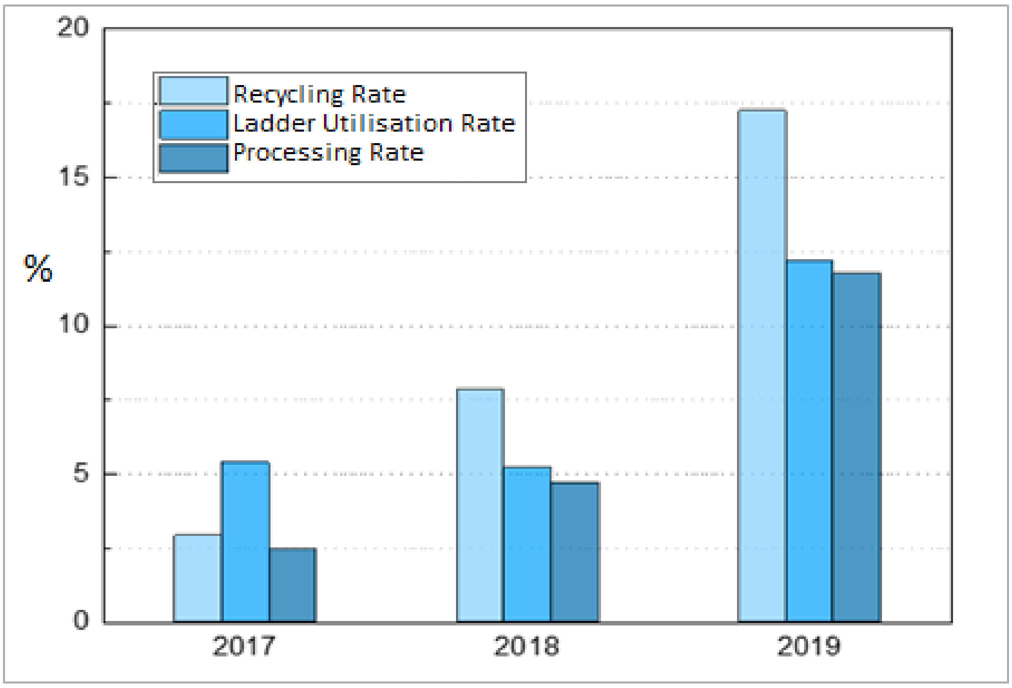
- **EV Battery Reuse and Recycling Industry**

Figure 3.9 shows the ecosystem of the EV battery reuse and recycling industry in China. Because automotive manufacturers are responsible for battery reuse and recycling under the extended responsibility of manufacturers because of the interim measures of 2018, they will have incentives actively to participate in each process, such as collection and residual value diagnosis and others.

Currently, businesses responsible for reuse and recycling EV batteries are broadly divided into two types. They are businesses established by automobile and battery manufacturers and businesses specialising in reuse and recycling. The former is primarily responsible for recycling batteries and has strengths in building recycling channels. The latter has strengths in recycling technology and experience; recycling and sales destination channels are improving.

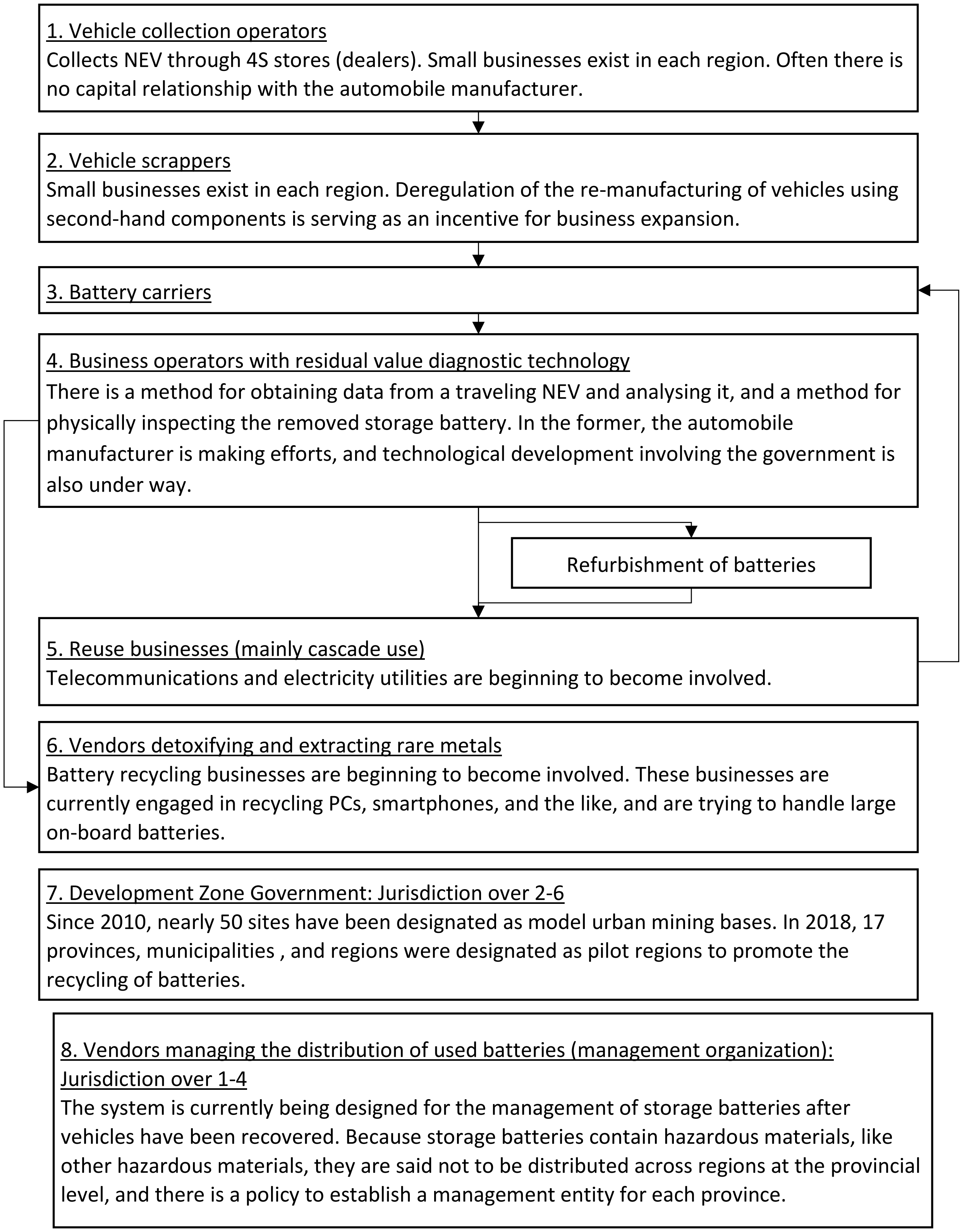
The Alliance of Technological Innovation in Compulsory Resources Recycling Industry, as part of a study commissioned by the National Development and Reform Commission, has conducted a performance evaluation related to the implementation of EV battery extended producer responsibility. According to a survey of 24 operators involved in the value chain (Figure 3.8), the recycling rate (see note below the figure), ladder utilisation rate, and processing rate in 2019 were 17.2%, 12.2% and 11.8%, respectively.

Figure 3.8. Total Recycling Rate, Ladder Utilisation Rate, Processing Rate of Power Batteries of the Applicant Enterprises



Note: Recycling is considered to mean 'the general term for the process of collecting, categorising, storing, and transporting waste/used automotive batteries' according to the definition of the term in the interim measures.
Source: ATCRR (2021).

Figure 3.9. Overview of the Ecosystem of EV Battery Reuse and the Recycling Industry in China



EV = electric vehicle, NEV = new energy vehicle.
Source: IEEJ created based on METI (2020).

- **Reuse Industry**

The main potential markets for cascading EV batteries are 12V and/or 24V car starter batteries, uninterruptible power supplies, energy storage systems, mobile power supplies, 36V and/or 48V electric motorcycle and bicycle batteries, and more (Shahan, 2021).

Telecommunications and electricity utilities are beginning to become involved as businesses. Regarding prices, it is assumed that reuse batteries will cost about one-third of new batteries and rebuilt batteries will cost about two-thirds of new batteries (IEA, 2020).

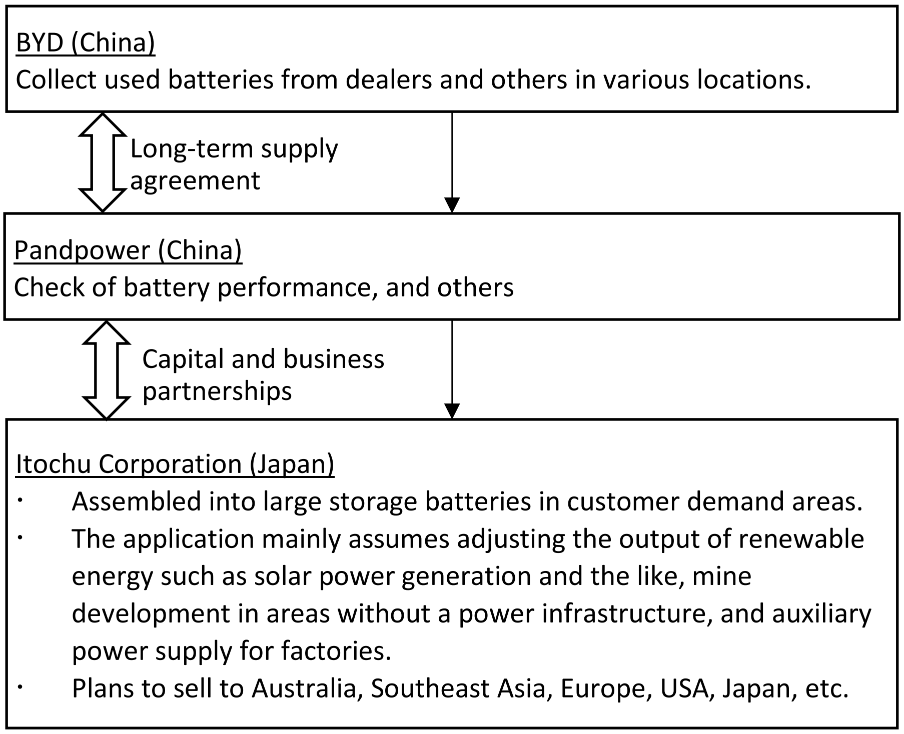
China Tower, the world's largest operator of communication towers, has been demonstrating the use of reuse batteries as a backup power source for base stations since 2015, and has received government support as a target company for pilot programmes since 2018. Furthermore, in the same year, it concluded partnerships with more than 16 major Chinese EV and battery manufacturers, including BYD. Traditionally, the backup power supply for base stations utilises lead batteries, which are costly and they are being replaced with second-hand LiBs. The price of reuse LiBs in China is about the same as that of lead batteries (approximately $100/kWh), and although second hand, they may be superior to lead storage batteries in terms of life and energy density. China Tower does not plan to purchase lead batteries after 2018 and claims it will replace all old lead batteries with reuse batteries in the future. The reuse potential is shown below (Na, 2018; Greenpeace, 2020).

- As of the end of 2019, China Tower uses more than 4.5 GWh of cumulative cascade batteries in 350,000 base stations
- Plans to replace 700,000 to 800,000 lead storage batteries in base station with lithium-ion batteries by 2020
- Overall, it operates nearly 2 million communication base stations with a potential of 54 GWh. 30 kWh per tower (= 1 EV battery pack), equivalent to 2 million EVs
- The popularisation of 5G is expected further to increase demand

Still further, the use for managing renewable energy power is being explored by electricity utilities.

The use of Chinese reuse storage batteries outside the country is also beginning to be considered. In the relationship with Japanese companies, Itochu and others will purchase batteries collected by BYD and re-build them to large storage batteries, and there are plans to sell to plants in Europe, the United States, and Asia in 2021 (Figure 3.10). The application mainly aims to adjust the output of renewable energy such as solar power generation, mine development in areas without a power infrastructure, and auxiliary power supply for factories. The price is below CNY150 thousand per kWh (a level that is 20%–30% cheaper than new industrial storage batteries). China's storage battery reuse start-up, Shenzhen Pandpower, will conduct performance inspections (Nikkei, 2020).

Figure 3.10. Flow of BYD Onboard Batteries Reused Overseas



Source: Created by IEEJ based on Pinegar and Smith.

- **Recycling Industry**

Raw material costs account for 50%–70% of total costs in battery manufacturing. With the rapid increase in battery production, primary resources are being rapidly consumed, while recycling is inadequate. Using cobalt as an example, between 2014 and 2016, primary ore resource production increased 4.75 times, while recycling increased only 0.23 times. According to expert calculations, in order to meet the current supply and demand balance of China's cobalt resources, the recycling rate must reach 90% or more (MIIT, 2018).

Table 3.11 shows an example of an EV battery recycling facility based in China. Currently, recycled batteries are mainly waste batteries generated in the process of research and development, and there are few used batteries in NEVs. In 2017, a total of approximately 11,000 tons of waste batteries were recycled and disposed. Of those, approximately 70%–80% was generated in the course of research and development. According to incomplete statistics, GEM, Brunp, and five other recycling companies have a planned processing capacity of about 250,000 tons. Some used batteries flow to other recycling companies through auctions, acquisitions, and other channels (ATCRR, 2020).

Table 3.11. Examples of EV Battery Recycling Facilities in China

Company	TRL level	Technology	Capacity (tonnes)
GEM High-Tech	Commercial	Mechanical and hydro	10,000
Brunp	Commercial	Mechanical and hydro	25,000–30,000

TRL = technology readiness level.
Sources: IEA (2020) created by Pinegar and Smith (2019) and Eduljee and Harrison (2020).

5.3. Issues and Hurdles

At the time of the announcement of interim measures in 2018, battery reuse and recycling had only just begun in China, and the Chinese government had organised the issues as shown below (State Council, 2018).

- Recycling system not established
  - Effective cooperation mechanisms have not been established between automobile manufacturers, battery production, and integrated use.
  - With regard to the implementation of an extended producer responsibility system, the relevant legal support must be further improved.
- Lack of technical capacity for recycling
  - Key common technologies and equipment breakthroughs, such as the ecological design of batteries, cascade utilisation, and efficient extraction of precious metals, are also needed.
  - There is a lack of standards for discharging, storing, and cascade-use batteries.
- Lack of guarantees for incentive policies and measures
  - The current recycling market for precious metals is not profitable because the technologies and markets are immature.
  - The associated fiscal and tax incentives are inadequate and market-based recycling mechanisms have not yet been established.

With regard to the establishment of the first point of the recycling system, the traceability system is operated by related companies, but the system only requires companies to report by themselves, and there is no official or third-party supervision or binding penalties. In some reports (Autohome, 2020), it was pointed out that 90% of batteries may have eventually flowed to informal recycling channels and could not be tracked by traceability systems (Zhang, et al., 2019).

As pointed out in the second and third points, the economy of scale does not work because the discharge of waste batteries is still low, and the cost of recycling is higher. In particular, economically feasible recycling technology is still lacking in the case of LFPs, which currently account for the majority of waste batteries. Recycling focuses on recovering cobalt and nickel in ternary materials, resulting in low lithium recovery rates (Shahan, 2021).

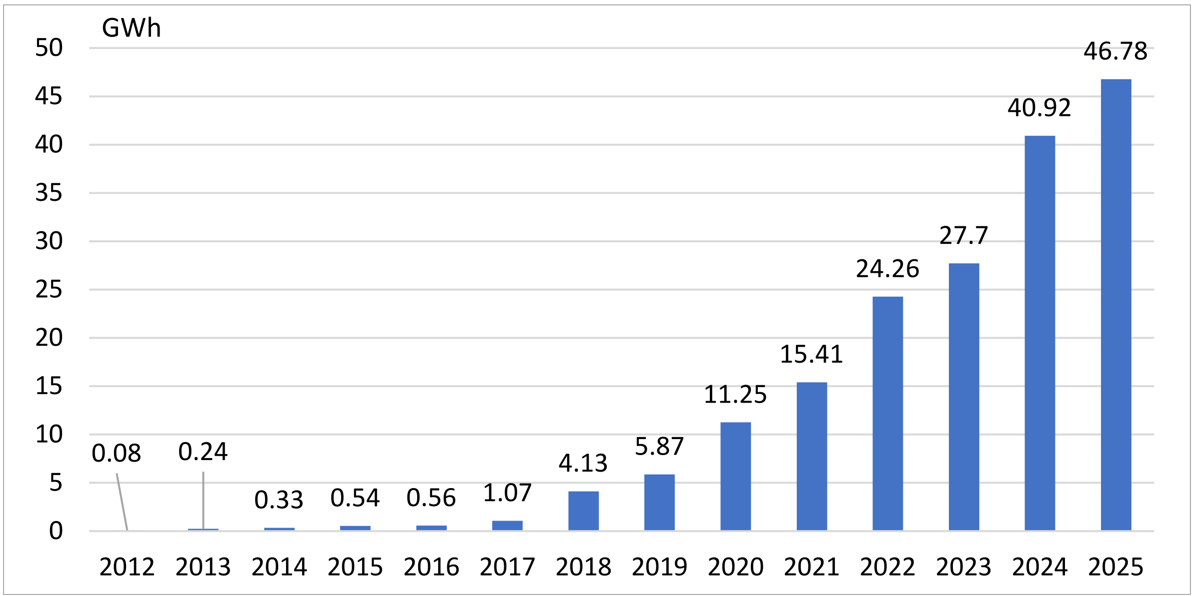
In addition, waste batteries pose safety risks because they are deteriorating. In January 2021, an explosion (Lee, 2021) occurred at a CATL-affiliated factory that operates LiB recycling business. Safety measures are required as a prerequisite for building the recycling and reuse industry.

5.4. Future Direction

Because the emissions of used batteries will increase rapidly in China in the future (Figure 3.11), it is believed that the expansion of the market scale, stricter regulation and operation over the life-cycle, performance inspection and recycling, and other related technical standards can continue to be strengthened.

Worldwide, it is expected that most of the used EV batteries supplied in the coming years will come from China. With regard to demand, applications in base stations as backup power sources in China account for a majority for now, but the potential for energy storage systems and charging stations is expected to grow in the future (Melin, 2018).

Figure 3.11. Estimation of the Amount of Retired Power Batteries for NEVs



GWh = gigawatt hour, NEV = new energy vehicle.
Source: ATCRR (2021).

In October 2020, the State Council announced the New Energy Vehicle Industry Development Plan (2021–2035) (Government of China, 2020). In this plan, the vision was expressed to reduce the average power consumption of BEVs in new vehicles to 12.0 kWh/100 kilometres by 2025, and to increase the sales ratio of NEVs to new vehicles from approximately 5% to approximately 20%. It was also mentioned to promote the development of the entire value chain of power batteries. The following viewpoints were described (NEDO, n.d.).

- Encourage companies to improve their ability to secure critical resources such as lithium, nickel, diamonds, platinum, and others.

- Construct and maintain a modularised power battery standard system, accelerate the progress of core manufacturing equipment, and increase technical standards and production efficiency.
- Develop recycling systems for the recovery, cascade-use, and recycling of power cells to encourage the joint construction and use of recycling channels.
- Establish and maintain a management system for all stages of power battery transportation, warehousing, repair and maintenance, safety inspection, retirement/withdrawal, collection, use, and the like, and strengthen the management and supervision of the entire life cycle.
- Ensure the implementation of an extended producer responsibility system, strengthen the construction of a power battery traceability management platform for new energy vehicles, and achieve traceability of the entire life cycle of the power battery.
- Support innovative applications of power cell cascade products in fields such as energy storage, energy reserves, charging, replacement and the like, and strengthen research and development of technologies such as residual energy measurement, residual value evaluation, reconfiguration and utilisation, and safety management.
- Optimise systems for the recycling industry, promote efficient extraction of valuable elements in used power batteries, and promote the development of industrial recycling, high added value, and greening.

In October 2020, the China Society of Automotive Engineers, commissioned by the Ministry of Industry and Information Technology, also released the Energy Saving Vehicles and New Energy Vehicles Technology Roadmap 2.0, a report showing the direction of energy-saving and new energy vehicles until 2035. In this roadmap, the following five items were indicated as specific goals for 2035 (JETRO, 2020).

- Increase the proportion of NEVs to 50% or more of the number of automobile sales
- Increase the proportion of net electric vehicles to 95% or more of the sales of new energy vehicles
- Set the number of fuel cell vehicles to approximately 1 million
- Commercial cars implement a model change to hydrogen power
- Make all passenger cars with traditional energy (such as gasoline or the like) power hybrid vehicles

6. Conclusions

In summary, approaches to the reuse of waste EV batteries differ by country and region.

The EU places the reuse of EV batteries in the context of establishing a circular carbon economy, and 'transparency' of the health of EV batteries is the key for its approach. A carbon footprint declaration will be required. 'Battery passports' linked to the information about the characteristics of each battery type and model provide valuable data to recyclers and second-life companies. These batteries will have to comply with minimum recycled content thresholds.

Japan, in addition to the unique efforts of automobile manufacturers, the industry group, the Japan Automobile Manufacturers Association, Inc., has also launched a joint collection network.

Preparations are under way to increase the number of reused EV batteries in the future. In addition, the Council for Electrified Vehicle Society and the Ministry of Economy, Trade and Industry, composed of electric power companies and automobile manufacturers, formulated 'Providing Information Guideline of In-vehicle Battery Performance' in June 2020, thereby clarifying specific measurement methods.

In China, the government will build a 'traceability management platform' under which information on all processes of battery production, sales, use, disposal, recycling, reuse, and others will be collected, and the status of implementation of recycling will be monitored.

The United States has not established regulations at the Federal level, while reuse and recycling regulations for EV lithium-ion batteries operate at the state level.

Based on the understanding over the issues/hurdles for the reuse of EV batteries, implications can be drawn to ensure the following.

- **Health and safety**: Monitoring mechanisms should be in place to understand the health and safety of EV batteries at the time of operation.
- **Technology**: Research and development (R&D) should be made to evaluate the performance of waste batteries.
- **Regulatory**: Regulatory requirements for manufacturers and owners should clearly formulate and strengthen the construction of a power battery traceability management platform for new energy vehicles and achieve traceability of the entire life cycle of the power battery.
- **Economic**: R&D should be encouraged to lower the cost of repurposing waste EV batteries. Large-scale implementation such as grid storage using repurposed batteries, and also identification of some small-scale projects – such as battery systems at distributed energy systems or other purposes as street lighting would need to be implemented simultaneously.

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Chapter 4

Reuse of Electric Vehicle Batteries: Economic Viability and Environmental Impacts

1. Introduction

This chapter investigates the economic viability of reused electric vehicle (EV) batteries. Comparison will be made in terms of projected sales price of reused EV batteries and new ones. The chapter also gain insights on the environmental implications of reuse of EV batteries. The chapter also provides a case study on the real practice of EV battery reuse, to draw implications for ASEAN countries.

2. How to Refurbish EV Batteries

As the previous chapter described, under the BEV ambitious scenario, as much as 2,166 gigawatt hours (GWh) of waste from reusable batteries from EVs will be available in the Asian market. Meanwhile, the gap between the stationary usage for flexibility adjustment and supply from used EVs will be substantial – the need for stationary backup batteries for the Indochinese Peninsula and the Malay Peninsula would be 500–600 GWh. This gap implies the importance for ASEAN countries to create the value chain of reusing the waste batteries.

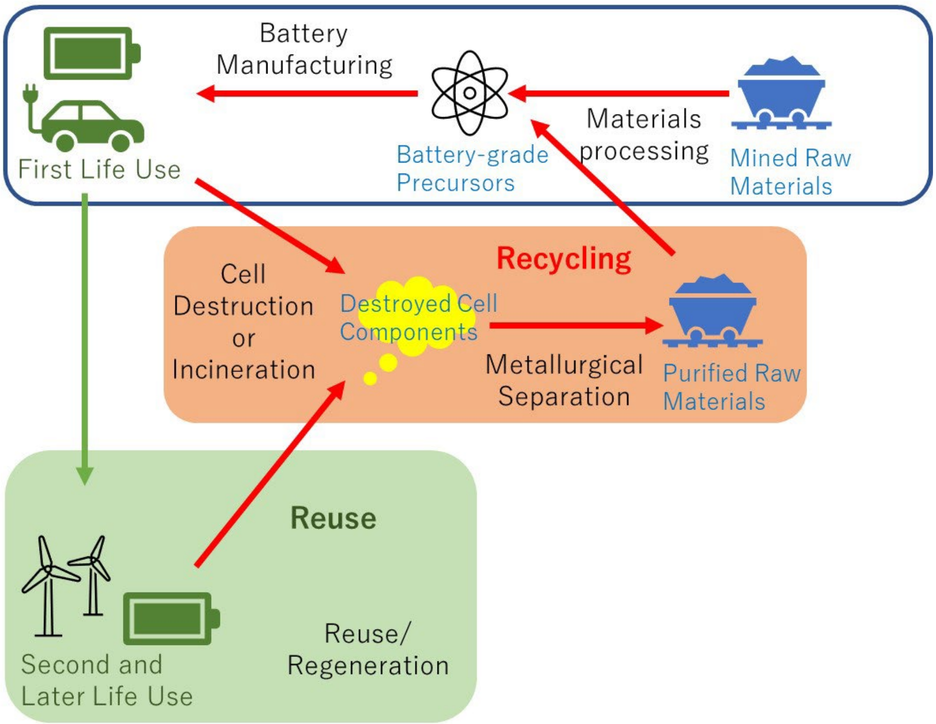
It is often described that EV batteries when the remaining capacity reaches 70%, would have to be replaced for safety reasons. Then how to establish a system that can allow the reuse of EV batteries? Figure 4.1 describes the reuse and recycling of EV batteries. As shown in the figure, the reuse is to refurbish the batteries for the other purposes. The reused batteries are also recycled after its end of life, to metallurgical separation of materials into raw materials such as cobalt, nickel, and lithium.

Depending on the quality of waste batteries, some of them will be directly placed into the recycling process to obtain raw materials.

The waste batteries could be reused into:

- reuse in EVs
- reuse in other battery applications (such as street lighting, elevators, wheelchairs, etc.)
- stationary energy storage for residential coupled with rooftop photovoltaic (PV) panels
- stationary energy storage for commercial and industry sector
- grid scale energy storage

Figure 4.1. EV Battery Reuse and Recycling Process



EV = electric vehicle, kWh = kilowatt hour.
Source: The Institute of Energy Economics, Japan (2021).

Some examples of reused batteries are listed in Table 4.1.

Table 4.1. Examples of Reused Battery Applications

Company	EV Battery Reuse Application	Location
Acceleron	Energy storage	United Kingdom
Audi	Forklifts and factory tugs	Germany
Audi	Energy storage	Germany
BJEV	EV charging and backup power	
BMW	Energy storage farm	Germany
Box of Energy	Stores energy from roof top solar panels to run elevators and lights	Sweden
BYD	Grid scale energy storage, backup power	
Chevrolet	Backup power at GM's Data Centre	United States
Daimler	Grid scale energy storage, commercial and industrial energy storage	
Hyundai	Grid scale energy storage	
Honda/American Electric Power	Grid integration of energy storage	

Company	EV Battery Reuse Application	Location
Nissan/Eaton/Mobility House	Energy storage	Netherlands
Nissan/Sumitomo	Street lighting	Japan
Nissan/Sumitomo	Large-scale power storge	Japan
Renault	Renewable storage	
Renault	Backup power for elevators	France
Toyota		
Toyota	Reuse of Prius hybrid batteries to run refrigerators in 7-Eleven stores	Japan
Volkswagen	Mobile charging station	Germany

Sources: Stringer and Ma (2018); Circular Energy Storage (2019).

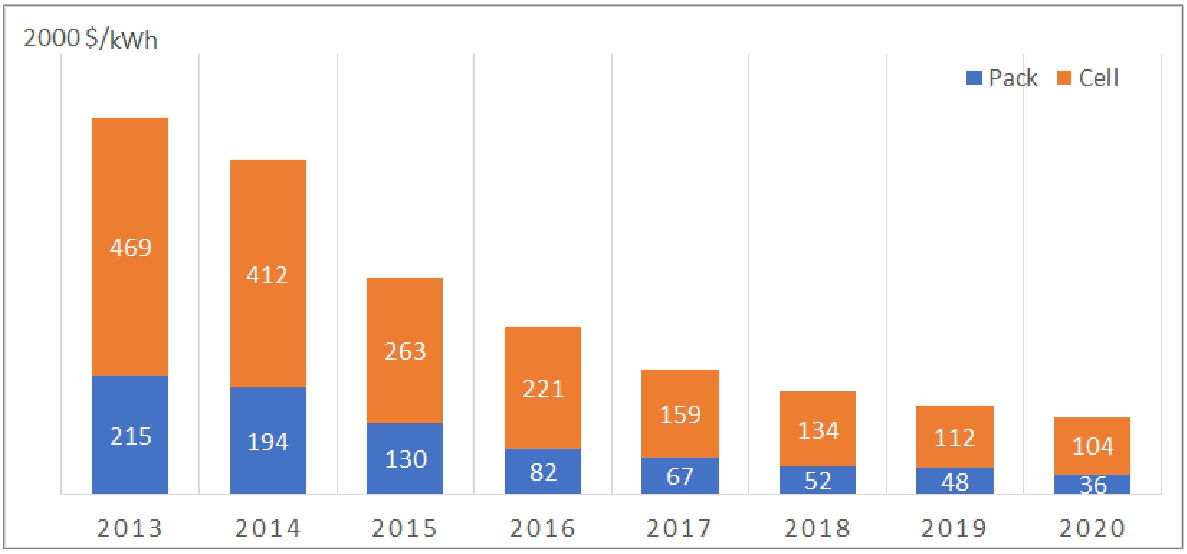
3. Economic Perspectives of Refurbishing EV Batteries

It is important to understand the cost of refurbishing EV batteries. Recently, the price of new batteries has substantially declined for increasing number of order, and new pack design (BNEF, 2020). Therefore, the economic viability of refurbished EV batteries depends on its competitiveness against new one – which is a challenging task for those companies engaged in the business as they would have to ensure operational safety in refurbished batteries, long-economic life at the same time.

The cost of EV battery packs declined substantially from $1,100 per kilowatt hour (kWh) in 2010 to $137 per kWh in 2020. This represents 86% reduction in 10 years as shown in Figure 4.2.

Despite the substantially reduction, EV batteries are the most expensive part in EV, as it utilises the rare metals. The cathode typically contains lithium ion and anode utilises a mix of graphite, and electrolytes. Typically, the cost share of battery pack and cell represents nearly 30%–50% of total EV costs.

Figure 4.2. Volume-weighted Average Pack and Cell Price Trends



kWh = kilowatt hour.
Source: BNEF (2020).

To understand the future economic viability of refurbished batteries, this section offers the estimation of the future cost of lithium-ion batteries. To estimate the cost, a learning curve analysis method is utilised. The basic concept of a learning curve analysis is that as the quantity of production units double, the cost of producing a unit is decreased by a constant percentage. For example, an '80%' learning curve implies that cost associated with the incremental output will decrease to 80% of their previous level (or 20% reduction from the previous level).

The learning curve can be explained as follows.

$$Y = AX^b$$

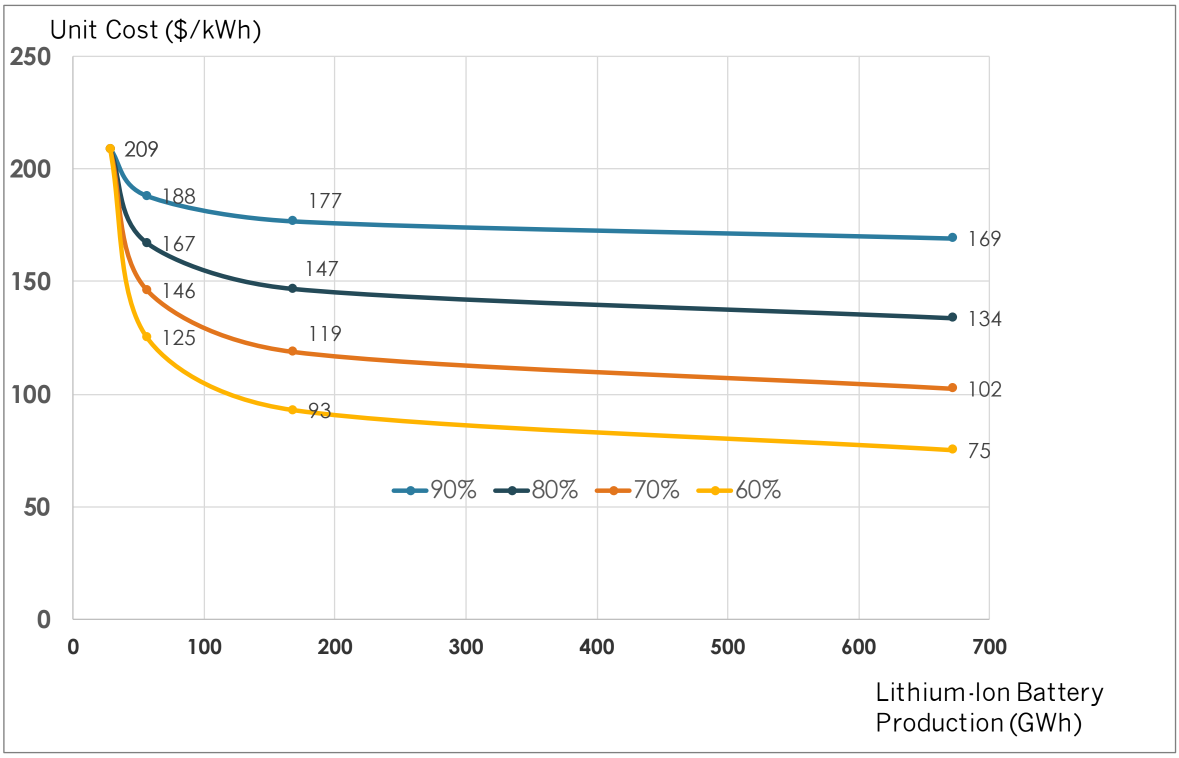
Y = average cost of unit X

A = the first unit cost

X = unit number (cumulative volume)

b = slope coefficient = $\dfrac{\log(\textit{slope of the learning curve})}{\log 2}$

Figure 4.3. Example of Lithium-ion Battery Cost Estimates using the Learning Curve

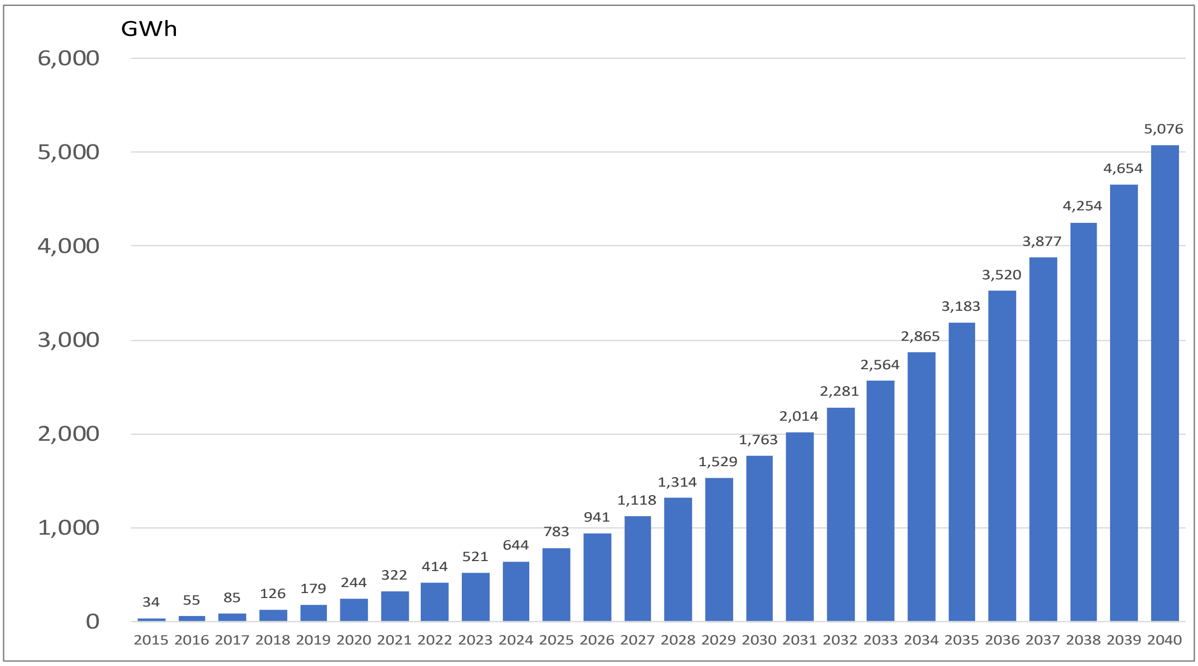


GWh = gigawatt hour, kWh = kilowatt hour.
Source: The Institute of Energy Economics, Japan (2018).

Figure 4.3 shows the example of lithium-ion battery cost estimates using the learning curve. As the figure shows, at different learning rate assumptions of 60%, 70%, 80%, and 90%, the estimated cost per kWh differs when the production units double. For example, at the assumption that lithium-ion battery module production doubles from the current 28 GWh to 56 GWh, the cost is estimated to decrease from $209/kWh to $167/kWh at the learning rate of 80%. With further doubling the production to 168 GWh, the cost is estimated to represent $147/kWh at the same learning rate.

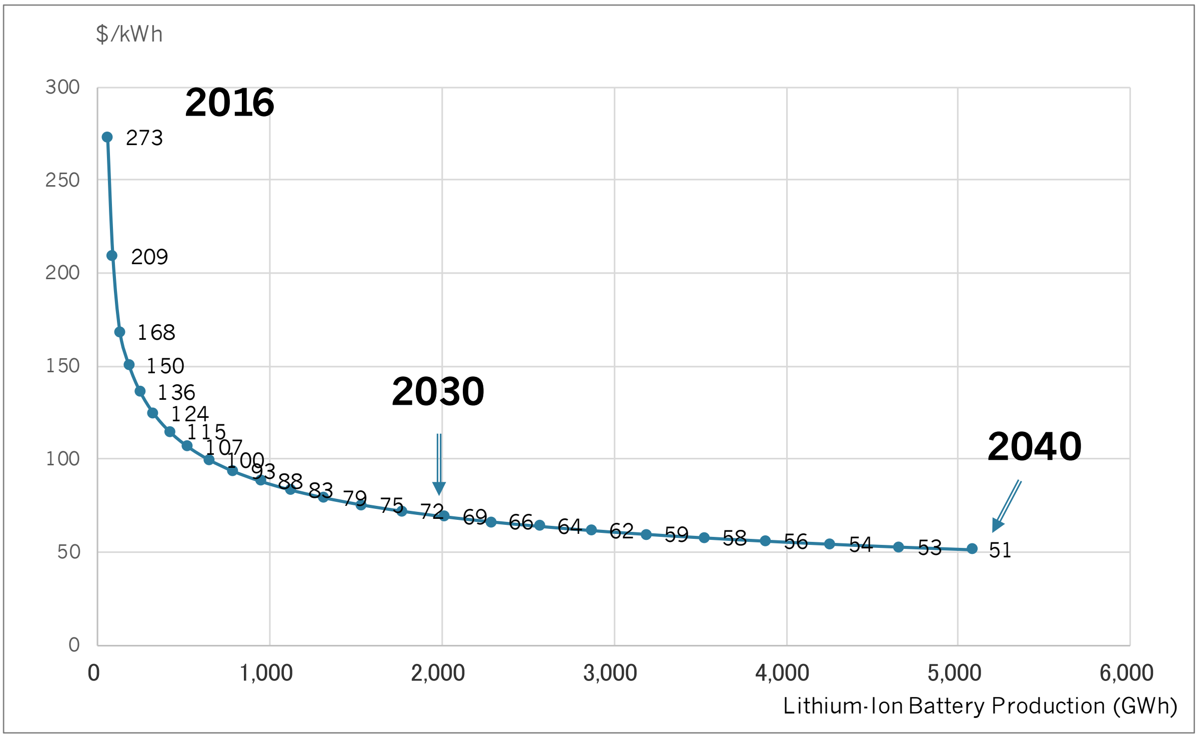
The cost estimate depends on the future production volume of lithium-ion battery modules. For this analysis, the IEEJ's outlook for lithium-ion battery modules (required to meet the future demand for hybrid vehicles, PHEV, and EV) is utilised. The assumption is being made that the 30% of total vehicle sales would be EVs by 2030, and 100% of vehicle sales would be EVs in 2050. With this analysis, the total lithium-ion battery production volume would reach cumulative level of 5,076 GWh by 2040 in contrast to mere 34 GWh in 2014.

Figure 4.4. IEEJ's Global Outlook for Lithium-Ion Battery for HEVs, PHEVs, and EVs (Cumulative)



EV = electric vehicle, GWh = gigawatt hour, HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: The Institute of Energy Economics, Japan (2017), World/Asia Energy Outlook.

Figure 4.5. Estimated Cost of Lithium-Ion Battery (2016–2040)



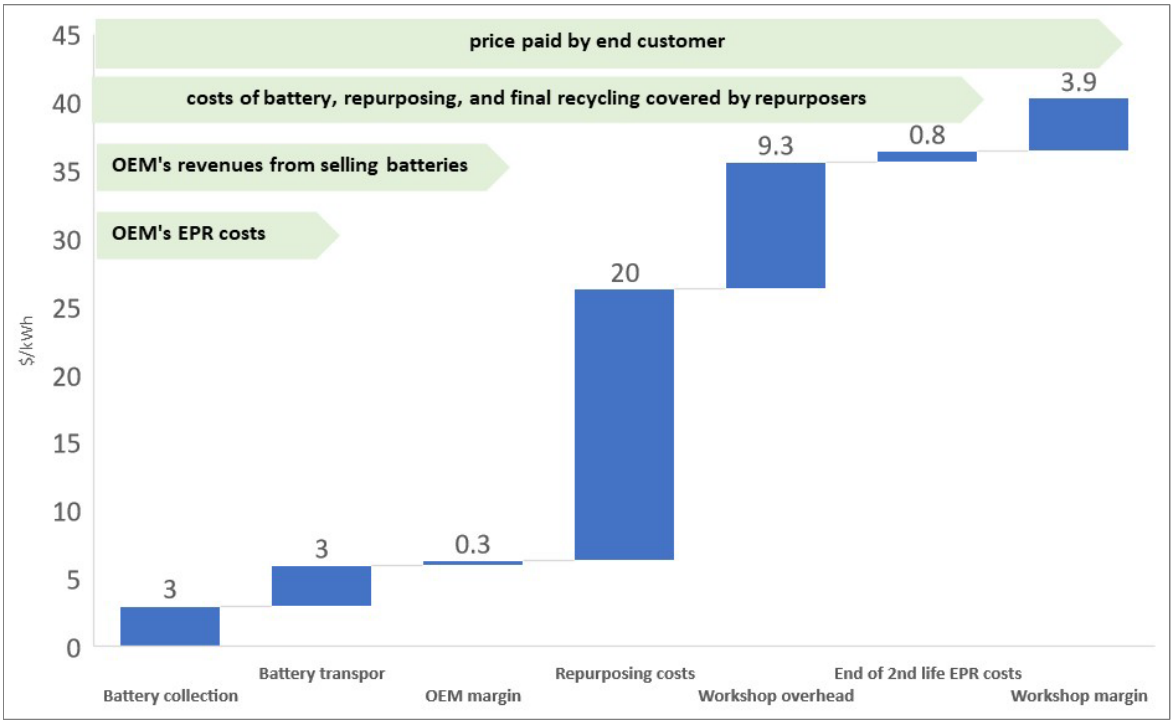
Source: The Institute of Energy Economics, Japan (2018).

Figure 4.5 shows the estimated cost of lithium-ion battery module by 2040. The figure shows the estimated relationship between the cumulative production of lithium-ion battery by 2040 and corresponding module cost per kWh. As the figure shows, the cost would decline to reach $72/kWh by 2030, and further reduced to reach $51/kWh in 2040.

Elementenergy has estimated the cost of repurposed batteries. The repurposing process in this analysis includes a series of process cost for: dismantling of the battery pack, potential separation and/or replacement of module, and reassembly into new packs. Then this will be purchased by end-customers (Elementenergy, 2019).

According to the analysis, the estimated price by end-customer for repurposed batteries will be $40.4/kWh in 2030, including battery collection, battery transport, original equipment manufacturer margin, repurposing costs, workshop overhead, end of 2nd life extended producer responsibility (EPR) costs, and workshop margin. Repurposing costs represent the biggest share – representing half of the overall price, followed by workshop overheads.

Figure 4.6. Price Breakdown of a Repurposed Battery Placed on Market in 2030



EPR = extended producer responsibility, kWh = kilowatt hour, OEM = original equipment manufacturer.
Source: Elementenergy (2019).

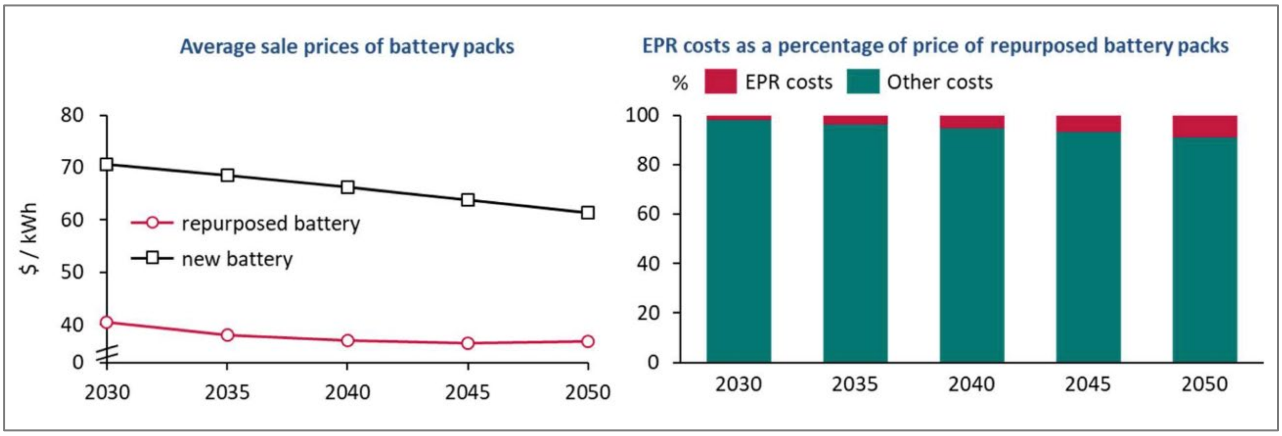
The same study by Elementenergy estimates the price of repurposed batteries up to 2040. The price is expected to slightly decrease up to 2040 – reaching $35/kWh. The reduction is likely to results from the volume build-up as shown in the left side of the Figure 4.7.

Meanwhile, it is important to note that the cost share of EPR will increase up to 2050. In 2030, the EPR share to the final price is estimated at 2%, while it is expected to exceed 9% in 2050. This is because of the need for larger volumes for exhausted second-life batteries. Despite the increasing

EPR costs, the cost of collection fees, repurposing fees, improvements in logistics, and process efficiency with scale will maintain the price of repurposed batteries at $35/kWh.

The study projects the sales price of new battery at $70/kWh – similar to the IEEJ's analysis and this is expected to continue declining to reach $60/kWh in 2050. As this shows, the repurposed battery's price will remain the lower level to that of new ones – nearly 42% price gap is expected to continue.

Figure 4.7. Average Sale Prices of Battery Packs (left) and EPR Contribution towards End Repurposed Pack Costs (right) – Baseline Recycling Case and Baseline EV Uptake



EPR = extended producer responsibility, EV = electric vehicle, kWh = kilowatt hour.
Source: Elementenergy (2019).

4. Environmental Impacts of Refurbishing EV Batteries

In view of the future growth of the EV sales, and to effectively utilise the rare materials, repurposing would be the important option. Meanwhile, the lifecycle assessment of the impacts of repurposing is necessary to understand the appropriate applications.

For the purpose of estimating the environmental impacts of applying reuse batteries, a study by Bobba, Mathieux, and Blengini (2018) compares the reference scenario and repurposed scenario for those three configurations (A, B, and C) specified in Table 4.2. The analysis is conducted to understand the life cycle assessment of (i) cumulative energy demand (CED), (ii) abiotic depletion potential, mineral resources (ADP-res), (iii) global warming potential (GWP), and (iv) human toxicity cancer effect (HTc).

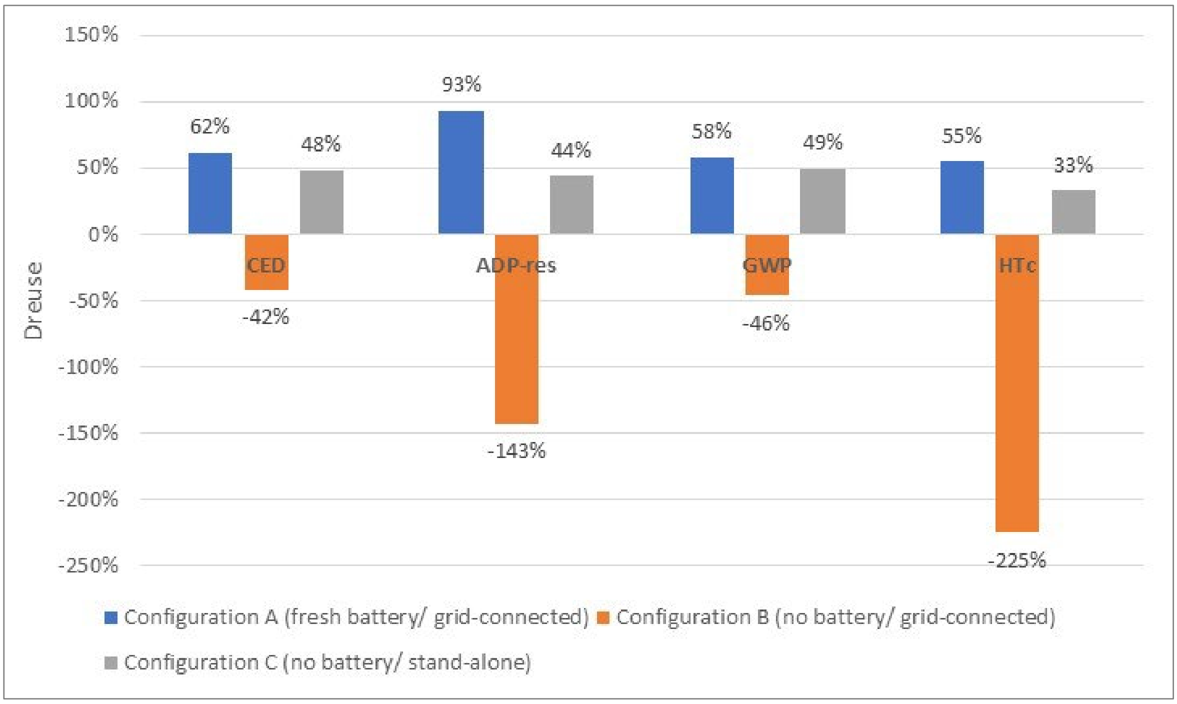
The scenarios are developed to consider the application of repurposed lithium-ion batteries for a residential household with PV installation. Amongst the reference scenario, configuration A represents the case is grid-connected house with 'new' lithium-ion battery, and configuration B assumes grid-connected house without lithium-ion battery. The configuration C is non-grid connected house with diesel generator.

Table 4.2. Main Characteristics of the Examined Scenario

Configuration	Reference Scenario	Repurposed Scenario
A	• Grid-connected house • PV installation • Fresh lithium-ion battery storing PV energy	• Grid-connected house • PV installation • Repurposed lithium-ion battery storing PV energy
B	• Grid-connected house • PV installation • No battery storage system	• Grid-connected house • PV installation • Repurposed lithium-ion battery storing PV energy
C	• Stand-alone house • PV installation • Diesel-electric generator used to satisfy the energy demand not met by PV	• Grid-connected house • PV installation • Repurposed lithium-ion battery storing PV energy

PV = photovoltaic.
Source: Bobba, Mathieux, and Blengini (2018).

Figure 4.8. Benefits of EV Battery Reuse by Configuration



CED = cumulative energy demand, ADP=res = abiotic depletion potential, mineral resources, GWP = global warming potential, and HTc = human toxicity cancer effect, EV = electric vehicle.
Source: Bobba, Mathieux, and Blengini (2018).

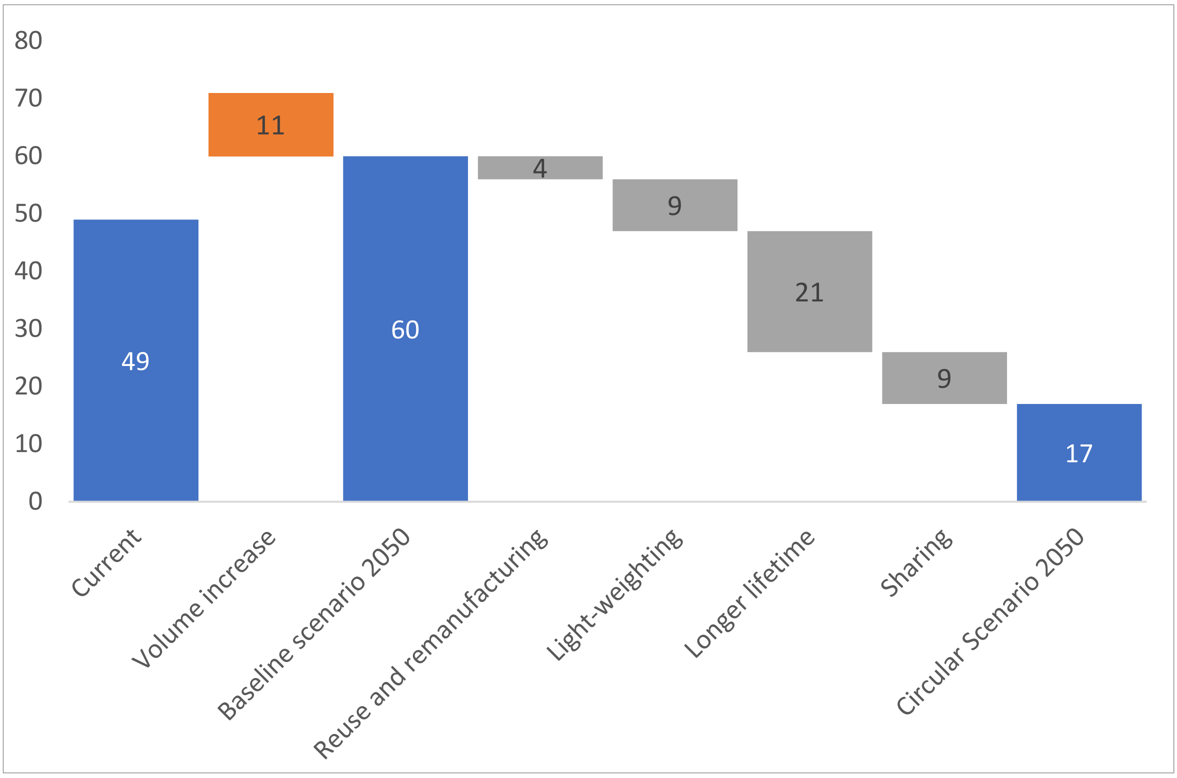
The analysis result is expressed as D-reuse. For example, D_{reuse}, GWP of 10% means that reusing the EV battery in energy storage would reduce 10% of the life cycle global warming potential compared with reference scenario.

For configurations A and C, life cycle impacts of reusing EV batteries can generate positive benefits in terms of CED, ADP-res, GWP, and HTc. As the effective utilisation of mineral resources, the highest benefits can result from configuration B, for ADP-res, representing 93%. Energy savings impacts would be substantial as represented by CED, in configuration A – reaching 62%. The contribution to GWP reduction potential is substantial especially for configuration A at 58%.

In contrast, configuration B – with the assumption of no installation of lithium-ion-battery under the reference scenario – has a negative impact from the application of reused battery. Naturally, additional energy, and resources utilisation would result in negative impacts on GWP. Meanwhile, caution needs to be paid for the impact assessment on health denoted as HTc because the analysis concludes lack of data and evidence would require further efforts for data collection, and assessment.

The magnitude of CO_2 emissions reduction from the reuse and/or recycling would be put in the context of other manufacturers' efforts for light-weighting, longer lifetime, and introduction of sharing services. A study by Material Economics (2018) offers the analysis based on scenario on the potential of EVs CO_2 emissions reduction from materials required to support mobility. As Figure 4.9 shows, EVs offer potential for 70% of CO_2 emissions reduction from baseline scenario in 2050. The biggest contribution would come from longer lifetime of vehicles, followed by light-weighting/sharing and reuse and remanufacturing.

Figure 4.9. CO_2 Emissions from Materials Fall by 70% in a Circular Scenario



Source: Material Economics (2018).

Table 4.3. Main Characteristics of the Examined Scenario

	Reference Scenario
Reduced weight per vehicle	• Lower average vehicle size in a shared car system, better matching vehicles to actual trip needs • Advanced design and materials choices
Reuse and remanufacturing	• Reduced waste in vehicles production • Modular design and replacement of components with limited lifetime • Increase reuse of durable components at end of life • Controls over inventory and flows in a fleet-managed system of shared cars
Sharing	• Large increase in utilisation in a shared-car system • Higher occupancy per vehicle with mobility as a service
Longer lifespans	• More intensive use increases incentives for durable design • Electric drivetrains with intrinsically better durability • Proactive maintenance of fleet-managed vehicles • Modular design to enable replacement of components with shorter lifespans

Source: Material Economics (2018).

5. Example of EV Battery Reuse: 4R Energy (Japan)

This section explores the cases of a business model and feasibility study on the reuse of EV batteries.

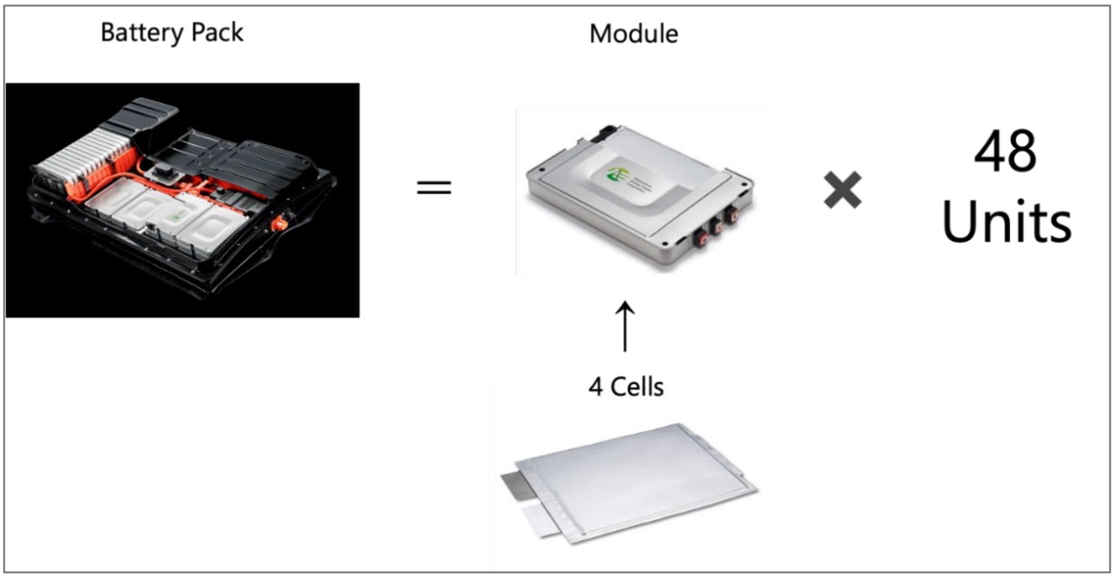
4R Energy is a joint venture between Nissan and Sumitomo Corp., established in 2010. The company utilises used batteries from the Nissan LEAF, and repurposes them for various applications, including for EV batteries, small EVs, large-scale storage, factory backup storage, and others shown in Figure 4.10.

Figure 4.10. 4R Energy's Applications of Used EV Batteries

EV = electric vehicle.
Source: 4R Energy (2018). https://www.4r-energy.com (accessed June 2021).

For the repurposing, it is important to assess the quality of the battery. The EV battery pack consists of 48 units of modules. Each module consists of four cells; therefore, even if the performance of one cell deteriorates, it affects the overall performance of the EV module. Therefore, after the end of the 1st life of EVs, 4R Energy collects the pack and evaluates the performance of each cell.

Figure 4.11. Composition of EV Battery Pack



EV = electric vehicle.
Source: Nissan (2018), https://ev2.nissan.co.jp/BLOG/474/

On 9 February 2021, the 4R Energy Corporation and East Japan Railway announced the use of repurposed batteries from the Nissan LEAF for the backup stationary batteries at railway crossings (East Japan Railway and 4R Energy, 2021). This backup battery is utilised at the time of railway crossing maintenance or electricity supply disruption. Interestingly, the backup battery has a longer lifetime – compared with the conventional lead battery, with lower cost, smaller space, and lighter weight.

Table 4.4. 4R Energy's Applications of Used EV Batteries

	Previous	Repurposed Battery
Type	• Lead battery	• Lithium-ion battery
Charing time	• 70 hours	• 24 hours
Lifetime	• 3–7 years	• 10 years
Cost	• -	• Maximum 40% lower than new one
Maintenance	• On-site monitoring	• Remote monitoring system
Space/Weight	• 530 mm×270 mm×470 mm/108 kg	• 480 mm×250 mm×430 mm /55 kg

kg = kilogramme, mm = millimetre.
Source: East Japan Railway and 4R Energy (2021).

6. Conclusions

As this chapter shows, various options are available to reuse the waste batteries from EVs. The options include reuse in EVs, reuse in other battery applications (such as street lighting, elevators, wheelchairs, etc.), stationary energy storage for residential coupled with rooftop PV, stationary energy storage for the commercial and industry sector, and grid scale energy storage.

Understanding the health of EV batteries is the key for establishing a value chain of waste batteries. The business practice by 4R Energy shows the interesting illustration that the health of batteries would be monitored from the time of operation in EVs. The company's evaluation and/or classification depending on the quality would provide multiple reuse options from high-quality, middle-quality, and relatively low-quality options of which utilisation frequency is only for emergency backup purposes.

The reuse of EV batteries would remain an economically viable option in future despite the observed substantial reduction of EV batteries pack price. From 2016 to 2020, the EV batteries average pack price has been lowered from $273/kWh in 2016 to $137/kWh in 2020. The IEEJ analysis shows that the new EV batteries' pack price is projected to reach $51/kWh with the assumption of 20% learning rate. Meanwhile, a study by Elementenergy shows that the sales price of reused EV batteries is likely to remain lower in future compared with that of new ones. The estimated sales price of reused EV batteries is likely to be somewhere around $35/kWh.

Caution needs to be paid in the assessment of future sales price of EV batteries. The sales price should depend on the quality. Currently, 4R Energy's sales price – available from media information – of reused EV batteries at $115/kWh is 16% lower than the global average price of new batteries at $137/kWh, as the former includes applications require high performance for reuse in EVs. It has to be also considered that the availability of waste batteries is small currently, but it is expected to increase from 2030 to reflect the higher uptake of EVs.

The environmental benefits of EV batteries reuse is important from policymaking purposes. A study that compares the environmental benefits of reused EV batteries generate positive performance for (i) energy savings, (ii) mineral resources savings, (iii) greenhouse gas emissions reduction, and (iv) health impacts. Nevertheless, careful planning should be required because reuse of EV batteries does not necessarily generate positive benefits if it is compared with the replacement for grid-connected electricity supply.

It is also important to put the reuse of EV batteries in a broader context to genuinely understand the benefits of EVs on the environment. For example, in terms of the magnitude of CO_2 emissions reduction, the largest contributions in future – under the decarbonised generation mix – would come from the operational stage, followed by light-weighting/sharing, which would be followed by the contributions from reuse and/or recycling benefits. Again, policy coordination is essential to plan for obtaining maximum environment benefits from EVs, from generation mix planning, designing, operation, and reuse and/or recycling.

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Chapter 5

Recycling and Reuse of Appliances Outside ASEAN

1. Introduction

This chapter discusses the recycling and reuse of appliances in the European Union (EU), the United States (US), Japan, and China. These practices are offered to draw implications for electric vehicle (EV) battery reuse policymaking in Association of Southeast Asian Nations (ASEAN) countries.

2. European Union

2.1. Overview of Directive on Waste Electrical and Electronic Equipment

In the EU, the purpose of the Directive on Waste Electrical and Electronic Equipment (WEEE) is to control the generation of WEEE, promote reuse and recycling, and reduce the amount of WEEE. By reducing the amount of WEEE, member countries and producers are required to build a WEEE collection and/or recycling system. It is required that producers should bear the cost based on the principle of producer responsibility, that is, the person who manufactures an environmentally-friendly product bears the cost of processing (recovery, recycling, reuse).

A revision was made to this directive in 2012 (European Parliament, 2012). The previous directive required member governments to meet the collection target of 4 kilograms per person. Meanwhile the collection target was revised that by 2016, 45% of the annual average weight of electrical and electronic equipment sold in the previous 3 years would have to be met, and by 2019, 65% of the average annual weight of electrical and electronic equipment sold over the previous 3 years, or 85% of the total weight of WEEE would have to be met. According to the European Commission, the 2019 recovery target is equivalent to about 20 kilograms of WEEE per person.

The categories covered in this directive are:

1. Temperature exchange equipment (such as air conditioners and refrigerators),
2. Screens, monitors, and equipment containing screens having a surface greater than 100 square centimetres (cm^2)
3. Lamps
4. Large equipment (any external dimension more than 50 cm) including, but not limited to:

   household appliances; information technology (IT) and telecommunication equipment; consumer equipment; luminaires; equipment reproducing sound or images, musical equipment; electrical and electronic tools; toys, leisure, and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; and equipment for the generation of electric currents. This category does not include equipment included in categories 1 to 3.

5. Small equipment (no external dimension more than 50 cm) including, but not limited to:

   household appliances; consumer equipment; luminaires; equipment reproducing sound or images, musical equipment; electrical and electronic tools; toys, leisure, and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents. This category does not include equipment included in categories 1 to 3 and 6.

6. Small IT and telecommunication equipment (no external dimension more than 50 cm)

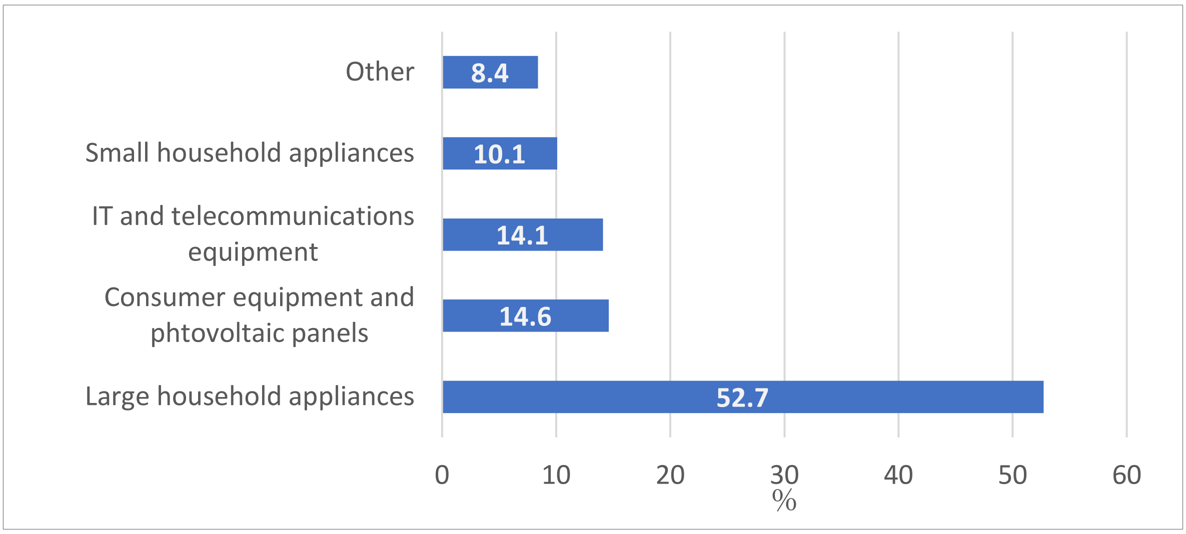
However, the definition of 'producer' in this directive is to resell products manufactured by other suppliers under their own brand, as well as those established in member countries that manufacture and sell WEEE under their own brand. This includes those who import to the EU on a commercial basis (both established in the member countries), and those established in the member countries or outside the EU for the purpose of selling directly to general households and other users via the Internet, etc.

Aside from the collection target, the directive has set out recovery and recycling targets for each product categories, ranging from 75% to 85% recovery rate, and from 55% to 80% of recycling rate.

2.2. Status of Collection Rate under WEEE

Eurostat records the status of collection of electronic and electrical equipment waste (e-waste) in the EU, as well as the recycling rate of these collected electronic and electrical equipment. As Figure 5.1 shows, of the total collected ones, large household appliances represent the largest at 52.7%, followed by consumer equipment and photovoltaic panels at 14.6%. The other product categories, such as electrical tools and medical devices, altogether account for only 7.2% of the collected e-waste which shows a challenging situation in the EU market (European Parliament, 2021a).

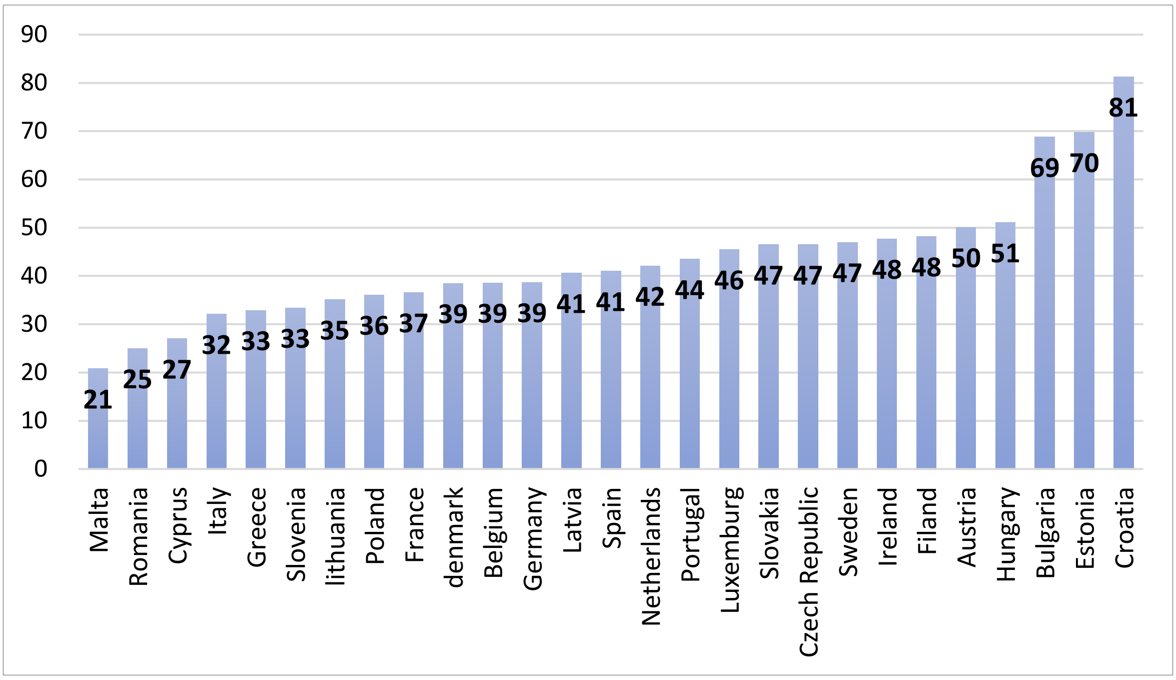
Figure 5.1. Share by Product Category in Total Collected Electronic and Electrical Waste in the European Union



Source: Eurostat (2020).

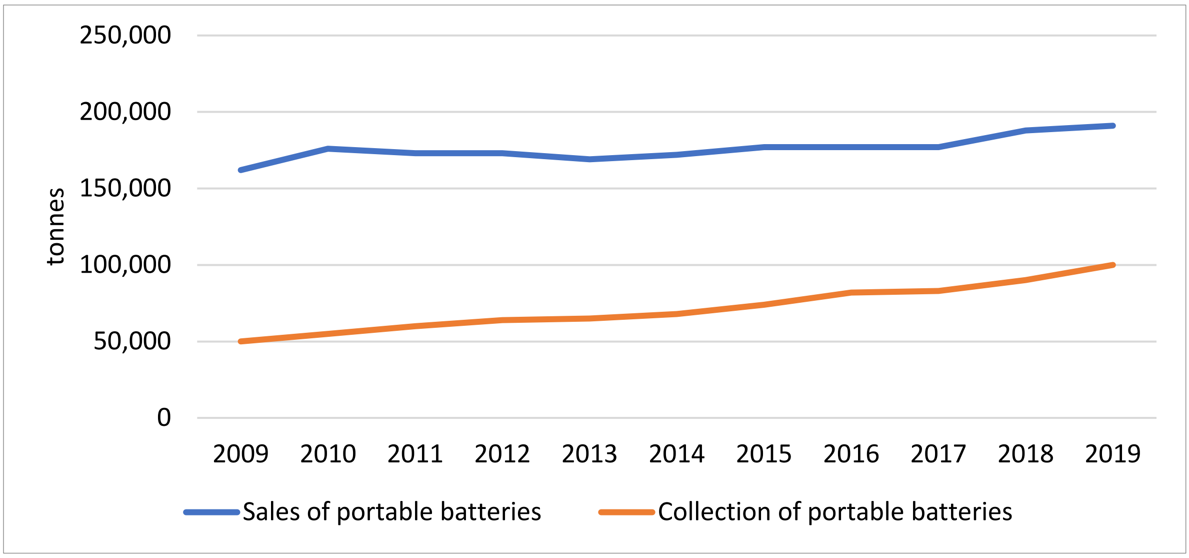
Figure 5.2 shows the recycling rate of e-waste in the EU. The overall recycling rate was less than 40%.

Figure 5.2. Recycling Rate of e-Waste in the European Union in 2017



Source: Eurostat (2020).

Figure 5.3. Sales and Collection of Portable Batteries and Accumulators, EU-27, 2009–2018



Source: Eurostat (2020).

Figure 5.3 shows the sales and collection of portable batteries in the EU from 2009 to 2018. The collection rate has improved from 31% in 2009 to 46% in 2018. To significantly improve the collection and recycling of portable batteries, a proposal on the new battery directive has been in place so the rate should rise to 65 % in 2025 and 70% in 2030. The European Commission's idea is that other batteries – industrial, automotive, or electric vehicle ones – have to be collected in full for the purpose of recovering valuable materials such as cobalt, lithium, nickel, and lead. (European Commission, 2020).

2.3. Future Direction: Towards the Establishment of a Circular Economy

It is recognised in the EU that recycling for e-waste sector is lagging behind production. In the global context as well, recycle rate reached 20% of total generated e-waste at 44.7 million metric tonnes (European Parliament, 2021a).

According to a Eurobarameter survey, 77% of EU citizens would repair their devices rather than replace them; 79% think that manufacturers should be legally obliged to facilitate the repair of digital devices or the replacement of their individual parts (Taylor, 2020).

The European Commission issued a new circular economy plan in March 2020. The proposal specifically outlines immediate goals like creating the 'right to repair' and improving reusability in general, the introduction of a common charger, and establishing a rewards system to encourage the recycling of electronics (Taylor, 2020).

Discussion is ongoing in the EU that is in line with the Circular Economy Action Plan. Members of Parliament stress the need to establish biding 2030 targets for material use and consumption footprint for covering the whole life cycle of each product category (European Parliament, 2021b).

Particularly, it is under discussion that broadening the scope of the Ecodesign Directive to include non-energy-related products. In other words, in the notion that the products durability should be determined at design phase, the Ecodesign Directive requires manufacturers to design energy consuming product to reduce energy consumption at its lifecycle basis. New rules on Ecodesign Directive are expected to be in place in 2021 (European Parliament, 2021c). Also, waste reduction targets for specific streams and other measures on waste prevention will be formulated in 2022 (European Commission, n.d.).

3. United States

3.1. Overall Waste Management System

In the United States, the Resource Conservation and Recovery Act (RCRA), enacted in 1976, is a federal law that establishes a national waste management system. RCRA targets are broadly classified into non-hazardous waste specified in Subtitle D and hazardous waste specified in Subtitle C. For non-hazardous waste, the RCRA sets minimum standards for federal waste landfill sites, while state governments are the main body for planning, regulation, and implementation, and can set more stringent standards. The management of hazardous waste is positioned under a comprehensive federal programme that is strictly controlled cradle-to-grave, which obliges the US Environmental Protection Agency (EPA) to develop standards to identify hazardous waste, standards, and requirements applicable to generators, transporters, and treatment, storage, and disposal facilities. However, it is authorised to delegate the development and implementation of specific programs to state governments (with the exception of Alaska and Iowa, where implementation authority is granted for all states) (EPA, n.d.).

To protect energy and natural resources, one of the RCRA's objectives, the EPA encourages recycling of whatever is possible, even hazardous waste, through a regulatory approach that is commensurate with the degree of hazard. Amongst other things, the five types of hazardous waste (batteries, pesticides, mercury-containing equipment, lamps, and aerosol cans) that can be found widely, including in general household items, are defined as universal waste, and regulations such as handling is relaxed to promote its recycling (EPA, n.d.).

3.2. Appliance Recycling

In the United States, there is no federal law equivalent to the EU's Waste Electrical and Electronic Equipment Directive. Twenty-five states including California and others, plus Washington, DC, have enacted and enforced their own recycling laws covering waste electronic equipment such as televisions and computers that are discarded from homes. The first Waste Electronics Recycling Act in the United States was enacted in California in 2003. Recyclable devices vary from state to state, but the big five, namely TVs, desktops, laptops, monitors, and printers are targeted in many states. For the target entities, households and consumers are targeted in all states, but the coverage of companies and public facilities is different. Regarding program funds, a method of some form of extended producer responsibility (EPR) has been adopted in states other than California, and manufacturers are collecting and recycling targeted devices that come from general households, small businesses, and the like, free of charge, at their own expense. Conversely, California operates the programme at a rate paid by consumers when they purchase targeted devices (ERCC, n.d.).

Also, under the Waste Management Hierarchy in the United States, landfill disposal is a last resort, and 19 states (ERCC LandFill Ban Map) including those that have not enacted recycling laws, prohibit landfill disposal of waste electronic equipment.

3.3. Battery Recycling

For battery management, the Mercury-Containing and Rechargeable Battery Management Act (the Battery Act) was enacted in 1996 as a federal law to phase out the use of mercury-containing batteries and to define the recycling of nickel-cadmium and certain small, sealed lead-acid rechargeable batteries. This act targets battery and product manufacturers and battery waste handlers and stipulates that uniform labelling requirements must be established and that batteries can be removed easily from products. Furthermore, batteries covered by the Battery Act are subject to universal waste rules throughout the United States under the RCRA (Call2 Recycle website).

In addition, 20 states have enacted their own battery recycling laws. For example, California enacted the California Rechargeable Battery Recycling Act in 2006. This act requires retailers to accept rechargeable batteries (including lithium-ion batteries, LiBs) contained in electronics, etc. from consumers free of charge for reuse, recycling, and appropriate disposal. If such a system is not in place, retailers are prohibited from selling batteries in California (Department of Toxic Substances Control).

LiBs are not covered by the Battery Act. For that reason, it is not clear whether they are universal waste under federal law, but they may meet RCRA-based hazardous waste definitions if they exhibit properties such as ignitability, reactivity, toxicity, and others, at the time of their disposal. Although the determination of whether an individual LiB is hazardous waste should be made by the operator that emits the waste, this determination may be difficult because of different properties depending on the chemical composition and the amount of charge remaining. For that reason, the EPA recommends that operators treat the LiB under the universal waste regulations. Conversely, LiBs is subject to the Hazardous Materials Regulations of the Department of Transportation (DOT) and must be treated as hazardous materials when transported. On the EPA website, it is recommended to contact the battery purchaser, such as a dealer or scrap collection facility, when disposing of automotive LiBs (EPA website).

4. Japan

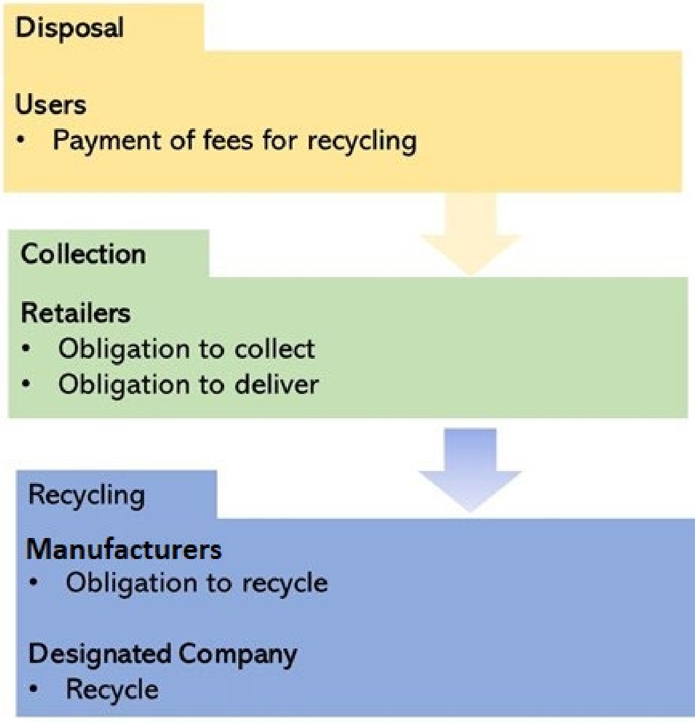
4.1. Legal System

For household appliances discarded from Japanese households, manufacturers, and others (manufacturers and importers) are required to recycle four items of household appliances under the Home Appliance Recycling Law and the Small Home Appliance Recycling Law, and business operators are required to implement the reduce, reuse, recycle (3R) initiatives for 10 industries and 69 items under the Law for the Promotion of Effective Utilization of Resources. In addition, the End-of-Life Vehicles Recycling Law mandates that automobile manufacturers and the like actively recycle and properly dispose of used automobiles.

- **Home Appliance Recycling Law**

The Home Appliance Recycling Law covers four home appliances: air conditioners, televisions (CRT, flat-panel), refrigerators and freezers, washing machines, and clothes dryers (which account for approximately 80% of the weight of all home appliances). Manufacturers and others (manufacturers and importers) are required to recycle the four home appliances that have been discarded. Manufacturers and others must separate the recovered parts and materials and make them available for use as parts or raw materials of the products themselves or for transfer (recycling) to persons who use them as parts or raw materials of the products for a fee or free of charge. Manufacturers and others are required to achieve a recycling rate (the amount of recycled goods/the weight of waste appliances to be treated) of at least a certain amount as a recycling standard for the four appliances. Figure 5.4 shows an overview of the system; Table 5.1 shows recycling criteria; Figure 5.5 shows the actual recycling rate.

Figure 5.4. Outline of Home Appliance Recycling Law



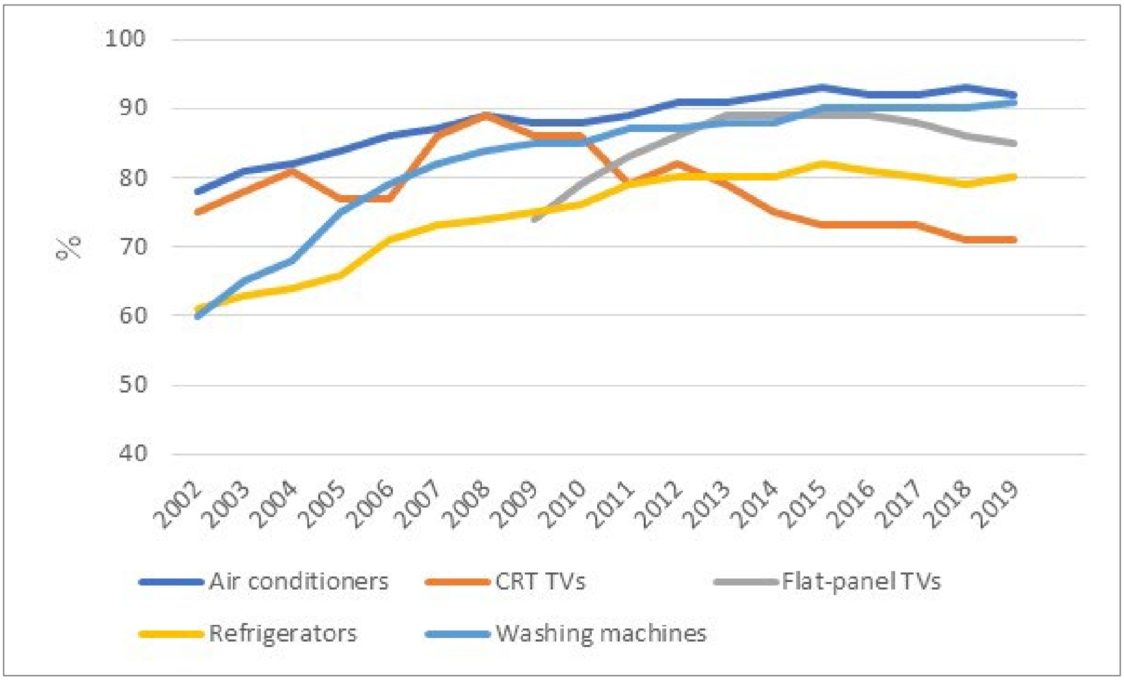
Source: The Institute of Energy Economics, Japan.

Table 5.1. Recycling Target

		From April 2001	From April 2009	From April 2015
Air conditioners		60%	70%	80%
TVs	CRT	55%	55%	55%
	Flat-panel	-	50%	74%
Refrigerators and freezers		50%	60%	70%
Washing machines and dryers		50%	65%	82%

TV = television, CRT = cathode ray tube.
Source: Ministry of the Environment.

Figure 5.5. Trend of Home Appliance Recycling Rate (%)

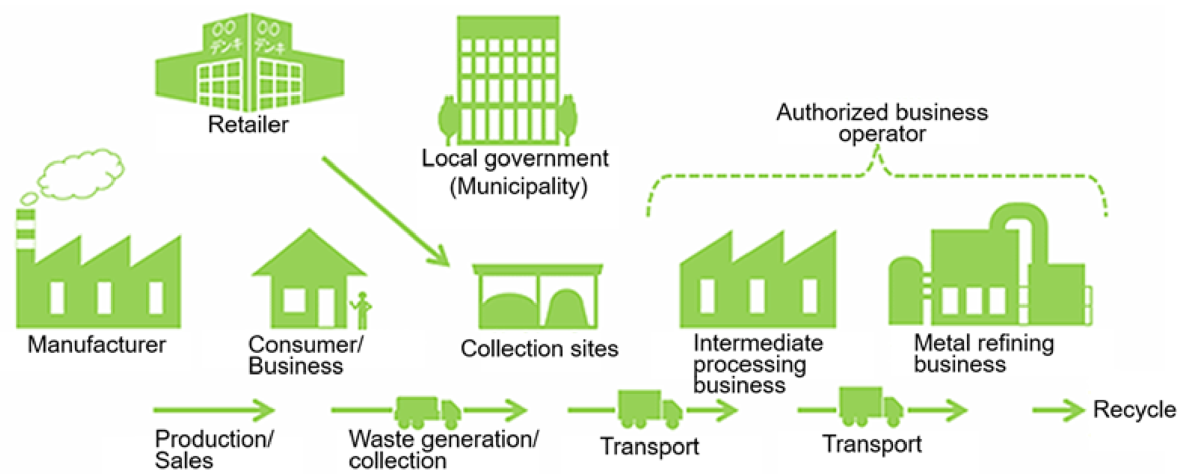


CRT = cathode-ray tube, TV = television.
Source: Association for Electric Home Appliances. (http://www.aeha-kadenrecycle.com/effort/#a_03)

- **Small Home Appliance Recycling Law**

In order to promote the recycling of small, used electronic devices and the like such as digital cameras and game consoles, the Small Home Appliance Recycling Law is a system that defines special exceptions concerning the licensing for certified waste disposal businesses following recycling business plans. Figure 5.6 is an overview of the system.

Figure 5.6. Process of Recycling End-of-life Small Home Appliances



Source: National Institute for Environmental Studies.
(https://www-cycle.nies.go.jp/eng/column/page/202005_01.html)

- **Law for the Promotion of Effective Utilization of Resources**

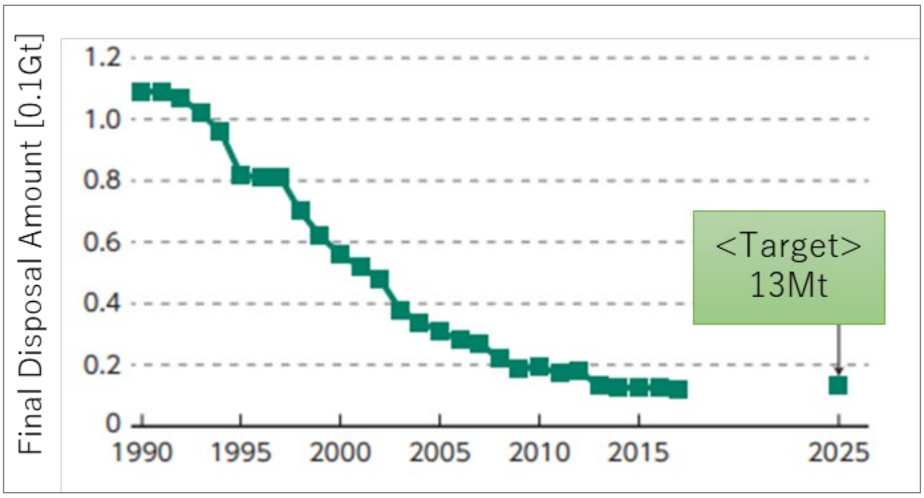
Business operators are required to undertake the reduce, reuse, recycle (3Rs) initiatives for 10 industries (pulp, steel manufacturing, chemistry, automotive manufacturing, and others) and 69 products (computers, small secondary batteries, and others covering approximately 50% of general and industrial waste) as target industries and products under this law.

Of these, the recovery and recycling of small secondary batteries (NiCad batteries, nickel-metal hydride batteries, nickel hydrogen storage batteries, lithium batteries, and sealed lead-acid batteries) is mandatory for manufacturers and others. Recycling rates are set at 60% or more of NiCad batteries, 55% or more of nickel-metal hydride batteries, 30% or more of lithium batteries, and 50% or more of sealed lead-acid batteries, respectively, to promote recycling. In 2018, with regard to the recycling status of small secondary batteries (including for mobile telephones), the processing amount of NiCad batteries was 739 tons (recycling rate 71.7%), the processing amount of nickel-metal hydride batteries was 204 tons (76.6%), the processing amount of lithium batteries was 337 tons (57.4%), and seal lead-acid batteries was 572 tons (50.0%). Furthermore, the actual recycling rate of each has achieved legal goals.

4.2. Final Disposal of Waste and Material Flow

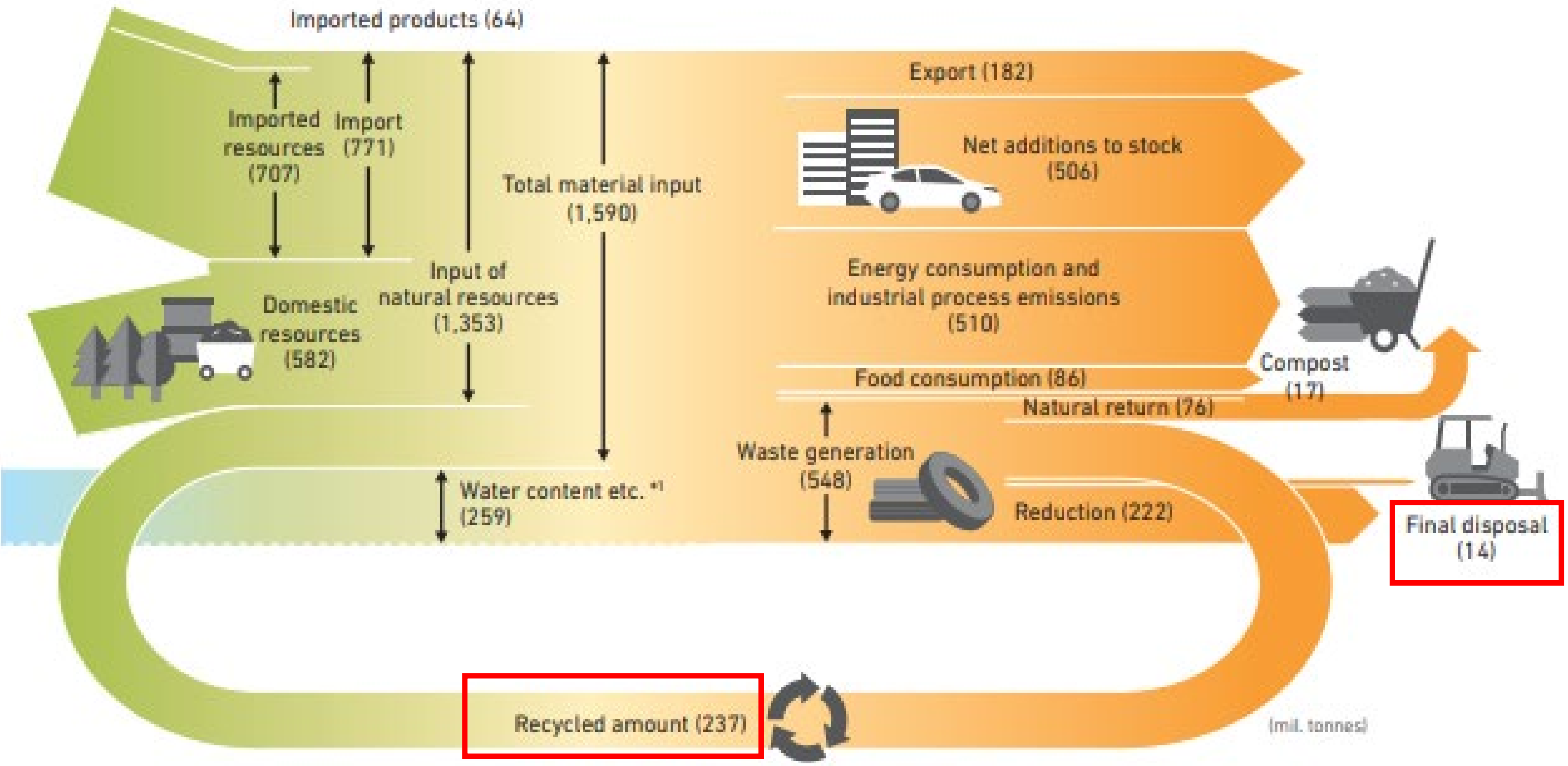
The final amount of waste discard in Japan is on a decreasing trend. It was approximately 14 Mt in 2018. Figure 5.7 shows the transition in the final amount of waste disposal. Figure 5.8 shows the material flow in 2017.

Figure 5.7. Final Disposal Amount



Gt = gigaton, Mt = metric ton.
Source: Ministry of the Environment.

Figure 5.8. Material Flow in Japan (2017)



Source: Ministry of the Environment.

5. China

5.1. Overall Waste Management System

In China, three laws have been enacted as basic laws for waste in general. Extended producer responsibility is the general principle. Also, under these basic laws, individual recycling regulations have been advanced, especially for automotive waste and electronic waste, which are expected to increase in the amount generated and offer significant economic benefits from recycling. In recent years, along with the strengthening of environmental regulations, the building of a regulatory system for importing waste is also progressing (Envix, 2020). The three laws are:

- Law on Prevention of Environmental Pollution Caused by Solid Waste (issued in 1995): Defines rules for the disposal of industrial waste, domestic waste, and hazardous waste, and clarifies the general principles of reduction, recycling, and rendering harmless for solid waste pollution prevention through amendments in 2020. It was also clarified that the aim is to strengthen the supervision and management of products such as electrical and electronic equipment, lead-acid batteries, and automobile-drive batteries by the State, and to establish an extended producer responsibility system.
- Cleaner Production Promotion Law (issued in 2002): In addition to adopting production processes that emit less pollutants, companies are required to produce products that are easy to collect, recycle, and reuse in the production process, and are also mandated to collect packaging after use.
- Circular Economy Promotion Law (issued in 2008): This defines extended producer responsibility for waste recycling. It includes comprehensive use of industrial waste, reuse and recycling of renewable resources.

5.2. Appliance Recycling

Regarding the recycling of waste electronic equipment, under the Chinese version of WEEE promulgated in 2009, the responsibilities of producers, importers, and the like are defined for 14 items of electrical and electronic equipment, such as adopting effective designs for the comprehensive use of resources and treatment to eliminate hazards from the design stage, and for being responsible for the disclosure of information on toxic and hazardous substances. Also, this establishes funds to assist in the costs necessary for the disposal and collection of such costs from manufacturers, importers, amongst others, under the concept of EPR. Still further, a qualification permit system has been created for waste electronic equipment processing companies. This defines restrictions on the use of hazardous substances (lead, mercury, cadmium, and other substances) in electrical and electronic equipment in the new Chinese version of the EU Restriction of Hazardous Substances promulgated and enforced in 2016 (JETRO, 2018) .

In China, waste electrical and electronic products are highly valued as resources, and regular recyclers are buying them from consumers. However, because non-regular vendors that do not bear the cost of preventing environmental pollution and damage to public health buy high-value waste electrical and electronic products at high prices, it is assumed that an overwhelming proportion of waste electrical and electronic products are still collected and processed through non-regular routes.

5.3. Battery Recycling

As described above, used batteries are also included in solid waste and are subject to reuse and recycling promotion under the Law on Prevention of Environmental Pollution Caused by Solid Waste. Furthermore, the Policy on Technologies for Waste Batteries Pollution Prevention promulgated by the Ministry of Ecology and Environment in 2016 provides practical guidance on the collection, transportation, storage, maintenance, use, and reuse of used batteries. In this policy, the main targets for waste battery collection include lead-acid batteries, lithium-ion batteries, nickel-metal hydride batteries, nickel-cadmium batteries, and button batteries containing mercury (MEE, 2016).

6. Conclusions

As it is shown by the relatively high rate of Japan's appliance recycling, it is important to establish a system that the system needs to be coordinated to involve manufactures, retailers, and designated recycling entities. In the case of appliance recycling, consumers in Japan would bear the cost of recycling, and they can hand over the waste appliances to retailers that will send the waste to designated recycling facility, of which establishment and operation is handled by manufacturing companies. In the case of reusing EV batteries, it would be important to make an accessible system for consumers/owners. The handling of the waste would have to be implemented by designated entities in order to avoid illegal damping or illegal transport to the other countries.

Additionally, as the survey results from consumers in the EU, consumers prefer to repair their devices rather than replace them or the replacement of their individual parts. This is in line with the EU's plan to establish a circular carbon economy. To this end, as the EU tries to enhance broadening the scope of the Ecodesign Directive – to enhance the production of goods and products with a long life, manufacturers should be encouraged to enhance the long life of EV batteries.

Regulatory oversight would be important to avoid the trade amongst non-regular vendors as it is observed in some cases. In this regard, traceability of EVs would be important not only to understand the operational quality, but also to maximise the reuse of EV batteries to attain mineral resources efficiency, energy savings, and CO_2 emissions reduction.

Regulatory frameworks of reuse and/or recycling of lithium ion batteries are not established in some countries, while that of nickel-cadmium (and certain small sealed lead-acid rechargeable batteries are established. Coordination is required to establish consistent regulation governing these.

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Chapter 6
Policy Implications

Amongst the Association of Southeast Asian Nations (ASEAN) countries, electric vehicles (EVs) are considered an important option for tackling local air pollution and enhancing energy security – away from oil dependence and climate change mitigation. Some countries such as Indonesia and Thailand consider EVs as an important option for developing a manufacturing basis. Indonesia has laid out plans for developing a battery manufacturing industry with the use of local resources, while Thailand aims to become the regional hub for the EV manufacturing industry.

Meanwhile, the plan for the reuse of waste batteries from EVs has not been formulated yet in ASEAN countries. Understanding the magnitude of waste batteries in the future is the first step, and the formulation of policies by each member country is necessary.

As this analysis result shows, a substantial number of reusable batteries from EVs will be available in ASEAN by 2040. The reference case analysis shows that the available supply would amount to 325 gigawatt hours (GWh), and it would expand to 778 GWh in the hybrid electric vehicle (HEV) bridge scenario. The ambitious battery electric vehicle (BEV) scenario is projected to generate 2,166 GWh of reusable batteries by 2040.

A mechanism is needed for dealing with such a large number of used batteries. For example, one method is to reuse them as backup batteries for variable renewable energy (VRE) power generation. According to an analysis on ASEAN power systems (focusing on the Indochinese Peninsula and the Malay Peninsula) by ERIA (2021), it is estimated to need backup batteries of 500–600 GWh when VRE accounts for 40% of the generation mix in 2040. A substantial gap is likely to exist.

It is necessary to consider a wide range of options for reusing and/or recycling batteries. Depending on the quality of the used batteries, they could be utilised as replacement EV batteries, or for large-scale grid storage. Other options could be used for residential storage, back up in factories, and street lighting.

To realise the reuse of EV batteries, the following practices need to be encouraged:

- **Health and safety**: Monitoring mechanisms should be in place to understand the health and safety of EV batteries at the time of operation. This would allow the timing of replacement, and conditions for repurposing as well.
- **Technology**: Research and development (R&D) should be made to evaluate the performance of waste batteries. Evaluation of used EV batteries is a time-consuming process, as it would have to check the performance by cell, pack, and module as a whole. R&D should be encouraged to develop a system as well as know-how that can shorten the time required for evaluation.
- **Regulatory**: Regulatory requirements for manufacturers and owners should be clearly formulated. They would strengthen the construction of a power battery traceability

management platform for new energy vehicles and achieve traceability of the entire life cycle of the power battery.

- **Economic**: R&D should be encouraged to lower the cost of repurposing waste EV batteries. Large-scale implementation such as grid storage using repurposed batteries, and also identification of some small-scale projects – such as battery system at distributed energy systems or other purposes as street lighting would need to be implemented simultaneously.
- **Collection System**: it is important to establish a system that needs to be coordinated to involve manufacturers, retailers, and designated recycling entities. Aside from the establishment of traceability, it is important to establish a system that consumers and/or owners are accessible to be involved in the value chain of EV batteries reuse. Dealers should be able to play the important role for maintenance as well as communication with consumers and/or owners in this regard.

The environmental benefits of reusing EV batteries would be important for policymaking purposes. In case the reused battery is replaced by a new one, it can generate benefits such as (i) energy savings, (ii) mineral resources savings, (iii) greenhouse gas emissions reduction, and (iv) health impacts. Nevertheless, careful planning should be required because the reuse of EV batteries does not necessarily generate positive benefits if it is compared with the replacement for grid-connected electricity supply.

It is also important to put the reuse of EV batteries in a broader context to genuinely understand the benefits of EVs on the environment. For example, in terms of the magnitude of CO_2 emissions reduction, the largest contributions in future – under the decarbonised generation mix – would come from the operational stage, followed by light-weighting and/or sharing, which would be followed by the contributions from reuse and/or recycling benefits. Again, policy coordination is essential to plan for obtaining maximum environment benefits from EVs, from generation mix planning, designing, operation, and reuse and/or recycling.