Chapter 3

Benefits and Costs of Alternative Vehicles

1. Introduction

This chapter presents the results of the cost–benefit analysis of alternative vehicles in Indonesia. Understanding the benefits and costs of alternative vehicles is important to support both personal and society usage of these vehicles.

The upfront costs of alternative transport (including HEVs, PHEVs, and EVs) are currently greater than that of conventional ICEVs. These additional costs are generally related to expensive electric components such as batteries, electric motors, and power electronics, as well as engineering development work on system management.[3] Such electronic components require stable conditions for operation, and liquid cooling is used to control the thermal balances, adding to the system costs.[4]

Nevertheless, it is important to note that the cost of lithium-ion batteries, the main determinant of the additional cost of alternative vehicles, has been declining substantially in recent years, and is expected to decline even more in the future due to research and development efforts as well as economies of scale stemming from the introduction of giga-production factories. Combined with the declining cost of batteries, the greater energy efficiency of alternative vehicles has great potential to benefit consumers in Indonesia, particularly starting with vehicles that travel long distances.

In recognition of the changing global market environment surrounding alternative vehicles, this chapter analyses the potential reduction in the cost of alternative vehicles, and how this would benefit both Indonesia's drivers and society as a whole. For this purpose, a cost–benefit analysis is made to ascertain policy implications for Indonesia in relation to Indonesia's announced plan to ban ICEV sales by 2040.

2. Analysis Framework

2.1. Cost–Benefit Analysis

Understanding the benefits and costs of alternative transport for both personal use and society as a whole is important for policy-making purposes.

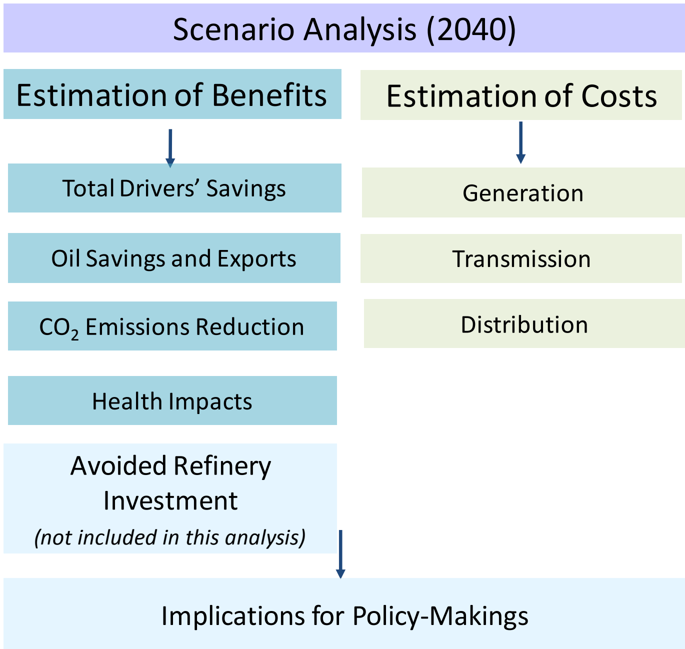
This analysis estimates the benefits from Indonesia's shift towards alternative vehicles, considering in particular the following aspects: (i) total benefits for Indonesian drivers, (ii) oil

[3] Lajunen, A. (2013), 'Energy Consumption and Cost–Benefit Analysis of Hybrid and Electric City Buses', *Transportation Research Part C*, 38(2014), pp.1–15.
[4] Ibid.

savings benefits derived from increased export earnings, (iii) benefits of reduced CO_2 emissions, and (iv) health benefits from improved air quality.

This analysis excludes the benefits of avoiding investment in refinery systems. Meanwhile, the estimated costs are those of generation, transmission, and distribution.

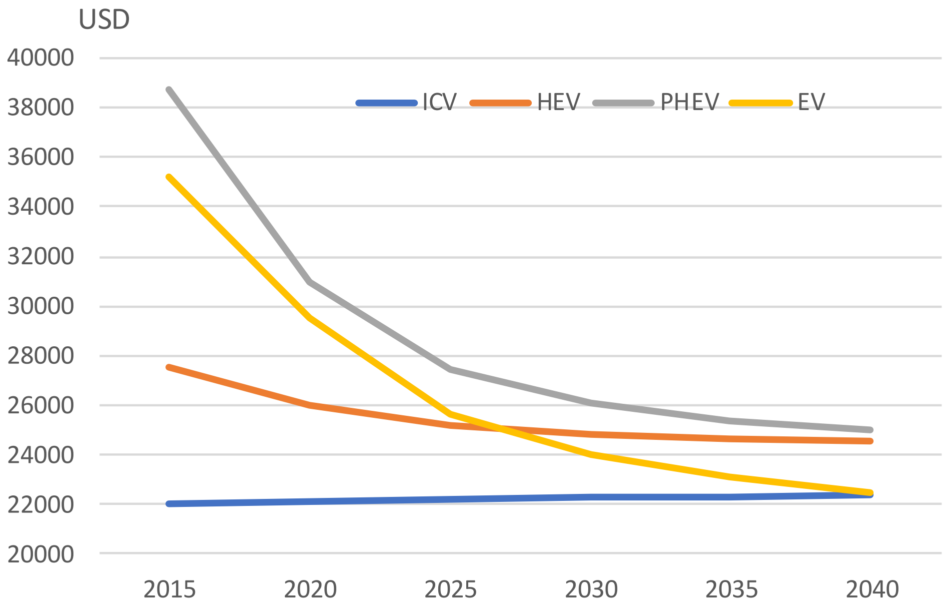
Figure 3.1: Analysis Framework



CO_2 = carbon dioxide.
Source: Authors.

Drivers' benefits are calculated by taking into consideration the annualised cost of vehicle ownership (by technology type), payments for energy (gasoline, diesel, or electricity), and maintenance. Vehicle costs are estimated through 2040 to analyse the different factors inherent in each type of technology (Fig. 3.2). The cost of ICEVs is assumed to increase slightly from the current level as the technological requirements for fuel economy improve. The cost of HEVs will decline as the cost of batteries decreases, and substantial cost reductions are expected with regard to PHEVs and EVs due to the estimated drop in the cost of lithium-ion batteries.

Figure 3.2: Vehicle Cost Assumptions ($)



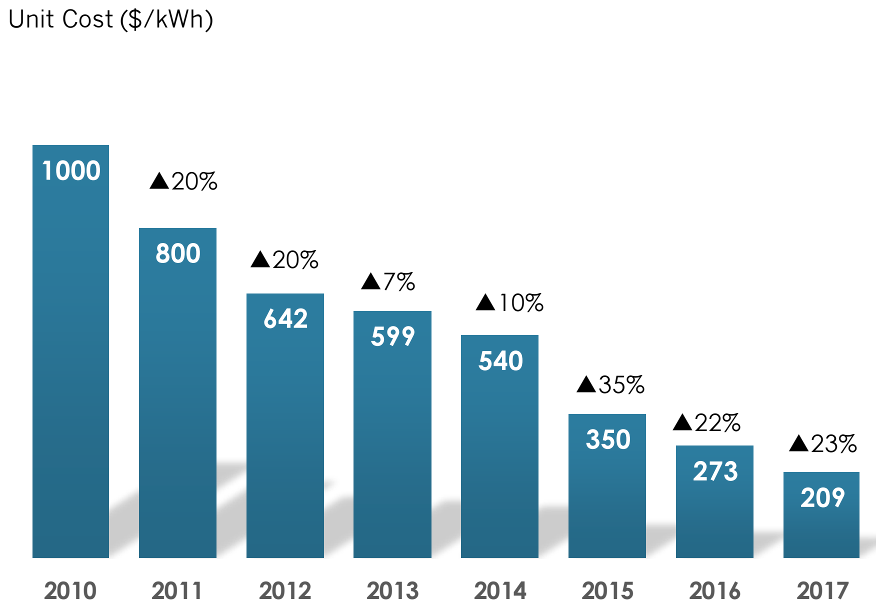
EV = electric vehicle, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Institute of Energy Economics, Japan (2018).

2.2 Estimation of the Cost of Lithium-Ion Batteries

The estimated cost of lithium-ion batteries is critically important for future cost estimations with regard to HEVs, PHEVs, and EVs. In fact, costs have been decreasing substantially over the past few years due to economies of scale, technological improvements, and the ongoing maturation of the manufacturing process (Fig. 3.3). The cost of lithium-ion battery modules decreased from $1,000 per kWh in 2010 to $209 per kWh in 2017, a 79% reduction in 7 years, or an average annual reduction of 20%.

To estimate the cost of lithium-ion batteries, the learning curve analysis method is utilised. The basic concept of the learning curve analysis is that, as the quantity of production units doubles, the cost of producing a unit decreases by a constant percentage. For example, an 80% learning curve implies that the cost associated with incremental output will decrease to 80% of the previous level (or a 20% reduction from the previous level).

Figure 3.3: Lithium-Ion Battery Module Cost Trends



kWh = kilowatt-hour.
Note: The figures include the cell plus pack price.
Source: Bloomberg New Energy Finance (2017).

The learning curve can be explained as follows.

$$Y = AX^b$$

Y = average cost of unit X

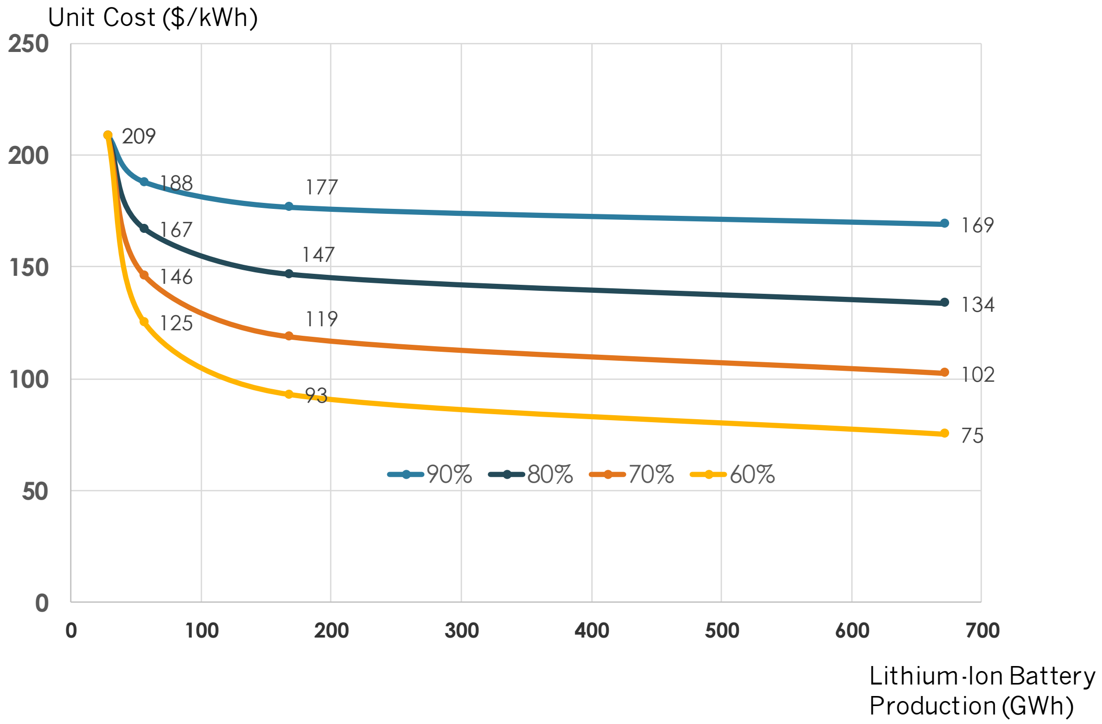
A = the first unit cost

X = unit number (cumulative volume)

b = slope coefficient = $\dfrac{\log(slope\ of\ the\ learning\ curve)}{log2}$

Figure 3.4, which presents an example of lithium-ion battery cost estimates using the learning curve, shows that the estimated cost per kWh differs when production units double, at different learning rate assumptions of 60%, 70%, 80%, and 90%. For example, when 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 a learning rate of 80%. When production doubles further to 168 GWh, the cost is estimated at $147/kWh at the same learning rate.

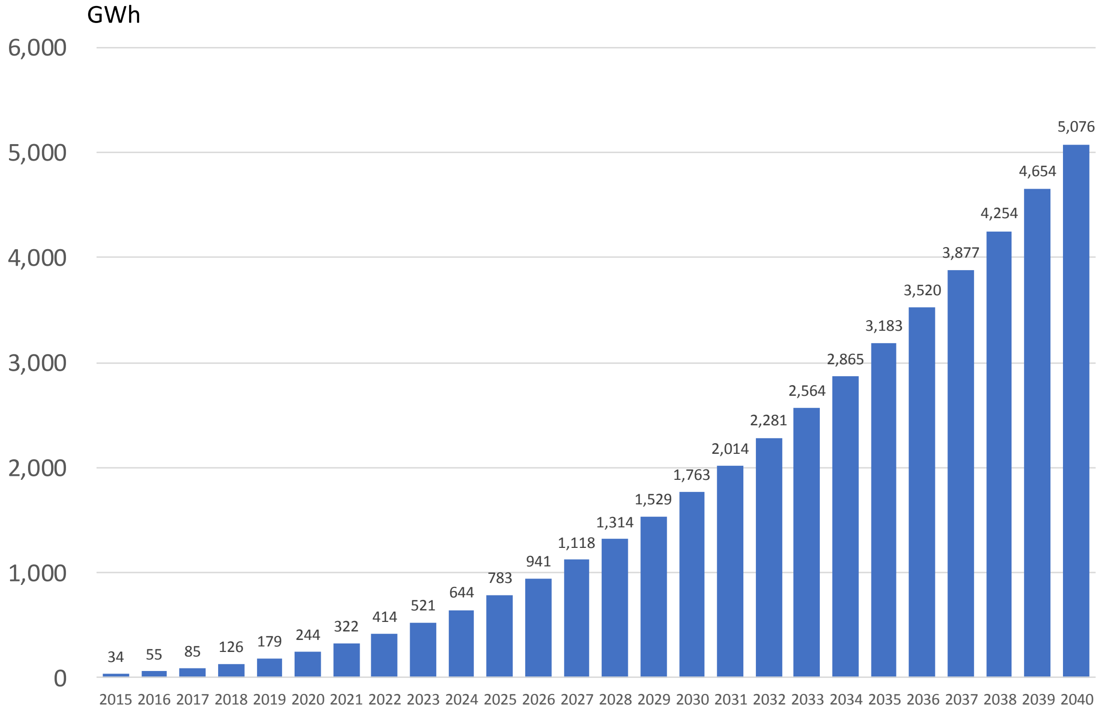
Figure 3.4: Example of Lithium-Ion Battery Cost Estimates Using the Learning Curve



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

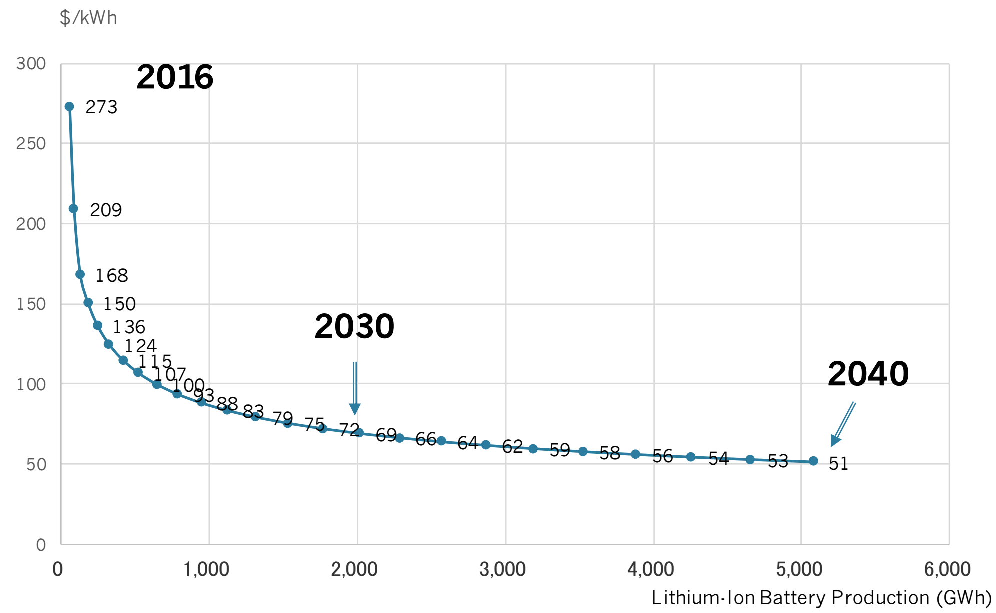
The cost estimate depends on the future production volume of lithium-ion battery modules. This analysis uses the outlook of the Institute of Energy Economics, Japan for lithium-ion battery modules (required to meet the future demand for HEVs, PHEVs, and EVs). The analysis assumes that EVs will account for 30% of total vehicle sales by 2030, and 100% by 2050. According to this analysis, the total production volume of lithium-ion batteries will reach a cumulative 5,076 GWh by 2040, compared to a mere 34 GWh in 2014.

Figure 3.5: Global Outlook of the Institute of Energy Economics, Japan for Lithium-Ion Batteries for Hybrid Electric Vehicles, Plug-In Hybrid Electric Vehicles, and Electric Vehicles (Cumulative)



GWh = gigawatt-hours.
Source: Institute of Energy Economics, Japan (2017), *World/Asia Energy Outlook*.

Figure 3.6: Estimated Cost of Lithium-Ion Batteries (2016–2040)



kWh = kilowatt-hours.
Source: Institute of Energy Economics, Japan (2018).

Figure 3.6, which shows the estimated cost of lithium-ion battery modules through 2040, demonstrates the estimated relationship between the cumulative production of lithium-ion batteries by 2040 and corresponding module cost per kWh. As the figure shows, this cost is projected to decline to $72/kWh by 2030, and further to $51/kWh by 2040.

3. Passenger Vehicles

Table 3.1 shows the total annual cost of using each type of passenger vehicle technology from 2015 to 2040. Gasoline or electricity costs for each type of technology (included in the table) are calculated by determining the energy requirements for driving a distance of 10,000 km per year. Due to their relatively simple technological composition, the maintenance cost for PHEVs and EVs is smaller than that for ICEVs and HEVs. However, PHEVs and EVs require personal chargers, incurring additional costs.

Table 3.1: Cost of Driving by Type of Technology

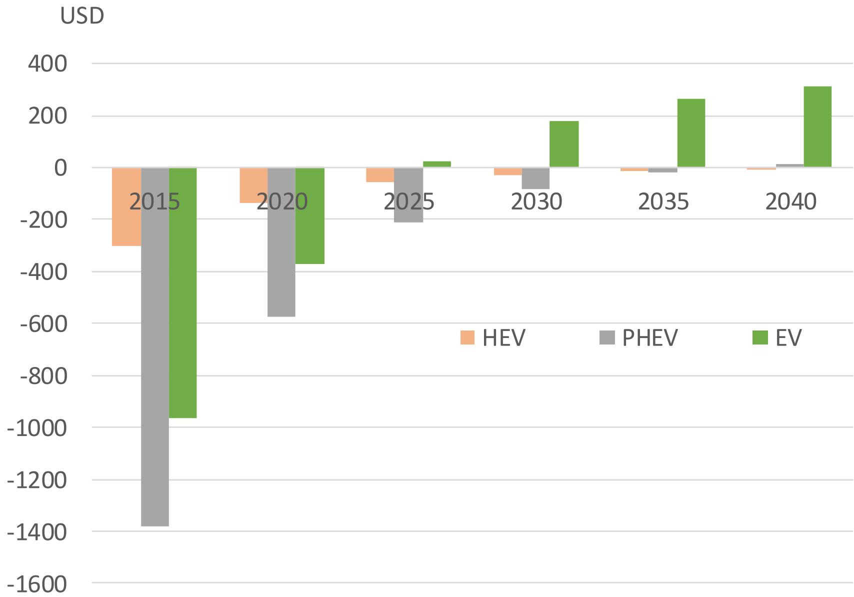
		2015	2020	2025	2030	2035	2040
ICV							
Initial Vehicle Purchase	$/10 years	22,000	22,066	22,165	22,248	22,319	22,381
Vehicle Purchase	$/year	2,200	2,207	2,217	2,225	2,232	2,238
Gasoline	$/year	634	611	586	561	537	514
Maintenance	$/year	110	110	111	111	112	112
Total Annual Cost	**$/year**	**2,944**	**2,928**	**2,913**	**2,897**	**2,881**	**2,864**
HEV							
Initial Vehicle Purchase	$/10 years	27,500	25,992	25,175	24,835	24,651	24,537
Vehicle Purchase	$/year	2,750	2,599	2,517	2,484	2,465	2,454
Gasoline	$/year	426	399	389	379	368	357
Maintenance	$/year	69	65	63	62	62	61
Total Annual Cost	**$/year**	**3,245**	**3,063**	**2,970**	**2,925**	**2,895**	**2,872**
PHEV							
Initial Vehicle Purchase	$/10 years	38,720	31,000	27,410	26,083	25,388	24,959
Vehicle Purchase	$/year	3,872	3,100	2,741	2,608	2,539	2,496
Gasoline+Electricity	$/year	287	270	264	259	254	248
Maintenance	$/year	97	78	69	65	63	62
Personal charger	$/year	70	56	49	47	46	45
Total Annual Cost	**$/year**	**4,325**	**3,503**	**3,123**	**2,980**	**2,902**	**2,851**
EV							
Initial Vehicle Purchase	$/10 years	35,200	29,502	25,639	23,974	23,054	22,472
Vehicle Purchase	$/year	3,520	2,950	2,564	2,397	2,305	2,247
Electricity	$/year	239	225	217	217	213	208
Maintenance	$/year	88	74	64	60	58	56
Personal charger	$/year	63	53	46	43	41	40
Total Annual Cost	**$/year**	**3,910**	**3,302**	**2,891**	**2,717**	**2,617**	**2,552**

EV = electric vehicle, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Institute of Energy Economics, Japan (2018).

Figure 3.3 shows the changing costs of using HEVs, PHEVs, and EV, calculated as the difference from the annual cost of using ICEVs. If the cost of using EVs is lower than that of using ICEVs, the resulting calculation shows a positive number in United States dollars.

As a result of the substantial reduction in the cost of EVs over the outlook period, drivers can expect to enjoy net benefits from EVs sometime after 2025. The reduced cost of purchasing EVs sometime after 2025 as well as the better fuel economy will lower the total usage cost of EVs below that of ICEVs (Fig. 3.7).

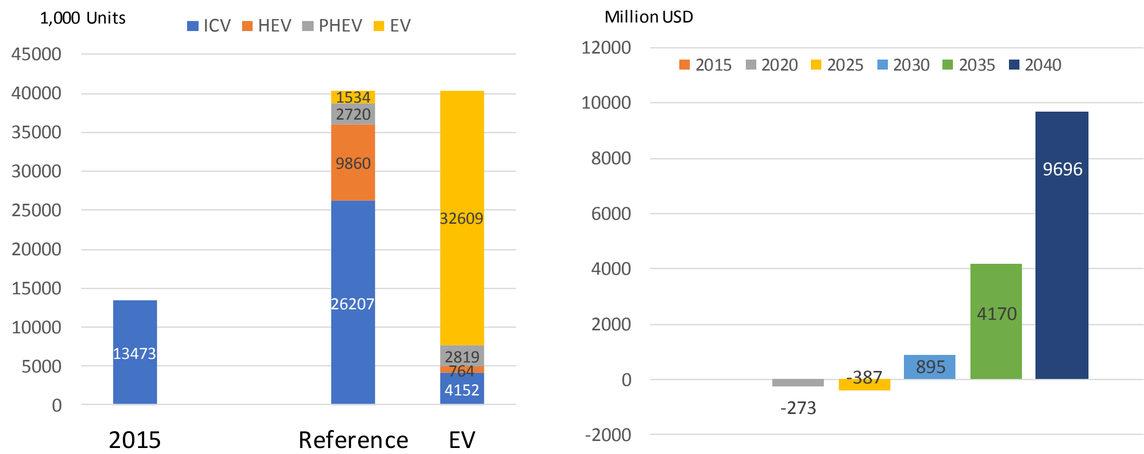
Figure 3.7: Tipping Point of Electric Vehicles (Passenger Vehicles)



EV = electric vehicle, HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Institute of Energy Economics, Japan (2018).

Based on the analysis of individual driver benefits, the impacts of this shift on Indonesia as a whole is analysed. The left side of Figure 3.8 shows vehicle stocks by technology type. The calculation multiplies the estimated annual cost of usage by the number of vehicle stocks (by type of technology). As discussed in Chapter 2, stocks of EVs are projected to account for 81% of all passenger vehicle stocks by 2040. The impacts of shifting to alternative vehicles would yield net benefits of $9.96 billion by 2040, as shown on the right side of Figure 3.8.

Figure 3.8: Passenger Vehicle Stocks by Technology (left), and Driver Benefits in Indonesia (right)

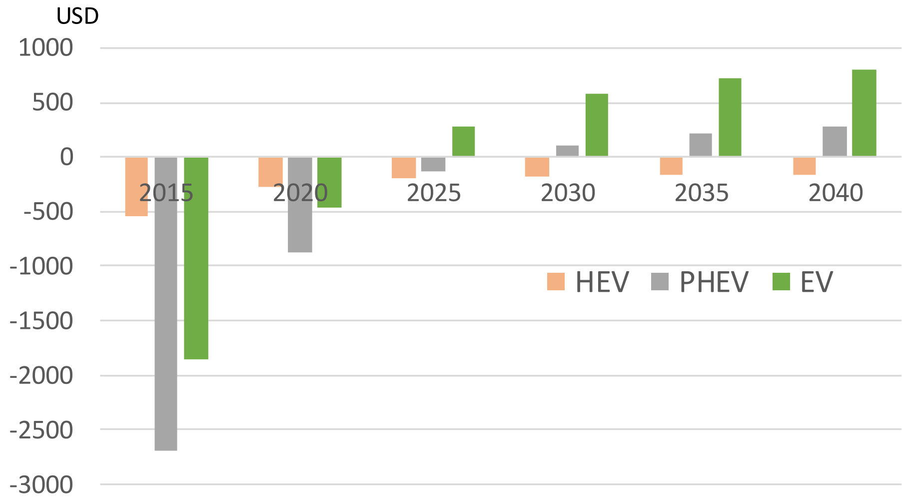


EV = electric vehicle, HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Institute of Energy Economics, Japan (2018).

4. Trucks

The net benefits to drivers of electric trucks are analysed using the same method used for passenger vehicles. As Figure 3.9 shows, drivers of electric trucks will enjoy these benefits from sometime after 2025, as a result of the substantial estimated reduction in the cost of lithium-ion batteries and a better fuel economy compared with that of ICEV trucks.

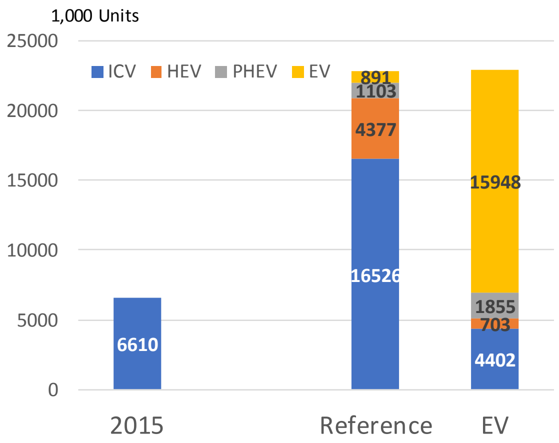
Figure 3.9: Tipping Point of Electric Vehicles (Trucks)

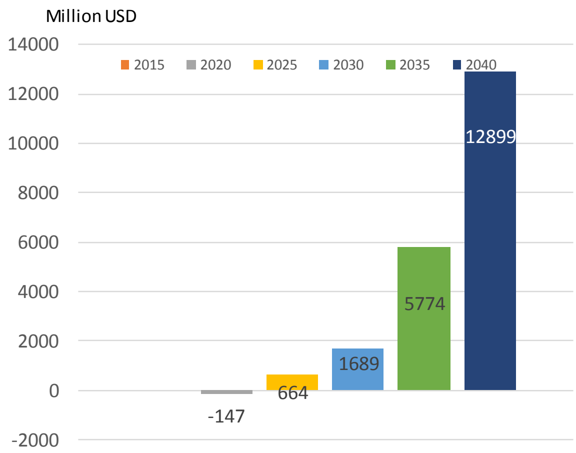


EV = electric vehicle, HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Institute of Energy Economics, Japan (2018).

The impact of shifting to electric trucks would yield much larger benefits for Indonesia as a whole, compared with the shift to passenger EVs, mainly because trucks travel longer distances. As the right side of Figure 3.10 shows, Indonesia's truck drivers will enjoy net benefits of $12.9 billion by 2040.

Figure 3.10: Truck Stocks by Technology Type (left), and Drivers' Benefits in Indonesia (right)





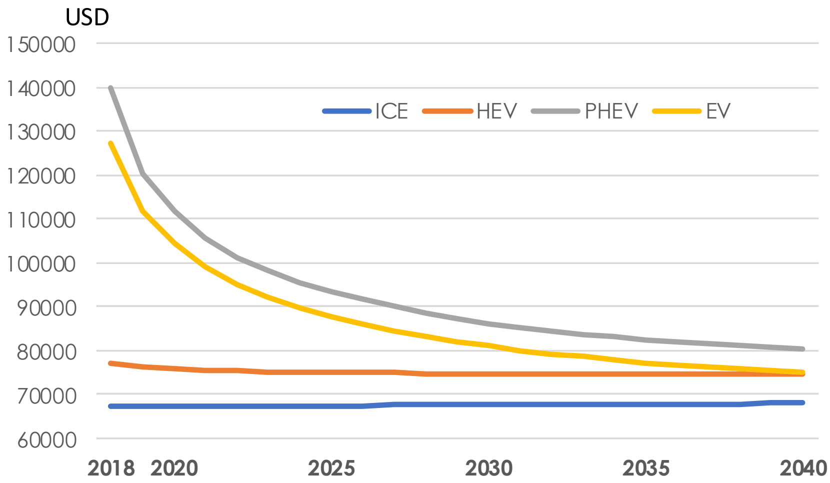
EV = electric vehicle, HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Institute of Energy Economics, Japan (2018).

5. Buses

It is difficult to estimate the costs of hybrid buses, plug-in hybrid electric buses, and pure electric buses because these have not yet been manufactured in large volumes, and because the development of this technology is not yet mature compared to conventional ICEVs. According to the literature, the cost of EV buses varies widely, ranging from 1.6[5] to 2.2[6] times that of conventional diesel buses.

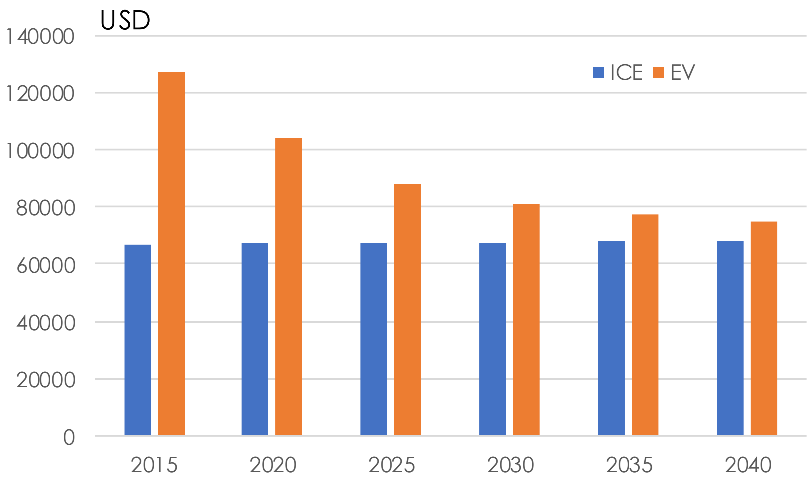
[5] Bloomberg New Energy Finance (2018). 'Electric Buses in Cities – Driving towards Cleaner Air and Lower CO_2', 29 March. London.
[6] Global Green Growth Institute (2016). 'Buses in India: Technology, Policy and Benefits'. Seoul.

Figure 3.11: Cost Assumptions



EV = electric vehicle, HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Institute of Energy Economics, Japan (2018).

Figure 3.12: Cost Assumptions

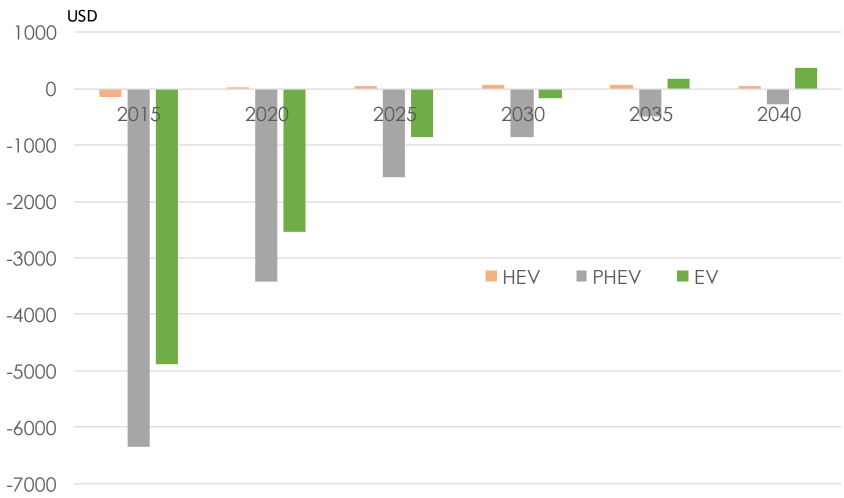


EV = electric vehicle, ICEV = internal combustion engine vehicle.
Source: Institute of Energy Economics, Japan (2018).

In this analysis, it is assumed that pure electric buses cost twice as much as ICEV buses (Figs. 3.7 and 3.8). It is important to note that bus size varies substantially in Indonesia, ranging from small mini-van types to large buses 12 metres in length, such as those deployed by Trans-Jakarta. The assumed cost in this analysis reflects an average of these various bus sizes.

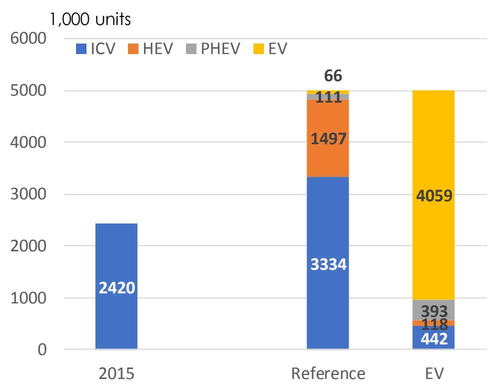
As the above figures show, the gap between the cost of ICEVs and that of pure electric buses will narrow in the future as the cost of lithium-ion batteries declines. By 2040, it is estimated that the cost of pure electric buses will have decreased from $127,300 in 2015 to $74,925, only 1.1 times the cost of ICEV buses. The benefits of making the bus system electric depend on distance travelled. This analysis assumes that each bus will travel 19,000 km per year, calibrated from the average fuel economy of buses and the number of bus stocks (analysed in Chapter 2).

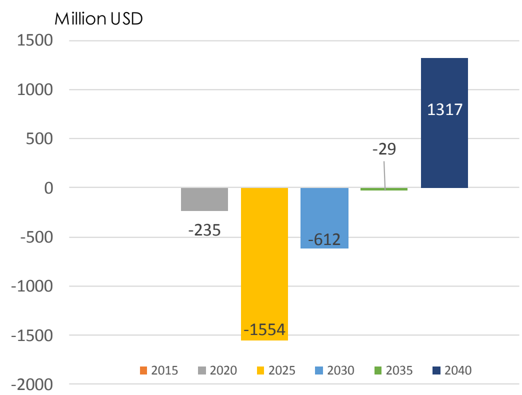
Figure 3.13: Tipping Point of Electric Vehicles (Buses)



EV = electric vehicle, HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Institute of Energy Economics, Japan (2018).

Figure 3.14: Bus Stocks by Type of Technology (left), and Drivers' Benefits in Indonesia (right)





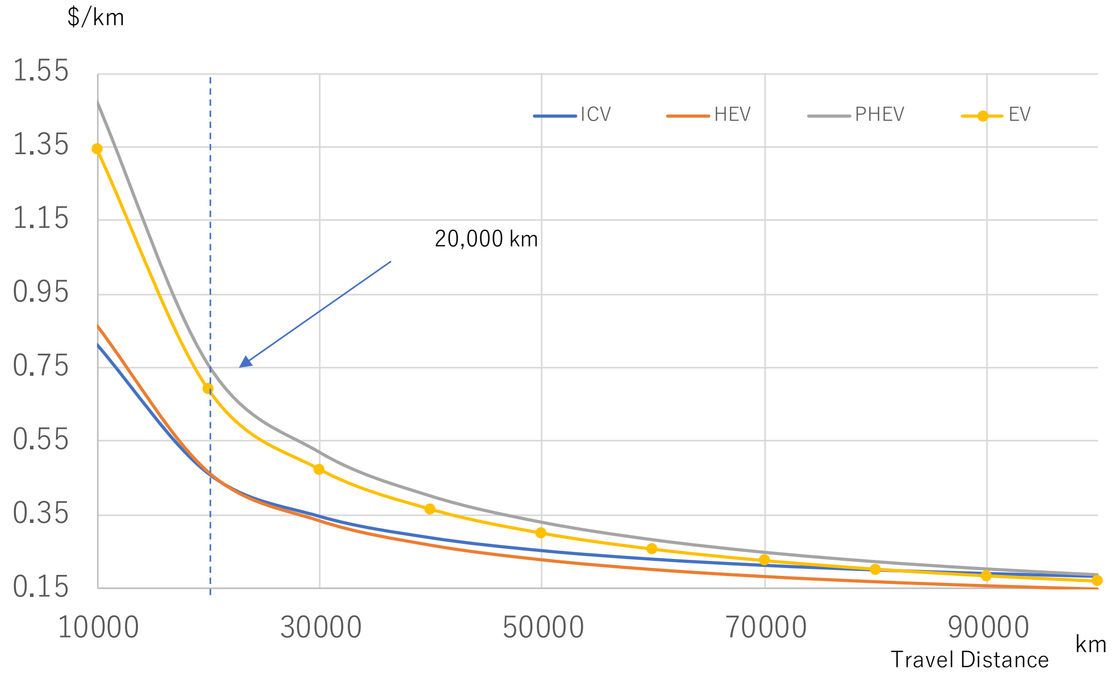
EV = electric vehicle, HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: Institute of Energy Economics, Japan (2018).

As the cost gap between EV and ICEV buses narrows towards the end of outlook period, drivers will be able to enjoy the benefits from the shift towards pure electric buses, even assuming a relatively short annual travel distance of 19,000 km. This analysis places the estimated tipping point of pure electric buses sometime after 2035 (Fig. 3.13). Based on this assumption, societal benefits from the shift towards EV buses would amount to $1.3 billion by 2040 (Fig. 3.14).

5.1 Sensitivity Analysis

A sensitivity analysis was conducted to understand (i) the impact of travel distance on the total cost of operation (TCO), and (ii) the impact of both travel distance and unit cost reduction on TCO.

Figure 3.15: Travel Distance and Total Cost of Operation per Kilometre (Based on 2017 Upfront Cost Assumptions)

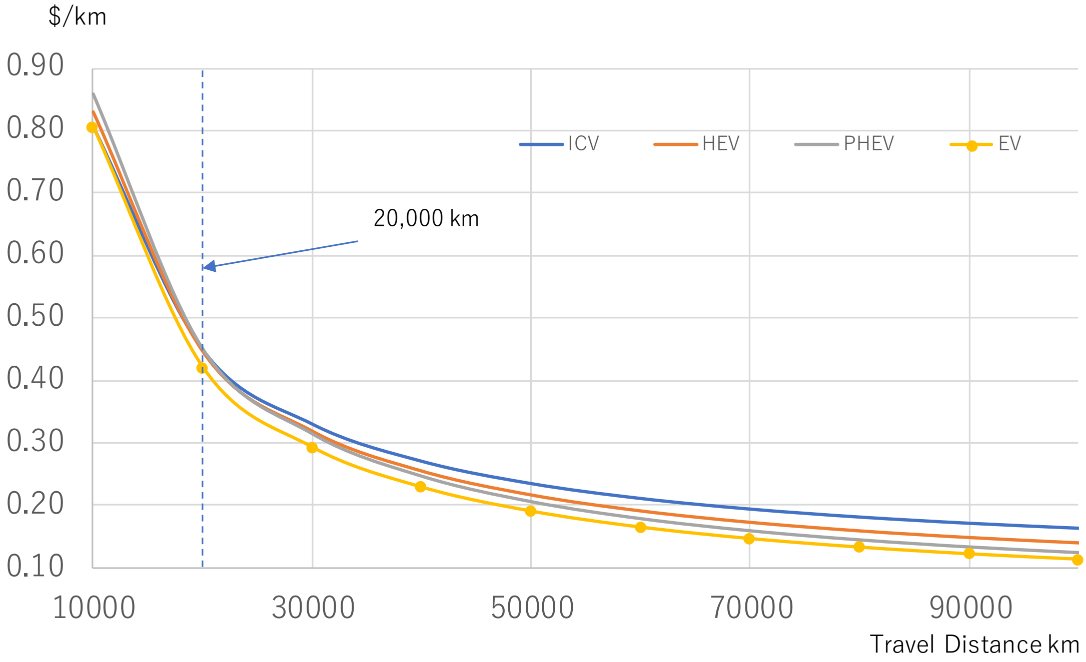


EV = electric vehicle, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, km = kilometre, PHEV = plug-in hybrid electric vehicle.
Source: Institute of Energy Economics, Japan (2018).

Figure 3.15 compares travel distance and TCO/km for ICEV, HEV, PHEV, and pure electric buses. Based on the 2017 upfront cost assumptions, the figure clearly shows that the TCO/km of pure electric buses would be nearly 50% higher than that of ICEV buses at $0.69 per km, while EV buses would be cost-competitive at travel distances surpassing 90,000 km.

Figure 3.16 compares travel distance and TCO/km for ICEV, HEV, PHEV, and pure electric buses using the estimated 2040 upfront cost assumption, which is 41% lower than the 2017 level. The figure shows that the TCO/km of EV buses would be lower than that of ICEV buses after surpassing a travel distance of 10,000 km.

Figure 3.16: Travel Distance and Total Cost of Operation per Kilometre (Based on 2040 Upfront Cost Assumptions)



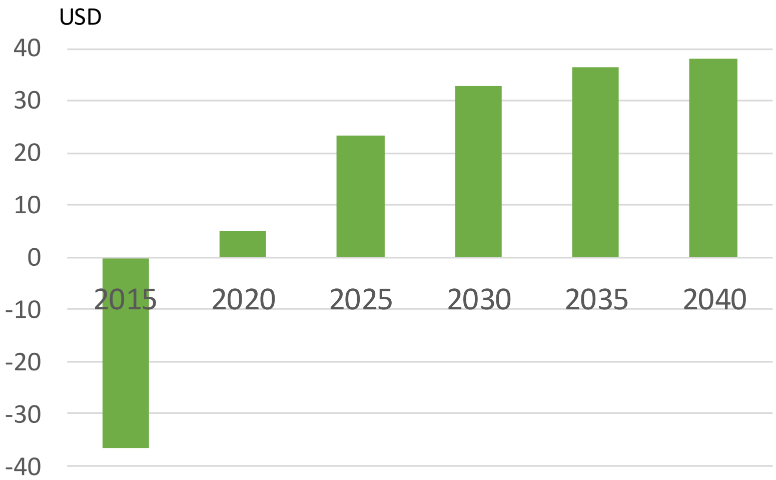
EV = electric vehicle, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, km = kilometre, PHEV = plug-in hybrid electric vehicle.
Source: Institute of Energy Economics, Japan (2018).

These findings suggest that, given the current cost gap, EV buses would be used on routes with long travel distances to ensure the realisation of the potential benefits from oil savings, reduced CO_2 emissions, and improved air quality as well as the drivers' benefit of lowered TCO. Also, until the upfront cost declines, supporting measures (such as the provision of subsidies or battery leasing) should be instituted to realise the full benefits from the introduction of EV buses.

6. Motorcycles

The net benefits to drivers of electric motorcycles are analysed using the same method as that used for passenger vehicles. As Figure 3.17 shows, drivers will enjoy the benefits of electric motorcycles from sometime after 2020, much earlier than drivers of electric passenger vehicles and buses. Likewise, the substantial estimated reduction in the cost of lithium-ion batteries will benefit drivers of electric motorcycles sometime after 2020.

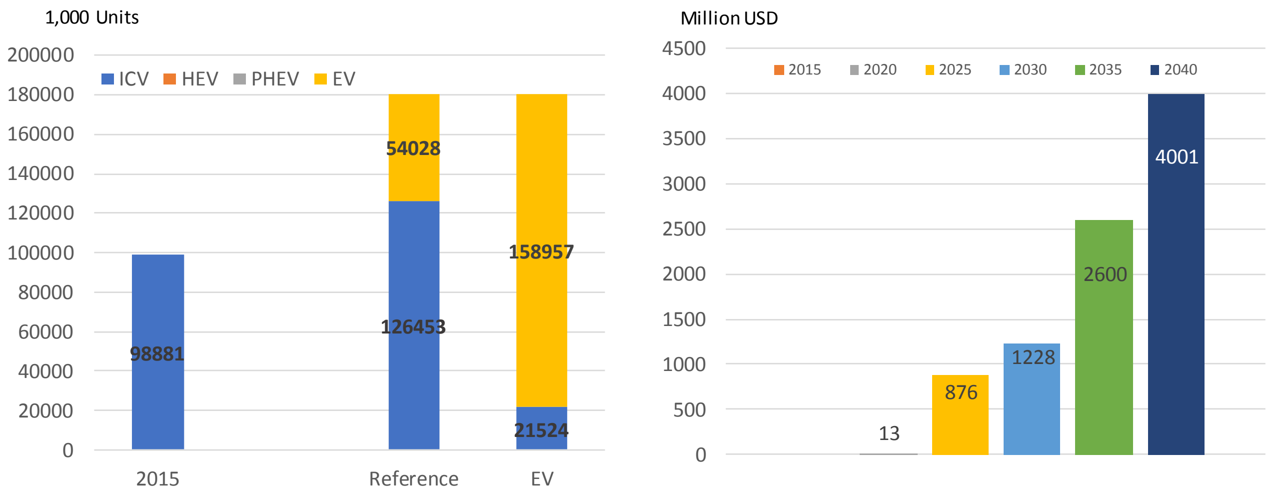
Figure 3.17: Tipping Point of Electric Vehicles (Motorcycles) ($)



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

Under the advanced EV scenario, the substantial introduction of EVs is estimated as resulting in 159 million electric motorcycles in 2040 (left side of Fig. 3.18). With this massive introduction of vehicles, drivers' benefits for shifting to electric motorcycles would amount to $4,001 million by this date.

Figure 3.18: Motorcycle Stocks by Type of Technology (left), and Drivers' Benefits in Indonesia (right)

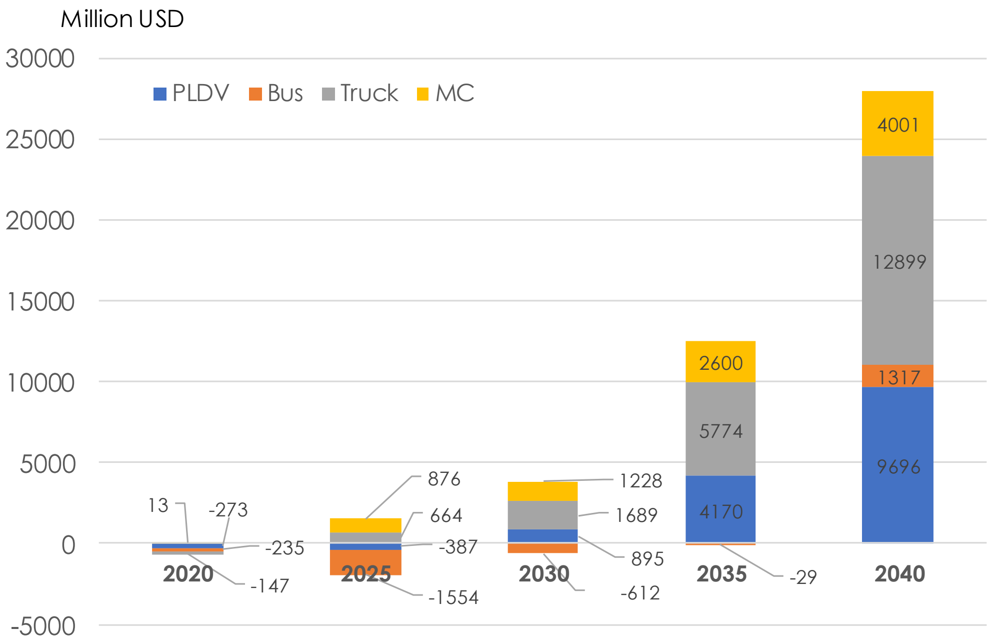


EV = electric vehicle, HEV = hybrid electric vehicle, ICEV = internal combustion engine vehicle, km = kilometre, PHEV = plug-in hybrid electric vehicle.
Source: Institute of Energy Economics, Japan (2018).

7. Summary of Drivers' Benefits

Figure 3.19 presents a summary of the net benefits to drivers from shifting the transport system in Indonesia to electric power. As the figure shows, truck drivers will enjoy the most net benefits ($12.9 billion by 2040) as they will incur the most oil savings due to relatively long travel distances (14,000 km per year). This group is followed by passenger vehicles at $6.7 billion, motorcycles at $4.0 billion, and buses at $1.3 billion.

Figure 3.19: Net Drivers' Benefits from Electrifying the Transport System (Passenger Vehicles, Trucks, and Motorcycles)



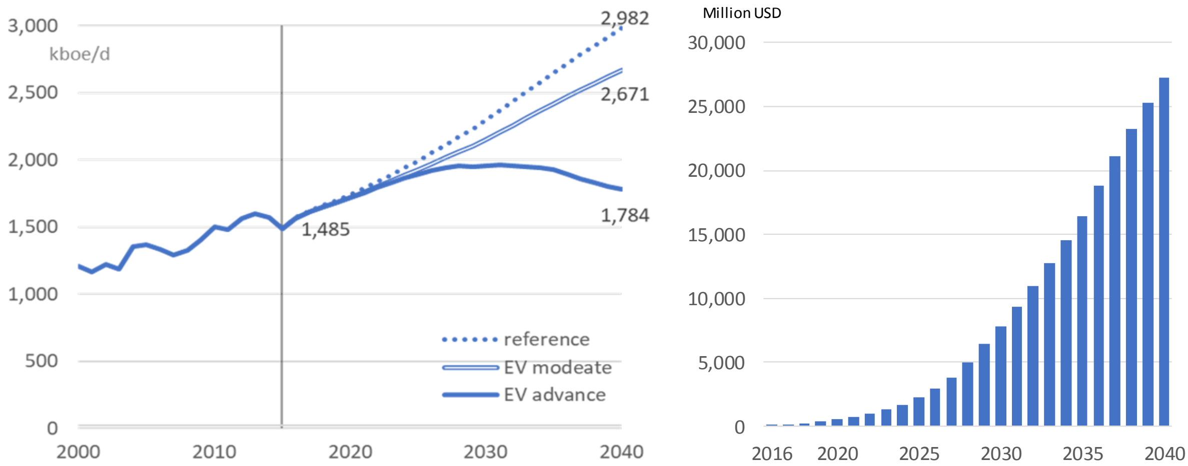
MC = motorcycles, PLDV = passenger light-duty vehicles.

8. Oil Savings Benefits

Under the advanced EV scenario, Indonesia's primary oil demand is expected to peak in 2031, and decline afterward at an average annual rate of 0.01% through 2040. Compared with the reference scenario, which assumed a demand of 2.98 million barrels per day (b/d) in 2040, the primary oil demand in the advanced EV scenario would be 40% lower at 1.78 million b/d. The oil savings would amount to 1.198 million b/d.

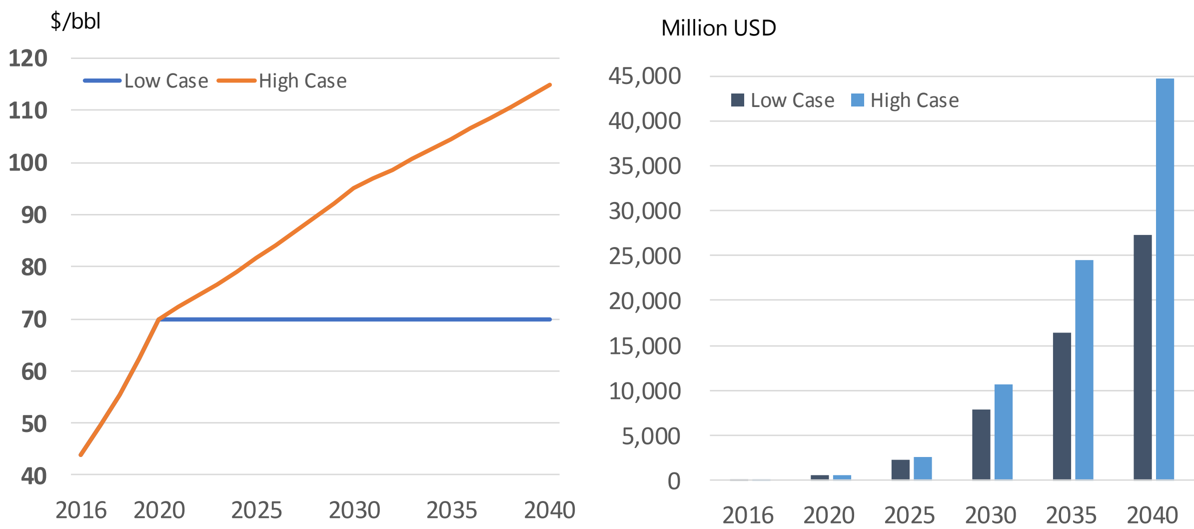
This analysis estimates the monetary benefits from primary oil demand savings at $27 billion by 2040, assuming that the saved oil would be exported to the global market at $70 per barrel (Fig. 3.21). A higher crude oil price assumption would of course lead to higher benefits from oil savings. For example, if the international oil price were to increase gradually to $115 per barrel, the benefits of oil savings from shifting to EVs would amount to $45 billion by in 2040 (Fig. 3.21).

Figure 3.20: Primary Oil Demand (left), and Oil Savings Benefits in Indonesia (right)



EV = electric vehicle, kboe/d = kilograms of barrel of oil equivalent.
Source: Institute of Energy Economics, Japan (2018).

Figure 3.21: Oil Price Assumptions (left), and Oil Savings Benefits in Indonesia (Low Case and High Case, right)



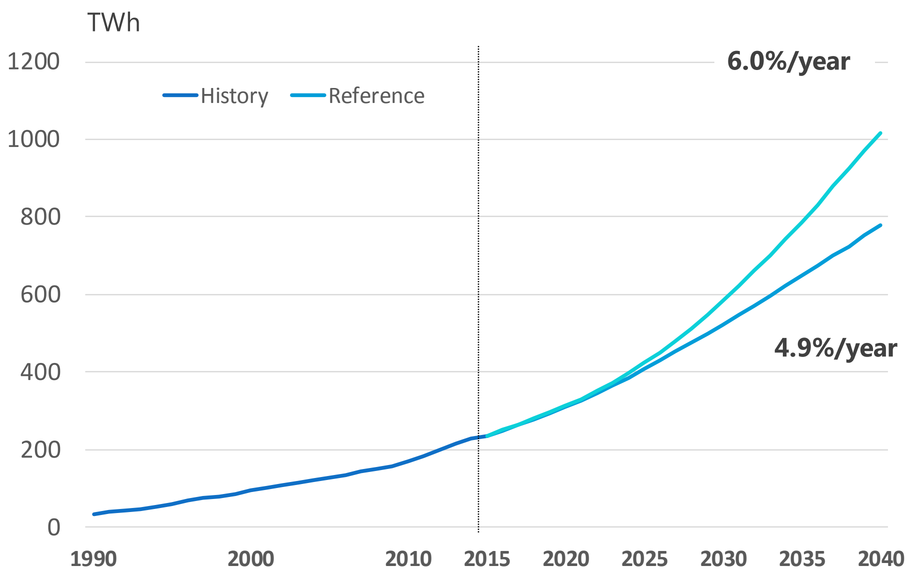
bbl = barrel.
Source: Institute of Energy Economics, Japan (2018).

9. Outlook of Electricity Generation

In addition to the economic benefits from shifting to EVs, it is important to consider the costs of meeting the increased electricity demand from EVs.

Figure 3.22 shows the projected electricity generation in both the reference and advanced EV scenarios.[7] Under the advanced EV scenario, electricity generation would increase by 6.0% per year, reaching 1,016 TWh by 2040. This figure is 30% higher than that in the reference scenario analysis. The gap between the EV and reference scenarios amounts to 238 TWh, almost equivalent to Indonesia's electricity generation requirements in 2015.

Figure 3.22: Oil Price Assumptions (left), and Oil Savings Benefits in Indonesia (Low Case and High Case, right)



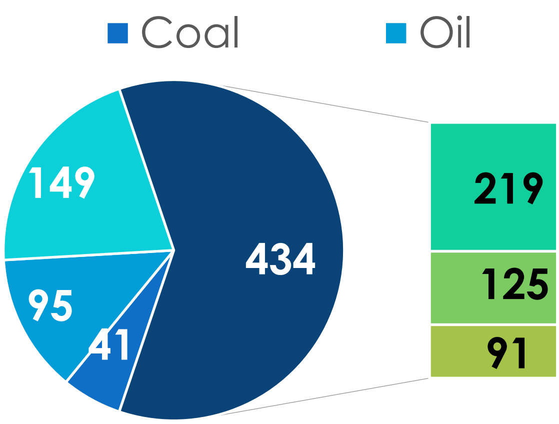
TWh = terawatt-hour.
Source: Institute of Energy Economics, Japan (2018).

To meet the energy demand as well as the necessary export and import of energy sources, Indonesia would require a cumulative investment of $719 billion, while the electricity sector represents the largest share (nearly 60%). Cumulative investment in the electricity sector alone would account for 14% of Indonesia's GDP in 2030. To meet the increased demand from EVs, investment in the electricity sector would need to increase by at least 30%.

[7] These generation requirements are estimated to meet the electricity demand for industry, transport, residential, and commercial, while covering losses during transmission and distribution.

Figure 3.23: Energy Sector Investment Requirements in Indonesia

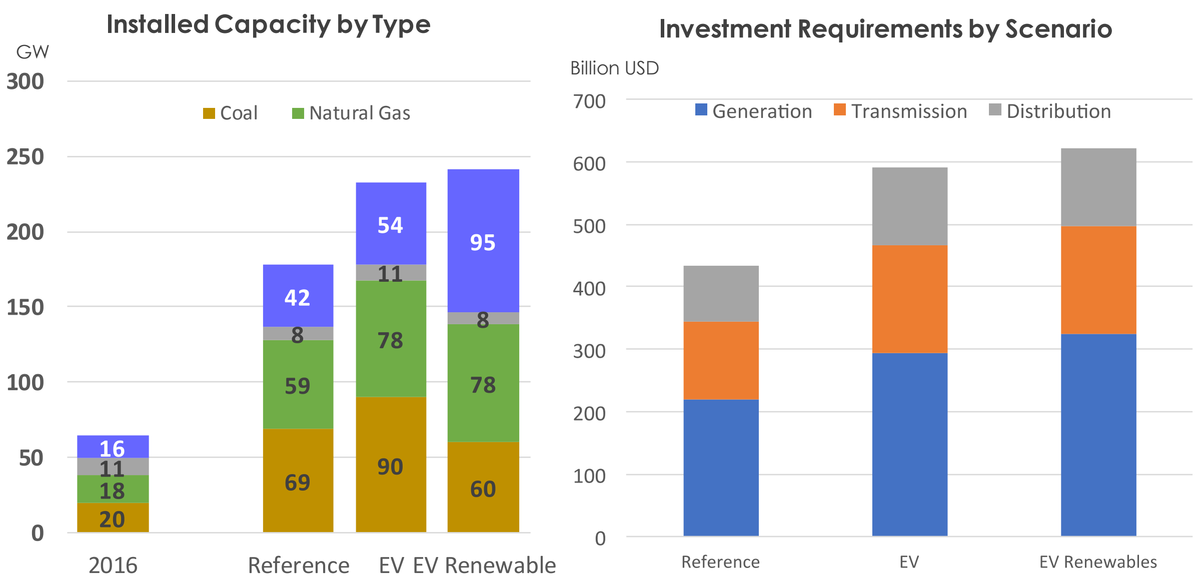
(reference case, $ billion)



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

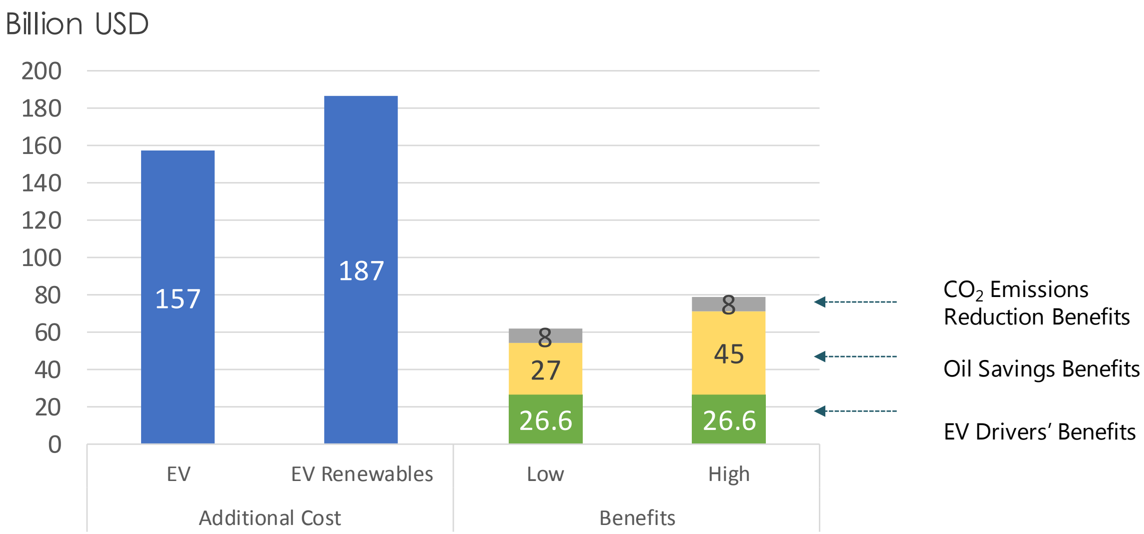
It is important to ensure integrated planning for the generation mix, as well as considering methods for the wider diffusion of EVs. The advanced EV scenario necessitates different investment requirements; by 2040 the electricity sector would require a cumulative investment of $591 billion under the conventional generation mix, and $621 billion with a higher share of renewables.

Figure 3.24: Electricity Investment Requirements in Indonesia (Scenario Comparison)



EV = electric vehicle, GW = gigawatt.
Source: Institute of Energy Economics, Japan (2018).

Figure 3.25: Electricity Investment Requirements in Indonesia (Scenario Comparison)



USD = United States dollars, CO_2 = carbon dioxide, EV = electric vehicle.
Source: Institute of Energy Economics, Japan (2018)

10. Conclusions

This chapter shows that introducing EVs would benefit Indonesian drivers by 2040. The substantial estimated reduction in the cost of lithium-ion batteries would ultimately lead to lower upfront costs in the future, and EVs' lower energy requirements per travel distance combined with lower maintenance cost requirements would benefit Indonesian drivers.

Meanwhile, it is important to note that the tipping point – when the estimated benefits from the shift to EVs would outweigh the lower cost of ICEVs – differs by mode. The tipping point is estimated to arrive much earlier for motorcycles (sometime after 2020) than for buses (sometime after 2035) due to the relative high upfront cost of EV buses compared with that of ICEV buses.

However, as the sensitivity analysis with regard to EV buses shows, the tipping point would differ depending on travel distance; this suggests that, given the current cost gap, EV buses would be used on routes with long travel distances to ensure that the potential benefits from oil savings, reduced CO_2 emissions, and improved air quality, as well as the drivers' benefit of lowered TCO are realised. In addition, until upfront costs are reduced, supporting measures (such as the provision of subsidies or battery leasing) should be instituted to realise the full benefits from the introduction of EV buses.

Substantial investment would be required to create the necessary electricity infrastructure. As the findings show, integrated planning would be necessary to consider both supply and demand and enable EVs to be used as an effective tool for reducing CO_2 emissions.