STUDY REPORT

IESR

A TRANSITION TOWARDS LOW CARBON TRANSPORT IN INDONESIA: A TECHNOLOGICAL PERSPECTIVE

IMPRINT

A transition towards low carbon transport in Indonesia:
a technological perspective

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Abbreviation list

°C : Degree Celcius
Aprobi : Indonesian Biofuel Producers Association
ASI : Avoid-Shift-Improve
BAU : Business as usual
BEV : Battery electric vehicle
BNEF : Bloomberg New Energy Finance
BPDPKS : Oil Palm Estate Fund Agency
BRT : Bus rapid transit
CAT : Climate Action Tracker
CNG : Compressed natural gas
CPO : Crude palm oil
CO : Carbon monoxide
CO_2 : Carbon dioxide
EPA : Environmental Protection Agency
ERIA : Economic Research Institute for ASEAN and East Asia
ETC : Energy Transitions Commission
EU : European Union
EUR : Euro (currency)
EV : Electric vehicle
FAME : Fatty acid methyl ester (biodiesel)
FCEV : Fuel-cell electric vehicle
Gaikindo : Indonesian Motor Vehicles Industries Association
GAPKI : Indonesian Palm Oil Association
GDP : Gross domestic product
GHG : Greenhouse gas
GIAMM : Indonesian Automotive Parts and Components Industries Association
GW : Gigawatt
HEV : Hybrid electric vehicle
HSR : High-speed rail
HVO : Hydrotreated vegetable oil
IATA : International Air Transport Association
ICAO : International Civil Aviation Organization
ICCT : International Council on Clean Transportation
ICE : Internal combustion engine
IEA : International Energy Agency
IESR : Institute for Essential Services Reform
IIEE : Indonesian Institute for Energy Economics
IMO : International Maritime Organization
ITDP : Institute for Transportation and Development Policy
ISPO : Indonesian Sustainable Palm Oil
km : Kilometer
kW : Kilowatt
kWh : Kilowatt hour
L : Liter
LCEV : Low carbon emission vehicle
LCGC : Low cost green car
Lge : Liter gasoline-equivalent
LNG : Liquefied natural gas
LRT : Light rapid transit
MEMR : Ministry of Energy and Mineral Resources
MMSCFD : Million standard cubic feet per day
MoI : Ministry of Industry
MoT : Ministry of Transportation
$MtCO_2e$: Million ton of carbon dioxide equivalent
MTOE : Million ton oil equivalent
MWh : Megawatt hour
NDC : National determined contribution
NDPE : No Deforestation, No Peat, No Exploitation
NG : Natural gas
NGV : Natural gas vehicle
NO_x : Nitrogen oxides
N_2O : Nitrous oxide
OECD : Organization for Economic Cooperation and Development
PASPI : Palm Oil Agribusiness Strategic Policy Institute
PHEV : Plug-in hybrid electric vehicle
PIKKO : Association of Small and Medium Automotive Component Industries
PLN : State-Owned Electricity Company
PSO : Public service obligation
PV : Photovoltaic
RAD-GRK : Regional Action Plans for the GHG Emission Reduction
RUEN : National Energy Plan
RUPTL : Electricity Supply Plan
R&D : Research and development
SOE : State-Owned Enterprises
SPR : Strategic Petroleum Reserve
TCO : Total cost of ownership
TOD : Transit oriented development
TOE : Ton oil equivalent
TWh : Terawatt hour
UCO : Used cooking oil
UK : United Kingdom
US : United States
USD : United States Dollar
VA : Volt-ampere
WTW : Well-to-wheels

Executive Summary

The transport sector has contributed significantly to the global greenhouse gas (GHG) emission with about 14% of the total GHG emission in 2016. Without a meaningful decarbonization policy and program, the transport's GHG emission is expected to increase faster than the other sectors, from 7.2 $GtCO_2e$ in 2010 to 12.8 $GtCO_2e$ in 2050. This increase in the emission is due to the burning of fossil fuel, more specifically petroleum fuels, in the transport sector. Petroleum fuels have served more than 90% of the energy demand in the transport sector.

However, this situation is expected to change. In the past two decades, petroleum's share in the global transport energy mix has decreased from 96% to 92%, mostly replaced by biofuels. The adoption of other technologies is also expected to increase in the future. Electric vehicles, in particular, have been touted to replace internal combustion engines. Vehicle manufacturers have been responding to this anticipated future by increasing R&D in electric vehicles and ramping up the EV production.

In Indonesia, the situation is no different. The GHG emission from the transport sector made up 26% of the energy-related emission in 2017, more than 90% was from the road transport. Along with increased GHG emissions, air pollution has also been increasing, especially in urban areas. Traffic congestion has made it even worse. The pollutant emission from the road transport has almost tripled between 1990–2010. Six urban agglomeration centers such as Jakarta, Medan, Bandung, Surabaya, Makassar, and Denpasar are among the cities with the worst transport problems.

Reliance on petroleum fuels has also driven up oil consumption, and as domestic oil production declines, oil imports become essential to meet the domestic demand. According to BP's statistics, Indonesia's net oil imports (including crude oil and refinery products) increased from 54 thousand barrels per day in 2003 to 814 thousand barrels per day in 2018. The heavy dependence on imported oil jeopardizes Indonesia's energy security and makes it vulnerable to global oil geopolitics and price fluctuation. All these issues force Indonesia to start shifting away from petroleum fuels, which has been carried out mainly by increasing the utilization of palm-oil-based biofuels and more recently by introducing electric vehicles.

The Avoid-Shift-Improve (ASI) framework is widely used in the transport sector as a strategy to enhance mobility, develop sustainable transport systems, and mitigate climate change. This framework employs three main strategies: "Avoid" unnecessary travel by means of integrated land-use planning and transport demand management; "Shift" to more efficient modes, namely public transport and non-motorized transport; and "Improve" vehicle technologies which include efficiency improvement and alternative energy use. All these measures have an essential role in decarbonizing transport, mainly through the energy efficiency improvement of the transport system.

However, in the end, to be able to reach zero-emission, alternative vehicle technologies that use renewable energy are needed to replace combustible fuels. There are currently several technological options available in the market, namely battery electric vehicles (including the hybrid ones), hydrogen-based fuel-cell electric vehicles, and internal combustion engines fueled by biofuels or synthetic fuels.

Many studies suggest that vehicle electrification should be the focus of transitioning the transport sector. Hence, decarbonizing the Indonesian transport system should also prioritize vehicle electrification. The land transport modes that are relatively easy to electrify, precisely passenger transport (such as motorcycle, car, and bus), should be electrified whenever possible. For other modes that might not be as easy to electrify, which include freight road transport, marine, and aviation, shifting the demand to other modes that are easier to electrify is essential. One example is to shift the demand of aviation to high-speed rail and long-distance trucking to rail and shipping. For the demand that could not be shifted, the alternative fuel needs to be deployed, which for Indonesia's case, biofuels might be the most promising option. At the same time, demand management measures should be implemented besides all these technological measures.

The government should then ensure that the transition succeeds and mitigate the risks of the transition to the stakeholders, including the industries, workers, and public in general. In order to achieve this objective, the government needs to perform the following measures:

- **Establish an integrated roadmap for low carbon transport in accordance with the Paris Agreement target**
  The transition to low carbon transport would not happen instantly; instead, it would require thorough planning and management to avoid major disruption to the infrastructure and stakeholders. Therefore, a roadmap of low carbon transportation is necessary to provide a clear signal and direction to the stakeholders on which technology needs to be developed and invested in. The roadmap needs to encompass quantifiable and integrated targets for different modes and technologies, along with the action plan and monitoring mechanism required to achieve the targets. The process of creating the roadmap should involve all relevant stakeholders in different governmental agencies, business/private sectors, impacted communities, experts, and public in general, and from different sectors including transportation, urban planning, energy, industry, etc.

- **Integrate sustainable mobility as part of urban planning**
  Efficiency is the main principle in low carbon transport, and "Avoid" and "Shift" measures are necessary to improve the transport system efficiency. As Indonesia is moving its capital and developing new metropolitan areas, it opens the opportunity to integrate sustainable mobility into the planning of these new urban areas. Thus, it is also crucial to start implementing push measures to drive the shifting to less carbon-intensive transport modes.

- **Implement measures to encourage the shifting from carbon-intensive transport modes**
  Synergy between pull and push measures is important to drive the shift away from fossil-fueled private vehicles in passenger road transport. However, the push measures, such as higher fuel cost, vehicle tax, and parking tariff, as well as car-free zones, are currently missing. In addition, modal shifting needs also to be enforced in other carbon-intensive modes, such as long-distance trucks to rail and shipping, and aviation to rail.

- **Establish stricter regulations on vehicle emissions**
  Implementation of stricter standards on pollutant and GHG emissions could help to improve urban air quality, enhance vehicle efficiency, and accelerate the shift to electric vehicles. Mandatory fuel economy standard, which is currently absent in Indonesia, is essential in improving vehicle efficiency and has already been applied in many countries. This standard could also be complemented with the emission-based taxation and fuel economy labelling. For air pollutants, the existing standard, which adopts Euro IV for four-wheelers and Euro III for two-wheelers, has already lagged behind the standards applied in most G20 countries.

- **Carefully plan the infrastructure development to anticipate the future evolution of different transport technologies**
  The transition towards a low carbon transport system would involve building supporting infrastructures, which need to be planned carefully to avoid wasteful investment. Infrastructure to support electric vehicles (power generation, grid, and charging) needs to anticipate the future technological development such as smart charging and vehicle-to-grid. The development of biofuel refineries needs to consider a potential drop of future demand as electric vehicles penetrate, so that no investment becomes stranded assets.

- **Conduct studies on the economic impact of the transition in the transport sector and subsequently plan for the impact mitigation**
  Disruption to the established automotive and petroleum industry is unavoidable as Indonesia shifts to a low carbon transport system. Stakeholders might fear that this change would result in declining economic activity and employment in these sectors. However, studies in other countries indicate that the transition could instead give rise to additional employment in new sectors. Therefore, the government needs to conduct similar studies in Indonesian context and plan for the impact mitigation. The mitigation could include, for example, identifying potential new economic sectors and the skills required for those jobs, then providing the training for workers to switch to the new jobs.

- **Establish enabling environment for the development of the electric vehicle market and industry**
  The government needs to provide supportive policies to spur the demand for electric vehicles. The support could be fiscal and non-fiscal incentives, as well as public charging infrastructure development. It is also important to provide incentives for attracting investment in the domestic electric vehicle supply chain industries, which could provide additional jobs to replace the job losses in the conventional vehicle industry. In addition, decarbonization in the power sector, ensuring sustainable mining practices, and proper battery disposal facilities would need to be enforced to ensure that the shift to electric vehicles would not create other environmental problems.

- **Intensify research on sustainable alternative liquid fuels for the non-electrified modes**
  A large proportion of the transport energy demand from the heavy-duty transport (i.e., heavy-duty road transport, shipping, and aviation) would be difficult to electrify. Until they can be electrified, for the time being, the combination of fuel efficiency measures and the use of non-petroleum fuels are feasible options. However, drop-in biofuel, synthetic fuel, and hydrogen fuel (and vehicle technology) are currently still in their infancy and not economically competitive. Globally, research is going on in these areas, and Indonesia should take its role, especially in the drop-in biofuel technologies, since there is abundant biofuel feedstock potential available, including the non-palm-oil ones.

- **Establish strict environmental and social safeguard mechanisms for biofuel development**
  The current palm-oil based biofuel poses sustainability issues, especially related to the land-use change and deforestation. To address this problem, continued improvement of the sustainability standards, such as the Indonesian Sustainable Palm Oil (ISPO), and the certification process is a must. In addition, it is also essential to enhance research on the upstream processes of biofuel, especially the sustainability of the feedstock. Data transparency and traceability need to be improved to support such research. Strict sustainability criteria should also be imposed on the whole biofuel supply chain. Moreover, research for alternative feedstock should be pursued, especially the utilization of waste materials such as agricultural waste and used cooking oil.

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1 Introduction

The need to develop a low carbon transport system has never been more pressing than it is today. Globally, the transport sector had contributed to 14% of the total annual greenhouse gas (GHG) emission or about 25% of the emission from the fossil fuel combustion in 2016 (Wang & Ge, 2019). Moreover, it is expected to increase faster than in other sectors. The Global Change Assessment Model projected that the transport's GHG emission would increase from 7.2 $GtCO_2e$ in 2010 to 12.8 $GtCO_2e$ in 2050 under no decarbonization policies (Wang & Ge, 2019). Nationally, the sector put up 147 $MtCO_2e$ into the atmosphere in 2017, contributing to 26% of the total GHG emission in the Indonesian energy sector (Ministry of Environment and Forestry, 2019). As the Indonesian economy will continue to grow, the emission from this sector will likely increase if Indonesia fails to shift to low carbon and sustainable transport systems.

The transport systems have long relied on fossil fuels and thus cost environmental damages such as air pollution and climate change. The poor transport planning and limited low carbon transport modes are some of the factors deemed contributing to these damages. However, the transition from energy-intensive to sustainable transport systems might be achievable if the government starts to put sustainability measures into the transport policies. This notion is especially true in Indonesia, as the transport infrastructure is still developing and urbanization is expanding.

In the past few years, the government has indicated its intention to shift away from petroleum-based transport by adopting biodiesel blending and electric vehicle policies. However, these measures are insufficient and lack the long-term plan to further transition into a low carbon transport system. Besides, there are other technological options that have not yet gained as much attention as the previous two, such as hydrogen and synthetic fuels. The transition in non-road transport, especially in aviation, has not been discussed much. Apart from the technological solutions, other efforts such as implementing fuel economy standards and encouraging modal shifting to public transport could also potentially help the sector reduce its emission before entirely switching to more sustainable transport systems.

The question then lingers over which transition pathway Indonesia should take to meet its Paris Agreement target and what it means for the country to opt for a certain pathway for its transport sector rather than the others. This study, therefore, aims to showcase the options available in the markets and provides policymakers with insights on how to lower the GHG emission in the transport sector. While the options laid out involve efficiency measures (i.e., demand management and vehicle efficiency improvements), this study will focus more on the alternative low carbon technologies.

This report starts with the ongoing transition in the global and Indonesia transport sector, followed by the technological options available to decarbonize the transport sector and the current transport policies and development in Indonesia related to the transition technologies. Then this report would discuss the scenarios to decarbonize Indonesia's transport sector. Lastly, it would conclude by presenting actions that need to be taken by the government to ensure a smooth transport transition in Indonesia.

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2 Transitions in the transport sector

2.1 Global transitions in the transportation sector

The global transportation system is undergoing a major change. The current system has suffered from various problems, e.g., climate change, air pollution, congestion, traffic accidents, noise pollution, dependence on oil and its geopolitics, landscape changes, and loss of spaces. All these problems have pushed countries to transition towards a more sustainable transport system. Technological and business innovation has helped drive the transition, i.e., renewable energy, alternative fuels, intelligent transport systems, electric vehicles, battery and storage, autonomous vehicles, and ride-sharing applications.

According to IEA's data (n.d.), the global energy consumption in the transport sector has more than doubled since the 1970s. Its share in the global energy consumption has increased from 23.2% in 1973 to 25.1% in 1990 and 28.9% in 2017. Road transport dominates this energy demand, contributing 77.3% in 2000. Of the road transport energy demand, the private passenger vehicles contributed 60%, freight transport 32%, and buses 8%. Rail, air, and sea transport comprised 1.5%, 11.6%, and 9.5% respectively (Moriarty & Honnery, 2016). As shown in Figure 1, the existing transport system relies heavily on fossil fuels, more specifically petroleum fuels. More than 90% of the total energy consumption has been served by oil products. However, there is an increasing trend of alternative fuels use in the past two decades, most noticeably biofuels.

However, this situation is expected to change in the future, especially in the road transportation. Many predictions and scenarios have been published in the last few years from various organizations; most agree that the era of internal combustion engines fueled by petroleum fuels is approaching its end. IEA estimated that in order to keep the temperature increase well below 2°C above the pre-industrial level, the internal combustion engine (ICE) vehicle fleet needs to comprise less than 50% and 6% of the passenger cars and light duty commercial fleets by 2040 and 2060, respectively (IEA, 2017a). BP, one of the biggest oil companies, predicted that the growth of energy consumption in transportation in the 2020–2030 period would be half as fast as the 2010–2020 period, mostly due to energy efficiency. Alternative energy sources, including natural gas, biofuel, and electricity, will dominate (about 80% of) the energy consumption growth in the road transportation from 2017–2040 (BP, 2019a). Bloomberg New

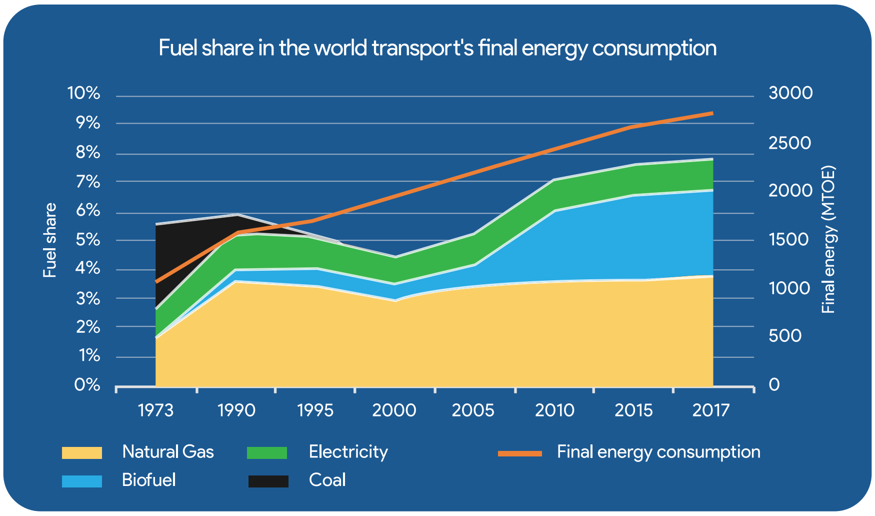

Figure 1. Share of various fuels in the world transport sector's final energy consumption. The remaining energy consumption not shown in the graph is supplied by oil products. Data from IEA (n.d.)

Energy Finance (BNEF) projected that the sales share of ICE vehicles would already drop to less than 50% of the total passenger vehicle sales by 2040. It also predicted that the global ICE vehicle stock would peak in 2030, and fuel demand by transportation will already decrease by about 20% in 2040 compared to the 2019 demand (BNEF, 2019). Although, it also sees that EV penetration in Southeast Asia, including Indonesia, would be generally more than 33% lower than the global rate until 2030 (Wehling et al., 2020).

2.2 Drivers of transition in the Indonesian transport sector

As the economy grows, the need for mobility in Indonesia is also increasing. The transportation sector is now the most significant final energy consumer. Its contribution to the final energy consumption increased from 31% in 2008 to 45% in 2013 and stayed around that level until 2018 (MEMR, 2019). However, the current transportation system that serves this need is highly dependent on fossil fuels, more precisely petroleum fuels. In 2018, about 94% of the final energy consumed in the transportation sector came from petroleum fuels (51% gasoline, 34% diesel, and 9% jet fuel) while the rest was supplied by biodiesel.

The reliance on petroleum fuels has raised the issue of increasing imports of crude oil and oil products. Indonesia has become a net oil importer since 2002 (BP, 2019b). An increase in mobility has driven up oil consumption, while the crude oil production has continuously been decreasing in the last two decades (see Figure 2). With the oil refinery capacity stagnating, more oil needs to be imported in the form of fuel products, which cost higher. The petroleum fuel is still partly subsidized by the government, and the amount of subsidy is directly correlated to the crude oil price, which is currently on the rise in the last three years (see Figure 3). The subsidy has put a burden on the state trade balance and state budget, thus encouraging the government to put more efforts on reducing oil consumption.

More importantly, the high degree of reliance on imported fuels exposing vulnerability to the global oil geopolitics and price fluctuation. In avoiding disruption in the energy supply, countries establish their strategic petroleum reserve (SPR). IEA member states, for example, are obliged to stock oil equivalent to 90 days of their net oil imports, although most have higher than the required. The stock can be held by industry, government, or agency (IEA, 2019d). Indonesia is yet to establish its SPR, which is already planned in Energy Law 2007. Currently, the only oil reserve is Pertamina's operational reserve of 21–23 day oil consumption equivalent. According to the Directorate General of Oil and Gas, the Ministry of Energy and Mineral Resources, the investment required was estimated to be USD 2.5 billion for 30 days of oil consumption reserve, equating to around 45 million barrels (Aziz, 2016).

Increasing oil consumption and imports will consequently expand the required strategic reserve in the future. The national energy plan (RUEN) estimates that oil consumption will reach 2,196 barrels per day (BPD) and 4,619 BPD by 2025 and 2050. This projection means that Indonesia's SPR will be at least 66 and 138 million barrels by 2025 and 2050. Assuming the same investment requirement as mentioned by the Directorate General of Oil and Gas above, fulfilling the 30-day SPR would require an additional investment of USD 1.2 billion for 2025 and USD 5.2 billion for 2050.

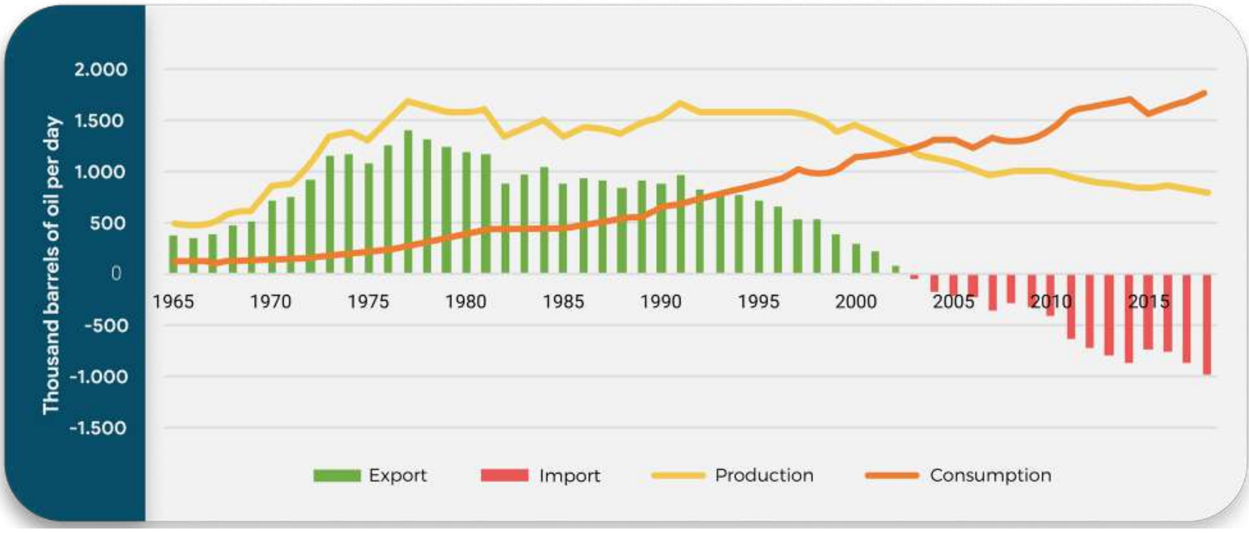

Figure 2. Oil trade balance. Data from BP (2019b)

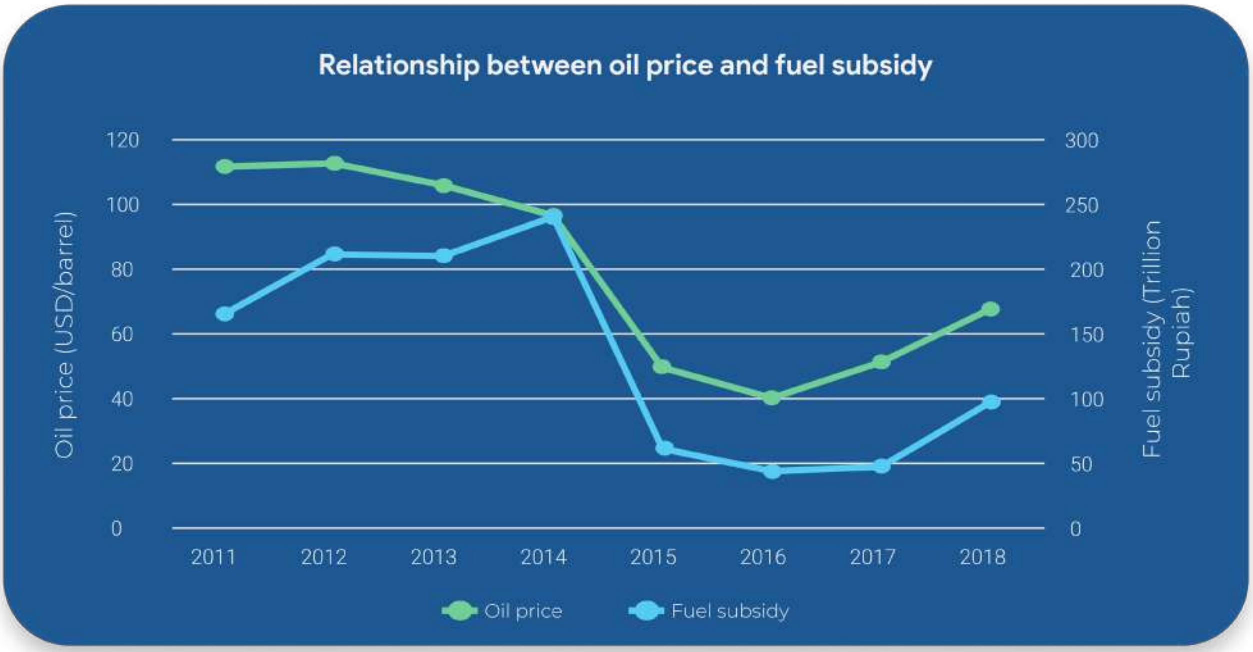

Figure 3. Direct correlation between the oil price and fuel subsidy. Oil price data from MEMR (2019b) and fuel subsidy data from MEMR (2019a)

As a result of the growing transport demand and reliance on petroleum fuels, the transport sector's carbon emissions made up a significant portion of the energy sector emissions. The latest data from 2017 indicated the GHG emission from the transport sector made up 26% of the energy-related emission, as shown in Figure 4. Of that number, the land transportation (mostly from the road transport) contributed to 91%. This number has not taken into account the emission from the oil fuel production process and the fugitive emission from the oil production, which could contribute around 7% of the total energy sector emission (Ministry of Environment and Forestry, 2019).

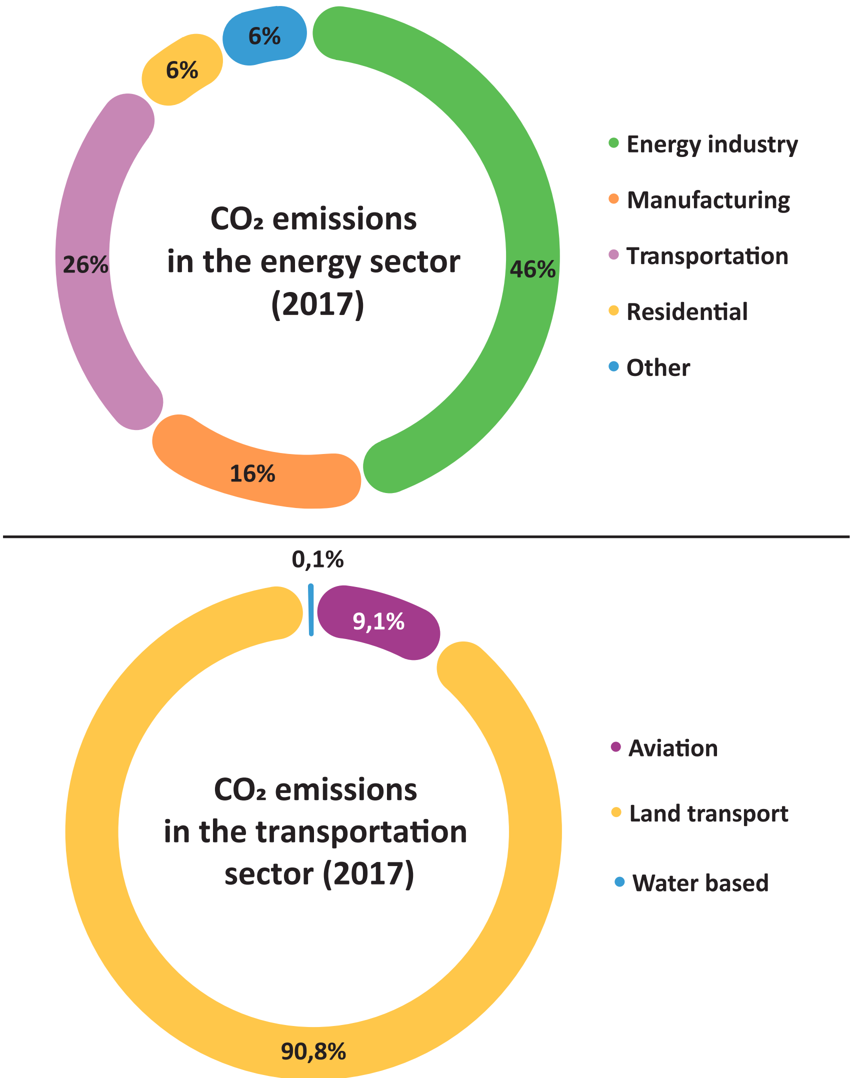

Figure 4. Share of the transport sector in the energy related GHG emission. Data from the Ministry of Environment and Forestry (2019)

In addition to the GHG emission, the transport sector also contributes significantly to air pollution, especially in big cities, where the increase in mobility need is fulfilled mostly by private vehicles, i.e., passenger cars and motorcycles. The share of private cars and motorcycles in Jakarta increased from 15% and 28% in 2002 to 24% and 51% in 2019 (Figure 5). Haryanto (2018) revealed that transport contributes to 80% of the air pollution in urban areas. He also showed that the pollutant concentration has almost tripled during the 1990–2010 period.

The traffic congestion caused by increasing use of private vehicles only worsened the air pollution problem (Greenwood et al., 2007), with six of the largest cities in Indonesia suffered the most (Hang Leung, 2016). Jakarta, for example, has been featured among the most congested cities in the world, although it has already made some improvement according to the Tomtom traffic index (Fickling, 2018; Jakarta Traffic Report, n.d.). Accordingly, it has also several times crowned as the city with the most polluted air in the world, according to AirVisual (Atika, 2019). A similar situation is happening with the other cities in Indonesia, though in different severity levels.

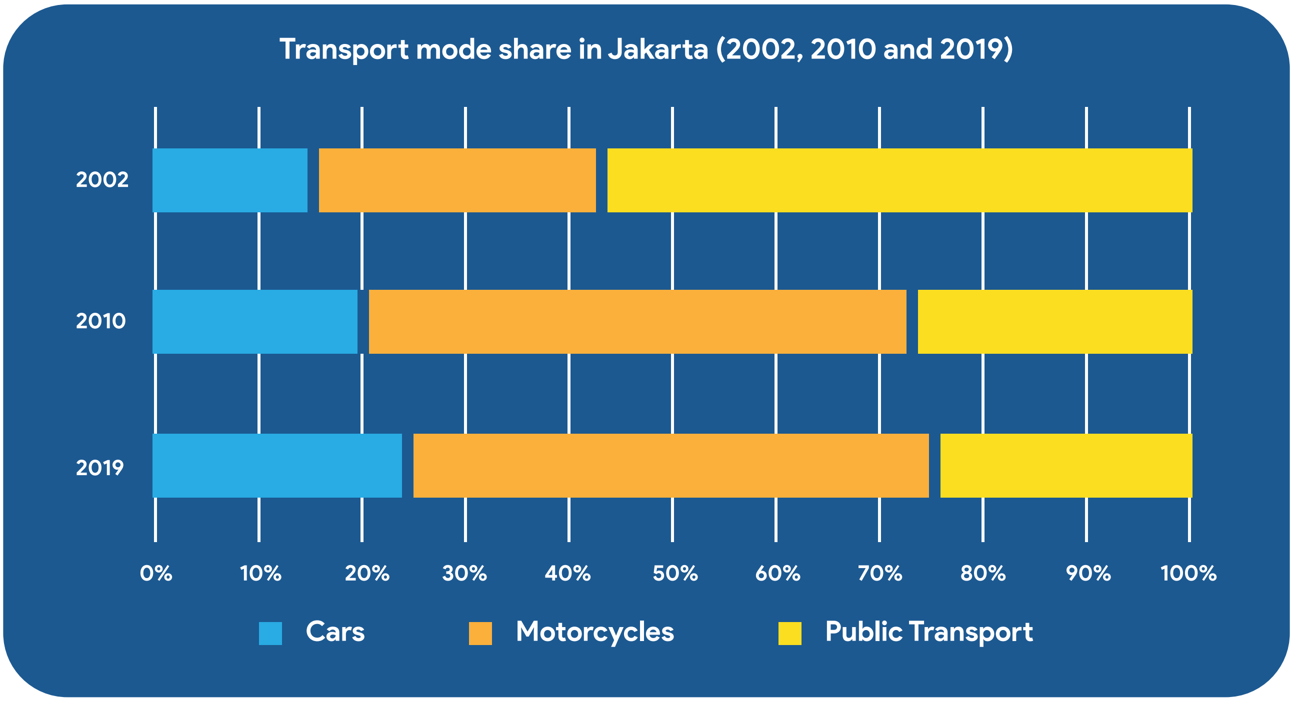

Figure 5. Transportation mode share in Jakarta over time. Data from ITDP (personal communication)

All these problems that the current fossil-fuel dependent transport system is facing have become the driving forces for Indonesia to transform it and move towards sustainable low-carbon transport.

The next chapter would discuss the currently available options for supporting the transition to low carbon transport.

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3 Technological opportunities for low carbon transportation

Transport policy has been dominated by the "predict and provide" paradigm, where transport planning and development follows the prediction of future demand. It focused on the movement of individual person or goods which creates the demand (Lyons, 2012). This concept has been deemed unsustainable; therefore, other thoughts followed that emphasize on the importance of shaping the demand (Goulden et al., 2014). The new mobility concept turns its focus away from the individual movement of individuals, and instead considers the "large-scale movements of people, objects, capital, and information across the world" and "local processes of daily transportation, movement through public space, and the travel of material things" (Lyons, 2012, p. 33). This alternative concept is manifested in the "Avoid-Shift-Improve (ASI)" framework that is currently championed as the guiding principles in transport planning (Zamora, 2014). Figure 6 illustrates the ASI framework.

"Avoid" aims to improve system efficiency by avoiding or reducing travel needs through integrated transport and spatial planning, as well as transport demand management. "Shift" intends to improve trip efficiency by using less polluting (more efficient) transport modes, such as public transport or non-motorized transport instead of private motorized vehicles. "Improve" refers to improving the energy efficiency and carbon intensity of vehicle technology, for example, through the implementation of eco-driving mode or alternative less-polluting fuels. The "Avoid" measures should be implemented first followed by "Shift" and then "Improve" as the last resort (Bongardt et al., 2019). This framework is in line with the finding from Agora Verkehrswende (2017), which concluded that efficiency is the main principle of transport transition.

IEA (2017a), in its below two-degree scenario, estimated that the "Avoid" and "Shift" measures could reduce about 15% of the global transport sector GHG emission in 2050. Policies commonly used for the "Avoid" and "Shift" measures might not be distinguished between each other. Those policies include putting a price for motorized

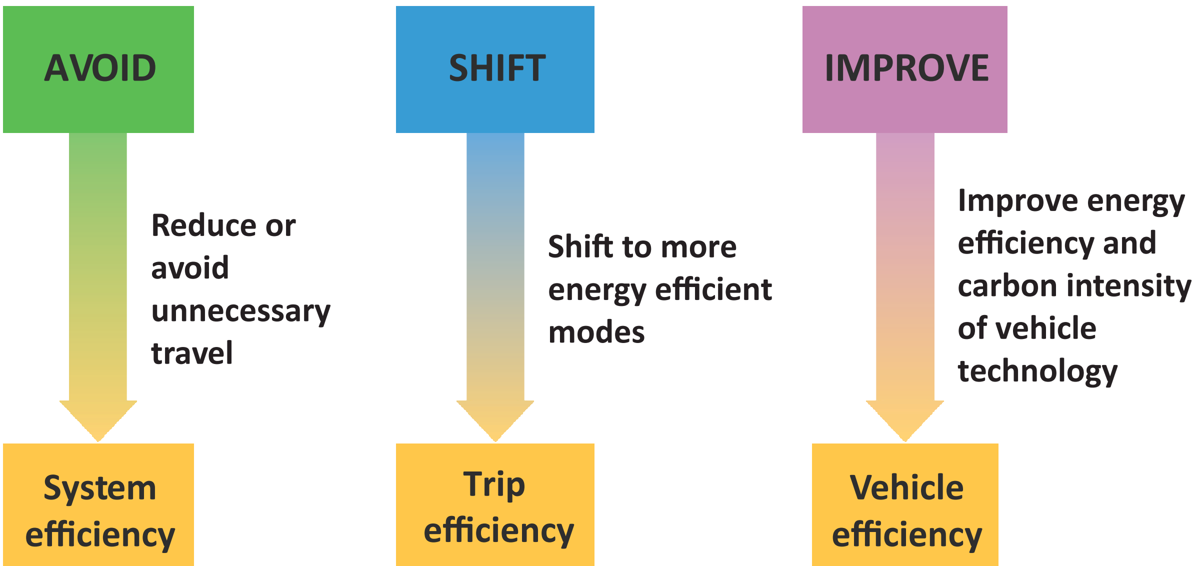


Figure 6. ASI framework. Adapted from GIZ GmbH (n.d.)

mobility (e.g., fuel tax, road pricing, congestion pricing, and license plate restriction); commuting reduction (e.g., teleworking, flexible working hours, and compressed work week); encouraging non-motorized transport (e.g., pedestrian and biking infrastructure improvement, and traffic calming); improving public transport; integrating transport in urban planning (e.g., transit-oriented development, urban planning codes, and car-free zones); and parking management (e.g., pricing, on-street parking restriction, and reducing parking spaces) (Bongardt et al., 2019; Zamora, 2014). However, Indonesia has not focused on the "Avoid" and "Shift" measures, with 67% of the proposed actions in the local mitigation action plans for the GHG emission reduction (RAD-GRK), could be categorized as the "Improve" measures (Jaeger et al., 2014).

For the "Improve" measures, one option is to improve the vehicles' energy efficiency. Many projections consider efficiency improvement as the primary contributor to the emission reduction in road transportation. BP Energy Outlook 2019 estimated that efficiency improvement would contribute about 70% of the 2040 road transport GHG emission reduction in its lower-carbon transport scenario (BP, 2019a). IEA (2017) also acknowledged the importance of improving vehicle efficiency through improved aerodynamics, weight reduction, engine improvement, exhaust heat recovery, and hybridization, especially for a short and medium term. It also estimated that about 20% of the emission reduction in non-OECD countries necessary to keep the temperature increase well below 2°C, would be from vehicle efficiency. Kodjak and Meszler (2019) projected that the road-vehicle efficiency improvement, including electrification, could reduce the GHG emission of road transport by 55%–70% compared to the current policy scenario, depending on the electricity generation mix. Excluding the electrification, the emission reduction potential could still reach 37% from the current policy scenario.

Combining all efficiency measures, IEA (2017a) estimated the emission from the transport sector could be reduced by 35%. A more ambitious projection by Teske et al. (2019) showed that the transport energy demand in non-OECD Asian countries could be cut by as much as 73% in 2050 by implementing energy efficiency measures, including demand management, mode shift, and technology improvement.

Despite the emission reduction potential of efficiency measures, in the end, to fully decarbonize the transport sector, alternative fuels or vehicle technologies are required to replace the current combustion engine that burns petroleum fuels. Figure 7 presented the available fuels and vehicle technologies to decarbonize the transport sector. Several studies also include natural gas as an alternative for decarbonization, at least for the transitional phase. However, it is not included in this study since it can only reduce a small amount of the GHG emission compared to petroleum fuels, and there is the potential of methane emission during the upstream processes.

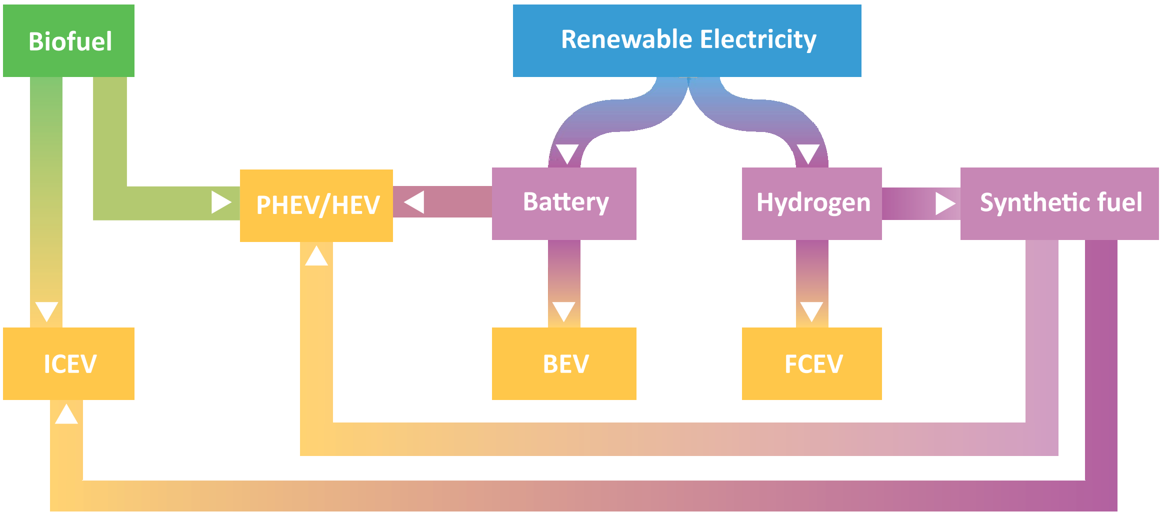


Figure 7. Alternative energy sources and vehicle technologies for low carbon transportation

Box 1 Indonesia's effort to transition to natural gas vehicles

The effort to reduce oil consumption by switching to other kinds of fuel started many years ago. In the late 1980s, Jakarta had already begun converting thousands of taxis into using compressed natural gas (CNG) engines instead of gasoline fueled engines. It was followed by a gubernatorial regulation on natural gas for public transportation and government vehicles in 2007 (BBC, 2012; Hartanto et al., n.d.). In 2012, driven by the increase of crude oil prices, the central government signed a presidential regulation to accelerate the conversion to natural gas by providing free converter kits for public vehicles. Ministerial regulation in 2017 tried to accelerate the shifting.

However, all the effort has not been taken off until now. Until 2018, there were only 68 units of public CNG refueling stations all over Indonesia, and 150 additions are expected in 2019 according to the ministerial roadmap (Agustinus, 2017), with a total consumption of 8.9 MMSCFD. Meanwhile, the target stated in RUEN was 140 units in 2018, with 80 MMSCFD use.

The GHG emission reduction of natural gas vehicles (NGV) is not significant while creating less air pollution and helping diversifying energy sources. It is caused by the lower efficiency of the natural gas engine compared to gasoline and diesel ones (Edwards et al., 2014). It could even be worse when considering the potential of methane leaking during the whole supply chain due to the adverse greenhouse effect of methane (IEA, 2017a). Considering the well-to-wheel emission (WTW), Edwards et al. (2014) showed that in most cases, NGV emits more GHG than diesel engines, although less than gasoline.

3.1 Electric vehicle

Many studies agree that vehicles' electrification is the most effective way to decarbonize the transport sector and should be done as much as possible (Agora Verkehrswende, 2017; Dominković et al., 2018; Pagenkopf et al., 2019). These studies asserted that vehicle electrification also provides other benefits than reducing the GHG emission, which include significantly less air and noise pollution, high energy efficiency, and the potential for integration with the power sector. The main idea of electrification is to supply the energy for mobility by electricity that is produced from renewable resources, such as solar, wind, hydropower, geothermal, and biomass. This measure makes achieving zero-emission possible, theoretically, when 100% of the electricity generation comes from renewables (Agora Verkehrswende, 2017).

Currently, electric vehicle technology is most mature in rail transport. Globally, in 2016, already 74% of passenger rail transport and 48% of freight rail transport activity were electrified (IEA, 2019c). Electric trains are 60–70% more energy efficient than the diesel ones. The state-of-the-art technology in electric trains uses overhead wires or third rails to provide electricity (Pagenkopf et al., 2019). The recent development of battery technology has brought forward the idea of battery-trains, or at least a combination with other technologies such as overhead lines or fuel-cell. Japan has already run battery trains for commercial passenger services since 2014. The train uses the battery power for 20 km non-electrified lines, with a 190-kWh battery (Thorne et al., 2019). In 2018, the German railway company had just started a trial of a battery train prototype that can serve 40 km between charges (Lambert, 2018). Just recently, in 2020, the UK has just completed the test of a hybrid train that runs on diesel and battery. The battery can serve about 100 km, with a 10-minute charge time (Zasiadko, 2020).

Electric vehicle technology is also rapidly developing in road transport, especially within the light-duty vehicles i.e. passenger cars, motorcycles, and light commercial vehicles (freight). In principle, electric vehicles (EV) are driven by electric motors instead of solely by internal combustion engines (ICE). There are many types of EV available in the market, i.e., hybrid (HEV), plug-in hybrid (PHEV), battery (BEV), and fuel-cell electric vehicle (FCEV). EVs require battery or hydrogen (in the case of FCEV) as the energy storage instead of liquid fuel for the ICE. A more detailed description of FCEV will be provided in the later section on hydrogen fuel.
HEV uses both an internal combustion engine and an electric motor that is not externally rechargeable. As the energy source, it uses conventional fuels (liquid or gas) and partly from the energy stored in the battery. The stored energy could come directly from the ICE or regenerative braking. The battery capacity is small, thus limiting the use of the electric motor. PHEV is defined as a hybrid electric vehicle that has at least 4 kWh battery storage, and the battery can be recharged from an external power source. PHEV can drive at least 16 km using only electric power (no petroleum fuel consumption) (Jain & Kumar, 2018). The current PHEVs normally have larger batteries and longer electric drive ranges. In the Chinese market, common PHEVs have at least 50 km all-electric range (Jin & He, 2019), while in the US market, they are clustered at 30 km all-electric range (EVAdoption, 2020). There are models of PHEV that have larger batteries, thus can operate mostly on electricity for urban mobility (up to 85 km). At the same time, the liquid fuel is used for more extended travel.

BEV eliminates the use of ICE, relying solely on battery storage and external charging. Therefore, the needed battery capacity is larger than the hybrid vehicles to accommodate a more extended driving range. BEV has several advantages over other types of EV, i.e., the system works simpler and avoids fuel combustion. The energy consumed

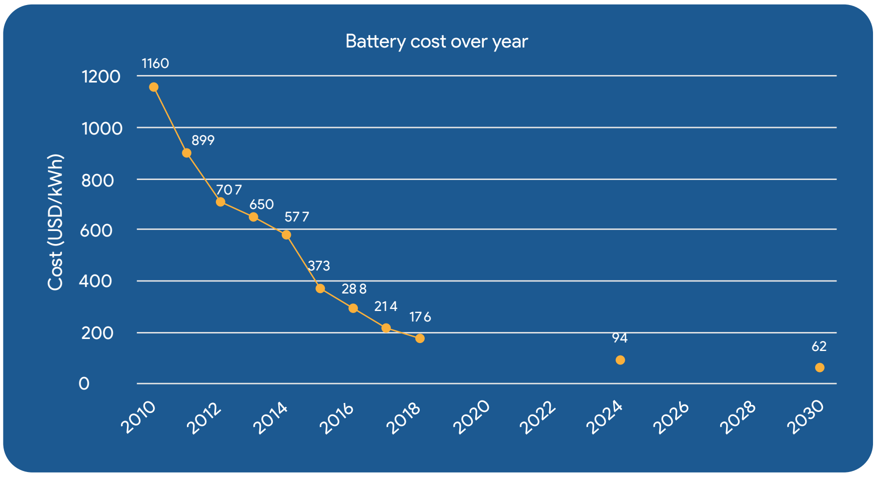


Figure 8. Historical decline of global lithium battery cost and projection until 2030 based on the BNEF survey. Data from Goldie-Scot (2019)

is significantly reduced since electric motors have up to 90% efficiency, while the combustion engines' is around 30–35%.

The cost of battery technology is currently the most significant hindrance to EV uptake globally. High battery cost makes the electric vehicle not competitive to conventional vehicles. Additionally, the relatively low energy density (energy per mass) of existing battery technology limits the feasible capacity. However, the development of battery technology in recent years showed significant improvement. McKinsey and BNEF predicted that in most passenger car classes, pre-tax upfront prices of BEV would reach parity with ICEV in the US and EU by the mid-2020s (Baik et al., 2019; Soulopoulos, 2017).

A BNEF survey from global EV industries in 2018 showed that the average battery pack price has declined by 85% during 2010–2018. They also estimated that the battery cost would keep falling from USD 176/kWh in 2018 to USD 94/kWh in 2024 and USD 62/kWh in 2030, as illustrated in Figure 8. This estimation assumes an 18% learning rate, meaning the price will drop by an 18% for every doubling of cumulative capacity. The portion of battery cost in BEV will drop from 57% in 2015 to only 20% in 2025 (Goldie-Scot, 2019). Additionally, the cost of other components, such as motors, inverters, and power electronics, is expected to decline by 30% by 2030 (Bullard, 2019).

On the other hand, the battery capacity has also been improving in the last few years. McDonald (2018) analyzed the driving range improvement of BEV in the US and found that the battery size increases by 15% each year on average during the 2011–2019 period. The study projected that the average BEV range in the US would reach 440 km by 2022 and 640 km by 2030. If the solid-state battery technology manages to get commercial by 2025, the range could even reach 800 km by 2030 (McDonald, 2018). In 2020, there are already new non-luxury BEV models that could drive more than 450 km without charging (EV Database, n.d.).

In addition to passenger cars, there are also electric two-wheelers/motorcycles available in the global market and quite recently, even in the Indonesian market. IEA's beyond two-degree scenario suggested that the two and three-wheelers will be all electrified by 2045, and along with rail would be the only modes that would reach 100% electrification by 2060 (IEA, 2017a). The electric two-wheelers include electric bikes (with pedal system, less than 0.25 kW motor, and less than 25 km/h maximum speed), electric mopeds or scooters (with less than four kW motor and 45 km/h maximum speed), and electric motorcycles or large scooters (with larger motor capacity and higher maximum speed) (Weiss et al., 2015).

The electric two-wheelers can be electrified sooner than the other vehicles due to its superior efficiency compared to the ICE counterparts and the small battery requirement due to low weight and short range required. Small battery size would limit the price difference from ICE and allow easier charging or battery swapping (IEA, 2017a). In India, for example, the price of electric motorcycles is about double the price of conventional bikes with similar features (Seethalakhsmi & Shyamala, 2019). In addition, banning the ICE motorcycles could help driving the electric two-wheelers penetration, as demonstrated in China (Weiss et al., 2015), which is currently the largest market of electric two-wheelers (Wehling et al., 2020). Following a similar path, India, the largest two-wheeler market in the world, has pledged to stop selling the ICE two-wheelers by 2025 (Partnership on Sustainable Low Carbon Transport, 2019). Other factors such as tight emission limits, increasing gasoline price, lack of public transport infrastructure, faster travel speed of electric two-wheelers compared to other modes, and even the occurrence of disease outbreak also influence the rise of electric two-wheeler adoption (IEA, 2017a; Weiss et al., 2015).

The global electrification of buses is much faster than the other road transport modes with a sales share exceeding 40% in 2020, although most sales occur in China (BNEF, 2019; Wehling et al., 2020). In the developing countries, urban public transportation, including buses, typically comprises only a small fraction of the total vehicle fleets but contributes disproportionately more significant to the energy consumption and the GHG emission (Sclar et al., 2019). This circumstance opens an opportunity for a significant GHG emission reduction through the electrification of public buses.

A recent report by BNEF estimated that about 20% of the existing global bus fleets is electric and will reach almost 70% by 2040 (Wehling et al., 2020). However, the growth has been concentrated in China with 98% of the global sales (Gavrilovic, 2019; Wehling et al., 2020). In 2018, electric buses comprised already 23% of the new bus sales in China. Shenzhen is one of the few cities that has already entirely switched to electric buses. Most of the existing electric buses are used for urban public transport, while for long-haul bus services, the electric buses are not going to start earlier than 2023 (Gavrilovic, 2019).

With a higher utilization rate than private vehicles, the higher upfront cost of electric buses could be paid off much faster by the lower operational cost it needs. BNEF estimated that the upfront cost of a European manufactured electric bus with 250 kWh battery capacity is about 30% higher than a diesel bus, and this would diminish by 2030 at the latest. However, on the total cost of ownership basis, which accounts for capital and operational costs, electric buses might already be cheaper than diesel buses, depending on the battery size and the distance traveled per day. The longer distance it goes per day, the lower the total cost ownership will be. For example, the price of a bus with 110 kWh, 250 kWh, and 350 kWh battery capacity will be already on par with a diesel bus when the distance traveled is above 80 km/day, 110 km/day, and 220 km/day respectively (BNEF, 2018).

Other modes of transport, including aviation and shipping, are not as easy to electrify. These modes of transportation are mainly limited by the low energy density of current battery technology. The high power required to run these vehicles requires a large battery capacity, which results in a heavier battery. Thus, other types of alternative technology are needed for these modes. Nevertheless, there are efforts to develop electric ships and airplanes. For example, electric ferries have been deployed in a few countries, with the largest now available in Denmark, with a 200-passenger capacity, supported by 4.3 MWh battery (Lambert, 2019b). Meanwhile, the largest electric airplane with a nine-passenger capacity was successfully flying for 30 minutes in June 2020 (Baraniuk, 2020).

As for the GHG emission, the determining factor is the share of fossil fuel in power generation mix. When coal dominates the power generation, the GHG emission will be relatively high compared to the condition with more electricity generated from renewables. Additionally, the battery production currently consumes a considerable amount of energy, and the energy source in the battery production facility will influence the total lifecycle emission. IESR provided an estimation of the GHG emission from electric car usage with the power generation mix as planned in RUPTL 2019–2028 and taking into account the GHG emission during vehicle manufacturing (IESR, 2019). According to the analysis, with the current emission factor of electricity generation, the use of BEV cars will slightly increase the GHG emission, due to the high proportion of coal in the generation mix. However, if the electricity is produced without the GHG emission, the shift to electric cars can reduce 58% of the GHG emission, assuming the emission from car manufacturing remains constant (IESR, 2020b). The GHG emission for the conventional and electric cars is illustrated in Figure 9.

For electric motorcycles, with 4.5 times better fuel economy, even with the current emission factor, a 35% GHG emission reduction compared to conventional motorcycles could already be achieved (IESR, 2019). For heavy-duty road transport, which includes trucks and buses, BEV will emit less CO_2 than diesel-fueled ones if the electricity emission factor goes below 875 gCO_2/kWh (ETC, 2018c).

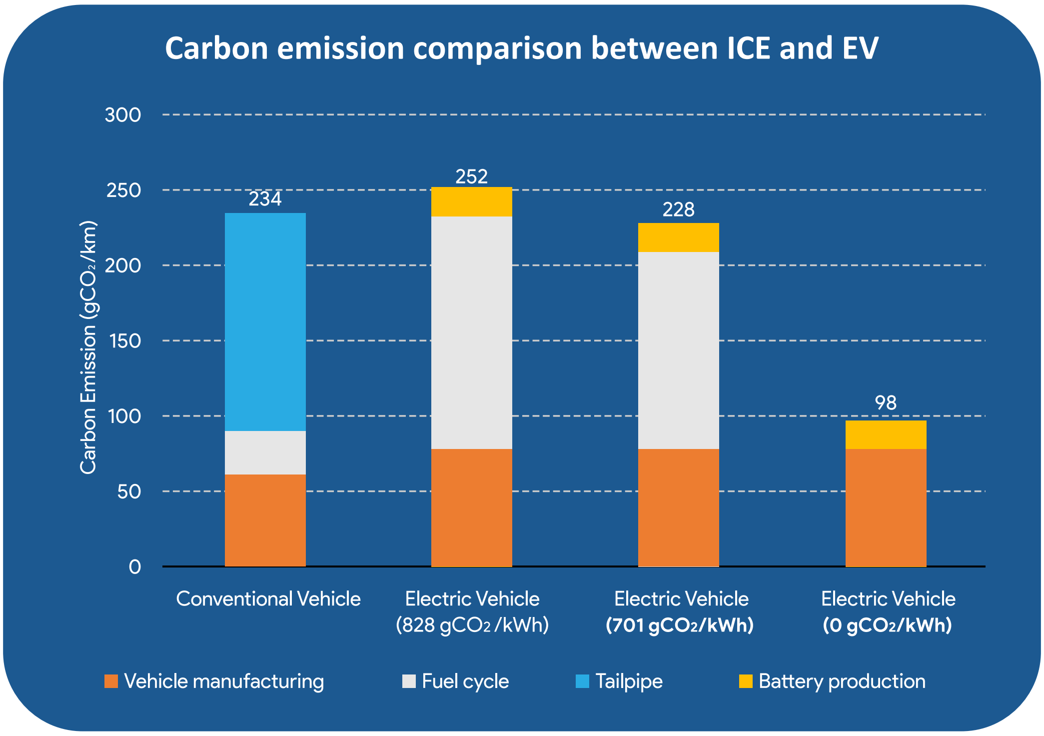


Figure 9. Life-cycle GHG emission comparison between ICE vehicles and BEV, under different electricity emission factors

3.2 Biofuel

In principle, biofuel is used to (partly) replace the fossil-based petroleum fuel in the existing vehicles and engines. Therefore, it does not require major technological change. Since biofuel is produced from plant biomass, the CO_2 emitted during combustion would come from the CO_2 it absorbs into plant biomass, making it seem carbon neutral. However, in reality, there are also CO_2 emitted along the supply chain, i.e., land use change, plant growing, biofuel production processes, and transporting, resulting in the positive carbon emission (Hanaki & Portugal-Pereira, 2018; Johnson, 2009). There are different kinds of biofuel, namely the conventional (oxygenated) biofuels, such as biodiesel and bioethanol, and drop-in biofuels (sometimes called bio-hydrocarbon).

Biodiesel is produced by a chemical process of animal or plant-based oil, known as transesterification. The product, fatty acid methyl ester (FAME) can be blended with petroleum diesel fuel and used in diesel engines (Bhatia, 2014a). Bioethanol is produced by fermentation of sugar or starch. There are also technologies to produce bioethanol from lignocellulosic feedstock such as agricultural residue. The product, ethanol, can be blended with gasoline and used in gasoline engines (Bhatia, 2014b). However, the characteristic of biodiesel and bioethanol is not 100% similar to that of petroleum diesel and gasoline, especially due to the oxygen content in its chemical structure, thus it needs to be blended with the conventional fuel.

Currently, there is already available vehicle technology that could cope with the change of combustion stoichiometry in higher blends of ethanol, called flex-fuel vehicles. The flex-fuel vehicles can run on pure gasoline, pure ethanol, or any combination of both, which now is highly popular in Brazil (Cardoso et al., 2019).

Additionally, there are also drop-in biofuels such as green diesel, biogasoline, or bio-jet fuel (for aviation) that have similar chemical and physical properties with the fossil fuel. Therefore, drop-in biofuels can directly replace the petroleum fuel, using the existing infrastructure and engines, without any modification. However, the production process is different from either biodiesel or ethanol. The process involves removal of oxygen content in the hydrocarbon chain, which is the primary difference between fossil fuels and conventional biofuels. The production process of drop-in biofuels is currently more costly than the conventional (Karatzos et al., 2017).

Biofuels are commonly produced using food/feed crops as the feedstock, such as vegetable oil (oil palm, rapeseed, soybean, etc.) for biodiesel and sugary or starchy crops (sugarcane, cassava, corn, etc.) for ethanol. The use of these crops for biofuel production might result in direct competition with food/feed production, leading to increased price for food/feed products. Second generation biofuels emerge to overcome this issue. The second-generation biofuels utilize agricultural waste, used cooking oil, or energy crops that grow in non-arable lands, thus not competing with food/feed production. However, the pretreatment of lignocellulosic feedstock (agricultural waste and lignocellulosic energy crops) is costly and hampers the development of the lignocellulosic second-generation biofuels (Dutta et al., 2014).

More recently, there is also a growing interest in (micro) algae as the feedstock for the third-generation biofuels (Dutta et al., 2014). Its advantages include high productivity, possibility to be genetically modified, and not requiring arable land. It has been researched extensively over the past years, supported by government subsidies in many countries. Yet, the microalgae technology is still currently not economically feasible except for producing the high value chemical products (Ruiz et al., 2016).

If produced responsibly, the use of biofuel can potentially reduce the carbon emission of fuel combustion. According to a WTW analysis conducted by the European Commission, the GHG emission from biofuel combustion is generally lower than gasoline/diesel, if the emission from the land use change is not considered. However, the extent of the GHG emission reduction depends on the production of the biofuel, i.e., the type of feedstock, the source of energy used in production, and the utilization of by-products. The cultivation of biofuel feedstocks also produces high N_2O emissions, which affect the climate 300 times as high as CO_2 (Edwards et al., 2014).

GHG emission saving per km driven from gasoline replacement by ethanol can get as high as 90% when the ethanol comes from waste material (e.g., wheat straw) (Edwards et al., 2014). The ethanol produced from sugarcane molasses as practiced in Indonesia could reduce the GHG emission by 67%. Efficient utilization of cane bagasse for electricity production could reduce the emission further up to 95%. Improper wastewater disposal, however, could generate a lot of GHG emissions cancelling all savings that could be obtained (Khatiwada et al., 2016). In reality, the actual emission reduction potential is limited by the blending with gasoline, which is currently around 10–15%. The possibility to use 100% ethanol, in a flex-fuel engine for example, is important to achieve the full potential of emission reduction.

For biodiesel as diesel replacement, the GHG emission saving which can be achieved is higher than 80% when using waste cooking oil as feedstock. When palm oil is used as feedstock, the saving ranges between 30% to 65%, depending on the availability of methane recovery units (in waste treatment) and waste heat utilization (Edwards et al., 2014). In practice, biodiesel is currently blended with fossil diesel at a maximum 30% ratio. Therefore, the actual reduction potential is only 30% as high, unless there is improvement in blending percentage. Hydrotreated vegetable oil (HVO), one of the drop-in diesel replacement fuels, performs similarly to biodiesel in terms of GHG emission reduction (Edwards et al., 2014), but it can be used without blending, thus resulting in more reduction in actual practice.

When the emission from land-use change is taken into account, the GHG emission of burning biodiesel might increase significantly. Traction Energy Asia

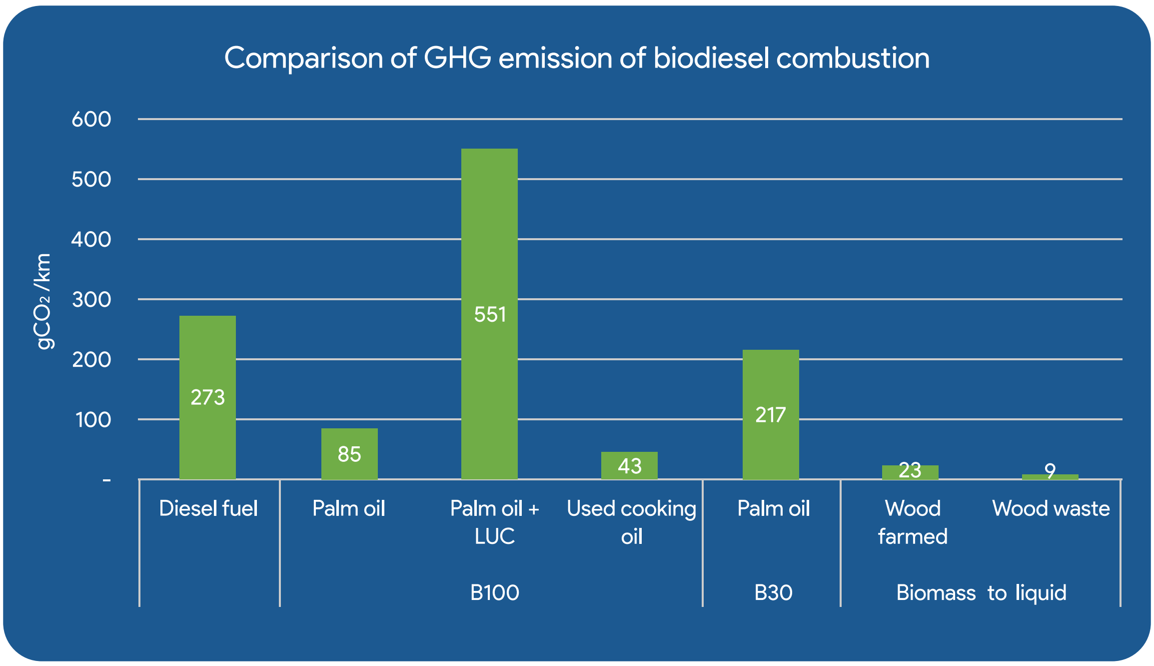


Figure 10. GHG emission comparison between diesel fuel and biodiesel combustion

(2019) reported that 83–95% of the total emission from biodiesel production in Indonesia comes from plantation to CPO production. In one of the biodiesel producers analyzed in the study, peat oxidation and land clearing contributed to 82% of the total emission, which reached 2.97 kg CO_2 per liter biodiesel, or 3.3 kg CO_2 per L of diesel fuel equivalent. This is already higher than the emission from diesel fuel combustion according to the US EPA that is 2.7 kg CO_2 per L (US EPA, 2014). In worse cases, the emission from biodiesel production can even reach 23 kg CO_2 per liter.

Figure 10 illustrates the GHG emission of different biodiesel sources and blending ratio based on the data from Edwards et al. (2014) and Traction Energy Asia (2019), adapted to Indonesia's fuel economy. The fuel consumption of an average diesel car in Indonesia is assumed to be about 11 km/liter (IEA, 2017b). The figure shows that the use of blended biofuel can only reduce the GHG emission by about 20%, assuming the biodiesel comes from used cooking oil and blended at a 30% ratio. It also shows that utilizing used cooking oil instead of crude palm oil as feedstock could reduce the emission significantly. Using drop-in biofuel produced from lignocellulosic biomass (biomass to liquid technology) could also reduce the emission further.

3.3 Hydrogen fuel

Another option is to use hydrogen fuel. Hydrogen can be used directly as a fuel in the internal combustion engine or indirectly using the fuel-cell technology that converts the energy to electricity to drive the electric motor (FCEV). However, due to the superior efficiency of electric motors compared to combustion engines, FCEV becomes the more reasonable option. Additionally, FCEV only produces water vapor as the by-product, while hydrogen combustion in ICE still emits NOx (Momirlan & Veziroglu, 2005).

Hydrogen can be produced from various processes, such as reforming of hydrocarbons (natural gas and oil), gasification or pyrolysis of solid fuels (coal, biomass, and refinery residues), and electrolysis. Natural gas is currently the predominant hydrogen production feedstock, accounting for 76% of the global hydrogen production, while coal accounts for 23% of the global hydrogen production and electrolysis for 0.1% of the global production. These figures do not account for the hydrogen produced as by-products (IEA, 2019b; van Hulst, 2019).

It is important to note that electrolysis-based hydrogen has lower efficiency compared to the fossil-based processes, leading to higher CO_2 emissions compared to the fossil-based processes if the electricity is not from renewables. For example, using the world average electricity mix, the CO_2 emission from the electricity-based hydrogen would be about three times higher than the hydrogen produced through natural gas reforming without carbon capture (IEA, 2019b).

Fuel cell electric vehicle total cost of ownership is currently much higher than other types of EV and ICEV due to the high price of hydrogen gas and the vehicle itself. Natural-gas-based hydrogen can be produced at EUR 1.5 per kg and around EUR 2 per kg when CO_2 price is considered (van Hulst, 2019). The cost could go as low as USD 1 per kg in countries with low natural gas prices such as the United States, Russia, and Middle Eastern countries (IEA, 2019b). Renewable-electricity-based hydrogen production cost is estimated at around EUR 3.5–5 per kg or EUR 0.9–1.3 per liter gasoline-equivalent (lge), but expected to drop by 70% in the next ten years if there is a considerable increase of capacity (van Hulst, 2019). Currently, the retail hydrogen fuel is sold at above USD 10 per kg in various countries, although expected to drop to about USD 6–8 per kg by 2030 (California

Fuel Cell Partnership, n.d.; Chung-un, 2019; Fraile et al., 2015).

Meanwhile, the fuel cell vehicle price is also relatively higher than other technologies. Toyota Mirai, for example, costs around USD 50,000 after a government subsidy of about USD 20,000 (Robitzski, 2019). However, many companies, especially Japanese manufacturers, are still developing the fuel cell technology; thus, the cost is expected to decline further in the future.

The WTW GHG emission of fuel cell vehicles is generally lower than conventional vehicles both via thermal process and electrolysis. However, this does not apply when the thermal process uses gasified coal as the feedstock, and the electrolysis uses the natural gas- or coal-generated electricity. The emission could reach almost zero when renewable power is used in electrolysis, or gasified biomass is used as the feedstock for the thermal process (Edwards et al., 2014).

3.4 Synthetic fuel from electricity

As previously mentioned, hydrogen gas can be produced from electricity through electrolysis. However, using hydrogen as a fuel requires modification to the existing infrastructure or vehicle technologies. The produced hydrogen can be further converted into other fuels that have already more established infrastructure, such as methane gas, and more importantly, liquid fuels. The conversion to these conventional fuels would avoid the necessity for infrastructure modification. Methane is produced through a reaction with CO_2, which can be obtained from biomass combustion or captured from the air to make the product carbon neutral. The produced methane can be directly injected to the existing natural gas infrastructure.

The advantage of this power-to-fuel technology is that it can be used in existing combustion engines, which is currently more mature than electric motor technology. However, it comes at the cost of efficiency, since there will be more conversion losses compared to direct use of electricity. When using an electric motor, the electricity will be converted into mechanical energy, which will result in 69% energy return. With the power-to-fuel concept, the electricity is first converted into chemical energy, and then to mechanical energy. The overall efficiency of power-to-liquid fuel can be as low as 13% (Agora Verkehrswende et al., 2018). Figure 11 shows a schematic of efficiency losses in different technologies.

The low efficiency makes synthetic fuel production very costly. Currently, the production in Europe is estimated to cost around 20–30 cents per kWh or EUR 1.8–2.7 per lge, excluding the network charge and distribution cost. It could reduce to about EUR 0.9 per lge when the capacity reaches 100 GW. The production cost of the synthetic fuel, however, depends on the cost of renewable energy used to produce, thus relying on the renewable energy available in the specific location. In Iceland, for example, it is estimated that the production costs as low as EUR 1 per lge (Agora Verkehrswende et al., 2018).

Currently, there is only one commercial production of electricity-based synthetic methanol with a 5 million liter annual production capacity, which is located in Iceland (Heyne et al., 2019). There are several other pilot plants with different products such as methanol, crude liquid hydrocarbon (oil), and diesel fuel.

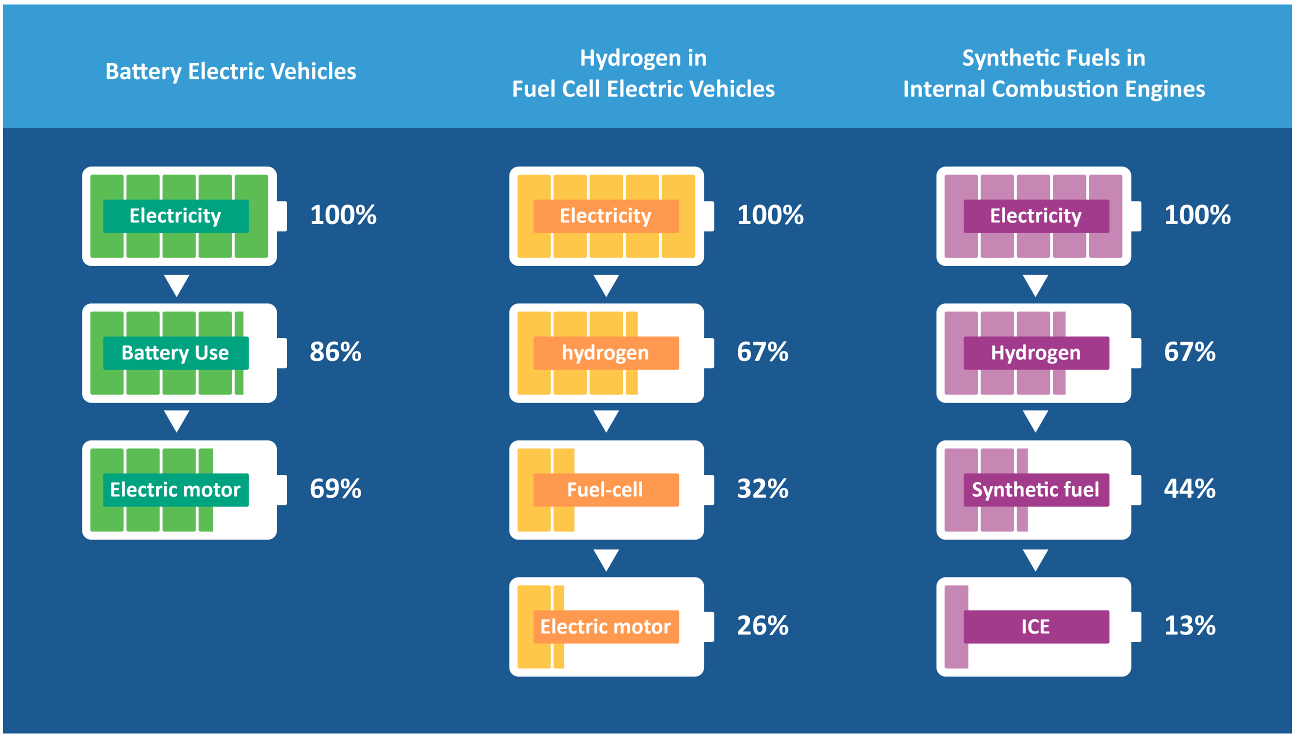


Figure 11. Energy efficiency of different vehicle technologies. Adapted from Agora Verkehrswende et al. (2018)

STUDY REPORT

4 Current transport policies and development in Indonesia

The Ministry of Transportation (MoT) is responsible for developing the national transport policy in coordination with the National Development Planning Agency which is responsible for the overall national planning. MoT is organized based on different transport modes, i.e., road, rail, air, and sea transport. As a consequence of this organization model, the transport policy lacks integration between the modes, with all modes having their respective laws and master plans.

In 2005, the MoT established the National Transport System regulation that acted as the guiding principles for transport planning in all policy levels, aiming to support the integration of the transport modes. However, it is not an integrated national transport master plan. Up until now, no regulation or law specifically addresses sustainable transport planning, let alone a master plan for sustainable transport.

Presidential Regulation No. 61/2011 on the National Action Plan for GHG Emission Reduction laid 16 action plans for the MoT to reduce the GHG emission in the transport sector, although only covering road and rail transport. In 2013, MoT issued the Ministerial Decree No. KP 201/2013 that expanded the emission reduction plan to include also the air and sea transport.

On the other hand, energy planning is conducted by the Ministry of Energy and Mineral Resources (MEMR) with the national energy plan (RUEN) as the master plan. RUEN is supposed to be a guideline for other ministries, including MoT, in formulating their strategic plan. It claims to comply with the unconditional GHG emission reduction target of Indonesia's NDC. The long-term development plan of MoT also stated that energy regulation in the transport sector should follow the national energy plan. As the GHG emission in the transport sector comes from energy use, and due to the lack of transport master plan from MoT, further analysis in this chapter will be based on RUEN.

However, RUEN does not provide a clear roadmap of which low carbon transportation technologies will be adopted in the future. In general, petroleum fuels will still dominate the energy source in the transport sector with a share of 84% of the total energy consumption in 2025 and 73% in 2050. Among the energy sources, the most substantial portion is expected to be supplied by biofuel, followed by natural gas and electricity as shown in Table 1. Other alternatives, such as hydrogen and synthetic fuels, are not included in the plan.

Table 1. Energy sources in the transportation sector according to RUEN

Energy sources	2025		2050	
	MTOE	%	MTOE	%
Petroleum fuels	62.8	84	123.2	73
Biofuels	9.6	13	31.2	18
Natural gas	2.6	3	11.9	7
Electricity	0.2	0	2.7	2

The plan implies that Indonesia will remain to be highly dependent on fossil oil with the petroleum fuel consumption expected to increase for the next 30 years. On the other hand, domestic oil production is projected to decline over the same period. This decline would only create a higher dependency on imported oil, which puts Indonesia's energy supply vulnerable to global oil price fluctuation and oil geopolitics. Currently, there is no clear focus on developing any of the alternative technologies.

Table 2 provides the list of actions in the transportation sector planned in RUEN within the time frame. According to this plan, the government should start establishing roadmaps and regulations on various alternative fuels or vehicle technologies before 2020. However, to this day, the government has yet to put the much-needed roadmaps and regulations in place. A roadmap for carbon tax implementation, a roadmap for long-term biofuel utilization, regulations on fuel economy standards, and regulations on hydrogen and synthetic fuels are yet to be issued. These roadmaps and regulations are essential to send a clear signal to the automotive and transport industry to start planning their shifting from the current oil-based system.

Table 2. List of actions planned in RUEN related to transport sector

Action plans	2019	2025	2050
Energy efficiency	- Develop fuel economy standards before 2020, especially private vehicles - Roadmaps for public and private transport modes - LRT development plan until 2050 - Electronic Road Pricing for urban main roads - Road preservation levies	- Public transport 30% modal share by 2025 - 10,000 Bus Rapid Transit fleets in 50 cities - Transit Oriented Development - Intelligent Transport System in 24 cities - Area Traffic Control System in 50 locations - Optimizing airplane traffic in 15 airports	- Public transport fleet rejuvenation - Develop train networks in 5 large islands - Develop urban rail networks in 13 cities - Sea toll consisting of 150 ships
- Roadmaps for public and private transport modes	- Incentive policies for the electric public transport - Incentive policies for the EV manufacturers	- 2,200 electric cars - 2.1 million electric motorcycles	- Build EV industries (upstream and downstream)
Biofuel	- Biofuel roadmaps for all transport modes (road, sea, air, and rail) - Policies for flex-fuel engine vehicles - Roadmaps for biofuel infrastructure development (and funding) - SOE/Regional SOE to produce and purchase biofuels - Roadmaps for priority feedstocks - Regulations for land use change for energy crops	- Implementation of biofuel blending for the road, sea, and air transport - 11.6 million kl biodiesel - 3.4 million kl bioethanol - 0.1 million kl bioavtur - Prepare 4 million hectares for biofuel feedstocks - Prioritize non-food competing feedstocks	- 54.2 million kl biofuel

Petroleum fuel	- Roadmaps for the carbon tax for fossil fuels - Policies for the petroleum fuel tax or other disincentive mechanisms	- Increase a refinery capacity to 2 MBOPD - Removing a petroleum fuel subsidy - Stop petroleum fuel imports	
Natural gas	- Roadmap NG for transport - Fiscal incentives for the manufacture of NGV - Incentives for the NG use in public transport	- 2 million units of NGV in 15 cities - 632 refueling stations with 282 mmscfd capacity in 15 cities	- 2,888 refueling stations with 1,291 mmscfd capacity
Liquified coal	- Roadmaps and development policies for liquified coal for fuels	- Liquified coal for fuel technology development	- 54.2 million kl biofuel
Hydrogen / fuel-cell	- Regulations for hydrogen use in public and personal transport		- Technology development of fuel-cell vehicles - Build FCEV industries
Synthetic fuel (SF)	- Regulations for synthetic fuel use in public and personal transport		Technology development of synthetic fuels
Solar PV utilization			- Solar PV at transport facilities (stations, airports, harbors, etc.) - Solar utilization in transport modes

Fuel economy standard is an important tool to push automotive industries to build more efficient vehicles. IEA (2017b) suggested that the fuel economy in Indonesia has not improved, and the absence of fuel economy standards is causing this lack of progress. Studies even suggested that the implementation of fuel economy standards will help accelerate EV adoption, considering the high efficiency of electric motors (Kodjak & Meszler, 2019; Meszler et al., 2016; Sen et al., 2017). The only regulation that might address the fuel efficiency in the transport sector is the Government Regulation No. 70/2009 on Energy Conservation. According to this regulation, entities with the annual energy consumption of more than 6,000 TOE have to implement energy conservation and report it to the government.

However, the enforcement of this regulation has been focused only on the industry sector, although transport companies generally consume more than 6,000 TOE or 7.1 million lge. For example, Garuda Indonesia, the state-owned aviation company, burned 2.18 billion liter avtur in 2018 (Garuda Indonesia, 2019). Another example, Blue Bird, one of the largest taxi companies, spent IDR 781 billion in 2019 for a fuel, equivalent to about 100 million liter gasoline (PT Blue Bird Tbk, 2020). Kereta Api Indonesia, the state-owned railway company, consumed 220 million liter diesel fuel in 2017 (Zuhriyah, 2018). Kereta Commuter Indonesia, which operates the commuter line in Jakarta, spent IDR 182 billion in 2018 for energy use, equivalent to about 11,000 TOE electricity (Kereta Commuter Indonesia, 2019).

In addition, the "Avoid" measures such as the Transit-Oriented Development (TOD) and the "Shift" measures to more efficient modes (i.e., road public or rail transport) are also already incorporated in the RUEN plan. The Ministry of Agrarian and Spatial Planning Regulation No. 16/2017 provides the guidelines for the TOD area development. Local governmental regulation, such as the Jakarta Gubernatorial Regulation No. 67/2019 also provides the mechanisms, management, and incentives for the TOD adoption in Jakarta. Rail network development in major islands is essential to offer alternative modes to air transport, which consumes a lot of energy.

On the other hand, the plan in RUEN still pushes for natural gas vehicles. According to IESR & IIEE (2019), building natural gas refueling stations planned in RUEN will need USD 1.78 billion by 2025 and USD 8.13 billion by 2050 or about USD 250 million per year. These new refueling stations might become a stranded investment in the future if we look into the projections made by many organizations that NGV will only contribute a tiny fraction of future vehicles (IEA, 2017a; Suehiro & Purwanto, 2019). From the climate perspective, the GHG emission reduction is not significant due to the high potential of methane emissions from leaking (IEA, 2017a).

Development of biofuels and electric vehicle technologies fared better than the other technological options, with several regulations already in place. The government has put significant efforts to push biofuel development and also has started to pay attention to electric vehicles recently. Current policies and the status of electric vehicles and biofuel technology are elaborated in the following sections.

4.1 Current electric vehicle policies and development

Development of electric vehicles (including hybrids) is mandated in RUEN, although targeting very low penetration with only 2,200 electric cars and 2.1 million electric motorcycles by 2025. Utilization of electric vehicles as public transport is targeted to reach 10% of the total urban public fleets by 2025. In addition, according to RUEN, the government should prepare fiscal incentives for electric vehicle manufacturers. Public charging stations are planned to reach 1,000 units by 2025. It lacks, however, the mandate to incentivize the consumers of electric vehicles.

As a follow-up, the government established the Presidential Regulation No. 55/2019, which aims to accelerate the development of battery electric vehicles. The regulation lays out several instruments that can be implemented to foster the growth of EV industries, mainly through fiscal and non-fiscal incentives, local content requirement, and charging infrastructure development by PLN. However, it does not mention anything about the need to set a roadmap for the EV ecosystem development, and the derivative regulations are still awaited (IESR, 2019). Moreover, the regulation also does not provide clear EV penetration targets and mentions nothing about the plan to stop the sales of conventional vehicles. Previously, the phasing-out of fossil-fueled cars and motorcycles by 2040 was expected to be included in this regulation (Prasetiyo, 2017).

On the other hand, the Ministry of Industry (MoI), in its automotive sector roadmap, targeted that in 2020, 10% of the motorcycle and car production should be low carbon emission vehicles (LCEV) that include BEV, PHEV, HEV, and FCEV. The LCEV share in vehicle production is expected to increase to 30% by 2035. Unfortunately, the 2020 target will not be achieved, as there were only 1,256 motorcycles and 40 cars on the road by the end of 2019 (IESR, 2019). Despite this failure for 2020, the government intends to keep these targets in place for the following years. The roadmap also targets 20% of the cars produced in 2025 will be low-cost green cars (LCGC), the highly efficient cars with engine capacity less than 1,200 cc and fuel consumption of at least 20 km/l gasoline

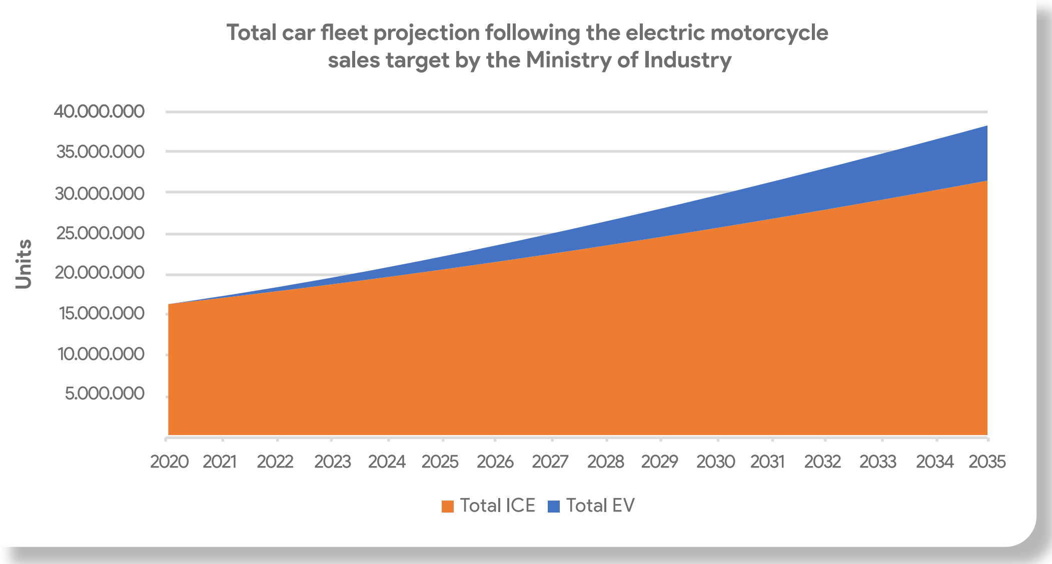
Table 3. The automotive industry production roadmap by the Ministry of Industry.
Data from the Directorate General of Metal Machinery Automotive and Defense Industry of the Ministry of Industry (2019)

Cars	2020	2025	2030	2035
ICEV	975,000	1,200,000	1,650,000	2,000,000
LCEV	150,000	400,000	750,000	1,200,000
LCGC	375,000	400,000	600,000	800,000
TOTAL	**1,500,000**	**2,000,000**	**3,000,000**	**4,000,000**
Domestic market	1,250,000	1,690,000	2,100,000	2,500,000
Export	250,000	310,000	900,000	1,500,000

Motorcycles	2020	2025	2030	2035
ICE	7,200,000	8,000,000	9,375,000	10,500,000
Electric	800,000	2,000,000	3,125,000	4,500,000
TOTAL	**8,000,000**	**10,000,000**	**12,500,000**	**15,000,000**
Domestic market	7,500,000	9,000,000	11,000,000	13,000,000
Export	500,000	1,000,000	1,500,000	2,000,000

(Directorate General of Metal Machinery Automotive and Defense Industry of the Ministry of Industry, 2019). The vehicle production targets based on the automotive sector roadmap is presented in Table 3.

This LCEV target by MoI is certainly more ambitious than RUEN. According to the target, an estimated 6.5 million LCEV cars would be on the road by 2035, comprising 17% of the total cars. This estimation assumes about 1.5% of the existing vehicles are taken out of the road each year. Similarly, an estimated 32 million electric motorcycles would be on the road by 2035, or 16% of the total fleet. The assumed replacement rate for motorcycles is slightly faster, with 3.5% per year. The 2020–2035 projection of car and motorcycle fleets is presented in Figure 12.



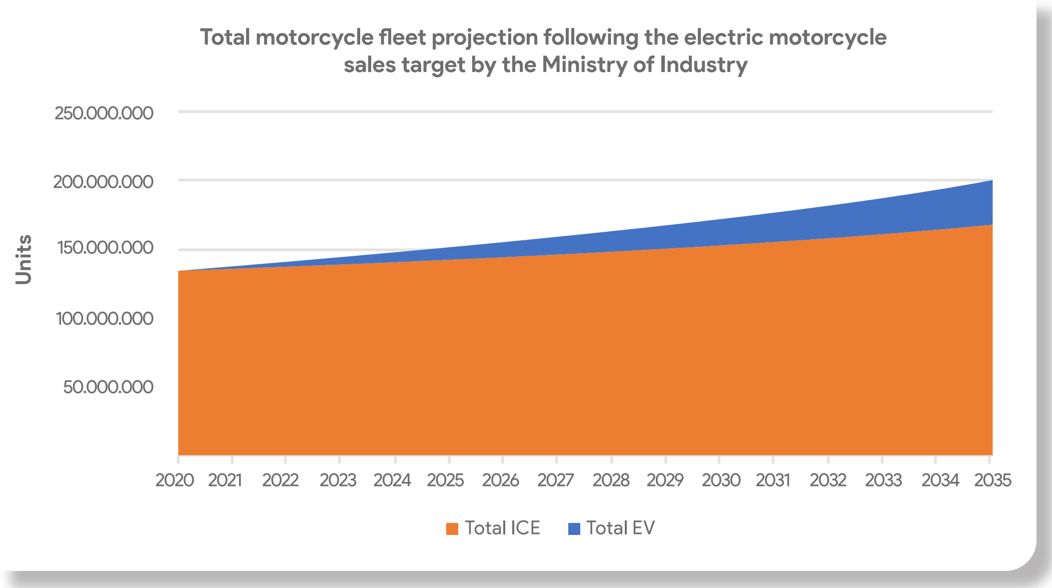


Figure 12. Total car and motorcycle fleet projection based on the roadmap by the Ministry of Industry

The influence of the established automotive industry on the development of low carbon transport

Vehicle manufacturing and sales make significant contributions to the Indonesian economy. The Ministry of Industry (MoI) claimed that the automotive industry contributed to 10.16% of the national GDP in 2017. In addition, MoI also stated that the automotive industry created 350 thousand direct and 1.2 million indirect employment (Kartika, 2018). The Indonesian Automotive Parts and Components Industries Association (GIAMM) released an even higher number, i.e., 480 thousand workers employed by the automotive component manufacturers and 2.5 million more employed by the service and spare part outlets (Surjadipradja, 2019).

Indonesian car and motorcycle markets are dominated by Japanese manufacturers, whose participation in the global EV sales is still low. In the top 10 of BEV sales for the first half of 2019, the cars from Japanese manufacturers were not in the list (Munoz, 2019). This situation might explain the reluctance of the existing car manufacturers in Indonesia to shift into electric vehicles. The Indonesian Motor Vehicles Industries Association (Gaikindo) even opposed the government's intention to ban the ICE vehicles sales by 2040, which was expressed by the Minister of Energy and Mineral Resources back in 2017 (Rudi, 2018).
Toyota, the world largest car producer, is the current car market leader in Indonesia with 32% of the 2019 market share, followed by Daihatsu (17%) and Honda (14%) (Gaikindo, n.d.). Toyota is yet to sell its first BEV globally, and it appears not to prioritize BEV development in its plan, focusing more on hybrid and fuel cell technologies (Lambert, 2019a). However, it has now acknowledged that BEV deployment is going faster than expected and thus plans to sell 4.5 million of HEV and PHEV, and 1 million of BEV and FCEV per year by 2025 (Schmitt, 2019). This plan is nevertheless much slower than Tesla and Volkswagen (the second largest global car maker) that expected to sell 1 million BEV per year by 2021 and 2022, respectively (Holland, 2019).

In the Indonesian motorcycle market, Japanese manufacturers also dominate the market. Honda contributed to over 75% of the total sales in 2019, followed by Yamaha (22%) (Nayazri, 2020). In the global market, these Japanese manufacturers are yet to mass-produce their electric motorcycles. Honda had just launched its first electric motorcycles for the Japanese market in 2018, and later also to other countries including Indonesia, with the corporate leasing mechanism due to an uncompetitive price (CNN Indonesia, 2019a; Honda, 2018).

Meanwhile, the start-ups producing electric motorcycles have been sprouting around the world, with the most successful one expected to reach 1 million sales by the end of 2019 (MotorCycles Data, 2019). In Indonesia, a few local manufacturers started to enter the electric motorcycle market (Ghozali, 2019a), although the actual sales are still quite low with only over 1,200 units by the end of 2019 (IESR, 2019). However, in 2019, aiming to improve the economies of scale, the four largest Japanese manufacturers announced that they were collaborating for standardized swappable battery technology and charging infrastructure (Tsantilas, 2019). This collaboration might significantly affect the business of the electric motorcycle start-ups, considering the strong market presence of these companies.

The fact that an electric motor requires only less than 20 components, much less compared to ICE which has more than 2,000 parts, has been feared to cause loss of employment in the automotive industry. The manufacturers of engine parts, clutch, radiator, and gear will be the worst affected. The other component producers, such as chassis, steering systems, seats, and brake lining, will not be much affected. Meanwhile, the electric motor, battery, sensor, and microprocessor industries will grow since they will be more needed in electric vehicles.

Several major car manufacturers, including BMW, Volkswagen, and Ford, stated that making electric motors requires less workforce than making gasoline-powered engines, with BMW specifically mentioning a 30% working hours difference (Behrmann, 2019). Another study estimated that while BEV production requires less labor by 33% to 38%, the production of HEV and PHEV increases the labor requirement by around 5% for HEV and 10% to 25% for PHEV (Cambridge Econometrics, 2018). Additionally, the fewer components used in EV make it require less maintenance. It means, much less service and maintenance industry might be needed, which will affect the 2.5 million employment in service and spare part outlets.

Fraunhofer IAO and the largest German labor union, IG Metall, conducted a study and suggested that a shift to EV will cost German automotive industries a net loss of 37,000–52,000 employment by 2030, taking into account the new jobs from new areas such as battery manufacturing. If productivity improvement is included, the number will increase to 80,000–90,000 job losses. This number equals to almost 10% of the current employment in automotive industries which is around 840,000 jobs, including 210,000 in drivetrain production that is impacted the most (Bauer et al., 2018).
However, some other studies could provide a different perspective. A study by M-Five expected about 300 thousand job losses in vehicle manufacturing and maintenance by 2035 assuming electrification in most road vehicles. But it also suggested that a net increase of 300,000 jobs in the German transport sector could be achieved if considering the non-manufacturing jobs such as public transport drivers, sharing services, bikes, and digitalization (Schade & Wagner, 2019). Becker et al. (2009) also argued that additional employment from charging infrastructure deployment would offset the job losses in automotive manufacturing due to vehicle electrification. They estimated that the net employment in the United States could increase by 130,000–352,000 depending on the EV adoption rate, taking into account the job losses in the automotive industry (manufacturing and services) and gas stations, as well as job gains in charging infrastructure deployment and battery manufacturing.

In addition, a study by Cambridge Econometrics argued that shifting away from ICE will reduce consumer spending on imported fuels. The disposable income will then be spent on other things, driving investment and economic activities in other manufacturing or service sectors. These economic activities will generate additional employment in the new sectors despite the decline of jobs in the automotive manufacturing and petroleum fuel industries (Harrison, 2018). A literature review by de Bruyn et al. (2012) also concluded that employment could increase if the switching from ICEs to EVs lowers the total cost of ownership, leading to additional consumer spending in other areas of the economy.

In Indonesia, GIAMM and PIKKO (the association of small and medium automotive component industries) have expressed their concern regarding electric vehicle penetration. GIAMM estimated that the number of engine manufacturers could decrease by 30% due to electric vehicle development. PIKKO, which consists of smaller industries, is more optimistic in welcoming the transition to EV since they produce lower technology components (Dananjaya, 2019).

In general, the significant role of the established automotive industry to the national economy and the fear of job losses might hamper the transition to electric vehicles in road transport. This could be inferred from the relatively low target of EV share set by MoI. With the current MoI target, the ICE industry would still grow for the next 15 years, as shown in Figure 12. This low target would mean that there will be still a significant amount of ICE vehicles on the road until 2050.

4.2 Current biofuel technology policies and development

Through RUEN, the government plans to increase the share of biofuels in the total energy consumption from 13% in 2025 to 18% in 2050. The13% share translates into 30% biodiesel, 20% ethanol, and 5% bioavtur blend mandates. The ethanol and biodiesel blend mandates will stay the same up to 2050, while the bioavtur mandate will increase to 10% in that year. In addition to blending targets, RUEN also requires the government to set up a roadmap for biofuel feedstocks (with the prioritization of non-food feedstocks) and the provision of incentives for the biofuel production in Indonesia.

The biofuel blending policy officially started in 2006 with the Presidential Instruction No. 1/2006. Then, it was followed by the MEMR Regulation No. 32/2008 that set targets for biodiesel, bioethanol, and vegetable oil for low/medium-speed engine marine fuels. These targets are updated several times, with the latest is the MEMR Regulation No. 12/2015. In this regulation, the blending targets are higher than the initial ones, and a biofuel blending target for aviation fuels is introduced. The blending targets for each type of fuel is presented in Table 4.

Despite the targets, by the end of 2019, biodiesel is practically the only biofuel that exists in Indonesia. However, even the biodiesel consumption was far below the target until 2015, with the biodiesel share was only below 3% of the total diesel fuel consumption. It only jumped to 11% in 2016, following the introduction of a biodiesel subsidy program funded by the CPO export levy, managed by the Oil Palm Estate Fund Agency (BPDPKS) (Arinaldo et al., 2018). The other biofuel targets are not implemented, and no specific policy is in place yet to incentivize the use of those biofuels. This situation puts a serious question of whether the biofuel blending targets other than biodiesel will be achieved at all.

Table 4. Biofuel blending targets in the MEMR Regulation No. 32/2008 and the MEMR Regulation No. 12/2015.

Biofuel	Regulation	2009	2010	2015	2016	2020	2025
Biodiesel	32/2008	1%	2.5% / 3%*	5% / 7%*		10%	20%
	12/2015			15%	20%	30%	30%
Bioethanol	32/2008	1% / 5%*	3% / 7%*	5% / 10%*		10% / 12%*	15%
	12/2015			1% / 2%*	2% / 5%*	5% / 10%*	20%
Marine fuel	32/2008		1%	3%		5%	10%
	12/2015			10%	20%	20%	20%
Jet fuel	12/2015				2%	3%	5%

In certain years, the blending target for the subsidized fuel is different from the non-subsidized one. The target of non-subsidized diesel is marked with asterisk (*)

The influence of the palm oil industry to the development of low carbon transport technologies

The biodiesel industries in Indonesia rely heavily on palm oil as its feedstock. Palm oil is an important commodity for the Indonesian economy. Crude palm oil and its derivatives have been the most significant contributor to Indonesia's export values for many years. Over the last five years, palm oil products contributed to 10–12% of the total non-oil and gas export values. Largest export destinations in 2018 were India, the European Union, and China with 6.7, 4.8, and 4.4 million tons respectively (Jayani, 2019). The palm oil production is concentrated in a few regions, with over 50% of the national CPO production in 2015 was produced in three provinces, namely Riau, North Sumatra, and Central Kalimantan (Dharmawan et al., 2018). The palm oil industries employ a large number of workers, which gives it an important position in the Indonesian economy, though no consolidated data published on it. Various governmental agencies mentioned between 8–21 million workers work in the palm industries, including plantations. A large proportion of these workers were day labor (Koalisi Buruh Sawit, 2018). In comparison, the national workforce in 2018 was 131 million (Databoks, 2019). However, the positive impact of the palm oil industry to these workers' welfare is questionable due to low salary and poor working conditions (Koalisi Buruh Sawit, 2018). In fact, according to the Palm Oil Farmers Union (SPKS), the small-holder palm oil farmers are mostly forced to sell their palm fruit at a low price to the middlemen (Darto, 2020).

Most of the downstream palm oil industries, including biodiesel, are owned by the palm oil companies. For instance, almost all of the 20 biodiesel producers listed in the Indonesian Biofuel Producers Association (Aprobi) are also operating palm oil plantations as one of their core businesses (Asosiasi Produsen Biofuel Indonesia, n.d.-a). Thus, most of the CPO export levy that is collected from the palm oil industry is mostly given back to them. Over the 2015–2018 period, 56% of the collected export levy was used to subsidize the biodiesel blending program (IESR, 2019). CNN Indonesia reported that in 2017, five major palm oil companies received subsidies amounting to IDR 7.5 trillion (about USD 500 million) for the biodiesel production, which was higher than their contribution in the export levy (CNN Indonesia, 2018).

As a result, the biofuel policy development in Indonesia has been influenced by palm oil trade development. Indonesia has been producing and exporting biodiesel since 2009, as shown in Figure 13. The export dropped between 2015 and 2017, influenced by the anti-dumping import duty policy imposed by the European Union at the end of 2013. The import duty policy led to an increase in the national biodiesel blending target and establishment of BPDPKS that collected a levy from the export of palm oil products and channeled it to various applications, including subsidizing biodiesel production (Kurniawan et al., 2018). The shifting of an export duty to an export levy allocated for this specific fund could potentially reduce the state revenue from the export duty when the CPO price increases over USD 750/ton (Prawita, 2015). However, most of the time, the CPO price is lower than that.

The biodiesel subsidy from BPDPKS initially only covered the blending with a subsidized diesel

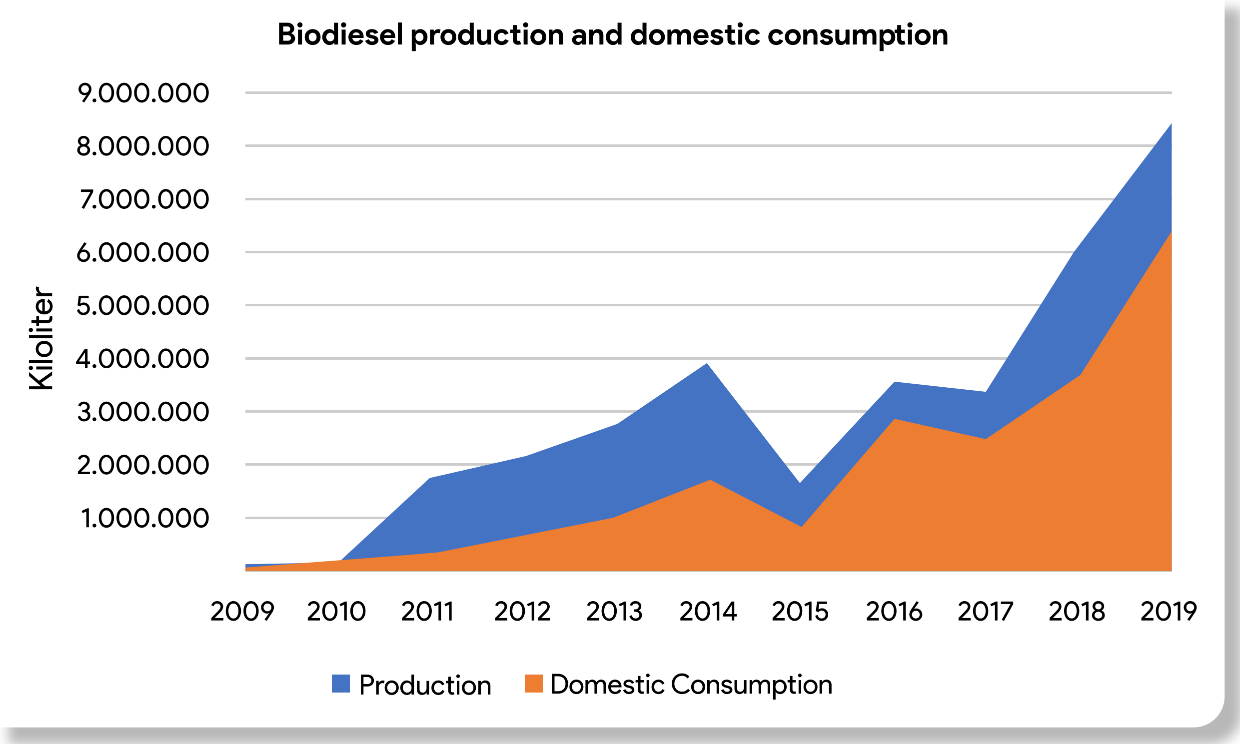


Figure 13. Development of biodiesel production, export, and domestic consumption. Data from Aprobi (n.d.-b)

fuel, known as public service obligation (PSO). Therefore, most of the biodiesel consumption was from the blending with PSO diesel fuel. As a result, the government failed to comply with the blending target set in the MEMR Regulation No. 12/2015 (Arinaldo et al., 2018). In 2018, the government decided to expand the coverage of biodiesel subsidy to the non-subsidized diesel fuel, which then successfully drove up the biodiesel consumption from only 2.6 million kl in 2017 to 6.4 million kl in 2019.

The tight intertwine between biodiesel and palm oil industries could hinder the development of biofuels from other feedstocks, which are necessary for sustainable biofuel future production. For example, the government, supported by the industry, is currently planning for the production of palm oil-based drop-in biofuels to reduce further petroleum fuel imports (CNN Indonesia, 2019b). Meanwhile, as mentioned in Chapter 3, biofuels from other feedstocks, such as used cooking oil (UCO) or lignocellulose have the potential to reduce more GHG emissions than the palm oil-based biofuel.

Moreover, if the GHG emission from the land-use change is not adequately addressed, the transition to biofuels would only shift the GHG emission from the transport sector to the land-use sector. As also discussed in Chapter 3, when the land-use change emission is considered, the emission from burning palm-oil biodiesels might double the conventional diesel. Meanwhile, the Chain Reaction Research (2017) estimated that currently there are already 6.1 million hectares of undeveloped palm oil plantation permits located in peatland, forest, or peat forest area. Another study indicated that the domestic biodiesel consumption had provided an escape route for the palm oil producers that have not adopted the “No Deforestation, No Peat, No Exploitation (NDPE)” policies. In 2020, companies without the NDPE policies will produce 19% of the allocated biodiesel (Chain Reaction Research, 2020). The government has exempted the palm oil used for biodiesel production from sustainability criteria regulated in the Indonesian Sustainable Palm Oil (ISPO), although recently an updated regulation would oblige all palm oil producers to comply with ISPO. Such sustainability measures are essential to ensure that the shift from petroleum fuels to biofuels would not increase the emission in other sectors.

STUDY REPORT

5 Towards a low carbon transport system in Indonesia

Under the current policy scenario, IESR (2020) projects that road transport will still dominate the energy consumption in the Indonesian transport sector until 2050 by contributing to 85%–88% of the total energy consumption in the sector (see Table 5). With this projection, the energy demand from passenger cars, buses, and trucks will triple over the next 30 years, while demand from motorcycles will only increase by almost 50%. This increase translates into demand for biofuels (biodiesel) at 20 MTOE, petroleum fuels at 140.5 MTOE, electricity at 0.1 MTOE, and natural gas at 0.1 MTOE by 2050. The demand for alternative fuels will be lower than RUEN forecast at 31.2 MTOE of biofuel, 11.9 MTOE of natural gas, and 2.7 MTOE of electricity. Meanwhile, the demand for petroleum fuels would increase from 123.2 MTOE projected in RUEN.

In terms of emissions, IESR projects that the GHG emission from the transport sector will reach 454 $MtCO_2$ by 2050 (see Figure 14). The projection was made by using Tier 2 CO_2 emission factor set by MEMR (2017) and the energy demand and fuel mix modelled by IESR (2020a). The GHG emission includes the CO_2 emission from direct fuel combustion in vehicle engines, CO_2 emission from electricity generation, and non-land-use related GHG emission from biodiesel production.

There are pathways that can be taken by the government to reduce the emission in the transport sector. A study by the Climate Action Tracker (CAT), for instance, laid out a pathway to decarbonize Indonesia's road and rail transport sector that complies with the GHG emission limit to keep global warming below 1.5°C (Climate Action Tracker, 2019). This pathway involves shifting to public transport and electrification of road passenger transport as a long-term strategy and improving fuel economy as well as increasing biofuel blending as a short-term measure. Although the study did not provide the pathways for the harder-to-abate sectors such as aviation, marine, and freight transport sectors, it suggested the government to develop a 1.5°C compatible plan for those sectors.

Another study by Dominković et al. (2018) provided a step-by-step process to figure out transition possibilities. It starts with the shifting to electricity, followed by shifting demand from the modes that cannot be electrified to other modes that can be electrified and choosing the alternative fuels for the remaining demand. This chapter attempts to provide the decarbonization measures using a similar approach for the passenger road transport (electrification) and the heavy-duty transport, before laying out the possibilities of modal shifting in the Indonesian transport sector.

Table 5. Projection of energy demand in the transport sector. Table is reproduced from IESR (2020a)

	Unit	2020	2021	2022	2023	2024	2025	2030	2040	2050
Passenger Car	MTOE	17.4	18	19	20	21	22	26.2	37.8	52.8
Bus	MTOE	4.6	4.9	5.1	5.3	5.6	5.8	7.0	10.1	14.1
Truck	MTOE	15.9	16.7	17.5	18.2	19.0	19.7	23.9	34.5	48.2
Motorcycle	MTOE	14.0	14.5	14.9	15.4	15.8	16.1	17.9	19.9	20.6
Passenger Train	MTOE	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.5	0.8
Freight train	MTOE	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3
Passenger plane	MTOE	4.4	4.6	4.8	5.0	5.2	5.4	6.7	10.1	14.5
Freight plane	MTOE	0.6	0.6	0.6	0.6	0.7	0.7	0.9	1.3	1.8

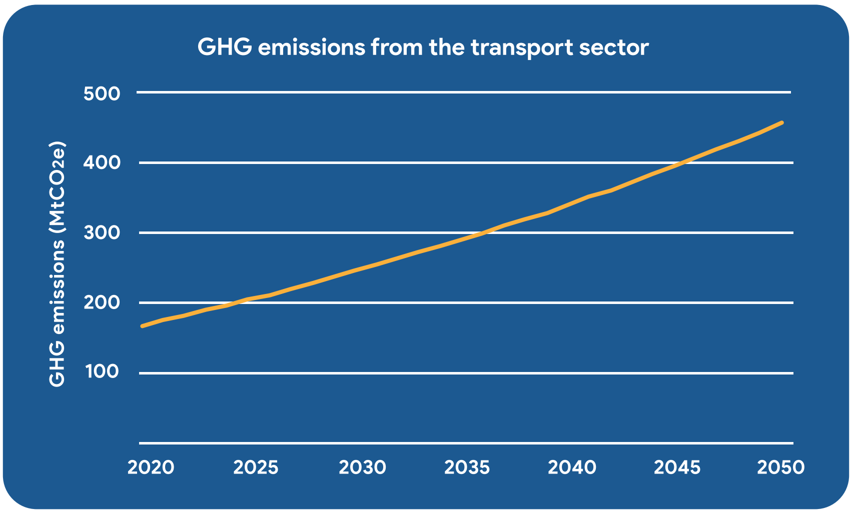


Figure 14. CO_2 emission projection based on the energy demand projection in Table 5. Data from the author's calculation

Box 2 Why not 100% biofuel?

In a hypothetical scenario with 100% of the energy demand being fulfilled by biofuels, the biofuels required to supply all energy demand from the transport sector will be challenging to produce sustainably. If the biofuels are produced from CPO, about 200 million tons of CPO will be needed as the feedstock by 2050. It assumes that the drop-in biofuel yield from CPO is 80%, which is considerably high (Srihanun et al., 2020). The palm plantation area in 2019 was about 16.4 million hectares and currently, there is a moratorium on new palm plantations in place. Even if the national average yield can reach the maximum yield potential of 8–10 tons CPO per hectare (Hoffmann et al., 2014), there will be only 150 million tons of CPO produced. The Palm Oil Agribusiness Strategic Policy Institute (PASPI) estimated that at the best case, the national average CPO yield could increase to 7.4 tons per hectare by 2050 (Tim Riset PASPI, 2018), giving about 100 million tons of CPO per year. This increase could be achieved by implementing best management practices and using high-quality seeds when replanting. However, the national average yield has been fluctuating from 2.76 tons per hectare in 2015 to 2.85 in 2018, before dropping back to 2.62 in 2019 (GAPKI, 2020). Linear extrapolation from historical data will result in palm oil yield lower than 4 tons per hectare by 2050.

In addition, assuming that the CPO consumption in the food and oleochemical industries annually grows at 1.1% and 5.1% respectively (extrapolating the estimation made by Kurniawan et al., [2018]), both industries will consume 15 million tons of CPO annually by 2050. If the national CPO yield could reach the PASPI projection and Indonesia stops exporting CPO derivatives, there will be about 85 million tons of CPO available for biofuel production. However, the number might be underestimated as a study (Saragih, 2017) predicted that there would be about 55 million tons additional global palm oil demand by 2050 coming from the industrial (food and non-food) sector.

Another study also estimated that aggressive global policies on biofuels could induce palm oil demand to increase to 67 million tons by 2030. Furthermore, global aviation will require 140 million tons of palm oil bio-jet fuel by 2050 if a quarter of the total biofuel demand from this sector is fulfilled by palm oil (Malins, 2018). All this shows that it will be nearly impossible for Indonesia to stop its CPO exports. Therefore, the palm oil-based biofuels could not be used as a single solution to decarbonize the transport sector.

5.1 Electrification of passenger road transport

Various studies suggested that electrification of road transport is imperative to decarbonize the transport sector (Agora Verkehrswende, 2017; Climate Action Tracker, 2019; Dominković et al., 2018). CAT, for example, suggested that to achieve the 1.5°C target, the whole road passenger fleets including cars, motorcycles, and buses have to be electric by 2050. With this target in mind, Indonesia has to stop the sales of conventional vehicles by 2035–2040 (Climate Action Tracker, 2019).

One of the main challenges for electrification is the high upfront costs of electric vehicles with much of these costs are import taxes (Ghozali, 2019b). With no domestically-produced-electric cars, it is estimated that in the MPV class, the imported HEV, PHEV, and BEV will cost about 2, 2.2, and 2.8 times the conventional cars. Meanwhile, Indonesia already has domestic electric motorcycle manufacturers which help keep the purchase price of electric motorcycles competitive at an average price point of 30% higher than the conventional motorcycles (IESR, 2020b).

IESR (2020b) suggested that through the implementation of supportive demand-side policy instruments, the EV market share in Indonesia could reach 85% for passenger cars and 92% for motorcycles by 2050. The provision of tax exemptions for EV and additional taxes for conventional vehicles, as well as the availability of public charging stations are the essential instruments to drive EV penetration in Indonesia. With those instruments, electric vehicles will comprise 74% and 83% of the car and motorcycle stock by 2050 (see Figure 15). It appears that demand-side incentives alone are not sufficient to stop the sales of conventional vehicles by 2035. Supply-side policies such as the implementation of fuel economy standard, the banning of ICE vehicle sales, and the limit of vehicle lifetime will be necessary to reach the penetration target.

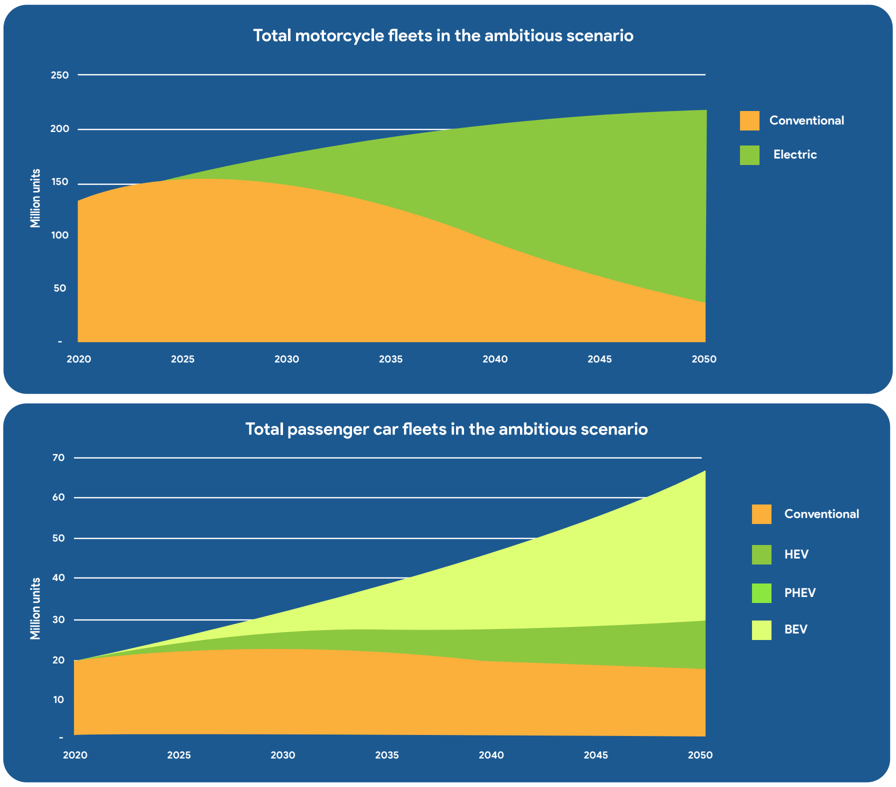


Figure 15. Shares of different vehicle technologies in car and motorcycle fleets in the ambitious EV penetration scenario. Reproduced from IESR (2020b)

Table 6. BRT fleet size in various cities

Cities	BRT fleet size	Sources
Jakarta	3,548	Sufa (2020)
Bandung	184	Dinas Perhubungan Kota Bandung (2017a, 2017b)
Semarang	153	Ade Bhakti Ariawan (n.d.)
Solo	150	Marwoto (2020)
Yogyakarta	128	Dinas Perhubungan Daerah Istimewa Yogyakarta (n.d.)
Surabaya	28	Parwata (2019)
Palembang	120	PT Sarana Pembangunan Palembang Jaya (n.d.)
Pekanbaru	75	Tari (2020)

Another study by the Economic Research Institute for ASEAN and East Asia (ERIA) estimated that for Indonesia to achieve 100% BEV sales by 2040, investments for EV technologies, charging infrastructure, and power generators will cost the country at least USD 386 billion. The required investments could increase to almost USD 600 billion if cleaner power generators are built. Moreover, a cumulative government subsidy of USD 180 billion until 2040 is needed to close the price gap between EVs and conventional vehicles (Suehiro & Purwanto, 2019). Imposing additional taxes for the conventional vehicles will significantly reduce the subsidy burden and may provide additional incomes for the government in the long-term (IESR, 2020b).

Other than private cars and motorcycles, buses are another mode that has the potential to be electrified. For buses, the easiest to electrify is the city bus networks since the government-owned companies manage most of them. By 2016, 20 cities have their own BRT systems, although some of these BRT networks are struggling to survive and even stopped their operation in a few cities (Aliy, 2016). The largest city bus network is in Jakarta, with 2,217 medium to large size bus fleets and 1,331 microbus fleets (Sufa, 2020), while other cities have much smaller bus networks (see Table 6).The Jakarta BRT company (Transjakarta) has already performed pilot tests and planned to deploy 100 electric buses by the end of 2020. It aims to electrify 50% and 100% of the total bus fleet by 2025 and 2030 respectively and procure 2,000 electric buses annually (Sufa, 2020). A study by Grütter Consulting on two corridors of Transjakarta indicated that the total cost of ownership (TCO) of an electric bus system is 30% to 110% higher than TCO of a diesel bus system, depending on the charging type used. The most expensive system is the system with overnight-charged electric buses due to their larger battery capacity requirement. If the buses are fast-charged (3–5 minute charging time) at both ends of their route, the system cost will reduce significantly due to much smaller battery capacity needed. If the charging infrastructure cost is not included, TCO of an electric bus system could match the diesel bus system. To electrify both corridors that are served by 137 buses, a total investment of USD 102 million will be required (Grütter & Franken, 2019).

Vehicle electrification would induce additional power consumption. In case of 100% EV sales for cars and motorcycles by 2040, IESR (2020a) estimated the additional electricity demand would be about 236 TWh by 2050, increasing by 19%

from the total electricity demand in the reference scenario. Meanwhile, the oil consumption would decrease by 48 MTOE, or about 30% reduction of the total oil consumption by the transport sector in 2050. Suehiro and Purwanto (2019) estimated that 100% full electric car and motorcycle sales by 2040 would result in 30% increase (220 TWh) in electricity demand by that year, while the oil consumption could be reduced by 52 MTOE (both calculations did not include the electrification in buses). Assuming an electric bus is 5.5 times more efficient than a conventional bus (Sufa, 2020), 100% electrification of buses in Indonesia could result in an additional 30 TWh of electricity demand in 2050.

The additional power demand can be fulfilled either by renewables or coal. With the global coal demand expected to decline, the government might shift coal consumption to the domestic market. If this happens, the electrification will be less impactful in reducing the GHG emission. As mentioned in the previous chapter, the shift to electric cars will only increase the total GHG emission in Indonesia under the current electricity generation mix. While the shift help reduce oil consumption, oil imports, and local air pollution in urban areas, it will also increase air pollution in the areas where new coal-fired power plants will be installed. In addition, the adoption of electric vehicles could provide an opportunity for the integration of the power and transport sector through the use of smart charging infrastructure and bidirectional charging (vehicle-to-grid) technology (Agora Verkehrswende, 2017). With most vehicles parked for 95% of the time, they could be connected to the grid and, with the help of bidirectional chargers, provide services to the power grid such as demand response through coordinated charging, peak shaving, active and reactive power regulation, and spin reserve (Ehsani et al., 2012). These services could help accelerate the decarbonization in the power sector. Therefore, the future charging and grid infrastructure should anticipate this potential benefit through the integration with the power sector.

Box 3 Electrifying public transport in Jakarta

Public transport such as taxis, motorcycle-taxis, ride-hailing services, and urban buses covers more daily distance than the private ones. Consequently, they consume more fuels and emit more emissions. Nevertheless, they are also arguably the easiest to electrify, because the higher efficiency of EVs would reduce the operational cost more significantly for the public transport.

Jakarta currently has the most motorized vehicles, and also the most public transport in Indonesia. There are about 500,000 to 1 million motorcycle-taxis (Ferdian, 2019; Nugraha, 2020), 24,000 car-taxis (Data Jumlah Taksi di Wilayah DKI Jakarta, 2018), 18,000 ride-hailing cars (Jannah, 2019), and 3,300 Transjakarta buses (Sufa, 2020) currently operating in Jakarta. Electrifying these vehicles would help reduce the GHG emission and oil consumption, as well as being a showcase for other regions in Indonesia.

IESR's calculation estimated that electrifying all the existing motorcycle-taxis by 2025 could reduce the annual GHG emission by 92,000 tCO_2. Electrifying all the taxis and ride-hailing cars could reduce the GHG emission by 28,800 tCO_2, and electrifying all Transjakarta buses could reduce the GHG emission by 150,000 tCO_2. Moreover, there would be more than 400 million liters of petroleum fuel and natural gas to be saved annually by electrifying the public transport in Jakarta.

Electrifying the public transport would require massive investment in public charging due to the high daily distance covered by these vehicles. For motorcycle-taxis, about 780 new public charging would need to be installed annually. For taxis and ride-hailing cars, in total, about 340 public fast chargers need to be introduced until 2025. In addition to public chargers, electrification of motorcycle-taxis and ride-hailing cars would require the drivers to upgrade their electricity subscription. The majority of the public subscribes to low capacity electricity: 450 VA (32%), 900 VA (40%), and 1,300 VA (15%) (Petriella, 2020). Meanwhile, charging an EV would need an additional capacity of about 450 VA for a motorcycle and 4,000 VA for a car. For electrifying all Transjakarta buses, assuming the use of flash charging at bus stops during passenger loading and unloading, it is estimated that 150 chargers with 200 kW rated power would need to be installed.

Electrifying these modes would help increase the public awareness of electric vehicles and help familiarize the public with EV riding experience. However, much support from the government would be needed. First, it would require a massive investment in the charging infrastructure. Second, fiscal incentives would also be needed to facilitate the purchase of electric vehicles, which are currently more expensive than conventional vehicles. For online taxi and motorcycle taxi drivers, which generally buy their own vehicle fleet, this would be even more important, as well as fiscal incentives to upgrade their home electricity connection.

5.2 Transitions in heavy-duty transportation

For heavy-duty transport, such as heavy-road transport (trucks), shipping, and aviation, direct electrification is more challenging to implement. IEA's Energy Technology Perspective, in its below 2°C scenario, estimated that by 2060, the global GHG emission reduction from trucks, shipping, and aviation should be reduced to 91%, 71%, and 85% of the emission level in 2015 respectively. By 2060, 66% of non-urban heavy-road transport will be using plug-in hybrid or catenary (overhead lines) electric vehicles, while only 8% will still use diesel engines. For urban heavy-transport, 43% will use battery electric vehicles, 28% plug-in hybrid or catenary, and only 3% will use diesel engines. For aviation, the report suggested significant efficiency improvement of 68%, a shift from aviation to high-speed rail to reduce aviation activity, and the use of advanced biofuels by 70% in 2060. For shipping, efficiency improvement, wind assistance, and switching to advanced biofuels will be the major contributors to the total emission reduction from the reference scenario in 2060, each by 33%, 19%, and 20% respectively (IEA, 2017a).

A study from the Energy Transition Commission (ETC) outlined a more ambitious scenario of achieving full decarbonization of heavy-duty transport by 2050. The study developed an illustrative pathway for energy mix in the hard-to-abate sectors, which aims to roughly indicate the order of magnitude of each technology deployment to achieve net-zero emissions. This pathway estimated that biofuels would play a major role in the decarbonization of aviation even for the long term. For shipping, biofuels will be important in the short term, but development in ammonia and hydrogen technology will replace biofuel demand in the long run. In heavy-duty road transport, electrification and fuel-cell electric vehicles will play the leading role (ETC, 2018a).

5.2.1 Heavy-duty road transport

ERIA (2018) estimated that TCO of full-electric trucks in Indonesia would be already lower than ICE trucks by 2025, assuming 15,000 km annual distance (which is considerably low). However, it did not specify whether that is for heavy-, medium-, or light-duty trucks. McKinsey projected that TCO for heavy-duty electric trucks (>14–16 tons, depending on countries) would reach parity with diesel ones for long haul usage (500 km/day) by 2030 in the US, Europe, and China. For medium- (>6–7.5 tons) and light-duty trucks (>1.8–3.5 tons) and for the shorter distance, the parity will be reached sooner (Heid et al., 2017). Considering the low fuel price in Indonesia, the parity might come later than those countries. This TCO advantage would result in improved competitiveness of electric trucks, primarily because the users of the commercial vehicles consider economic factors highly in making a purchase decision (Heid et al., 2017). ETC estimated that globally the capital cost (excluding taxes) of BEV and FCEV would be only about 20% higher than ICE trucks by 2030; therefore, the operational cost (majority from fuel cost) will be a deciding factor. With higher efficiency and cheaper electricity, BEV will be economically superior to biofuels (ETC, 2018c).

However, despite the cost parity projection by those studies, the BNEF projection suggests that the penetration of electric trucks in Indonesia would be much lower than the global trend, at least until 2030 (Wehling et al., 2020). According to the projection, the global penetration of medium- and heavy-duty trucks in 2030 would reach 6% and 4% of the sales. In Indonesia, the penetration is expected to be less than two-thirds of that rate. This situation would improve in 2040, with the penetration in Indonesia is expected to be only 10%–33% lower than the global rate. The global penetration rate, though, would only be 19% and 10% of the medium- and heavy-duty truck sales in 2040.

The limitation of existing battery technology poses a significant challenge for electrifying heavy-duty trucks. ETC estimated that for a truck with 700 km distance between charging, an additional 2 to 3 tons of weight can be expected, resulting in reduced freight capacity. Charging will be another issue since the 700 km range would require about a 600-kWh battery, which would take quite some time to charge even with the fast chargers, e.g., 1.5 hours with 400 kW chargers (ETC, 2018c). Although, the greater availability of fast charging locations might solve this issue by allowing drivers to charge more often at a shorter charging time, depending on their trip requirement.

The case might be more difficult for the FCEV penetration. Globally, the hydrogen cost needs to be lower than USD 0.09/kWh to keep it competitive with the diesel ICE in 2030, while the electrolysis-based hydrogen is expected to cost USD 0.15/kWh. The hydrogen produced through natural gas reforming is expected to cost only USD 0.05/kWh in 2030, which could outcompete the diesel ICE and become comparable with BEV. However, considering the lower fuel price in Indonesia, it could be even more difficult for FCEV to enter the market (ETC, 2018c).

Natural-gas-fueled trucks might be more competitive than electric and fuel-cell trucks. BNEF estimates that the role of natural-gas-fueled trucks would comprise a significant part (24%) of the heavy-duty truck fleet in major markets (United States, China, Europe, Japan, India, and South Korea) in 2040, compared to electric (16%) and fuel-cell (8%) (Wehling et al., 2020). However, the natural gas vehicles, as mentioned previously, could not reduce the GHG emission significantly compared to the conventional petroleum-based ICE.

Another option that might help the transition is to shift to rail and shipping, which is far more energy-efficient than trucks. At a global scale, about 35% and 5% of the long-haul road freight can be shifted to rail and shipping (ETC, 2018c). This shifting results in about a 10% GHG emission reduction from the total heavy-road duty transport. Dominković et al. (2018) suggested an even more ambitious assumption that 90% of heavy-duty trucks could shift into electrified rail transport. In their most ambitious scenario, Siagian et al. (2015) assume that about 20% of the freight activity can be served by rail transport by 2050, an increase from only 3% in 2010.

5.2.2 Marine transport

Marine transport is expected to contribute a small fraction of the transport energy demand, i.e., about 5% by 2050, mostly for freight transport. The International Maritime Organization (IMO) pledged to reduce the GHG emission from shipping by at least 50% by 2050 compared to the 2008 level. Energy efficiency improvement can be achieved through a speed reduction and implementation of an energy efficiency standard for new fleets. A 10% speed reduction can reduce the emission by 19%. IMO has the Energy Efficiency Design Index that mandates new ships to be 20% and 30% more efficient in 2020 and 2025, which might be modified into a stricter target.

Halim et al. (2018) provided pathways to decarbonize international shipping, with the maximum intervention scenario achieving a 95% GHG emission reduction by 2035. Several assumptions in this scenario are demand adjustment due to decline in fossil fuel trade and rise in intra-regional trade; maximum ship speed reduction (26% to 65% of current standard operation leading to a 43% emission reduction); technical improvement (e.g., wind assistance and block coefficient improvement) reducing up to 30% emission; 10% share of electric ships in total shipping fleets; and hydrogen and ammonia dominating the fuel mix by 70%, together with biofuels (22%) and liquefied natural gas (LNG) (5%). In contrast, ETC (2018d) suggested that optimizing operational efficiency, including reducing speed, will only result in a 4% emission reduction. Technical efficiency improvement could improve the energy efficiency of the new fleets by 30% to 55%, while retrofitting existing fleets could improve efficiency by 15%. As for the alternative energy source, emission-wise, hydrogen and ammonia fuel-cell could be less polluting than diesel fuels and biofuels if the carbon intensity of electricity goes below 200 and 50 gCO_2/kWh. LNG would only reduce the GHG emission by 12% at most, neglecting the upstream methane leakage. Cost-wise, synthetic ammonia would outcompete biofuels when the electricity price goes below USD 0.06/kWh, assuming that the biofuel costs 200% higher than the conventional marine diesel. It noted though that the biodiesel price could decline in the future, making ammonia less cost-competitive. It also indicated that ammonia is still in the development stage, thus will not be deployed in the near future. Considering the long lifespan of ship vessels, about 25 years (Halim et al., 2018), biofuels might still play a considerable role by 2050, even if ammonia becomes more competitive.

ETC's study also suggested that decarbonizing shipping might increase the cost of sea transport by 110%. However, since a majority of shipping is for freight transport, the impact of the additional cost to the price of the end product is negligible. In addition, Halim et al. (2018) also estimated that the cost increase induced by these improvements would not significantly affect the modal share of freight transport.

5.2.3 Aviation

IESR (2020a) projected that energy demand from aviation would triple by 2050, contributing about 10% of the total transport energy demand, with about 90% coming from passenger flights. The International Air Transport Association (IATA) forecasted that Indonesia passenger flights would increase more than three times over 20 years, from 129 million passengers in 2017 to 411 million passengers in 2037 (IATA, 2018).

The International Civil Aviation Organization (ICAO) estimated that under an optimistic technology improvement scenario, until 2050, 0.98% annual energy efficiency improvement can be achieved. Another 0.39% improvement can be achieved through operational improvement (i.e., air traffic management and infrastructure use) (Fleming & de Lépinay, 2019). According to the IATA roadmap, as cited by ETC (2018b), energy efficiency improvement can reduce 30–45% GHG emission compared to the BAU scenario in 2050.

Further decarbonization requires the use of alternative fuel or engine technology. The low energy density of existing battery technology limits its application in long-haul flights. The battery energy density needs to improve five times to 1.5 kWh/kg to be technically feasible for extended flight use (ETC, 2018b). Either bio-jet fuel or synthetic jet fuel will have to be used as a replacement of the petroleum jet fuel. The production cost of bio-jet fuel is currently about two to three times the conventional jet fuel, though it could be lower with increasing production worldwide. Synthetic fuel is expected to be cheaper than biofuel when the electricity price is lower than USD 0.03 per kWh. The switch to alternative fuels will induce an additional 50% to 100% of fuel cost, which could result in about a 10–20% ticket price hike in a long-haul flight (ETC, 2018a).

Modal shifting from flights to high-speed rail (HSR) could reduce the GHG emission significantly. In the European Union average, the WTW GHG intensity (gCO_2/pkm) of the air transport is about six times higher than the high-speed rail (IEA & International Union of Railways (UIC), 2012). Even in countries with carbon-intensive electricity such as China, the GHG per pkm of HSR is comparable to EU average, although the GHG per train km is considerably higher by about three times (IEA & International Union of Railways (UIC), 2017).

IEA in Railway Handbook 2017 suggested that HSR has not caused a major change to global aviation activity. However, for certain routes, HSR could reduce aviation volume significantly, by about 50% (IEA & International Union of Railways [UIC], 2017). D'Alfonso et al. (2016) listed various studies indicating that HSR could compete with air transport for trips of 200–1,000 km while offering low benefits for trips below 150–200 km and uncompetitive for trips above 800–1,000 km. ETC, however, suggested that the short-haul flights comprise a small fraction of global aviation so that even with a third of the short-haul flights shifted to HSR, only about a 10% GHG emission reduction will be achieved (ETC, 2018b).

Considering those trip distances, in Indonesia, a large part of inner-island flights, especially in Java island, could potentially be shifted to HSR. Such inner-island flights are estimated to contribute considerably to the total domestic flights, although the actual data is not available. For example, about 25% of the domestic flights departing from Soekarno-Hatta Airport in Jakarta are inner-island flights, with about 700 km trip length at most (Jakarta–Surabaya).

5.3 Options for decarbonizing the transport sector

The decarbonization of the transport sector should aim to fulfill the 1.5°C scenario, which means limiting transport's GHG emission at 2 $MtCO_2e$ in 2050 (Climate Action Tracker, 2019). Considering the technological options as described above, the electrification of light-duty road transport and some parts of heavy-duty road transport would be the main strategy. Meanwhile, biofuel utilization should be aimed at decarbonizing the rest of heavy-duty road transport, marine transport, and aviation.

Before assessing the potential for electrification and biofuel utilization, possible demand reduction needs to be identified first. However, due to a lack of data, it is not possible to establish a specific pathway to decarbonize the Indonesian transport sector. In the following parts, we attempt to lay out possible options for decarbonizing the sector.

- **Demand management**

  A study by Replogle and Fulton (2014) estimated that by increasing the share of public transport to about 58% of the total travel demand by 2050 could keep the GHG emission of urban passenger transport close to the 2010 emission level. This equates to about 30% reduction from the emission in the 2050 baseline scenario, which assumes only 30% of travel demand is fulfilled by public transport. If applied to Indonesia's emission projection in Figure 14 and assuming that urban passenger travel comprises 60% of the total passenger transport's energy demand, the emission reduction from modal shifting could reach 47 $MtCO_2e$, accounting for 10% of the total GHG emission.

  For freight transport, IEA (2009) estimated that shifting 50% of the truck travel demand growth between 2005–2050 to rail could reduce the land (road and rail) freight transport GHG emission by about 18%. This number would translate into about 27 $MtCO_2e$ emission reduction in the Indonesia projection. For passenger air transport, IEA estimated that cutting 25% of air travel growth between 2005–2050 would reduce about 25% of the emission in the baseline scenario, equaling to 11 $MtCO_2e$ emission reduction.

- **Fuel economy improvement of conventional vehicles**

  Global Fuel Economy Initiative analysis indicates that globally, fuel economy improvement plays a significant role in reducing the GHG emission, especially in passenger cars and heavy-duty trucks (Kodjak & Meszler, 2019). In the case of Indonesia, however, the contribution of fuel economy improvement of motorcycles could be more significant. The fuel economy improvement could be driven by efficiency improvement of ICE vehicles and penetration of electric vehicles. The same report suggests that the average fuel economy of new ICE cars, heavy-duty trucks, and motorcycles needs to be improved annually by 2.1%, 1.7%, and 1.4% respectively. Applying this recommendation to Indonesia's situation, the potential GHG emission reduction from ICE cars, heavy-duty trucks, and motorcycles are estimated at around 24%, 20%, and 13% respectively by 2050, compared to the BAU scenario.

- **Vehicle electrification**

  As suggested by the Climate Action Tracker (2019), to comply with the 1.5°C compatible scenario, the electrification of passenger cars, motorcycles, and buses needs to reach almost 100% of the total fleets by 2050. This would mean that there are no new sales of conventional vehicles by 2035. The EV penetration projection by IESR (2020b) for passenger cars and motorcycles is modified to reach 100% EV sales in 2035, resulting in 95% EV share in both passenger car and motorcycle fleets by 2050. Bus electrification is assumed to follow the penetration of passenger cars, due to the limited data available. In fact,

Table 7. Electrification ratio assumptions for each transport mode

	2025	2030	2035	2040	2045	2050
Passenger cars	9%	26%	45%	70%	86%	95%
Motorcycles	2%	16%	37%	61%	82%	95%
Buses	9%	26%	45%	70%	86%	95%
Trucks	2%	6%	9%	14%	19%	25%

long-distance buses might not be as easy to electrify as passenger cars. However, there is no available information on the share of urban buses and long-distance buses. BNEF (2020) projected that 67% of the global bus fleet would be electric by 2040. This number is close to the passenger car penetration rate used in this analysis.

The electrification of freight transport is assumed to be about 20%–25% of passenger transport, assuming that electric trucks penetrate slower than passenger cars in all weight classes. BNEF (2020) projects that only 25% of the light-duty trucks and less than 10% of the medium- and heavy-duty trucks would be electric by 2040. While there are opportunities to electrify rail transport, the share of rail transport in the GHG emission is negligible, hence its electrification is not assessed in this section. Similarly, no electrification of ships is assessed despite Halim et al. (2018) predicted that 10% of the ship fleets could be electric by 2035. No electric airplane is assumed to be deployed by mid-century. The electrification assumption for this simulation is presented in Table 7.

- **Biofuel utilization**

Currently, biofuel is the most promising low carbon alternative for the non-electrified modes. However, it is not well understood the amount of biofuel required to decarbonize the rest of the transport sector. For this assessment, biofuel is assumed to gradually supply all non-electrified parts of the transport sector, up to 100% by 2050. The biodiesel/green-diesel share is assumed to increase from the existing 30% starting in 2025 and to reach 100% by 2040. The biogasoline share is assumed to increase from 0% starting in 2025 and reaching 100% by 2040. The bio-jet fuel share is assumed to increase to 2% in 2025, 85% in 2040, and 100% in 2050, following the "Maximum" scenario by the ICAO Secretariat (2017). For shipping, the biofuel blend is assumed to be 20% in 2025 and 100% in 2045. Figure 16 simulates how each option listed above affects the transport GHG emission if enacted individually or combined. All options in the simulation assume that the emission from biofuels is 35% of the petroleum fuel emission (excluding the land-use emission) and power generation mix used follows the realization scenario by IESR (2020a), except the "combined low carbon" scenario. For the combined low carbon scenario, the biofuel emission assumes the waste biomass-based biofuel (as presented in Figure 10) and electricity generation follows the energy transition scenario by IESR (2020a). The energy transition scenario sees no new coal power plant after 2025, and old diesel and gas power plants are phased out by 2024.

This simulation indicates that there is no single policy option that could fully decarbonize the transport sector. As a single action, switching to biofuel would reduce the GHG emission the most, if the land-use emission is not factored in. However, as argued at the beginning of Chapter 5, the total switch to biofuel would not be possible without opening new plantations,

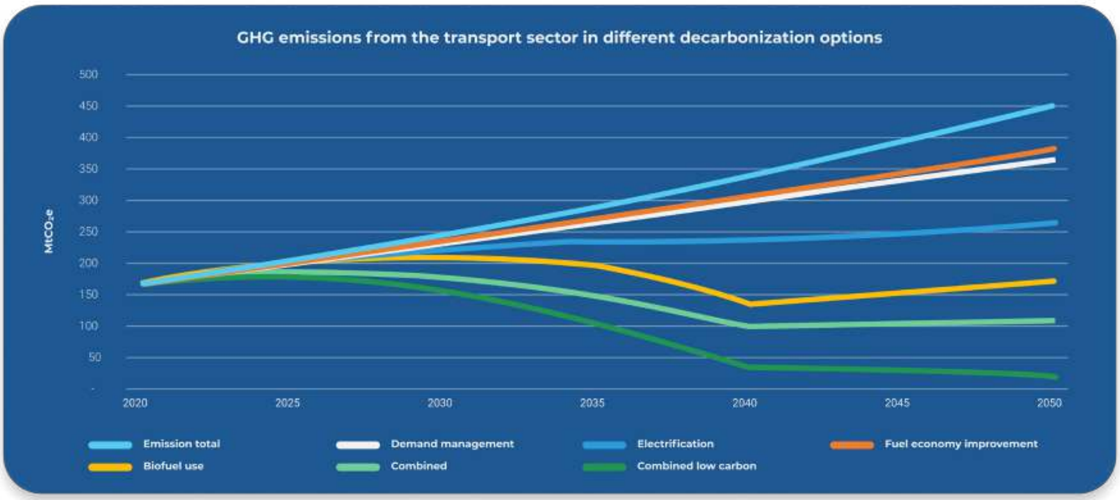


Figure 16. Implication of different decarbonization options to the GHG emission from the transport sector. Data from the author's calculation

which could potentially induce more land-use GHG emissions. Combining all options could reduce the emission by about 75%. Ensuring decarbonization in the power sector and using less emission feedstock for biofuels could reduce the emission by more than 90%.

Figure 17 presents the final energy mix based on the combined decarbonization options. With intensive demand management, fuel economy improvement, and electrification in passenger road transport, the energy demand will drop significantly to only 70 MTOE by 2050, instead of 160 MTOE. The higher efficiency of electric vehicles mostly drives this decline in energy demand. About 30% of the energy demand in 2050 will be supplied by electricity, while the rest by liquid fuels, in this case, biofuels. However, even if the biofuel blending proceeds at a slower rate, the need for petroleum fuels is already reduced considerably, basically kept at the current level.

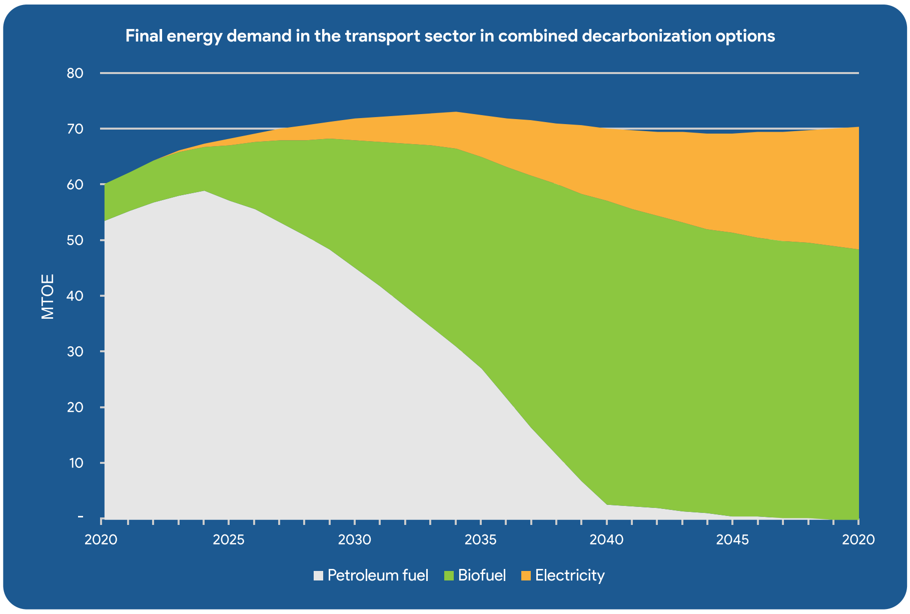


Figure 17. Mix of the final energy demand in the transport sector by energy sources based on the combined decarbonization options. Data from the author's calculation

Figure 18 shows the share of each type of biofuel according to the combined decarbonization option scenario. This illustration suggests that as the ICE vehicle sales in road transport stop in 2035, biofuel demand will consequently decline. This decline is more apparent in the biogasoline demand, which is consumed by passenger cars and motorcycles. The biogasoline consumption is projected to reach a stable peak of about 14 MTOE over a short period between 2035 and 2040. After 2040, increasing penetration of electric vehicles would drive the biogasoline fueled ICE out of the market. Bio/green diesel consumption is expected to also peak in about 2040, although there would still be relatively high demand due to the low electrification rate of the trucks. However, if the electrification of medium- and heavy-duty trucks grows faster, the demand could also be significantly reduced after 2040.

This situation might create an overproduction of biogasoline (and probably also green diesel). However, with EV uptake increases globally, there might not be much demand from other countries either. Fortunately, with the electric propelled airplanes not expected to be common by mid-century, the increasing demand for bio-jet fuel might cover the decline in biogasoline and green diesel demand. Moreover, there is also a possibility to convert the biofuel production facilities into biobased chemical production since some biofuel production processes undergo similar routes with basic chemical products (de Jong et al., 2020; Karatzos et al., 2017). The demand for the biobased chemical is also expected to increase in the future. Dornburg et al. (2008), for example, estimated that the biobased chemical demand could reach more than 100 million tons in 2050 if the condition is favorable (e.g., high oil price, rapid technological development, low biomass feedstock price, high demand growth, and available subsidy). Therefore, the biofuel production facilities should consider the future potential to switch into other products.

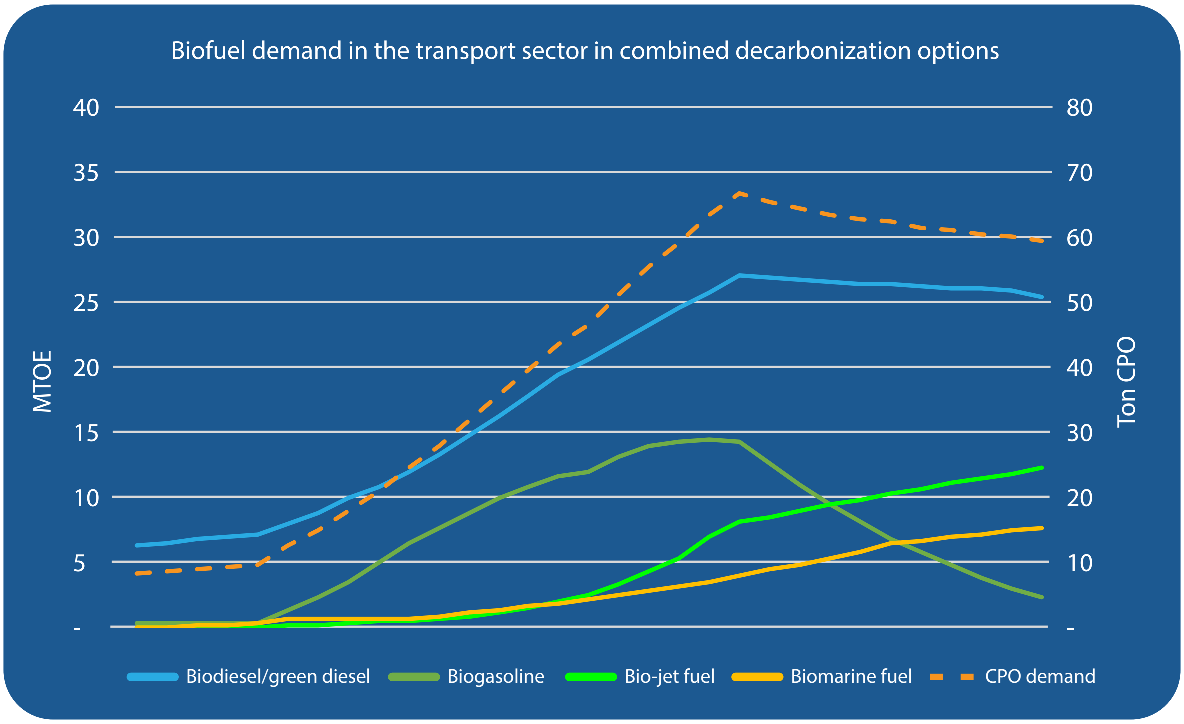


Figure 18. Estimated biofuel and CPO demand in the transport sector by type of biofuels based on the combined decarbonization options. Data from the author's calculation

6 Steps forward

With the pressing problems of climate change, air pollution, and fuel import dependency, a transition from the existing fossil-fueled transport system is inevitable. From the technological aspect, there are different options available, i.e., efficiency improvement, vehicles electrification, and sustainable fuels (biofuels, hydrogen, or synthetic fuels), each with their respective benefits and drawbacks. Each transport mode has different characteristics, hence requiring different approaches. For instance, while electrification is widely acknowledged to be the main strategy for light-duty vehicles, the heavy-duty transport modes might benefit more from the use of sustainable biofuels and improved fuel efficiency.

The issue is how to make the transition successful as well as how to mitigate the risks of the transition to the stakeholders, including the industries, workers, and public in general. The existing policies and regulations have not provided a clear vision of what the future transport system would look like, let alone the pathway to get there. To smoothen the transition process in the Indonesian transportation sector, the government needs to perform the following actions.

- **Establishing an integrated roadmap and measurable plan for low carbon transport in accordance with the Paris Agreement target**

  As already elaborated above, the transition to low carbon transport will involve efficiency improvement (both system and technology), electrification of vehicles, and the utilization of alternative low carbon fuels. All these would not happen overnight, but instead, require thorough planning and management to avoid major disruption to the infrastructure and stakeholders. Therefore, an integrated roadmap of low carbon transportation is necessary to provide a clear signal and direction to the stakeholders on which decarbonization options and technologies need to be developed and invested in. More importantly, this roadmap should be guided by the Paris Agreement, which aims to limit global warming below 1.5°C from the pre-industrial level. This would mean that the GHG emission from the transport sector needs to come close to zero by 2050.

  However, there is no integrated low carbon transportation roadmap that is based on the GHG emission targets. Instead, different planning documents related to transport sectors are not aligned with each other, e.g., the energy planning for the transport sector in RUEN, a roadmap of low carbon emission vehicle production by the Ministry of Industry, a roadmap of biofuel development by MEMR, and the presidential regulation on electric vehicles. Moreover, the existing roadmaps have not been implemented seriously. For example, the biofuel target failed to come into realization in most of the years since the first stipulation back in 2008. This lack of coherence will only confuse and send unclear messages to the market to move forward, resulting in delayed, if not misdirected transitions.

  The process of creating the roadmap should involve all relevant stakeholders in the different governmental agencies, business/private sectors, impacted communities, experts, the public in general, and from various sectors including transportation, urban planning, energy, industry, etc. The stakeholders need to realize that a transition is taking place and understand their respective roles. This can be done, for example, through the establishment of a transition task force, as in the case for Germany (Amelang, 2018) or Chicago on a more local scale.

- **Integrating sustainable mobility as part of urban planning**

  As promoted by the ASI framework for sustainable transport, it becomes increasingly important to integrate mobility as part of urban planning. This integration resonates with the "Avoid" and "Shift" principles of the framework, which has so far been largely neglected, as noted by Jaeger et al. (2014). This is especially important when considering that Indonesia is a growing nation, with new urban areas emerging across the country. Moreover, Indonesia is also moving its capital and developing new metropolitan areas.

This situation means that new urban development plans, including the transport system plan for these areas, need to be established. It is a significant opportunity to integrate the transport system with spatial planning as the “Avoid” measure. This move would not only result in an emission reduction but also better public wellbeing in general. For instance, better urban planning will reduce travel time and travel cost, which, according to Winata & Rarasati (2018) are some of the sustainable transport variables that correlate with social wellbeing. Other benefits include a reduction of congestion, air pollution, traffic noise, and accidents as well as health improvement due to increased active (non-motorized) transport. In addition, avoided transport would also mean fewer resources needed for vehicle manufacture, less waste produced as vehicles reach end-of-life, and fewer infrastructure impacts (Smith et al., 2016).

As importantly, integrated urban planning should include policies that could encourage modal shifting to public and non-motorized transport. Such policies include the expansion of pedestrian and biking infrastructure, integration and improvement of public transport, establishment of vehicle-free zones, and parking system management. Wider implementation of traffic improvement technologies, such as intelligent transport system and area traffic control system is also a part of the sustainable mobility planning.

- **Implementing measures to encourage the shifting from carbon-intensive transport modes**

In passenger road transport, it is also essential to start implementing push measures to discourage the use of carbon-intensive transport, such as fossil-fueled private vehicles. While there is some evidence of pull measures in public transport policy (e.g., subsidies for bus rapid transit programs in several cities) and non-motorized transport (e.g., bike lanes and pedestrian improvement), the push measures are missing. Cheap fuel and parking tariff, low private vehicle tax, and absence of car/motorcycle-free zones are indicating the lack of push measures. Meanwhile, a synergy between push and pull measures is necessary to create a successful modal shift (Dijk et al., 2018).

The need for modal shifting measures also applies to other carbon-intensive transport modes. An example for the aviation sector, a study from the United Kingdom proposed that imposing a progressive levy for frequent flyers could potentially reduce flight demand as well as distributing the flights more equally across the income groups (Devlin & Bernick, 2015). Another example, in June 2020, the French government has asked Air France to cut 40% of its domestic flights, especially when the alternative rail with less than 2.5 hours travel available, as a part of the bailout package for the company (Patel, 2020). In freight transport, modal shifting from long-distance trucks to rail and shipping could also reduce the energy consumption and GHG emission significantly since rail and shipping are much more efficient modes.

- **Establishing more stringent regulations on vehicle emissions**

In parallel, it is essential to establish more stringent regulations on vehicle emissions, both for the pollutant and GHG emissions (through fuel efficiency regulation). Currently, there is no regulation for mandatory fuel efficiency improvement. The average fuel consumption of passenger cars in Indonesia in 2017 was considerably high, at 7.9 lge/km compared to other emerging economies and global average which were at 7.5 and 7.2 lge/km respectively (IEA, 2019a). Establishing a mandatory standard for fuel economy is essential to drive its improvement. It has been implemented in 10 of 15 major countries which make up about 70% of the global car market. Countries with fuel economy regulation and incentives experienced 60% faster improvement compared to those that have none (IEA, 2019a). Implementation of such standards may even help driving up the adoption of alternative vehicles such as electric vehicles (IESR, 2020b).

ICCT suggested that long-term standards provide sufficient time to allow manufacturers to strategize for compliance. Besides, allowing some flexibility for manufacturers in complying with the standards can reduce cost, boost technology innovation, and give rise to cost-effective ways for long-term fuel economy improvement. This flexibility can be provided through several methods: targeting improvement of corporate average instead of an individual model, allowing accumulation and trading of credits, allowing credits for improvement that cannot be measured using standard fuel economy measurement procedure, and giving super credit for alternative vehicles (e.g., electric vehicle and flex-fuel vehicle) through credit multiplier or other tools. Besides, fiscal incentives (through emission-based taxation) and fuel economy labeling are also important instruments to complement the fuel economy standards (Yang & Bandivadekar, 2017).

As for pollutant emissions, the existing regulation for passenger cars adopts Euro IV standard (to be implemented in 2021 for diesel engines), while for motorcycles, the regulation has been applying Euro III standard since 2013. These standards are already lagging behind the standards applied in most of the G20 countries, including Brazil, China, India, Russia, and Mexico (Du & Miller, 2017). Stricter emission standards will also require better quality fuel, which can partly be covered by biofuels. In general, biofuel burning emits less air pollutant than petroleum fuels due to its lower sulphur content, except for the NOx emission that, in some cases, is higher than petroleum fuels. Even though a stricter pollutant emission standard will not directly reduce the GHG emission, it can help disincentivize producers and consumers to use ICE vehicles and foster the adoption of electric vehicles that emit no pollutants.

In addition to road vehicles, Indonesia also lags for the emission control in marine transport. While the International Maritime Organization (IMO) requires the use of fuel with less than 0.5% sulphur content for international ships, Indonesian government imposes less stringet requirement on domestic ship trips (Christina & Khasawneh, 2019).

- **Carefully planning infrastructure development to anticipate the future evolution of different transport technologies**

Transition towards a low carbon transport system will involve building supporting infrastructures, although the extent of development will depend on the pathway pursued. The new infrastructures include, for example, renewable power generators, smart grid, charging infrastructure for electric vehicles, refineries for biofuel, or hydrogen production plants and refueling stations for fuel cells.

Transition to electric vehicles needs to be thoroughly planned to ensure that the electricity infrastructure can cover the demand at the least cost. Emerging power demand from electric vehicles might require additional power generation capacity and grid expansion. However, this additional investment can be minimized by employing demand management measures, such as the utilization of smart-charging technologies. Furthermore, there is a growing global interest in the potential of vehicle-to-grid technology to support the integration of power and transport sector. These technological developments need to be anticipated and integrated into the infrastructure planning. Otherwise, wasteful investment might be made. For example, not considering smart-charging may lead to unnecessary investment in additional power generation and grid capacity.

The utilization of biofuel needs to be planned carefully to avoid overcapacity of biofuel refineries which may become stranded assets when electric vehicles dominate the fleet. This is especially important considering that the government has been putting much focus on biofuel program. As presented in Section 5.3, aggressively increasing biogasoline share in low-duty road transport may result in refinery overcapacity after the year 2040, along with the maturing phase of electric vehicle adoption. While there is a possibility to revamp biofuel production facilities into bio-based chemical refineries, it needs to be planned in advance since not all biofuel production processes are similar to those for bio-based chemical.

It is also important to consider the existing petroleum fuel infrastructure future, especially with the newly built refineries that will start their operation in the next five years. Even with the existing 30% biodiesel blending program, Indonesia can already self-fulfill its diesel fuel demand. This means further increase of biodiesel blending rate will instigate overcapacity of petroleum diesel refineries.

- **Conducting studies on the economic impacts of transition on transport sector and subsequently planning the mitigation therefor**

Transition to low carbon transport, to some extent, will inevitably affect the established automotive industry. Increasing utilization of electric vehicles might eventually replace the existing automotive industry which is based on internal combustion engines. Transport demand management measures can suppress the demand growth for motor vehicles. Some countries having strong automotive industry presence fear that this potential decline will affect their economy. However, studies indicate that the decline in conventional automotive industry might drive economic activity in other sectors, which may even lead to increased job opportunities. Apart from automotive industry, other sectors that may be negatively affected by the transition are the petroleum industry and, to a lesser extent, the biofuel/palm oil industry.

In relation to the transformation in automotive and petroleum industry, some jobs might become obsolete and be replaced by new types of jobs. These jobs might require different skills from the existing automotive industry. With employment in conventional automotive industry expected to decline due to vehicle electrification, it is necessary to identify the kinds of jobs that potentially emerge in the planned low carbon transport system and the kinds of knowledge and skills needed for those new jobs. For example, electric vehicles will introduce digitalization to transport sector. These new jobs will require a type of work that differs from that of the conventional automotive industry that is mostly manufacture-based. It might not be possible to involve the existing manufacture-oriented automotive workforce in this kind of jobs, and therefore, something needs to be arranged for these workers.

Studies concerning the foregoing situation are still limited in Indonesia despite the importance of automotive industry in the national economy. Therefore, the government should conduct studies on the economic impact of transition to low carbon transport on the national economy. Only then, the government can plan the appropriate actions to be taken to minimize, or even avoid, the negative effects while gaining the most of the benefits. Special attention should be given to the millions of labor force and hundreds of small-medium enterprises that might be directly affected by the transition.

All potential negative effects to the existing industry should not turn the government away from the transition to low carbon transport. Instead, it should encourage the government to take the lead in the process and ensure a just transition for all stakeholders.

- **Providing an enabling environment for the development of electric vehicle market and domestic industry**

As concluded by IESR (2020b), the government needs to provide supportive policies to spur the demand for electric vehicles. Fiscal incentives provided through the emission-based taxation scheme and tax exemption for EV are necessary to reduce the price gap between EVs and ICEs, especially for car market. Besides, non-fiscal incentives such as free parking, toll exemption, odd-even exemption, and use of bus lanes can help increase the attractiveness of EV. Investment in public charging facilities is necessary for EV market to develop once it becomes price competitive.

Once the market is ready, indicated by increasing uptake of EV in the market, the industry will need to be developed. Otherwise, the increasing demand will be supplied by imported vehicles, which means missed investment and job creation opportunities. In developing the industry, supply-side incentives will be necessary to help the domestic industry competes with EV industries abroad. Several countries such as Germany, Sweden, China, and the United States (California) provide various financial incentives for research and development (R&D) activities through research grants or national research programs (Qiao & Lee, 2019; van der Steen et al., 2015). In China and California, the manufacturers are also incentivized through zero-emission vehicle standards that give credits to manufacturers that comply with EV production quota, which can be traded with other manufacturers (Qiao & Lee, 2019). Indonesia's automotive industry has never focused on R&D, but since the new (and local) players emerge to participate in electric vehicle industry, this may change, particularly because EV technology itself is still developing, unlike ICE.

While a shift to electric vehicles is expected to minimize the environmental impacts from transport sector, without proper regulation, it may be otherwise. First, it is crucial to decarbonize power sector, since with a coal-dominated power generation mix, switching to electric vehicles might actually increase the GHG emission, without even considering the possible rebound-effect of using "clean" vehicles. Second, production of batteries–a significant component in electric vehicle–will bring about increased mining activities for the material, especially nickel, which is abundantly available in Indonesia. Mining activities have been known to incur environmental damages and social conflicts. This has to be mitigated to ensure the transition's benefits. Stricter monitoring for mining activities needs to be established. Also, battery management plans need to be arranged to avoid the accumulation of battery waste in the next 20 years. The government has to make sure that all electric vehicles related projects perform a proper environmental and social assessment.

- **Intensifying research on sustainable alternative fuel for non-electrified modes**

A large proportion of energy demand from transport sector will not be for electricity, which comes from heavy-duty transport, i.e., heavy-duty road transport, shipping, and aviation. This demand needs to be supplied by alternative low carbon fuel in the form of biofuel, hydrogen/ammonia, or synthetic fuel produced by electricity. Currently, only biofuel has been developed, although limited to conventional biodiesel (FAME). Conventional biodiesel can be blended with petroleum diesel to fuel heavy-duty road transport and part of the ships that use high-speed diesel engines.

To fully decarbonize heavy-duty transport, it is impossible to rely solely on conventional biodiesel, especially since it needs to be blended with petroleum diesel. Instead, drop-in biofuel or synthetic fuel needs to be used if the existing infrastructures and engine technologies are to be kept. Otherwise, hydrogen/ammonia fuel-cell technology poses a potential to be used in heavy-duty road transport and marine transport in the future, even though it requires new infrastructures. This fuel-cell technology has a significant advantage over biofuels and synthetic fuels in terms of local air pollution.

Drop-in biofuel, synthetic fuel, and hydrogen fuel (and vehicle technology) are currently still in their infancy and not economically competitive. Globally, research is going on for the foregoing and Indonesia should take its role–especially in drop-in biofuel technology–since there is abundant biofuel feedstock potential available, even without considering palm oil. With the government's enthusiasm in supporting biodiesel program, it will be wise to also invest in the development of drop-in biofuels. The future of biofuel lies in the drop-in types since it can be used 100% in the existing infrastructures and engines, which is especially crucial for aviation fuel. The future demand of aviation biofuel is expected to increase with global jet fuel demand potentially reaches 300 million tons by 2030 and 600 million tons by 2050. This will open a vast market of aviation biofuel in the future.

- **Establishing strict environmental and social safeguard mechanisms for biofuel**

Research on the upstream processes of biofuel, especially for the sustainability of feedstock, should be enhanced. The current palm oil-based biodiesel is shadowed by its sustainability issue arising from land use change and deforestation (Malins, 2018). Currently, the data available on the life cycle GHG emission of palm oil-based biofuel production in Indonesia are very limited. Data transparency and traceability of feedstocks are lacking, making it difficult to properly perform the life cycle analysis. As a result, there has been incessant debate over biofuel sustainability. Improving transparency and traceability should be the first step to achieve sustainable biofuel production.

Strict sustainability criteria should be imposed on the whole biofuel supply chain. Domestic biodiesel industry, if not regulated by strict sustainability criteria, will provide a market for non-sustainable palm oil that is unacceptable in other markets that implement sustainability policies such as NDPE. Additionally, monitoring and enforcement mechanisms should be established. Improving transparency may increase public participation in the monitoring process.

Further, intensive research for alternative feedstock and improvement in existing palm oil plantation productivity should be enhanced. Development of alternative feedstocks should consider their sustainability aspect to avoid similar problems that challenge palm oil industry today. Utilization of waste materials (e.g., waste biomass and used cooking oil), in particular, will result in significantly higher GHG reduction and less social-environmental hurdles compared to energy crops. That said, there might be challenges in resource collection and continuity. In addition, more diverse feedstocks will also reduce dependence on certain resources.

References

Ade Bhakti Ariawan. (n.d.). BRT Trans Semarang. http://transsemarang.semarangkota.go.id/materi/1.PAPARAN%20%20BRT%20TRANS%20SEMARANG.pptx

Agora Verkehrswende. (2017). Transforming Transport to Ensure Tomorrow's Mobility—12 Insights into the Verkehrswende (short version). Agora Verkehrswende. https://www.agora-verkehrswende.de/fileadmin/Projekte/2017/12_Thesen/Agora-Verkehrswende-12-Insights_short-version_EN_WEB.pdf

Agora Verkehrswende, Agora Energiewende, & Frontier Economics. (2018). The Future Cost of Electricity-Based Synthetic Fuels. https://www.agora-energiewende.de/fileadmin2/Projekte/2017/SynKost_2050/Agora_SynKost_Study_EN_WEB.pdf

Agustinus, M. (2017, April 25). Ada 150 SPBU Jual BBG, Ini Daftar Lokasinya. Detik Finance. https://finance.detik.com/energi/d-3483416/ada-150-spbu-jual-bbg-ini-daftar-lokasinya

aliy. (2016, August 21). Pengamat Bilang, Target Program SAUM Bisa Tak Tercapai. Berita Trans. http://beritatrans.com/2016/08/21/pengamat-bilang-target-program-saum-bisa-tak-tercapai/

Amelang, S. (2018, September 19). Germany launches task force to kickstart shift to sustainable mobility. Clean Energy Wire. https://www.cleanenergywire.org/news/germany-launches-task-force-kickstart-shift-sustainable-mobility

Arinaldo, D., Adiatma, J. C., & Simamora, P. (2018). Indonesia Clean Energy Outlook—Reviewing 2018, Outlooking 2019. Institute for Essential Services Reform (IESR). http://iesr.or.id/wp-content/uploads/2018/12/Indonesia-Clean-Energy-Outlook-2019-new.pdf

Asosiasi Produsen Biofuel Indonesia. (n.d.-a). Anggota Aprobi. Aprobi. Retrieved April 18, 2020, from https://aprobi.or.id/partners/

Asosiasi Produsen Biofuel Indonesia. (n.d.-b). Data. Aprobi. Retrieved April 20, 2020, from https://aprobi.or.id/project

Atika, S. (2019, August 8). Airvisual: Jakarta declared world's most polluted city on Thursday afternoon. The Jakarta Post. https://www.thejakartapost.com/news/2019/08/08/airvisual-jakarta-declared-worlds-most-polluted-city-on-thursday-afternoon.html

Aziz, A. (2016, September 9). Indonesia Tanpa Cadangan Penyangga Minyak. Tirto. https://tirto.id/indonesia-tanpa-cadangan-penyangga-minyak-bH65

Baik, Y., Hensley, R., Hertzke, P., & Knupfer, S. (2019). Making Electric Vehicles Profitable. McKinsey & Company. https://www.mckinsey.com/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Making%20electric%20vehicles%20profitable/Making-electric-vehicles-profitable.ashx

Baraniuk, C. (2020, June 18). The largest electric plane ever to fly. BBC. https://www.bbc.com/future/article/20200617-the-largest-electric-plane-ever-to-fly

Bauer, E. H. W., Riedel, O., Herrmann, F., Borrmann, D., & Sachs, C. (2018). ELAB 2.0 Wirkungen der Fahrzeugelektrifizierung auf die Beschaftigung am Standort Deutschland. Fraunhofer IAO.

BBC. (2012, January 30). Konversi BBM ke BBG, kebijakan setengah hati. BBC. https://www.bbc.com/indonesia/laporan_khusus/2012/01/120130_bbgenergi

Becker, T. A., Sidhu, I., & Tenderich, B. (2009). Electric vehicles in the United States: A new model with forecasts to 2030. Center for Entrepreneurship and Technology, University of California, Berkeley. http://www.ehcar.net/library/rapport/rapport051.pdf

Behrmann, E. (2019, April 11). The Twilight of Combustion Comes for Germany's Empire of Engines. Bloomberg Businessweek. https://www.bloomberg.com/features/2019-bmw-electric-car-german-engines/

Bhatia, S. C. (2014a). Biodiesel. In Advanced Renewable Energy Systems (pp. 573–626). Woodhead Publishing India.

Bhatia, S. C. (2014b). Ethanol. In Advanced Renewable Energy Systems (pp. 523–572). Woodhead Publishing India.

BNEF. (2018). Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO_2. Bloomberg New Energy Finance. https://data.bloomberglp.com/professional/sites/24/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf

BNEF. (2019). Electric Vehicle Outlook 2019 (free public report). Bloomberg New Energy Finance. https://about.bnef.com/electric-vehicle-outlook/#toc-viewreport

BNEF. (2020). Electric Vehicle Outlook 2020 Executive Summary. Bloomberg New Energy Finance. https://bnef.turtl.co/story/evo-2020/page/1?teaser=yes

Bongardt, D., Stiller, L., Swart, A., & Wagner, A. (2019). Sustainable Urban Transport: Avoid-Shift-Improve (A-S-I). Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://www.transformative-mobility.org/assets/publications/ASI_TUMI_SUTP_iNUA_No-9_April-2019.pdf

BP. (2019a). BP Energy Outlook 2019 edition. BP p.l.c. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf

BP. (2019b). BP Statistical Review of World Energy 2019.

Bullard, N. (2019, April 12). Electric Car Price Tag Shrinks Along With Battery Cost. Bloomberg. https://www.bloomberg.com/opinion/articles/2019-04-12/electric-vehicle-battery-shrinks-and-so-does-the-total-cost

California Fuel Cell Partnership. (n.d.). Cost to refill. California Fuel Cell Partnership. Retrieved July 9, 2020, from https://cafcp.org/content/cost-refill

Cambridge Econometrics. (2018). Reviewing the impact of the low-carbon mobility transition on jobs. Cambridge Econometrics. https://www.camecon.com/wp-content/uploads/2018/09/Employment-impacts-review-Sep18.pdf

Cardoso, L. C. B., Bittencourt, M. V. L., Litt, W. H., & Irwin, E. G. (2019). Biofuels policies and fuel demand elasticities in Brazil. Energy Policy, 128, 296–305. https://doi.org/10.1016/j.enpol.2018.12.035

Chain Reaction Research. (2017). Indonesian Palm Oil's Stranded Assets – 10 Million Football Fields of Undevelopable Land. https://chainreactionresearch.com/report/indonesian-palm-oils-stranded-assets-10-million-football-fields-of-undevelopable-land/

Chain Reaction Research. (2020). NDPE Policies Cover 83% of Palm Oil Refineries; Implementation at 78%. https://chainreactionresearch.com/report/ndpe-policies-cover-83-of-palm-oil-refineries-implementation-at-75/

Christina, B., & Khasawneh, R. (2019, July 26). Indonesia will not enforce IMO low-sulphur fuel rules on domestic fleet. Reuters. https://www.reuters.com/article/indonesia-shipping-regulations-idUSL4N24R14F

Chung-un, C. (2019, March 20). [Hydrogen Korea] Japan paves way for hydrogen future, but public unconvinced. The Korea Herald. http://www.koreaherald.com/view.php?ud=20190320000706

Climate Action Tracker. (2019). Scaling up climate action—Key opportunities for transitioning to a zero emissions society—Indonesia Full Report. Climate Action Tracker. https://climateactiontracker.org/publications/scalingupindonesia/

CNN Indonesia. (2018, January 17). Lima Konglomerat Sawit "Disuntik" Subsidi Mega Rp7,5 Triliun. CNN Indonesia. https://www.cnnindonesia.com/ekonomi/20180116202504-92-269411/lima-konglomerat-sawit-disuntik-subsidi-mega-rp75-triliun

CNN Indonesia. (2019a, des). Harga Masih Kemahalan, Honda Tetap Fokus pada PCX Listrik. CNN Indonesia. https://www.cnnindonesia.com/teknologi/20191211122724-384-456002/harga-masih-kemahalan-honda-tetap-fokus-pada-pcx-listrik

CNN Indonesia. (2019b, September 9). Pemerintah Cari Solusi Agar Pertamina Bisa Jangkau Harga CPO. CNN Indonesia. https://www.cnnindonesia.com/ekonomi/20190909070259-85-428626/pemerintah-cari-solusi-agar-pertamina-bisa-jangkau-harga-cpo

D'Alfonso, T., Jiang, C., & Bracaglia, V. (2016). Air transport and high-speed rail competition: Environmental implications and mitigation strategies. Transportation Research Part A: Policy and Practice, 92, 261–276. https://doi.org/10.1016/j.tra.2016.06.009

Dananjaya, D. (2019, September 12). Era Kendaraan Listrik Ancam Industri Komponen Otomotif. KOMPAS.com. https://otomotif.kompas.com/read/2019/09/12/182909115/era-kendaraan-listrik-ancam-industri-komponen-otomotif

Darto, M. (2020, February 25). Biodiesel: Pilih Petani atau Perusahaan? Katadata Forum - Biodiesel untuk Kesejahteraan Petani, Jakarta.

Data Jumlah Taksi di Wilayah DKI Jakarta. (2018). Jakarta Open Data. Retrieved June 16, 2020 from https://data.jakarta.go.id/dataset/dat-jumlah-taksi-di-wilayah-dki-jakarta

Databoks. (2019, March 15). Jumlah Pekerja Tumbuh Lebih Kencang Dibanding Angkatan Kerja, Pengangguran Turun. Databoks. https://databoks.katadata.co.id/datapublish/2019/03/15/angkatan-kerja

de Bruyn, S., Brinke, L., Kampman, B., & Koopman, M. (2012). Literature review on employment impacts of GHG reduction policies for transport. CE Delft. http://www.cedelft.eu/publicatie/literature_review_on_employment_impacts_of_ghg_reduction_policies_for_transport/1287

de Jong, E., Stichnothe, H., Bell, G., & Jørgensen, H. (2020). Bio-based Chemical: A 2020 Update. IEA Bioenergy. https://www.ieabioenergy.com/wp-content/uploads/2020/02/Bio-based-chemicals-a-2020-update-final-200213.pdf

Devlin, S., & Bernick, S. (2015). Managing aviation passenger demand with a frequent flyer levy. New Economics Foundation. https://neweconomics.org/uploads/files/58e9fad2705500ed8d_hzm6yx1zf.pdf

Dharmawan, A. H., Nuva, Sudaryanti, D. A., Prameswari, A. A., Amalia, R., & Dermawan, A. (2018). Pengembangan Bioenergi di Indonesia—Peluang dan tantangan kebijakan industri biodiesel. Center for International Forestry Research (CIFOR). http://www.cifor.org/publications/pdf_files/WPapers/WP242Dharmawan.pdf

Dijk, M., Givoni, M., & Diederiks, K. (2018). Piling up or Packaging Policies? An Ex-Post Analysis of Modal Shift in Four Cities. Energies, 11(6), 1400. https://doi.org/10.3390/en11061400

Dinas Perhubungan Daerah Istimewa Yogyakarta. (n.d.). Data Trans Jogja. Data Trans Jogja. Retrieved April 23, 2020, from https://dishub.jogjaprov.go.id/trans-jogja

Dinas Perhubungan Kota Bandung. (2017a, July 25). Tahun 2016—Data Koridor dan Jumlah Unit Trans Metro Bandung. Portal Data Kota Bandung. Retrieved April 23, 2020, from http://data.bandung.go.id/beta/index.php/portal/detail_data/97b49f07-922e-44a7-adce-1901361d9986

Dinas Perhubungan Kota Bandung. (2017b, November 20). Tahun 2017—Data Jumlah Armada Dan Rute Bis Damri Kota Bandung. Portal Data Kota Bandung. Retrieved April 23, 2020, from http://data.bandung.go.id/beta/index.php/portal/detail_data/a3b997bd-1ec7-4903-ad54-7ceea30ba636

Directorate General Metal Machinery Automotive and Defense Industry Ministry of Industry. (2019, December 17). Memacu Investasi Energi Bersih dalam Mendukung Transformasi Menuju Sistem Energi Rendah Karbon di Indonesia. Indonesia Clean Energy Outlook 2020, Jakarta. http://iesr.or.id/wp-content/uploads/2019/11/Presentasi-Dirjen.-ILMATE-IESR-171219.pdf

Dominković, D. F., Bačeković, I., Pedersen, A. S., & Krajačić, G. (2018). The future of transportation in sustainable energy systems: Opportunities and barriers in a clean energy transition. Renewable and Sustainable Energy Reviews, 82, 1823–1838. https://doi.org/10.1016/j.rser.2017.06.117

Dornburg, V., Hermann, B. G., & Patel, M. K. (2008). Scenario Projections for Future Market Potentials of Biobased Bulk Chemicals. Environmental Science & Technology, 42(7), 2261–2267. https://doi.org/10.1021/es0709167

Du, L., & Miller, J. (2017). Status of policies for clean vehicles and fuels in select G20 countries. The International Council on Clean Transportation. https://theicct.org/sites/default/files/publications/Status-of-policy-post-TTG_ICCT-Briefing_15082017_vF.pdf

Dutta, K., Daverey, A., & Lin, J.-G. (2014). Evolution retrospective for alternative fuels: First to fourth generation. Renewable Energy, 69, 114–122. https://doi.org/10.1016/j.renene.2014.02.044

Edwards, R., Hass, H., Larivé, J.-F., Lonza, L., Maas, H., & Rickeard, D. (2014). Well-to-Wheels Report Version 4.a: Well-to-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context. European Union. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/well-wheels-report-version-4a-jec-well-wheels-analysis

Ehsani, M., Falahi, M., & Lotfifard, S. (2012). Vehicle to Grid Services: Potential and Applications. Energies, 5(10), 4076–4090. https://doi.org/10.3390/en5104076

ERIA. (2018). An Analysis of Alternative Vehicles' Potential and Implications for Energy Supply Industries in Indonesia. Economic Research Institute for ASEAN and East Asia. https://www.eria.org/uploads/media/ERIA_RPR_2017_15.pdf

ETC. (2018a). Mission Possible: Reaching Net-Zero Carbon Emissions from Harder-to-Abate Sectors by Mid-Century. Energy Transitions Commission. http://www.energy-transitions.org/sites/default/files/ETC_MissionPossible_FullReport.pdf

ETC. (2018b). Mission Possible—Sectoral Focus: Aviation. Energy Transitions Commission. http://www.energy-transitions.org/sites/default/files/ETC%20sectoral%20focus%20-%20Aviation_final.pdf

ETC. (2018c). Mission Possible—Sectoral Focus: Heavy Road Transport. Energy Transitions Commission. http://www.energy-transitions.org/sites/default/files/ETC%20sectoral%20focus%20HeavyRoadTransport_final.pdf

ETC. (2018d). Mission Possible—Sectoral Focus: Shipping. Energy Transitions Commission. http://www.energy-transitions.org/sites/default/files/ETC%20sectoral%20focus%20-%20Shipping_final.pdf

EV Database. (n.d.). Range of full electric vehicles. EV Database. Retrieved July 30, 2020, from https://ev-database.org/cheatsheet/range-electric-car

EVAdoption. (2020, January 3). Available PHEVs (In the US) – EVAdoption. Retrieved July 3, 2020, from https://evadoption.com/ev-models/available-phevs/

Ferdian, I. (2019, August 16). Ojek Online Padat Merayap, Jumlah Dianggap Lebihi Batas, Pemerhati Sebut Kuota Harus Diatur. Otomotifnet. https://otomotifnet.gridoto.com/read/231820238/ojek-online-padat-merayap-jumlah-dianggap-lebihi-batas-pemerhati-sebut-kuota-harus-diatur

Fickling, D. (2018, November 8). We're Running Out of Road. Bloomberg. https://www.bloomberg.com/opinion/articles/2018-11-07/think-new-york-traffic-is-bad-try-bangkok-or-jakarta

Fleming, G. G., & de Lépinay, I. (2019). Environmental Trends in Aviation to 2050. In 2019 Environmental Report: Destination Green—The Next Chapter (pp. 17–23). International Civil Aviation Organization (ICAO). https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg17-23.pdf

Fraile, D., Lanoix, J.-C., Maio, P., Rangel, A., & Torres, A. (2015). Overview of the market segmentation for hydrogen across potential customer groups, based on key application areas. CertifHy. http://www.certifhy.eu/images/D1_2_Overview_of_the_market_segmentation_Final_22_June_low-res.pdf

Gaikindo. (n.d.). Indonesian Automobile Industry Data. Gaikindo. Retrieved April 21, 2020, from https://www.gaikindo.or.id/indonesian-automobile-industry-data/

GAPKI. (2020, February). Kinerja Industri Sawit Indonesia 2019. https://gapki.id/KINERJA_INDUSTRI_SAWIT_INDONESIA_2019.pdf

Garuda Indonesia. (2019). 2018 Sustainability Report. https://www.garuda-indonesia.com/content/dam/garuda/pdf/investor-relations/annual-sustainability-report/SR%20Garuda%20(2018)%20Final%20(High).pdf

Gavrilovic, T. (2019, September 16). Global Electric Bus Adoption to Triple by 2025. Greentech Media. https://www.greentechmedia.com/articles/read/global-electric-bus-adoption-is-set-to-triple-by-2025

Ghozali, K. I. (2019a, August 11). Daftar Motor Listrik yang Sudah Bisa Dibeli di Indonesia. Tempo. https://otomotif.tempo.co/read/1234750/daftar-motor-listrik-yang-sudah-bisa-dibeli-di-indonesia

Ghozali, K. I. (2019b, August 12). Pajak Barang Impor Mobil Listrik Diharapkan Bisa Ditekan. Tempo. https://otomotif.tempo.co/read/1234963/pajak-barang-impor-mobil-listrik-diharapkan-bisa-ditekan

GIZ GmbH. (n.d.). Sustainable Urban Transport: Avoid-Shift-Improve (A-S-I). https://ledsgp.org/wp-content/uploads/2016/01/SUTP_GIZ_FS_Avoid-Shift-Improve_EN.pdf

Goldie-Scot, L. (2019, March 5). A Behind the Scenes Take on Lithium-ion Battery Prices. BloombergNEF. https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

Goulden, M., Ryley, T., & Dingwall, R. (2014). Beyond 'predict and provide': UK transport, the growth paradigm and climate change. Transport Policy, 32, 139–147. https://doi.org/10.1016/j.tranpol.2014.01.006

Greenwood, I. D., Dunn, R. C., & Raine, R. R. (2007). Estimating the Effects of Traffic Congestion on Fuel Consumption and Vehicle Emissions Based on Acceleration Noise. Journal of Transportation Engineering, 133(2), 96–104. https://doi.org/10.1061/(ASCE)0733-947X(2007)133:2(96)

Grütter, J., & Franken, B. (2019). E-Buses for BRT Corridors 1 and 6 of Transjakarta. Grütter Consulting.

Halim, R. A., Kirstein, L., Merk, O., & Martinez, L. M. (2018). Decarbonization Pathways for International Maritime Transport: A Model-Based Policy Impact Assessment. Sustainability, 10(7), 2243. https://doi.org/10.3390/su10072243

Hanaki, K., & Portugal-Pereira, J. (2018). The Effect of Biofuel Production on Greenhouse Gas Emission Reductions. In K. Takeuchi, H. Shiroyama, O. Saito, & M. Matsuura (Eds.), Biofuels and Sustainability: Holistic Perspectives for Policy-making (pp. 53–71). Springer Japan. https://doi.org/10.1007/978-4-431-54895-9_6

Hang Leung, K. (2016). Indonesia's Summary Transport Assessment. ADB Papers on Indonesia, 15. www.adb.org;

Harrison, P. (2018). Fuelling Europe's Future: How the transition from oil strengthens the economy. Cambridge Econometrics and Element Energy. https://www.camecon.com/wp-content/uploads/2018/02/ECF-Fuelling-Europe_EN_web.pdf

Hartanto, A., Susanti, V., Subekti, R. A., Saputra, H. M., Rijanto, E., & Hapid, A. (n.d.). Program Konversi dari BBM ke BBG untuk Kendaraan. Lembaga Ilmu Pengetahuan Indonesia. http://www.opi.lipi.go.id/data/1228964432/data/13086710321320817915.makalah.pdf

Haryanto, B. (2018). Climate Change and Urban Air Pollution Health Impacts in Indonesia. In R. Akhtar & C. Palagiano (Eds.), Climate Change and Air Pollution: The Impact on Human Health in Developed and Developing Countries (pp. 215–239). Springer International Publishing. https://doi.org/10.1007/978-3-319-61346-8_14

Heid, B., Hensley, R., Knupfer, S., & Tschiesner, A. (2017, September). What's sparking electric-vehicle adoption in the truck industry? McKinsey & Company. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/whats-sparking-electric-vehicle-adoption-in-the-truck-industry

Heyne, S., Bokinge, P., & Nyström, I. (2019). Global production of bio-methane and synthetic fuels-overview. CIT Industriell Energi AB. https://www.miljodirektoratet.no/globalassets/publikasjoner/m1421/m1421.pdf

Hoffmann, M. P., Castaneda Vera, A., van Wijk, M. T., Giller, K. E., Oberthür, T., Donough, C., & Whitbread, A. M. (2014). Simulating potential growth and yield of oil palm (Elaeis guineensis) with PALMSIM: Model description, evaluation and application. Agricultural Systems, 131, 1–10. https://doi.org/10.1016/j.agsy.2014.07.006

Holland, Dr. M. (2019, June 8). Toyota Plans To Lose To Tesla—Just 1 Million Electric Vehicles By 2025. Clean Technica. https://cleantechnica.com/2019/06/08/toyota-plans-to-lose-to-tesla-just-1-million-electric-vehicles-cumulative-by-2025/

Honda. (2018, November 29). Honda to Begin Lease Sales of Electric Scooter "PCX ELECTRIC." Honda. https://global.honda/newsroom/news/2018/2181129eng-pcx-electric.html

IATA. (2018, October 24). IATA Forecast Predicts 8.2 billion Air Travelers in 2037. IATA. https://www.iata.org/en/pressroom/pr/2018-10-24-02/

ICAO Secretariat. (2017, October 11). Trends and Scenario on Alternative Fuels. Conference on Aviation and Alternative Fuels, Mexico City. https://www.icao.int/Meetings/CAAF2/Documents/CAAF.2.WP.006.4.en.Revised.pdf

IEA. (n.d.). Data tables – Data & Statistics. IEA. Retrieved July 8, 2020, from https://www.iea.org/data-and-statistics/data-tables

IEA. (2009). Transport energy and CO_2: Moving towards sustainability. OECD Publishing. https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/transport2009.pdf

IEA. (2017a). Energy Technology Perspectives 2017. International Energy Agency (IEA). https://www.iea.org/reports/energy-technology-perspectives-2017

IEA. (2017b). International comparison of light-duty vehicle fuel economy—Ten years of fuel economy benchmarking: INDONESIA. International Energy Agency (IEA). https://www.globalfueleconomy.org/media/461034/asia_indonesia.pdf

IEA. (2019a). Fuel Economy in Major Car Markets: Technology and Policy Drivers 2005-2017. International Energy Agency (IEA). https://www.globalfueleconomy.org/media/708177/gfei-wp19.pdf

IEA. (2019b). The future of hydrogen: Seizing today's opportunities. IEA. https://webstore.iea.org/download/direct/2803

IEA. (2019). The Future of Rail: Opportunities for energy and the environment. International Energy Agency (IEA).

IEA. (2019d, November 27). Oil security—The global oil market remains vulnerable to a wide range of risk factors. IEA. https://www.iea.org/areas-of-work/ensuring-energy-security/oil-security

IEA, & International Union of Railways (UIC). (2012). Railway Handbook 2012: Energy Consumption and CO_2 Emissions. International Energy Agency (IEA). https://www.uic.org/com/IMG/pdf/iea-uic_2012final-lr.pdf

IEA, & International Union of Railways (UIC). (2017). Railway Handbook 2017: Energy Consumption and CO_2 Emissions. International Energy Agency (IEA). https://uic.org/IMG/pdf/handbook_iea-uic_2017_web3.pdf

IESR. (2019). Indonesia Clean Energy Outlook: Tracking Progress and Review of Clean Energy Development in Indonesia. Institute for Essential Services Reform. http://iesr.or.id/pustaka/iceo2020/

IESR. (2020a). National Energy Plan (RUEN): Existing Plan, Current Policies Implication, and Energy Transition Scenario. Institute for Essential Services Reform (IESR).

IESR. (2020b). The Role of Electric Vehicles in Decarbonizing Indonesia's Road Transport Sector. Institute for Essential Services Reform. http://iesr.or.id/pustaka/the-role-of-electric-vehicles-in-decarbonizing-indonesias-road-transport-sector/

Jaeger, A., Nugroho, S. B., Zusman, E., Nakano, R., & Daggy, R. (2014). Governing Sustainable Transport in Indonesia. The Institute for Global Environmental Strategies. https://www.files.ethz.ch/isn/183568/IGES_Working_Paper_No.2014-01.pdf

Jain, S., & Kumar, L. (2018). 31—Fundamentals of Power Electronics Controlled Electric Propulsion. In M. H. Rashid (Ed.), Power Electronics Handbook (Fourth Edition) (pp. 1023–1065). Butterworth-Heinemann. https://doi.org/10.1016/B978-0-12-811407-0.00035-0

Jakarta traffic report. (n.d.). TomTom. Retrieved May 1, 2020, from https://www.tomtom.com/en_gb/traffic-index/jakarta-traffic/

Jannah, S. M. (2019, June 27). Apa Memang Perlu Jumlah Taksi Online Dibatasi? Tirto. https://tirto.id/apa-memang-perlu-jumlah-taksi-online-dibatasi-edaE

Jayani, D. H. (2019, August 8). Inilah 10 Negara Tujuan Utama Ekspor CPO pada 2019. Databoks. https://databoks.katadata.co.id/datapublish/2019/08/08/inilah-10-negara-tujuan-utama-ekspor-cpo-pada-2019

Jin, L., & He, H. (2019). Comparison of the electric car market in China and the United States. The International Council on Clean Transportation. https://theicct.org/sites/default/files/publications/ICCT_US-China_EV-mkt-%20comp_20190523.pdf

Johnson, E. (2009). Goodbye to carbon neutral: Getting biomass footprints right. Environmental Impact Assessment Review, 29(3), 165–168. https://doi.org/10.1016/j.eiar.2008.11.002

Karatzos, S., Dyk, J. S. van, McMillan, J. D., & Saddler, J. (2017). Drop-in biofuel production via conventional (lipid/fatty acid) and advanced (biomass) routes. Part I. Biofuels, Bioproducts and Biorefining, 11(2), 344–362. https://doi.org/10.1002/bbb.1746

Kartika, A. (2018, March 29). Menperin: Industri Otomotif Sumbang 10,16 Persen ke PDB. Tempo. https://bisnis.tempo.co/read/1074289/menperin-industri-otomotif-sumbang-1016-persen-ke-pdb

Kereta Commuter Indonesia. (2019). 2018 Annual Report. http://www.krl.co.id/wp-content/uploads/2019/09/KCI-AR-2018_Webversion-min.pdf

Khatiwada, D., Venkata, B. K., Silveira, S., & Johnson, F. X. (2016). Energy and GHG balances of ethanol production from cane molasses in Indonesia. Applied Energy, 164, 756–768. https://doi.org/10.1016/j.apenergy.2015.11.032

Koalisi Buruh Sawit. (2018). Lembar Fakta Perlindungan Buruh Sawit Indonesia. http://www.turc.or.id/wp-content/uploads/2018/07/Lembar-Fakta-Koalisi-Buruh-Sawit-Indonesia-2018.pdf

Kodjak, D., & Meszler, D. (2019). Prospects for fuel efficiency, electrification, and fleet decarbonization. The International Council on Clean Transportation. https://www.globalfueleconomy.org/media/708302/gfei-working-paper-20.pdf

Kurniawan, A. A., Alexander, K., Prionggo, A., Bramantyo, J., Peterson, J., Indrarto, G. B., & Sekarsari, A. (2018). Dynamics of Indonesian Biodiesel Downstream and Upstream Industry. Koaksi Indonesia. https://coaction.id/download/full-report-dynamics-of-indonesian-biodiesel-downstream-and-upstream-industry/

Lambert, F. (2018, September 14). Bombardier unveils a new battery-powered train. Electrek. https://electrek.co/2018/09/14/bombardier-battery-powered-train/

Lambert, F. (2019a, June 7). Toyota unveils images of upcoming all-electric cars, accelerates EV plans by 5 years. Electrek. https://electrek.co/2019/06/07/toyota-electric-car-images-accelerate-plan/

Lambert, F. (2019b, August 21). World's largest all-electric ferry completes its maiden trip. Electrek. https://electrek.co/2019/08/21/worlds-largest-electric-ferry/

Lyons, G. (2012). Visions for the future and the need for a social science perspective in transport studies. In F. W. Geels, R. Kemp, G. Dudley, & G. Lyons (Eds.), Automobility in Transition? A Socio-Technical Analysis of Sustainable Transport (pp. 29–48). Routledge. http://www.routledge.com/books/details/9780415885058/

Malins, Dr. C. (2018). Driving deforestation: The impact of expanding palm oil demand through biofuel policy. Cerulogy and Rainforest Foundation Norway. https://d5i6is0eze552.cloudfront.net/documents/Publikasjoner/Andre-rapporter/Cerulogy_Driving-deforestation_Jan2018.pdf?mtime=20180122234132

Marwoto, B. D. (2020, March 17). Jumlah penumpang Batik Solo Trans turun hampir 100 persen. Antara News. https://www.antaranews.com/berita/1361862/jumlah-penumpang-batik-solo-trans-turun-hampir-100-persen

McDonald, L. (2018, October 27). US Electric Car Range Will Average 275 Miles By 2022, 400 Miles By 2028—New Research (Part 1). CleanTechnica. https://cleantechnica.com/2018/10/27/us-electric-car-range-will-average-275-miles-by-2022-400-miles-by-2028-new-research-part-1/

Meszler, D., German, J., Mock, P., & Bandivadekar, A. (2016). CO2 Reduction Technologies for the European Car and Van Fleet, A 2025-2030 Assessment. The International Council on Clean Transportation.

MEMR. (2017). Kajian Penggunaan Faktor Emisi Lokal (Tier 2) dalam Inventarisasi GRK Sektor Energi. https://www.esdm.go.id/assets/media/content/content-kajian-emisi-gas-rumah-kaca-2017.pdf

MEMR. (2019a). Energi Berkeadilan: 5 tahun kinerja, realisasi hingga triwulan III 2019. Ministry of Energy and Mineral Resources Republic of Indonesia. https://drive.esdm.go.id/wl/?id=PdTKgxTXXC17pbT6CjaFoibcLFGwNBYM

MEMR. (2019b). Handbook Of Energy & Economic Statistics Of Indonesia 2018 Final Edition. Ministry of Energy and Mineral Resources Republic of Indonesia.

Ministry of Environment and Forestry. (2019). Statistik Tahun 2018 Direktorat Jenderal Pengendalian Perubahan Iklim. Ministry of Environment and Forestry. http://ditjenppi.menlhk.go.id/reddplus/images/adminppi/dokumen/statistik_PPI_2018_opt.pdf

Momirlan, M., & Veziroglu, T. N. (2005). The properties of hydrogen as fuel tomorrow in sustainable energy system for a cleaner planet. International Journal of Hydrogen Energy, 30(7), 795–802. https://doi.org/10.1016/j.ijhydene.2004.10.011

Moriarty, P., & Honnery, D. (2016). Global Transport Energy Consumption. https://doi.org/10.1002/9781119066354.ch61

MotorCycles Data. (2019, April 16). Niu. The first e-scooter to sell over 1 million units worldwide! MotorCyclesData. https://motorcyclesdata.com/2019/04/16/niu/

Munoz, F. (2019, July 29). Global sales of pure electric vehicles soar by 92% in H1 2019. JATO. https://www.jato.com/global-sales-of-pure-electric-vehicles-soar-by-92-in-h1-2019/

Nayazri, G. M. (2020, January 14). Honda Kuasai 75 Persen Pasar Sepeda Motor Indonesia. Kumparan. https://kumparan.com/kumparanoto/honda-kuasai-75-persen-pasar-sepeda-motor-indonesia-1sdpqqWQQXP

Nugraha, A. R. (2020, April 9). Organisasi Ojol: Ada 4 Juta Driver Ojol di Indonesia. Kumparan. https://kumparan.com/kumparantech/organisasi-ojol-ada-4-juta-driver-ojol-di-indonesia-1tBrZLEXOEI

Pagenkopf, J., van den Adel, B., Deniz, Ö., & Schmid, S. (2019). Transport Transition Concepts. In S. Teske (Ed.), Achieving the Paris Climate Agreement Goals: Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5°C and +2°C (pp. 131–159). Springer International Publishing. https://doi.org/10.1007/978-3-030-05843-2_6

Partnership on Sustainable Low Carbon Transport. (2019). E-Mobility Trends and Targets.

Parwata. (2019, December 30). Selalu Ramai, Jumlah Suroboyo Bus Yang Bayarnya Pakai Botol Plastik Akan Ditambah, Pangkas Waktu Tunggu. Gridoto. https://otomania.gridoto.com/read/241969869/selalu-ramai-jumlah-suroboyo-bus-yang-bayarnya-pakai-botol-plastik-akan-ditambah-pangkas-waktu-tunggu

Patel, T. (2020, June 22). France Takes Aim at Budget Carriers With Ban on Short Routes. Bloomberg.Com. https://www.bloomberg.com/news/articles/2020-06-22/france-takes-aim-at-low-cost-carriers-with-ban-on-short-routes

Petriella, Y. (2020, April 16). PLN Belum Punya Data Pelanggan 900 VA Mampu dan 1.300 VA yang Terdampak Corona. Bisnis.Com. https://ekonomi.bisnis.com/read/20200416/44/1228277/pln-belum-punya-data-pelanggan-900-va-mampu-dan-1.300-va-yang-terdampak-corona

Prasetiyo, W. (2017, August 25). Mobil Bahan Bakar Fosil Dilarang Dijual di RI 2040, Negara Lain 2030. Kumparan. https://kumparan.com/kumparannews/mobil-bahan-bakar-fosil-dilarang-dijual-di-ri-2040-negara-lain-2030

Prawita, D. (2015, September). Bea Keluar dan Pungutan Dana Perkebunan atas Ekspor Kelapa Sawit, CPO dan Produk Turunannya. Warta Bea Cukai, 47(9), 5–11.

PT Blue Bird Tbk. (2020). 2019 Annual Report. https://www.bluebirdgroup.com/wp-content/uploads/2020/06/LAPORAN-TAHUNAN-2019-PT-BLUE-BIRD-TBK.pdf

PT. Sarana Pembangunan Palembang Jaya. (n.d.). BUS RAPID TRANSIT (BRT) TRANS MUSI. Retrieved April 25, 2020, from https://sp2j.co.id/nbrt

Qiao, Q., & Lee, H. (2019). The Role of Electric Vehicles in Decarbonizing China's Transportation Sector. Belfer Center for Science and International Affairs. https://www.belfercenter.org/sites/default/files/files/publication/RoleEVsDecarbonizingChina.pdf

Replogle, M. A., & Fulton, L. M. (2014). A Global High Shift Scenario: Impacts and Potential for More Public Transport, Walking, and Cycling with Lower Car Use. Institute for Transportation and Development Policy & University of California, Davis. https://theicct.org/sites/default/files/A%20Global%20High%20Shift%20Scenario_WEB.pdf

Robitzski, D. (2019, March 19). Toyota is Selling a Hydrogen Fuel Cell Car for $50,000. Futurism. https://futurism.com/toyota-selling-hydrogen-fuel-cell-car

Rudi, A. (2018, May 23). Usulan Stop Mobil Konvensional 2040 Ditentang Gaikindo. Kompas. https://otomotif.kompas.com/read/2018/05/23/090200515/usulan-stop-mobil-konvensional-2040-ditentang-gaikindo

Ruiz, J., Olivieri, G., Vree, J. de, Bosma, R., Willems, P., Hans Reith, J., M. Eppink, M. H., M. Kleinegris, D. M., H. Wijffels, R., & J. Barbosa, M. (2016). Towards industrial products from microalgae. Energy & Environmental Science, 9(10), 3036–3043. https://doi.org/10.1039/C6EE01493C

Saragih, B. (2017). Produktivitas Sumber Pertumbuhan Minyak Sawit yang Berkelanjutan. https://www.iopri.org/wp-content/uploads/2017/07/I-01.-Makalah-Prof-Bungaran-Saragih-Produktivitas.pdf

Schade, D. W., & Wagner, U. (2019, October 16). Beschäftigungseffekte nachhaltiger Mobilität—Eine vergleichende Analyse der Perspektiven bis 2035. Die Automobilindustrie im Wandel Vortrag auf der Veranstaltung von IGBCE und Fraunhofer IMWS, Berlin.

Schmitt, B. (2019, June 7). Toyota, Subaru, Suzuki, and Mazda to Throw Their Combined 16 Million Might Behind BEVs. The Drive. https://www.thedrive.com/tech/28424/toyota-subaru-suzuki-and-mazda-throw-their-combined-16-million-might-behind-bevs

Sclar, R., Gorguinpour, C., Castellanos, S., & Li, X. (2019). Barriers to Adopting Electric Buses. World Resources Institute. https://www.wri.org/publication/barriers-adopting-electric-buses

Sen, B., Noori, M., & Tatari, O. (2017). Will Corporate Average Fuel Economy (CAFE) Standard help? Modeling CAFE's impact on market share of electric vehicles. Energy Policy, 109, 279–287. https://doi.org/10.1016/j.enpol.2017.07.008

Siagian, U. W. R., Dewi, R. G., Boer, R., Hendrawan, I., Yuwono, B. B., & Ginting, G. E. (2015). Pathways to Deep Decarbonization in Indonesia. SDSN - IDDRI. http://deepdecarbonization.org/wp-content/uploads/2015/11/DDPP_IDN.pdf

Smith, A. C., Holland, M., Korkeala, O., Warmington, J., Forster, D., ApSimon, H., Oxley, T., Dickens, R., & Smith, S. M. (2016). Health and environmental co-benefits and conflicts of actions to meet UK carbon targets. Climate Policy, 16(3), 253–283. https://doi.org/10.1080/14693062.2014.980212

Soulopoulos, N. (2017). When Will Electric Vehicles be Cheaper than Conventional Vehicles? Bloomberg New Energy Finance. http://www.automotivebusiness.com.br/abinteligencia/pdf/EV-Price-Parity-Report.pdf

Srihanun, N., Dujjanutat, P., Muanruksa, P., & Kaewkannetra, P. (2020). Biofuels of Green Diesel–Kerosene–Gasoline Production from Palm Oil: Effect of Palladium Cooperated with Second Metal on Hydrocracking Reaction. Catalysts, 10(2), 241. https://doi.org/10.3390/catal10020241

Suehiro, S., & Purwanto, A. J. (2019). Study on Electric Vehicle Penetrations' Influence on 3Es in ASEAN (ERIA Research Project FY2019 No.06). Economic Research Institute for ASEAN and East Asia. https://www.eria.org/uploads/media/RPR_FY2018_06.pdf

Sufa, F. (2020). Low-to-No Emissions Journey of TransJakarta BRT System. https://www.ccacoalition.org/en/file/6838/download?token=CEDn_24_

Surjadipradja, H. (2019, October 2). Indonesian Automotive Components Industry. Workshop tentang Dampak Pengembangan KLBB terhadap Industri Otomotif dan Sistem Ketenagalistrikan, Jakarta.

Tari, D. N. (2020, April 7). Cegah Corona, Operasional Busway di Pekanbaru Dibatasi. Bisnis.Com.

https://sumatra.bisnis.com/read/20200407/533/1223588/cegah-corona-operasional-busway-di-pekanbaru-dibatasi
Teske, S., Pregger, T., Naegler, T., Simon, S., Pagenkopf, J., van den Adel, B., & Deniz, Ö. (2019). Energy Scenario Results. In S. Teske (Ed.), Achieving the Paris Climate Agreement Goals: Global and Regional 100% Renewable Energy Scenarios with Non-energy GHG Pathways for +1.5°C and +2°C (pp. 175–401). Springer International Publishing. https://doi.org/10.1007/978-3-030-05843-2_8
Thorne, R., Amundsen, A. H., & Sundvor, I. (2019). Battery electric and fuel cell trains: Maturity of technology and market status (No. 1737/2019). Institute of Transport Economics (TØI). https://www.toi.no/getfile.php?mmfileid=52027
Tim Riset PASPI. (2018, January 16). Tingkat Suku Bunga Kredit, Replanting / Produktivitas & Penggunaan Dana Sawit. Gabungan Pengusaha Kelapa Sawit Indonesia (GAPKI). https://gapki.id/news/3966/tingkat-suku-bunga-kredit-replanting-produktivitas-penggunaan-dana-sawit
Traction Energy Asia. (2019, May 7). Emisi Produksi Biodiesel di Indonesia Berdasarkan Analisa Daur Hidup (Life Cycle Analysis).
Tsantilas, S. (2019, April 5). Japan's big four announce consortium for electric motorcycle battery tech. New Atlas. https://newatlas.com/honda-kawasaki-suzuki-yamaha-2019-electric-motorcycle-consortium/59178/
US EPA. (2014, April 4). Emission Factors for Green House Gas Inventories. United States Environmental Protection Agency. https://www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf
van der Steen, M., Van Schelven, R. M., Kotter, R., van Twist, M. J. W., & van Deventer MPA, P. (2015). EV Policy Compared: An International Comparison of Governments' Policy Strategy Towards E-Mobility. In W. Leal Filho & R. Kotter (Eds.), E-Mobility in Europe: Trends and Good Practice (pp. 27–53). Springer International Publishing. https://doi.org/10.1007/978-3-319-13194-8_2
van Hulst, N. (2019, April 23). The clean hydrogen future has already begun – Analysis. IEA. https://www.iea.org/commentaries/the-clean-hydrogen-future-has-already-begun
Wang, S., & Ge, M. (2019, October 16). Everything You Need to Know About the Fastest-Growing Source of Global Emissions: Transport. World Resources Institute. https://www.wri.org/blog/2019/10/everything-you-need-know-about-fastest-growing-source-global-emissions-transport
Wehling, M., Izadi-Najafabadi, A., Lu, S., & Abraham, A. T. (2020, June 4). Driving Change: Electrifying Mobility in Asia. BloombergNEF Webinar.
Weiss, M., Dekker, P., Moro, A., Scholz, H., & Patel, M. K. (2015). On the electrification of road transportation – A review of the environmental, economic, and social performance of electric two-wheelers. Transportation Research Part D: Transport and Environment, 41, 348–366. https://doi.org/10.1016/j.trd.2015.09.007
Winata, D. T., & Rarasati, A. D. (2018). Sustainable infrastructure transportation to improve society wellbeing in Karawang. IOP Conference Series: Earth and Environmental Science, 105, 012008. https://doi.org/10.1088/1755-1315/105/1/012008
Yang, Z., & Bandivadekar, A. (2017). 2017 Global Update: Light-Duty Vehicle Greenhouse Gas and Fuel Economy Standards. The International Council on Clean Transportation. https://theicct.org/sites/default/files/publications/2017-Global-LDV-Standards-Update_ICCT-Report_23062017_vF.pdf
Zamora, J. C. P. (2014). The "Avoid-Shift-Improve" Model: A Powerful Planning Tool for Transportation Schemes with Low GHG Emissions. Climate Change - A Global Challenge, Contribution of Infrastructure Planning, 2, 141–150. https://www.researchgate.net/profile/Alexander_Marful2/publication/305627794_MASTER_PLANNING_TO_HARNESS_THE_SUN_AND_WIND_ENERGY_The_Case_of_Shagaya_Renewable_Energy_Master_Plan_Project_Kuwait/links/5798e3d508ae33e89fb0b55a.pdf#page=147
Zasiadko, M. (2020, January 27). Vivarail certifies UK's first battery-powered train. RailTech.Com. https://www.railtech.com/rolling-stock/2020/01/27/vivarail-certifies-uks-first-battery-powered-train/
Zuhriyah, D. A. (2018, September 12). KAI Klaim Sudah Gunakan B20 Per 1 September 2018. Bisnis.Com. https://ekonomi.bisnis.com/read/20180912/98/837316/kai-klaim-sudah-gunakan-b20-per-1-september-2018