

Critical review on the biofuel development policy in Indonesia



Imprint

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Executive Summary

In 2017, 138 billion liters of biofuel were produced globally, increasing from only 18 billion liters in 2000. Almost 90% of the biofuel produced was conventional biofuel from food competing feedstock, i.e. bioethanol from sugar (e.g. sugar cane) or starch crops (e.g. corn, cassava) and biodiesel from oil crops (e.g. rapeseed, sunflower, palm oil). These types of biofuel have different characteristics from petroleum fuel, which limits their potential to fully replace petroleum fuel. These differences include oxidation stability, biodegradability, moisture absorption, and corrosiveness. In addition, the feedstock competition with food consumption raised concerns about the sustainability of those biofuels.

Trying to solve those concerns, more advanced types of biofuels have been developed in the form of second, third, and fourth-generation biofuels as well as drop-in biofuels. Drop-in biofuels have similar properties to petroleum fuel, thus could fully replace the petroleum fuel without modification of the combustion engines and distribution infrastructure. Second-generation biofuels use waste materials as feedstock, while third and fourth-generation use microalgae. However, only 12% of the current biofuel production are drop-in or second-generation biofuels.

Biofuel development in Indonesia

The development of biofuel in Indonesia was initiated in 2006 as a response to the increasing price of petroleum and increasing fuel import as domestic crude production plummeted. The energy diversification policy was stipulated in the 2006 National Energy Policy (KEN), including biofuel utilization. Since the enactment, there are several important policy milestones, including the set-up of blending mandate, pricing mechanism, and subsidy/incentive scheme, as shown in Figure 1. In 2008, the biofuel mandate roadmap was established, setting blending targets for bioethanol, biodiesel, and pure vegetable oil. However, many of these targets have not been achieved for years, mainly due to price uncompetitiveness to the petroleum. Only recently, in 2019, the biodiesel target of 20% diesel consumption was achieved. Meanwhile, bioethanol consumption as fuel is virtually non-

existent after the small blending portion had been introduced in 2009.

With the pressing need to fill the price gap of FAME and petroleum products, the government established the oil palm plantation fund (OPPF)

2006

Initial biofuel program through:
-National Energy Policy, Presidential Instruction, and establishment of Timnas BBN

2008

- Stipulation of the biofuel mandate roadmap
- Subsidy provision for biofuel from state budget

2015

- The latest update to biofuel mandate roadmap which increase the blending target
- Biofuel subsidy from state budget is stopped
- Revision of biodiesel pricing mechanism
- Establishment of OPPF to provide biodiesel incentive in PSO segment

2016

Revision of bioethanol pricing mechanism

2018

Expansion of the biodiesel incentive to Non-PSO segment

Figure 1
Chronological overview of biofuel
policy changes in Indonesia

as the source of subsidy² for biodiesel in 2015, replacing the previous subsidy from the state budget that was halted earlier in the same year. The fund is collected from an export levy on CPO and its derivatives. Within 6 years, IDR 58.2 billion has been disbursed to support the biodiesel blending program. Initially, the subsidy covered only biodiesel blending in subsidized diesel fuel (Public Service Obligation/PSO). Later, in 2018, the subsidy is expanded to cover the non-PSO diesel fuel, which played an important role in fulfilling the biodiesel blending mandate in 2019. However, the use of OPPF for biodiesel subsidy has attracted criticism, for example, from the Anti-Graft Commission (KPK). They argue that the biodiesel subsidy using OPPF is not consistent with the Plantation Law.

The success of the biodiesel program has been largely helped by the various incentives and subsidies received along the supply chain. Other than the subsidy received from OPPF, there are also subsidies for diesel fuel consumption, fiscal incentives for the biofuel industry (lower stamp duties, accelerated depreciation and amortization, lower income tax, etc.), and incentives received by the palm oil producers (e.g. fertilizer subsidy, subsidy for seeds and saplings, soft loans, etc.). These incentives are estimated to reach IDR 19.6 billion per year. However, the large majority is directed for general government support such as fertilizer subsidy, fuel subsidy, and infrastructure development, which cannot be allocated specifically to the biofuel industry.

More recently, the government intended to further expand the biodiesel program up to 100% share in diesel consumption. However, this remains unofficial and not getting passed into the regulatory framework. Increasing the blending rate might require drop-in biofuel instead of conventional biodiesel. The government has included a drop-in green diesel plant in the mid-term national development plan (RPJMN) and Pertamina has planned to start producing green diesel in 2022. Yet, there is still no regulation

Economic, environmental, and social considerations

Biodiesel and bioethanol reference price

published by MEMR has always been higher than petroleum fuel for most of the time. A techno-economic analysis of several drop-in biofuel technologies indicates that the drop-in biofuel also costs higher than petroleum fuel. The biofuel production costs USD 0.54 to USD 1.60 per kg, while the petroleum diesel reference price was USD 0.38 per kg (2020 average). For the palm oil based biofuel, the higher cost is mainly due to high feedstock price, while for the lignocellulosic biofuel, it is due to more complex and expensive process equipment. Green diesel made from palm oil, the one currently in Pertamina's plan, is a mature technology and requires less capital cost, but the high feedstock cost will be the main barrier for large-scale deployment. Using waste cooking oil as feedstock could help **reduce the cost**, although an effective collection mechanism needs to be sorted out. Meanwhile, the production cost of lignocellulosic (e.g. agricultural waste, forest residue, etc.) biofuel through thermochemical processes potentially cost up to 35% **cheaper** than palm oil based biofuel. However, the technology is still in development and the investment risk could double the estimated capital cost. In addition, the availability and collection of the scattered feedstock could also be challenging, while using a commercially available feedstock such as wood pellets could increase the cost by about 50%, making it more expensive than the palm oil based biofuel.

From the environmental perspective, biofuel has long attracted criticism. The use of biofuel in many countries and Indonesia is intended to reduce GHG emissions from petroleum fuel burning. However, various studies on first-generation biofuel (including palm oil) life cycle analysis indicate that this assumption is mostly valid when GHG emissions from land-use change are neglected. When land-use change is considered, most first-generation biofuel emits more than petroleum fuel. A number of studies find different ranges of Indonesian biodiesel GHG emission, Traction Energy Asia estimated the widest ranges from 730 gCO₂e/liters up to 22,850 gCO₂e/liters when peat conversion took place. Growing biofuel crops also often requires large amounts of water, and the use of chemicals in the plantations could pollute water bodies. Biofuel development in Indonesia also has social implications. The B20 program in 2019 is estimated to create 801 thousand jobs. However,

¹ There are different views on the usage of the term 'subsidy'. Some stakeholders, including the government prefer the term 'incentive'. The subsidy in this context does not suit with the government's definition of subsidy that has to be provided directly from the state budget for the public. Nevertheless, it adheres to the broader definition of subsidy used internationally.

there are still issues regarding the health and safety of workers, child labor, discrimination, especially in palm oil plantations. As smallholder farmers own a large part of palm oil plantations, they are supposed to be benefitted from the growing demand. However, the weak position of the smallholders in the supply chain limits the benefits that reach them. The issues faced by smallholders include a strong presence of middlemen, unsupportive pricing formula, and low productivity.

Biofuel has also contributed significantly to the national and local economy. For example, in 2019, it helped reduce the trade deficit and saved USD 2.9 billion of foreign exchange. At the local level, palm oil plantations contributed by a sustained boost to the value of agricultural output, manufacturing output, and regional GDP in some provinces. However, palm oil plantations also often cause land conflicts and loss of access to resources for local communities.

There have been various responses to mitigate the negative environmental and social implications. There are several sustainability certifications available for the biofuel supply chain at the international level. In Indonesia, Indonesia Sustainable Palm Oil (ISPO) certification for oil palm plantations is now mandatory following the latest Presidential Regulation No. 44/2020. Up until now, only about a third of the oil palm

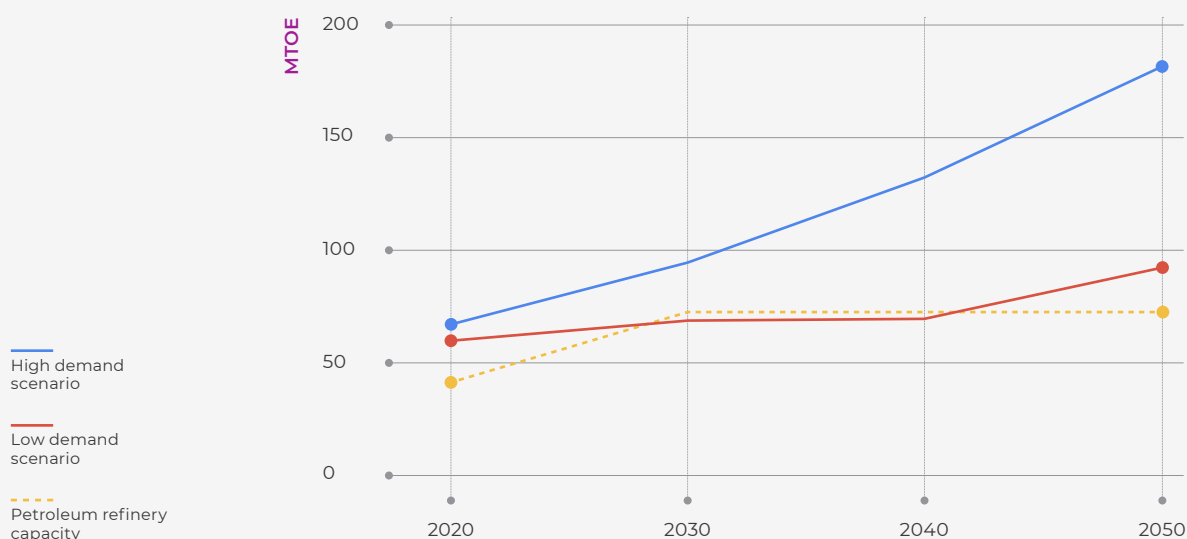
plantations area are ISPO certified. In addition, the government also issued a moratorium on oil palm expansion in 2018. In the private sector, No Deforestation, No Peat, No Exploitation (NDPE) commitment has been adopted by many companies in the palm oil supply chain, although implementation has been inconsistent. Nevertheless, these initiatives have not been really successful in overcoming the problems.

The future of biofuel policy

Biofuel would act as the main substitute for petroleum fuel, especially in the transportation sector. The future potential of biofuel demand is highly uncertain due to the rapid development of alternative technologies, especially electric vehicles. In business-as-usual, the potential biofuel demand could increase to 190 MTOE in 2050 from the current demand of 8 MTOE. However, in high electric vehicle penetration and high modal shifting to public transportation, biofuel demand potential might be reduced to only 93 MTOE in 2050. As the demand in light-duty vehicles collapses, the remaining demand potential would be heavy-duty transportation and industry. If the biofuel is only used to substitute fuel import, the potential would be lower, as there is already a plan to expand the petroleum refinery capacity to 73 MTOE by 2026, as illustrated in Figure 2.

In the past few years, there have already been several biofuel targets set by the government, from the long-term target set in RUEN, mid-term

Figure 2
Potential liquid fuel demand in high demand (BAU) and low demand (high electrification and efficiency) scenario



Tabel 1
Different biofuel
targets set in
different national
documents
(in MTOE)

Policy	2020	2025	2030	2040
RUEN (2017)	7.6	13.2	19.7	32.3
RPJMN (2019)	9.5	16.5 (2024)	-	-
Grand energy strategy (2020)	8.5	11.2	12.7	13.7
Biofuel roadmap (2020)	9.0	11.7	15.2	-

target in Grand National Energy Strategy draft and biofuel roadmap by the MEMR, to short-term target set in RPJMN. RUEN targets include biodiesel and bioethanol, while the other targets mostly include only biodiesel and green diesel. The targets set are different for each policy document. The target set in the most recent document, the Grand Energy Strategy, is the least aggressive, as seen in Table 1.

These targets are relatively safe strategies as mostly set on diesel substitute biofuel, predominantly used in heavy-duty transportation, industry, and special use (construction, agriculture, mining). These sectors are expected to still have substantial markets until 2050. There will also be a wide potential in green avtur demand, including in the global market, since there is limited low carbon alternative. Meanwhile, for gasoline substitutes, both global and domestic demand could cease in the case of high electric vehicle adoption. Therefore, planning for the production infrastructure for the gasoline substitutes needs to consider the low-demand scenario to minimize the potentially stranded assets.

Since biofuel costs higher than petroleum fuel, it needs financial support to enter the market. The annual subsidy needed to run the biofuel targets listed in Table 1 ranges from IDR 29 trillion to IDR 57 trillion between 2021 and 2024. This subsidy amount could even double if the CPO price increases to its highest level in the past 10 years (USD 970/ton annual average). However, the subsidy could also be eliminated if crude oil price increases to USD 80/bbl instead of USD 41/bbl in

2020. The uncertainty shows the risky nature of biofuel development in the country.

Other than subsidy, the expansion of biofuel demand might also induce expansion of palm oil plantations, which is one of the most important causes of environmental and social problems. While it is possible to reduce palm oil export or increase plantation productivity to cover the increase of domestic biofuel demand, data from the past years indicates otherwise. The export has kept increasing despite the additional domestic demand from the biodiesel program. Meanwhile, the plantation productivity has only increased by 0.34% per year. Hence, the increase of biofuel demand as planned by the government would result in an additional four to six million hectares of plantation in 2024, which exceeds the available and suitable land estimated by some studies.

Recommendations

Considering the economic, environmental, and social implications of biofuel, as well as the uncertainty of biofuel future demand, there are things that the government needs to act on.

- **Develop a long-term strategy of biofuel's role in energy transition, aligned with the development of alternative technologies**

The future potential demand for biofuel is uncertain. Increasing biofuel mandate too aggressively could risk the infrastructure becoming stranded assets. The government needs to be prudent in developing the long-term plan for biofuel and putting it under the broader energy transition plan. The most

recent plan in the Grand Energy Strategy draft has tried to integrate biofuel planning with electric vehicle adoption and petroleum refinery development. In addition, to reduce the risk of stranded assets, investment in biofuel could be directed to retrofitting existing plants for co-processing or developing biofuel refineries that are more flexible in product portfolio and transformable to other products such as chemicals.

- **Set clear and transparent criteria to measure economic, social, and environmental benefits of biofuel program**

The biofuel program is intended to provide economic, social, and environmental benefits. However, there are problems in the current practices that undermine those intentions. Clear and transparent criteria are needed to keep the program's goals on track. Criteria could be adopted to the existing certification scheme, ISPO. The ISPO could also be redesigned to encourage the improvement of current practices instead of only fulfilling the minimum requirements. In addition, sustainability criteria for the other (non-palm oil) feedstock and the general biofuel industry will also be needed.

- **Diversify the biofuel feedstock Current biofuel relies only on palm oil as feedstock.**

Feedstock diversification could provide benefits in terms of environmental impact, land requirement, and economic sustainability of biofuel production. Diversified feedstock could reduce the risk when disruption occurs on the feedstock supply. Potential non-food crops for biofuel production that could grow in degraded land such as nyamplung, kemiri sunan, and malapari, deserve to be further investigated for their feasibility. There are

also abundant waste materials available for alternative biofuel feedstock, for example, waste oil and agricultural and plantation residue.

- **Establish policy support to incentivize the production and development of second and next-generation biofuels**

Policy support is needed to encourage the production of second-generation biofuels. Financial incentives, specific mandates, loan guarantees, and soft loans could help drive the production of biofuel technologies that are ready to commercialize, such as waste oil-based HVO or lignocellulosic ethanol. For less developed technologies, public spending for R&D and demonstration plants is needed. For the third and fourth generation biofuels, the government needs to prepare a development pathway, for example, by first focusing on the production of higher value chemicals from microalgae, which has already been demonstrated in other countries.

- **Transform the incentive scheme to encourage innovation and sustainability**

To support the innovation towards more sustainable biofuels, the existing incentive scheme needs to be transformed. The incentive scheme should incorporate sustainability aspects as the requirement. The Low Carbon Fuel Standards (LCFS) is an example where the incentive is based on carbon intensity; the higher incentive is received by fuel produced at lower carbon intensity. The utilization of the Oil Palm Plantation Fund should also be directed to improve sustainability, such as for smallholders replanting to increase their productivity and sustainable practices, and for research and development of plantation waste utilization as a biofuel feedstock.

Despite the rapid growth recently, Indonesia's palm oil biofuel has been scrutinized for its environmental, social, and economic sustainability.

01. Introduction



Introduction

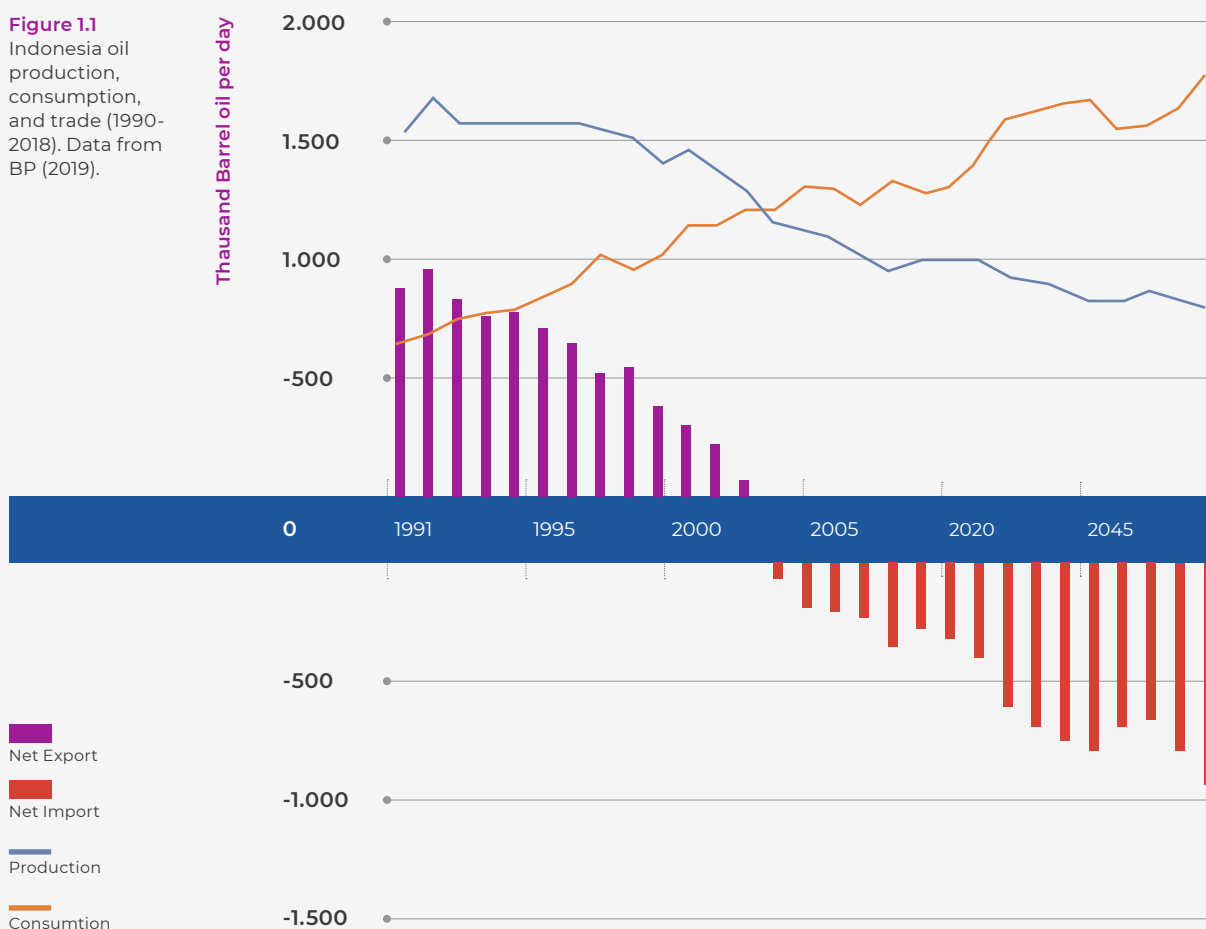
Once a significant oil-exporting country, Indonesia has imported oil since the mid-2000s to meet increasing domestic demand (Figure 1). However, relying on imported oil has its drawbacks since it causes Indonesia's national energy security to be vulnerable to fluctuations in world crude oil price and supply/demand. As a response to the risk, the government took measures necessary to diversify the energy supply. One of the measures used is to replace petroleum oil with biofuels.

The initiative to develop biofuel as a strategy to reduce fuel import was first regulated by Presidential Regulation No.5/2006, which targeted biofuel usage to be 5% of the total primary energy by 2025. This regulation was followed with the issuance of mandatory use of biofuel through the Minister of Energy and Mineral Resources (MEMR) Regulation No.32/2008. This mandatory

target has been revised several times. The latest, through MEMR Regulation No.12/2015, sets new targets of biodiesel and bioethanol to be 30% and 20% respectively of the total demand for diesel oil and gasoline by 2025.

Since the issuance of mandatory regulations in 2008, biofuel utilization in Indonesia has not been effective. The Indonesian government put more attention to biodiesel than bioethanol even though the consumption of diesel is much smaller than gasoline. Biodiesel production increased from 0.24 million kl in 2010 to 8.4 million kl in 2019, while consumption increased from 0.22 million kl to 6.4 million kl for the same period (Aprobi, 2020). On the other hand, bioethanol consumption as fuel has remained virtually zero since 2010 due to its much higher price than gasoline and lack of financial support mechanism (Rahmanulloh, 2019).

Figure 1.1
Indonesia oil
production,
consumption,
and trade (1990-
2018). Data from
BP (2019).



Domestic biodiesel consumption has grown significantly in the past few years. Over the 2017-2019 period, the domestic consumption of biodiesel has almost tripled from 2.5 billion liters to 6.4 billion liters in 2019. Palm oil has been used as the sole feedstock for all biodiesel production, despite the early excitement of other potential sources such as jatropha. This rapid growth is driven by the B20 program (blending biodiesel to petroleum diesel products at a 20% rate) that is supported by financial incentives (subsidy) through the establishment of the crude palm oil (CPO) fund. With the successful implementation of the B20 program, the Indonesian government moved forward with the B30 program beginning in January 2020 and is currently conducting the trial use of B40. The trial is expected to be completed by the end of 2020, while the implementation is initially targeted to commence in July 2021 (N. Harsono, 2020). In addition, the government plans to also develop palm oil based green diesel. A 20,000 bpd green diesel production facility is listed as one of the priority projects in the mid-term national development plan (RPJMN) 2020-2024.

Despite the recent growth, palm oil based biodiesel in Indonesia has been scrutinized by various domestic and international organizations for its impact on social and environmental sustainability, especially in the upstream sector, the palm oil industry. One of the most discussed issues is the deforestation and land use change (Malins, 2018) as well as the associated GHG emissions (S. S. Harsono et al., 2012; Traction Energy Asia, 2019). Other than that, various social conflicts are associated with the palm oil industry such as land conflict, unfair contract and working conditions, and local environmental destruction (Barreiro et al., 2016; Zakaria et al., 2017).

In addition, biodiesel is more expensive than petroleum diesel. Therefore, an incentive is needed to make it attractive for businesses to produce and sell biodiesel in Indonesia. To avert consumers from bearing this additional cost, the government provides assistance or subsidy for biodiesel, known as Oil Palm Plantation Fund (OPPF) which is managed by Oil Palm Plantation Fund Management Agency (BPDPKS). OP PF is collected from the export of palm oil and its derivative products. From 2015-2019, IDR 30.2 trillion of public funds has been disbursed to cover the price gap between biodiesel and petroleum diesel through the BPDPKS (BPDP, 2020).

The government's aggressive plan to increase the utilization of palm oil based biofuel poses questions on its impacts on various sectors. It is especially important in the context of energy transition. With the rapid development of renewable electricity and electric vehicle technologies in the past decade, it is important to reassess these trends and the future of biofuel, and what benefits and costs it might incur.

This study aims to carefully assess the plan's impact from the economic/financial, environmental, and social perspectives. It starts with an overview of various biofuel technologies available and the biofuel policies, followed by the development of biofuel policies and status in Indonesia. It then assesses the techno-economic of several prospective biofuel technologies and the social and environmental impact of biofuel development. Last, it also discusses the potential impact of the government's aggressive biofuel plan and the policies required to address such implications.

Of the global biofuel production in 2018, 62% was bioethanol, 26% biodiesel, and only 12% advanced biofuel, which include drop-in biofuels and cellulosic ethanol.

02.

Biofuel technology overview



2.1 General overview

The role of biofuels in global energy consumption has been increasing significantly in the past 2 decades, mainly in the transport sector. The production of biofuels increased from only 17 billion liters in 2000 to 160 billion liters in 2018 (WBA, 2020). Of the produced biofuel in 2018, 62% was in the form of bioethanol, 26% biodiesel, and the rest included more advanced technologies such as HVO and cellulosic ethanol.

The United States and Brazil are the main producers and consumers of bioethanol. In 2018, the US and Brazil produced 60 and 32 billion liters of bioethanol, mainly for domestic consumption. Other significant bioethanol producers are European Union with 5 billion liters and China

with 3 billion liters. For biodiesel and HVO, the main producers are the European Union with 15 billion liters (mainly from France, Germany, Spain, and the Netherlands). The United States, Brazil, and Indonesia are other major biodiesel producers with 7.8, 5.2, and 4 billion liters in 2018.

The majority of the biofuel currently produced utilizes conventional feedstock, i.e. sugar crops or oil crops. Only 9% of the biofuel produced in 2018 was derived from non-food-crop feedstock, which IEA calls advanced biofuel. Almost 90% of these advanced biofuels are biodiesel and HVO made from fat, oil, grease (FOG) waste, tallow oil, and used cooking oil (UCO).

Figure 2.1
Global biofuel
production
by type (in
billion liters).
From World
Bioenergy
Association/
WBA (2020).

	2000	2005	2010	2015	2016	2017	2018
Biofuels	17.3	37.1	103	136	142	148	160
Bioethanol	13.5	27.2	67.6	90.4	93.8	98.9	98.4
Biodiesel	0.72	3.43	19.5	30.6	34.2	36.0	41.8
Other Biofuels	3.13	6.51	15.8	15.1	13.8	13.2	19.6

2.2 Biofuel products, processes, and characteristics

There are different types of biofuel products that are available in the market. Based on the characteristics, biofuels can be generally classified into oxygenated and non-oxygenated biofuel. Oxygenated biofuel contains oxygen molecules in its chemical composition, which differs from the conventional petroleum fuel that contains only carbon and hydrogen molecules. As a result, oxygenated biofuel has different characteristics, and therefore cannot completely replace petroleum fuel without modifying the combustion engine. Conventional biodiesel

(FAME) and bioethanol fall into this category. On the other hand, non-oxygenated biofuel, or familiarly called drop-in biofuel, contains no oxygen molecules and is touted to have similar characteristics as petroleum fuel. Therefore, it can replace the petroleum fuel entirely without any engine and infrastructure modification, hence the term "drop-in." There are also different types of drop-in biofuels that could replace the different petroleum products, i.e. gasoline, diesel, and jet fuel.

2.2.1. Oxygenated biofuel

Biodiesel

Biodiesel is used as a partial substitute for petroleum diesel. It is blended with petroleum diesel at various blending ratios, with the highest ratio is currently 30% in Indonesia. In other countries, it is commonly blended at less than a 10% ratio, with the exception of Thailand (20%) and Brazil (12%). Some countries, such as Paraguay and Malaysia, are also planning to increase the biodiesel blending rate above 10% (Lane, 2019).

Due to the presence of oxygen molecules, biodiesel has about 11% lower energy content than petroleum diesel (Karatzos et al., 2017). In terms of air pollutants, biodiesel combustion generally emits less particulate matter (PM), hydrocarbon (HC), carbon monoxide (CO), and sulfur oxides (SO_x) but more nitrogen oxides (NO_x) than conventional diesel. Biodiesel solidifies at a higher temperature than conventional diesel, which becomes an issue in 4-season countries. Biodiesel is more easily degradable biologically, about 4 times faster than the petroleum counterpart. Consequently, it is vulnerable to

microorganism contamination when the water content is too high.

Production process

Biodiesel can be produced from plant- or animal-based oil through a chemical process called transesterification. In this chemical process, the triglyceride in the plant- or animal-based oil reacts with alcohol, forming fatty acid methyl esters (FAME), or biodiesel, as the main product. As a side-product, this reaction also produces glycerol. Methanol is commonly used as an alcohol substrate. This process uses a strong alkali, such as sodium hydroxide or potassium hydroxide, as the catalyst.

The transesterification of triglycerides occurs at 60-70°C in the presence of the catalyst and excess alcohol. When the reaction finishes, two layers of liquid will be formed, glycerol and excess alcohol in the bottom and FAME in the top. These two layers of liquid could be separated with a separation unit (decanter). Then, the FAME needs to be washed with water to remove the glycerol that is contained in the FAME layer.

Bioethanol

Ethanol is a simple alcohol compound with two carbon atoms. It can be produced from biological sources through fermentation, such as in alcoholic beverages or petroleum feedstock. Bioethanol specifically refers to the first.

Ethanol has a 34% lower energy density than gasoline due to its high oxygen content. However, the presence of oxygen makes it superior in octane number, which exceeds 100. This leads to the practice of blending ethanol into gasoline to improve its octane number, replacing the use of MTBE, a toxic compound that was used to improve octane number (Bhatia, 2014).

Ethanol is a corrosive material and it easily absorbs moisture, thus affecting the metal component of an engine.

Production process

In general, bioethanol is produced through a fermentation process of sugar compounds, followed by separation and purification. As the

feedstock, different types of plants can be used: sugar crops (e.g. sugar cane, sugar beet); starch (e.g. cassava, corn); or cellulose (e.g. agricultural waste, grass). Different processes are required to convert the different feedstocks to bioethanol (Figure 2.1).

Fermentation of sugar or starch crops is the most common way of bioethanol production. For sugar crops, the sugar juice is extracted from the crops through physical means such as milling. The sugar juice consists of simple sugars, which are readily fermentable by the yeast. For starch crops, the sugars are present in a more complex form, which requires liquefaction and enzymatic hydrolysis to break the chemical bonds of the starch, producing simple sugars, which can then be fermented (Riazi & Chiaramonti, 2018).

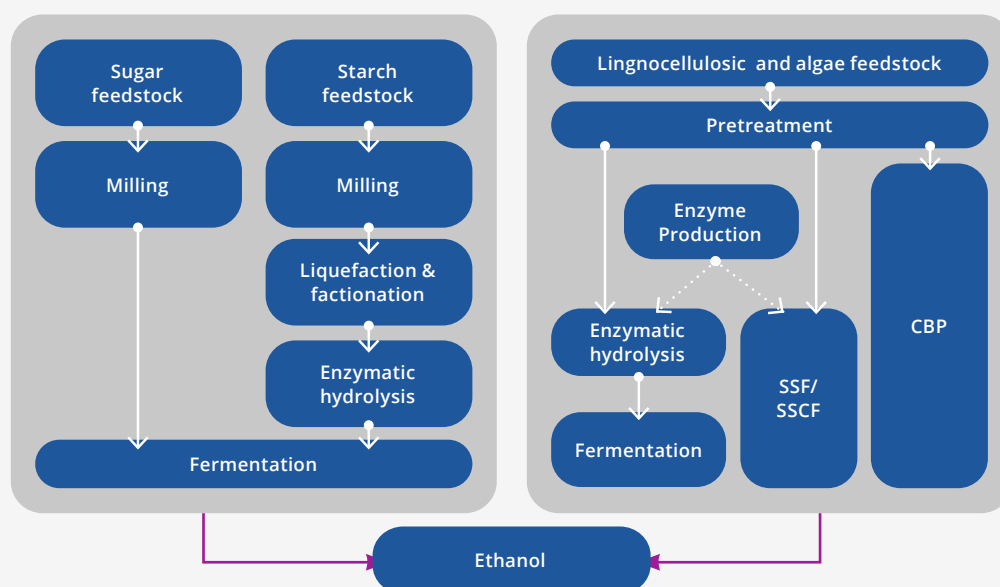
Production of bioethanol from lignocellulosic biomass requires a far more complicated process. Biomass is made of a combination of lignin, cellulose, and hemicellulose. Only the latter two can be converted into sugar and ethanol. The

chemical structure of lignocellulosic biomass prevents the hydrolytic enzymes from accessing the cellulose and hemicellulose. Therefore initial pretreatment is required to make the cellulose and hemicellulose accessible to the enzyme (Riazi & Chiaramonti, 2018).

There are many options available for the pretreatment of biomass, which can be categorized into physical, chemical, physicochemical, and

biological. Each method has its advantages and drawbacks, and there is no best one. Physical treatments aim to reduce the biomass particle size. Chemical treatments aim to break down the lignocellulose into simpler compounds through a chemical reaction. Physicochemical treatments decompose the lignocellulose by a combination of oxidation and thermal treatment. Biological treatments aim to treat hemicellulose and lignin with microorganisms (Kucharska et al., 2018).

Figure 2.1
Bioethanol production processes from sugar, starch, and lignocellulosic feedstock. From Riazi & Chiaramonti (2018).



2.2.2. Drop-in biofuels

According to Karatzos et al. (2014), drop-in biofuels are “liquid bio-hydrocarbon that are functionally equivalent to petroleum fuels and are fully compatible with existing petroleum infrastructure.” Similar to petroleum fuels, drop-in biofuels consist of a mixture of different hydrocarbons. The main difference between drop-in biofuels and conventional biofuels is the removal of oxygen. The drop-in biofuels have several advantages over biodiesel and bioethanol, i.e., are not limited by blending ratio, can use the existing petroleum infrastructure (e.g. pipeline and storage tanks), and have higher energy density.

Drop-in biofuels can be produced via different pathways, i.e. oleochemical, thermochemical,

and biochemical. Similar to biodiesel, oleochemical drop-in biofuels are made of oil/fat feedstocks, which product is called with various terms such as hydroprocessed esters and fatty acids (HEFA), hydrotreated vegetable oil (HVO), or hydrotreated renewable oil (HRO). The thermochemical pathway utilizes lignocellulosic biomass through a high-temperature process and catalytic conversion to produce fuels and chemicals. The biochemical pathway is similar to bioethanol production, converting sugar compounds into less oxygenated biofuels using microorganisms. These production processes of drop-in biofuel could be partly integrated into existing petroleum refineries called co-processing, usually to reduce the investment cost required.

Hydrotreated vegetable oil (oleochemical pathway)

Currently, most of the drop-in biofuel produced globally is HVO, which refers to diesel-like biofuel produced through the oleochemical route. The main goal of the process is to remove the oxygen present in vegetable (or animal) oil by reacting with hydrogen gas. The process basically involves two main steps, hydrotreatment to remove the oxygen and hydrocracking to obtain the required chemical structure to match the characteristics of existing petroleum fuels. The hydrogen needed is about 3-4% of the feedstock oil (on a mass basis).

The process yield is typically about 80%, predominantly diesel-like fuel accompanied by a smaller jet fuel fraction. However, different feedstock, catalyst, and process conditions would

alter the yield and product composition. Most vegetable oils have a carbon chain length similar to diesel (C16-22), which explains why most of the product would fall in the diesel range. The product is commonly called green diesel or renewable diesel, to differentiate from FAME biodiesel. Changing the process condition of the second step (hydrocracking) could result in a higher fraction of lighter products (jet fuel and gasoline), but at the expense of lower product yield, because some of the product will be very short chain hydrocarbon, which is undesirable. Several vegetable oils such as camelina oil, palm kernel oil, or some microorganism-produced oils have shorter carbon chains, which are more suitable for the production of jet fuel.

Thermochemical pathway biofuel

There are two main techniques to convert lignocellulosic biomass to liquid fuel through thermochemical processes, involving high temperature and catalyst. The first one is through the gasification of biomass, resulting mainly in a mixture of gas compounds called syngas. The second one is pyrolysis, which produces mostly liquid, known as bio-oils or biocrudes. The gasification or pyrolysis products still contain oxygen molecules, and therefore need to be further upgraded into deoxygenated hydrocarbons using hydrogen.

Gasification has been used to produce liquid fuel from coal and natural gas. However, the technology is not fully compatible with biomass feedstock, limiting its application until now. One of the challenges is syngas purification, which is more needed for biomass gasification. Another challenge is the very large production scale of coal gasification, which is not compatible with biomass feedstock (van Dyk et al., 2019).

Gasification is performed under high pressure (1-50 bars) and high temperature (800-1000°C) in the presence of a gasifying agent, such as air, oxygen, or steam. Gasification is basically partial oxidation. Therefore the reaction is carried out under a limited amount of oxygen. The product of gasification is mainly (about 85%) in a gaseous phase, called syngas. The syngas

typically consists of mainly hydrogen and carbon monoxide, with carbon dioxide, methane, and water vapor as minor components. The energy content of produced syngas depends on the gasifying agent, about 4 MJ/Nm³ for gasification with air to 18 MJ/Nm³ for gasification with steam. The higher the ratio of hydrogen to carbon monoxide in the syngas, the better it is for biofuel feedstock.

The syngas could then be converted into liquid biofuel through Fischer-Tropsch (FT) synthesis, which is an established chemical process developed during the 1920s. The different catalysts and process conditions would result in different products. FT synthesis at 300-350°C with iron catalyst would produce gasoline range hydrocarbons, while reaction at 200-240°C with cobalt catalyst would result in heavier range products (diesel and wax). The higher hydrogen to carbon monoxide ratio also drives the product range to lighter hydrocarbons. The FT liquid would then need to be upgraded into fuel grade through hydrotreating, hydrocracking, isomerization, and fractionation.

Alternatively, the syngas could be converted into methanol, which could then further processed into gasoline through an established Methanol to Gasoline process, developed by ExxonMobil in the 1970s (*Synthetic Fuel Process*, n.d.).

Pyrolysis, on the other hand, is performed at around 5000C, also in the absence of oxygen. The product is a mixture of gas, char, and bio-oil liquid. The bio-oil contains about 40% of oxygen, which then needs to be removed through hydrotreating in the form of water, or through

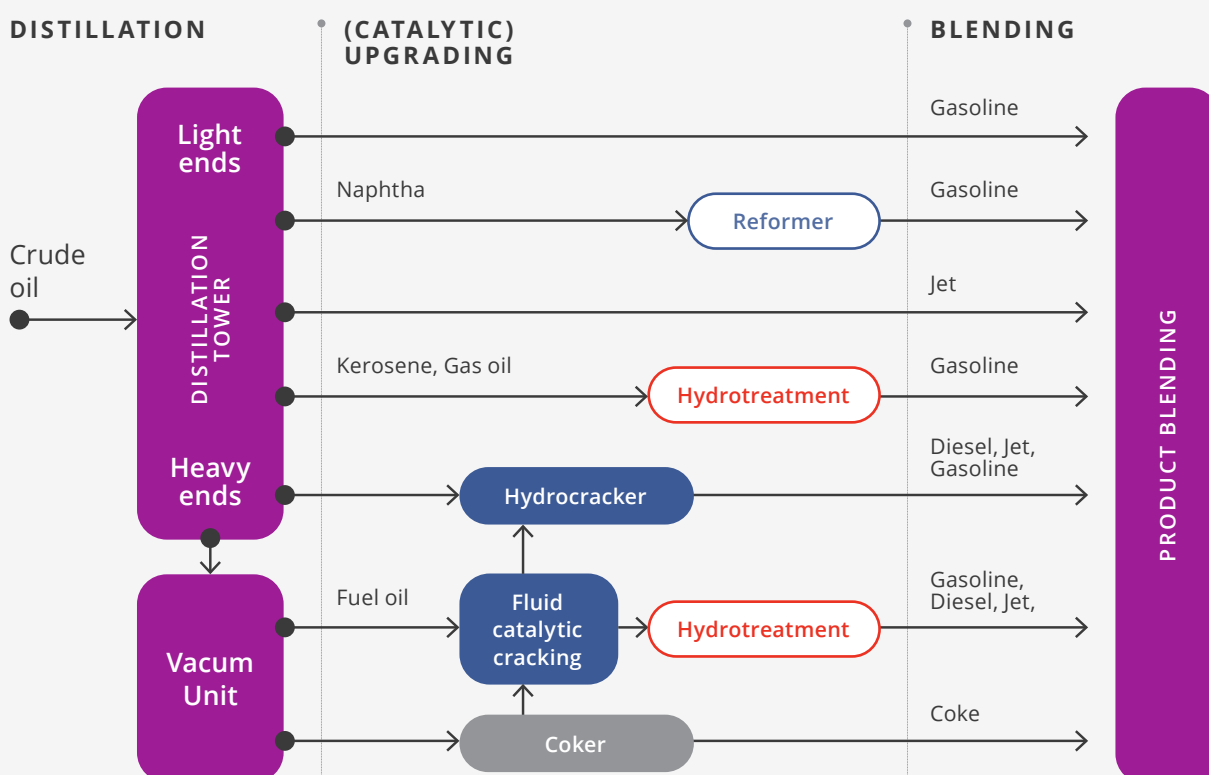
zeolite cracking in the form of carbon dioxide. Hydrotreating requires a lot of hydrogen gas as an input, while zeolite cracking consumes no hydrogen. However, as the zeolite cracking expels carbon molecules from the bio-oil, it reduces the biofuel yield.

Co-processing in petroleum refinery

In order to lower the production cost, the drop-in biofuel could be produced in the existing oil refineries, by adding the bio feedstock in one of the refinery steps. The feedstock could come from vegetable oil or from thermochemical processes. There are two functions that need to be performed by the refinery units to the biocrudes, i.e., oxygen removal and carbon chain shortening (cracking). There are several points in the refinery process where biocrudes could be inserted into, i.e., distillation, fluid catalytic cracking (FCC), hydrotreating, and hydrocracking (van Dyk et al., 2019).

Each insertion point requires a certain feedstock specification. Biocrudes addition in the FCC is considered the most attractive since the catalysts are less sensitive to the feedstock's high oxygen content. Catalysts in hydrotreaters and hydrocrackers are less tolerant to contaminants and oxygen content. Similarly, the input for distillation units needs to be similar to petroleum crude since the product will be distributed to all other refinery units (see Figure 2.2). Alternatively, oxygen removal could be performed prior to insertion into the petroleum refinery. Then the deoxygenated biocrudes could be further upgraded into fuel products in the refinery.

Figure 2.2.
Simplified schematic of oil refinery
processes. From van Dyk et al. (2019).



2.3 Biofuel feedstocks

There is also another way to categorize biofuels based on the feedstock characteristics. The first generation biofuels are the biofuels that are produced from food plants that contain sugar, starch, or oil and fat. The second generation biofuels are produced from non-food biomass.

The third generation biofuels are produced from algae due to its high productivity compared to terrestrial plants. They are called fourth generation biofuels when genetically modified algae or other microorganisms are used.

2.3.1. First generation biofuels

The first generation biofuels come from feedstocks that compete with food or feed sources. First generation bioethanol is produced from sugar or starch crops, such as sugarcane, sugar beets, corn, cassava, etc. First generation biodiesel is produced from vegetable oils such as palm oil, rapeseed oil, soybean oil, and sunflower oil.

The use of food crops for biofuel feedstock has raised concerns about the potential impact on food price. A review by Malins (2017b) presented a lot of economic modeling literature agreeing that biofuel demand could increase food commodity prices. In addition, the review also concluded that biofuel demand could induce volatility to food prices by reducing the stocks of crop products, adding inflexible demand through mandatory blending, and passing on the oil price volatility to food prices. It also noted that the biofuel demand had played an important role in the world food price crisis in 2006-2008, although there are differences in the extent of the role.

On the other hand, there are also studies indicating that there is no or little evidence that biofuel has induced food price increase. One recent study by Shrestha et al. (2019), for example, concluded that there had been no significant influence of biofuels demand on the US food price. They also found that 96% of the food price index variability could be explained by the crude oil price and world population.

Despite the debate on food versus fuel has not been concluded, many review studies indicated that indeed biofuel production affects food price, although the extent of the impact cannot be agreed on due to differences in methodologies and difficulties to model the land markets and land transformation processes (Bentivoglio & Rasetti, 2015; Malins, 2017b; Oladosu & Msangi, 2013; Persson, 2015). With the potential impact of biofuel demand on food prices, efforts have been directed to utilize non-food crops as biofuel feedstock, resulting in the development of second generation biofuels.

2.3.2. Second generation biofuels

Second generation biofuels utilize non-food sources, including forest or agricultural residues (e.g. corn stover, sugarcane bagasse), woody (lignocellulosic) biomass crops (e.g. grass crops), organic part of municipal waste, and nonedible oil seeds (e.g. jatropha oil, karanja oil) (Aron et al., 2020; Dutta et al., 2014). Several studies also consider UCO and animal fat as second generation biofuel feedstock (Bhuiya et al., 2014; Dutta et al., 2014).

No competition with food crops and lower GHG emissions are the main benefits of second generation biofuels (Aron et al., 2020). Biofuels production from waste materials does not require additional land to grow the crops. Also, grass crops and nonedible oil crops can be grown in marginal lands, which are unsuitable for growing food crops.

However, producing second generation biofuels often requires higher capital costs due to more

complicated processes, especially for the lignocellulose-based biofuels (Aron et al., 2020). As already described in section 2.1, lignocellulosic feedstock can be converted to biofuel through the fermentation process (into bioethanol or other alcohol) or a thermochemical process (into drop-in biofuels or alcohol). Both processes require higher capital investment than first generation biofuels. Recently, a newer approach, which mimics the biochemical process occurring in nature (biomimetic), has been researched and promising lower costs. The biomimetic process occurs at milder temperatures compared to the thermochemical process².

In 2018, only 9% of the biofuel production came from non-food feedstock. Almost 90% was made from nonedible oil and fat, and the rest made of lignocellulosic biomass. Several countries have policies to encourage specifically advanced biofuels (biofuels that do not compete with food sources). For example, the US and some European countries impose specific mandates for advanced biofuels on top of the mandate for general biofuels (Ebadian et al., 2020). In addition, other policies such as research and development funding, financial incentives, and low carbon fuel standards are also available in those countries to encourage the development and commercialization of advanced biofuels (Ebadian et al., 2020).

2.3.3. Third and fourth generation biofuels

The third generation biofuels are produced from (micro)algae biomass which has a higher growth rate compared to terrestrial crops and can be grown anywhere (does not require arable land). Microalgae is also easier to be genetically modified than terrestrial plants, thereby bringing up the idea of fourth generation biofuels. The fourth generation biofuels come from genetically modified microalgae, which are expected to absorb more CO₂, have higher productivity, and be adaptable to specific environments (Aron et al., 2020). However, despite the promising potential, currently producing biofuels from microalgae is far from being economical. Other than biofuels, the components from microalgae could also be converted into more valuable products such as bulk chemicals (e.g. biopolymers, lubricants, surfactants, etc.), food products, and specialty chemicals (e.g. food additives, cosmetics). Due to the high production cost, only specialty chemicals can currently be produced commercially from microalgae (Ruiz et al., 2016).

Biofuel production from microalgae consists of three major stages, biomass cultivation and harvesting, separation and purification, and biofuels production (Shuba & Kifle, 2018). The biomass cultivation and harvesting is the most expensive stage, costing about 40% of the total biofuel production cost from microalgae (Oh

et al., 2018). However, it is expected that this cost could reduce significantly. Ruiz et al. (2016) estimated that the cost of biomass cultivation could go down from EUR 3.4-5.2 per kg to 0.5 EUR per kg in 10 years. Biomass harvesting is done through separation from the reactor suspension, followed by biomass concentration. This stage is estimated to contribute about 5-30% of the total biomass production cost, depending on the cultivation method used (Oh et al., 2018; Ruiz et al., 2016).

The obtained microalgae biomass contains various useful components, i.e. lipids, fatty acids, proteins, pigments, and cellulose. These components need to be separated through physical and chemical methods (e.g. pressing, milling, extraction). For biofuel production, the lipid is the targeted component (Shuba & Kifle, 2018). The other components are also valuable, and therefore the separation techniques need to be carefully arranged not to destroy the other components. Proteins and carbohydrates should be extracted first, followed by lipid, and the last is the insoluble compounds. The obtained lipid could then be converted into different biofuels following similar processes as other vegetable oils. The carbohydrates and cellulosic components could also be converted into biofuels through fermentation or thermochemical processes.

² Tatang Hernas Soerawidjaja, personal communication

03.

Biofuel policies and development in Indonesia



Since the 2000s, Indonesia's crude oil production has been on a continuing downward trend due to a lack of exploration and investment in this sector (Kusnandar, 2019). The government's oil production target at the beginning of each year has not been achieved for several consecutive years because most of the oil production comes from old oil fields. This decline in oil production combined with increasing domestic demand, has turned Indonesia into a net oil importer.

Indonesia's demand for oil, either in the form of crude oil or refined products (diesel, gasoline, etc.), is steadily increasing. From 2000 until 2019, Indonesia's total oil import has increased from

25.4 million tons to 34.3 million tons, with the biggest total import occurring in 2013, reaching 45.6 million tons (BPS, 2020b). Large oil imports will directly impact the Indonesian state budget because higher oil prices will result in more spending on imports, which ultimately burdens the state foreign exchange reserves. Therefore, to reduce pressure on the state budget as a direct result of the increase in oil prices, it is important to consider other energy sources to reduce oil consumption and replace it.

The first government's effort to encourage the reduction of petroleum oil is by encouraging the usage of biofuel as mandated by Presidential Regulation No. 5/2006 on National Energy Policy (KEN). This regulation was targeting the use of biofuel at least 5% of total primary energy by 2025. The KEN was later upgraded into the higher level Government Regulation No. 79/2014. In the same year, the government also established the National Team for Biofuel Development (Timnas BBN) through Presidential Decree No. 10/2006. The Timnas BBN was responsible for developing the blueprint and roadmap for biofuel development to reduce poverty and unemployment. This agency recommended the use of sugarcane, sorghum, jatropha, and oil palm as biofuel feedstock (*Timnas BBN Gelar Workshop Sosialisasi Pengembangan Bahan Bakar Nabati* (BBN), 2008).

In 2008, the government released the Minister of Energy and Mineral Resources Regulation No. 32/2008 as a follow-up, which obliged the petroleum fuel distributors and consumers to utilize biofuel. According to this regulation, biofuel utilization in Indonesia is regulated by determining the minimum blend of biofuel with petroleum oil. This regulation set the mandatory biofuel blending target for different products, such as biodiesel, bioethanol, and straight vegetable oil (SVO), and for different sectors (i.e. transportation, industry, commercial, and power generation). Later, the blending targets have been updated three times through MEMR Regulation No. 25/2013, MEMR Regulation No. 20/2014, and MEMR Regulation No. 12/2015. The blending targets were increased in all three updates despite never being successfully fulfilled due to various factors described later.

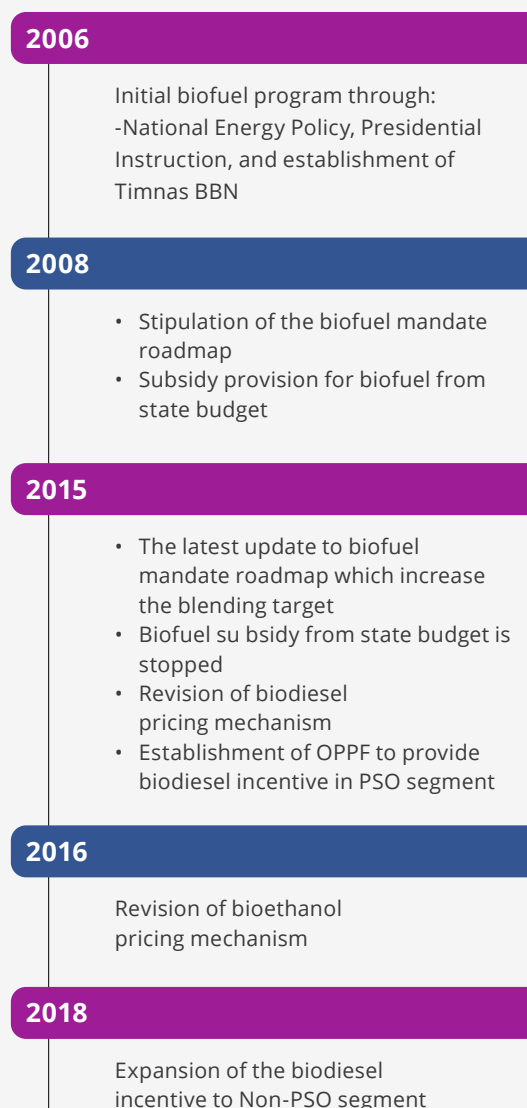


Figure 3.1.
Chronological overview of biofuel policy
changes in Indonesia

3.1 Current policies on biofuel production, utilization and trade in Indonesia

MEMR Regulation No. 12/2015 is the latest update of MEMR Regulation No. 32/2008, which set the biofuel mandatory blending rate. Under this regulation, biodiesel should be 30% of the total diesel demand starting from January 2020. For bioethanol, the percentage varies depending on the sector and starting date, as shown in Table 2 below.

Besides MEMR Reg. No.12/2015, there are other regulations and ministerial decrees that govern specifically biodiesel utilization, such as Presidential Regulation No.61/2015. Biodiesel is generally more expensive than petroleum diesel. To boost domestic consumption while meeting the blending target, the Government of Indonesia, through Presidential Regulation No. 61/2015 and its amendments (No. 24/2016 and No. 66/2018), began collecting levy on

palm oil and palm oil derivatives export and manage it as Oil Palm Plantation Fund (OPPF). This fund is then partly used to support the domestic biodiesel consumption (Harahap, 2018). Presidential Regulation No. 61/2015 stipulates that the subsidy to cover the price gap between biodiesel and petroleum diesel is only given for PSO diesel fuel, while in Presidential Regulation No. 66/2018, the coverage is expanded to all diesel use.

BPD PKS, as a public service institution under the Ministry of Finance, is tasked with managing the OP PF. According to Plantation Law No. 39/2014, this fund should be used for various purposes related to plantation development, i.e. improving human resources, research and development, and promoting palm oil plantations replantation, and developing facilities and infrastructure.

Table 3.1.
Biodiesel and
bioethanol
mandatory
target in
Indonesia

Sectors	January 2020		January 2025	
	Biodiesel	Bioethanol	Biodiesel	Bioethanol
Small-scale enterprise, fishery, agriculture, transportation and public service obligation (PSO)	30%	5%	30%	20%
Transportation non-PSO	30%	10%	30%	20%
Industry and commercial	30%	10%	30%	20%
Power plant	30%	-	30%	-

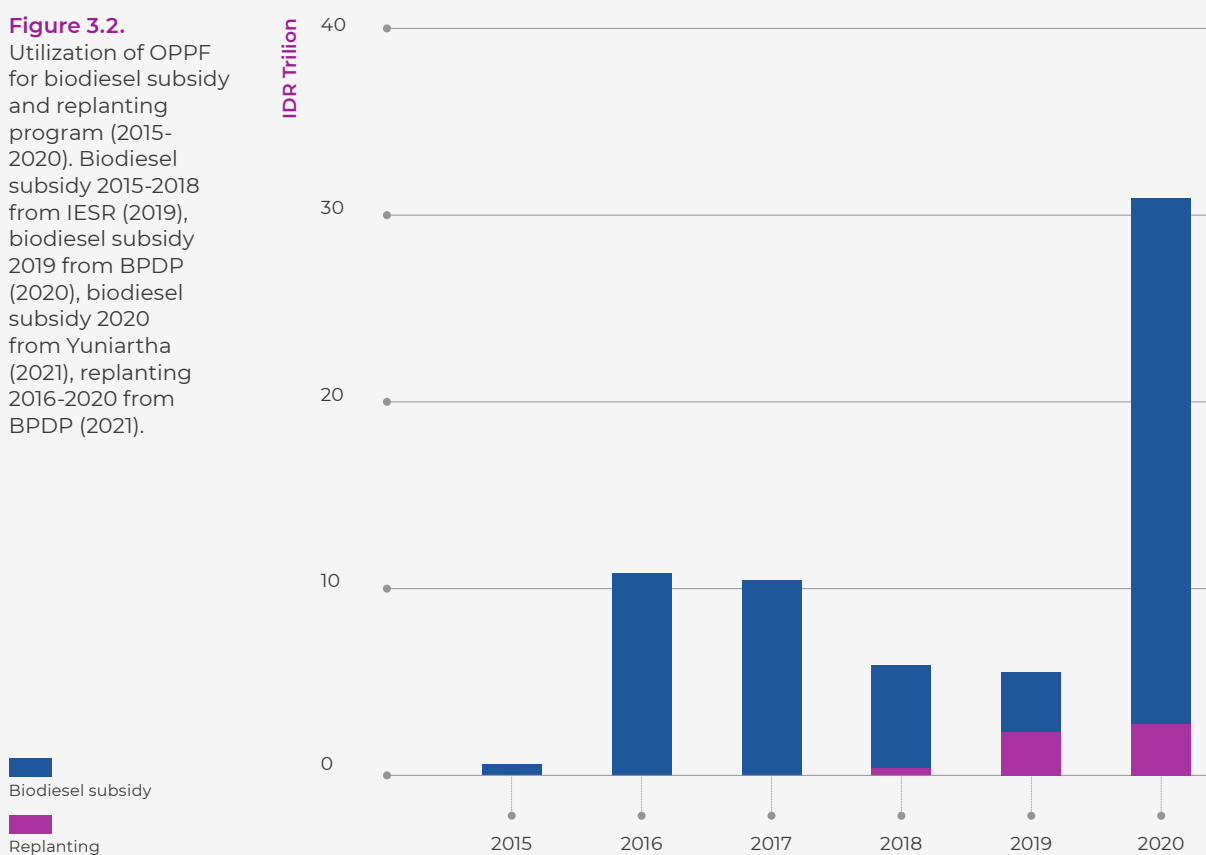
However, in the Presidential Regulation 61/2015 and the amendments, the purpose is expanded to also include biofuel subsidy (KPK, 2016). For the realization, about 90% of the fund has been used for biodiesel subsidy, as shown in Figure 3.2. The Anti-Graft Commission (KPK) argues that the fund utilization for the biodiesel program, as accommodated in the Presidential Regulation, is not consistent with the Plantation Law and could hamper its use for sustainable oil palm development.

More recently, the government has issued in public statements their intention to further expand the biofuel program. In mid-2019, the president publicly announced the plan to start 50% biodiesel blending (B50) by the end of 2020, and further increased it to B100. However, it was later postponed due to lack of available funding for the subsidy (IESR, 2021). The government has clarified that the higher blending rate might require drop-in biofuel, the HVO (or green diesel). The government has also included the construction of a green diesel plant in the mid-term national development plan (RPJMN). However, green diesel is not included in the biofuel mandate's latest regulation (MEMR Reg.

No. 12/2015). There is also no regulation that specifies the pricing and incentive mechanism for green diesel, although Pertamina is already planning to start pure green diesel production in 2022.

For bioethanol, there was also a plan to start implementing 2% ethanol blending in East Java province in early 2020. However, it remains unrealized until the end of the year due to a lack of financial incentives (IESR, 2021). Another idea of A20 blending in gasoline (5% methanol and 15% ethanol) has also been around since 2019 but is still being studied by the MEMR and not yet stipulated as formal policy (Hastuti, 2019; MEMR, 2021).

Figure 3.2.
Utilization of OPPF
for biodiesel subsidy
and replanting
program (2015-
2020). Biodiesel
subsidy 2015-2018
from IESR (2019),
biodiesel subsidy
2019 from BPDP
(2020), biodiesel
subsidy 2020
from Yuniartha
(2021), replanting
2016-2020 from
BPDP (2021).



3.2 Current status of biofuel development in Indonesia

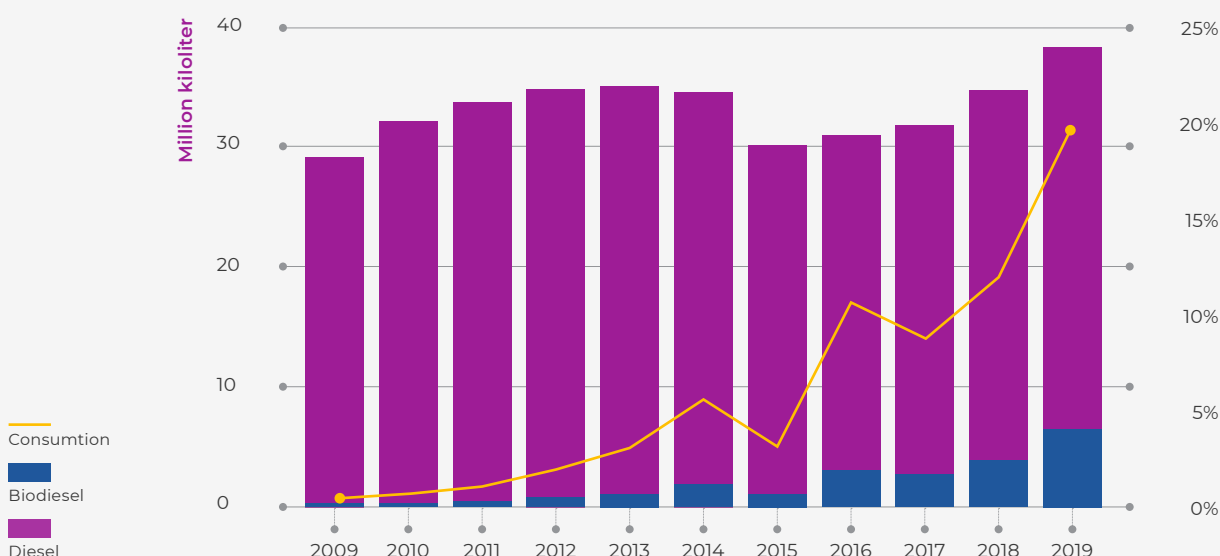
Currently, only the biodiesel blending program works in Indonesia. Prior to 2018, the biodiesel blending has only been successful in the PSO segment, as the subsidy and incentive were provided only for this segment. The biodiesel blended with PSO diesel fuel was subsidized through the state budget with a subsidy ceiling up to IDR 1,000 per liter in 2008-2010, IDR 2,000 per liter in 2011, and IDR 2,500-3,000 per liter in 2012. Nevertheless, the actual subsidy was much lower, only about IDR 100-120 per liter, because the subsidy only covers the price difference between biodiesel and conventional diesel³. The biodiesel reference price was determined based on the petroleum diesel (MOPS) price. Additionally, the reference price did not take into account the transport fee, which reached USD 60-120 per ton biodiesel according to USDA (Slette & Wiyono, 2013) or USD 7-70 according to Paulus Tjakrawan⁴.

In 2015, the biodiesel subsidy from the state budget was halted, causing the biodiesel

consumption to cease, explaining the drop of biodiesel share in that year, as shown in Figure 3.2. The government later introduced a new subsidy scheme through BPDPKS instead of the state budget, which managed to spur consumption in the last quarter of 2015 (Dharmawan et al., 2018). The government also revised the formula to determine the biodiesel reference price based on CPO price, conversion factor, profit margin, and transport fee.

After the implementation of BPDPKS subsidy, biodiesel consumption has been increasing. However, since the subsidy only covered the PSO sector, the implementation in the non-PSO sector was still struggling. On the other hand, the PSO sector only contributed to about half of the total diesel consumption. With the expansion of the subsidy to non-PSO diesel fuel in late 2018, the biodiesel share increased to 20% in 2019 (Figure 3.3), which means that for the first time, the government managed to achieve the overall blending target.

Figure 3.3. Biodiesel shares in domestic diesel consumption. Data from MEMR (2020).



³ Paulus Tjakrawan, personal communication

⁴ Paulus Tjakrawan, personal communication

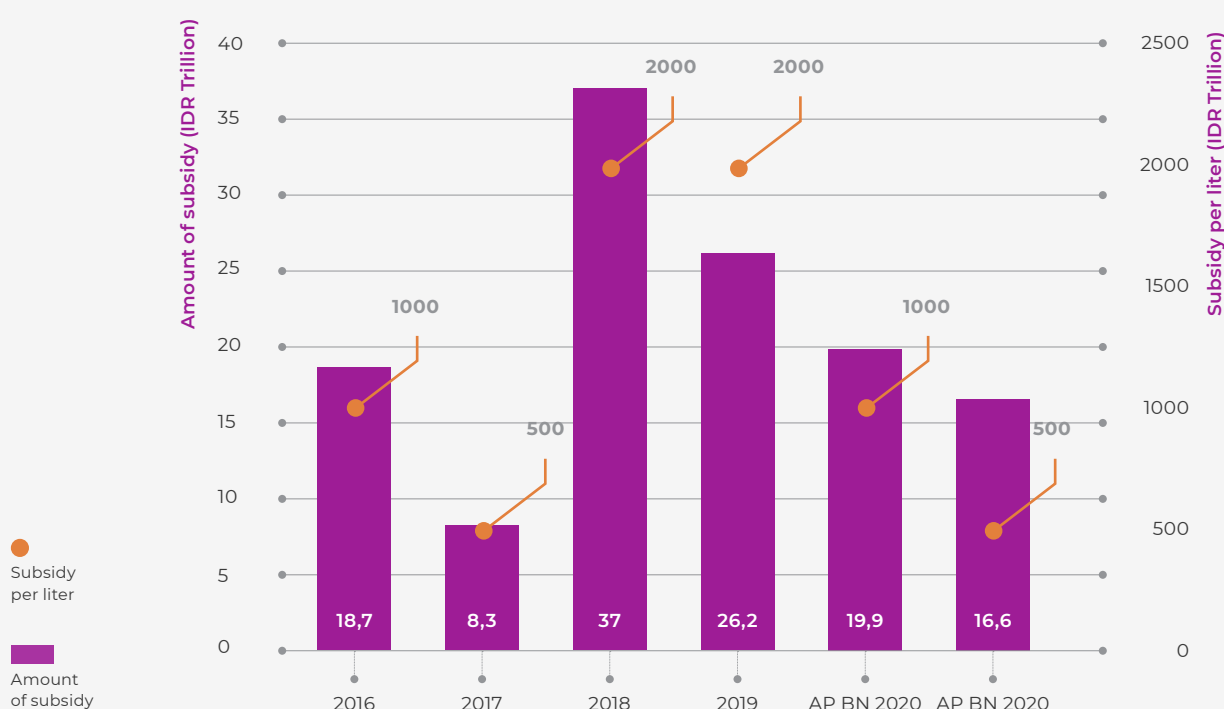
Meanwhile, Indonesia only produced 1.7 million liters of fuel-grade bioethanol between 2006 and 2009. The bioethanol consumption was only increased from 50,000 liters in 2006 to 1,26 million liters in 2009 (Slette & Wiyono, 2010). Bioethanol consumption ceased in 2010 due to price disagreement between the government and the producers. The industry requested to alter the reference price formula to be based on domestic price instead of Argus reference price for Thailand FOB bioethanol as per MEMR Decree No. 0219K/12/MEM/2010 (Slette & Wiyono, 2011). The high tax imposed on ethanol products made bioethanol fuel even more expensive (Siahaan et al., 2013). Despite the change in the pricing mechanism in 2016, there is still no bioethanol production and consumption due to the lack of incentive to cover the gap between the bioethanol reference price and the gasoline reference price. Currently, the installed capacity of fuel grade bioethanol plants is only 42 million liters per year (MEMR, 2020). However, there is another 300 million liters per year installed capacity of industrial-grade bioethanol plants.

The main challenge of the developing biofuel has been its price uncompetitiveness to the petroleum fuel. Both biodiesel and bioethanol are more expensive than unsubsidized petroleum

diesel and gasoline. While bioethanol has not been subsidized and thus failed to enter the market, biodiesel has been heavily supported by various incentives. Laan and McCulloch (2019) suggested that biodiesel is subsidized in two ways: first through the BPDPKS subsidy, and second by the subsidy provided from the state budget for PSO diesel fuel. While the BPDPKS subsidy covers the gap between the reference price of biodiesel and conventional diesel, the state budget covers the gap between the reference price of conventional diesel and retail price of PSO diesel fuel.

Figure 3.4 shows the annual subsidy given for diesel fuel purchase. Of that number, 20% goes to biodiesel since it contributes 20% of the sold diesel fuel. For example, in 2019, the government disbursed IDR 26.2 trillion for diesel fuel subsidy and about IDR 5.2 trillion of it goes to subsidize biodiesel. In 2020, with the implementation of B30, the share of biodiesel grew to 30% of the allocated diesel subsidy.

Figure 3.4. Indonesia PSO diesel fuel subsidy (solar and biosolar). Data from APBN.



There are also various fiscal incentives received for biofuel production in the form of lower stamp duties, reduction of investment tax, accelerated depreciation and amortization, lower income tax, VAT exemption, and relief from import duties for goods used in biofuel production (Dillon et al., 2008; McFarland et al., 2015). It needs to be understood that these incentives are not specific to the biofuel industry. Also, the biofuel producers have not been utilizing these incentives as many were built before the regulation was enacted in 2007⁵.

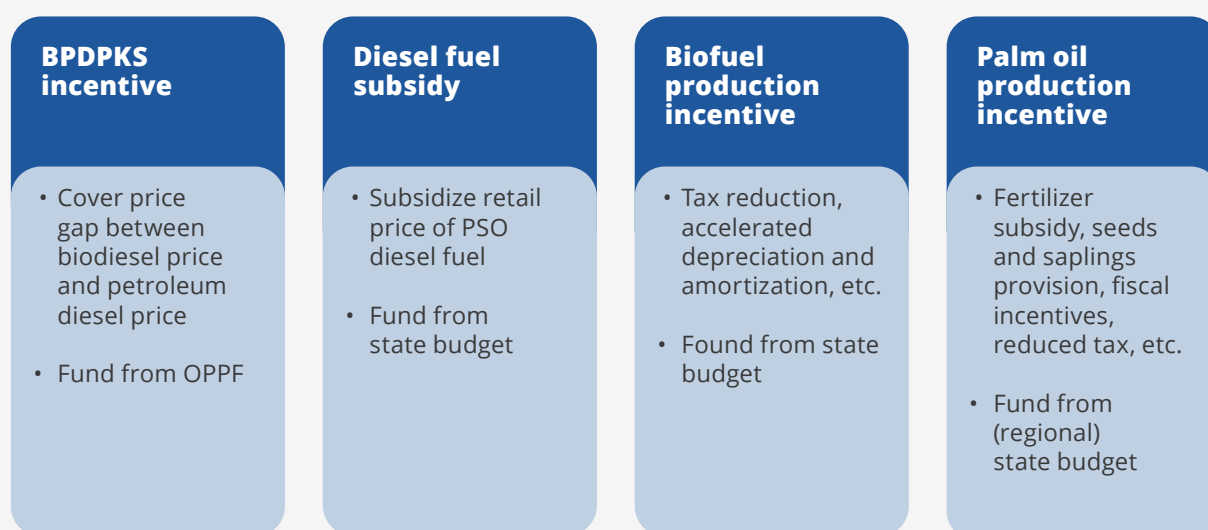
In addition, McFarland et al. (2015) also identified the various incentives received by palm oil producers, which currently is the only source for biodiesel feedstock. It is rather difficult to estimate the exact amount of incentives per year for palm oil production due to a lack of available data. However, McFarland et al. (2015) provides insight into the various incentive and subsidy schemes received by palm oil producers with an estimated value of USD 19.6 billion per year. Although, most of this value comes from the general government support such as fertilizer subsidy for smallholders (USD 1.8 billion), fuel subsidy (USD 3 billion), and infrastructure development (USD 12 billion), which cannot be allocated specifically to oil palm. There are incentives allocated specifically for the palm

oil industry, such as subsidy for new strains R&D, subsidy for seeds and saplings provision, fiscal incentives (soft loans and tax breaks), and reduced export tax for refined palm oil and other downstream palm oil products.

The high reliance on subsidies puts the sustainability of the biodiesel program into question. The biodiesel production technology is well established, and the technology cost (investment and operational cost) is not expected to decline in the future. Also, about 80% of its production cost comes from the feedstock (Harahap et al., 2019), which fluctuates over time, causing the price of biodiesel to also fluctuate. On the other hand, the sustainability of the biodiesel program also relies on the changes in petroleum oil prices.

The recent decline of crude oil price in 2020 has widened the price gap, as shown in Figure 3.6. As the price gap widens, the subsidy necessary to run the biodiesel program also increases. According to BPD PKS, in 2020 (as of August), its spending for biodiesel subsidy has been higher than the revenue from the palm oil export levy (Umah, 2020). GAPKI estimated that in 2020, BPD PKS would incur a deficit of about IDR 6.2 trillion. With the existing export levy and biodiesel subsidy scheme, GAPKI estimated

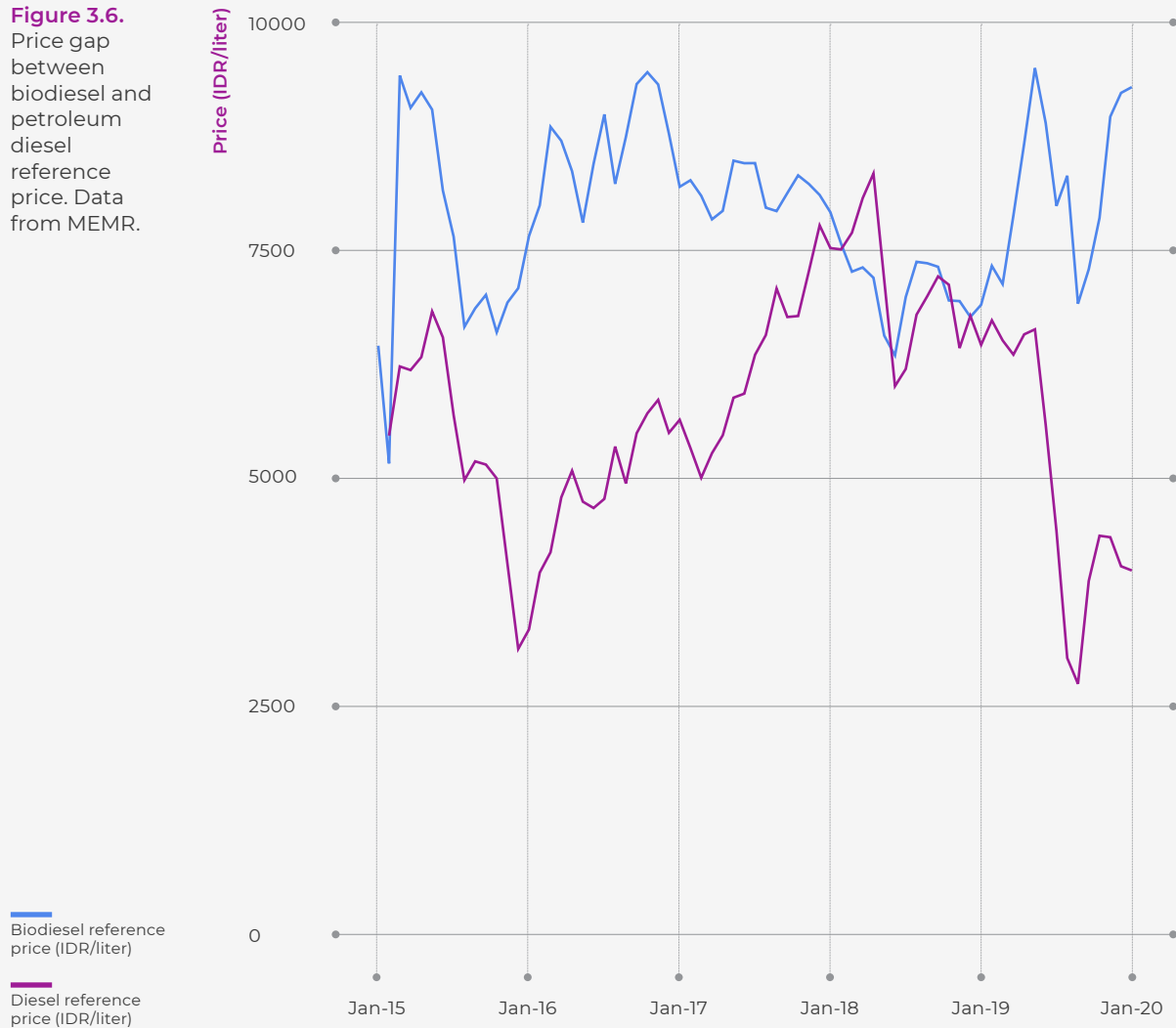
Figure 3.5. The types of financial support flowing into the biodiesel supply chain



⁵ Paulus Tjakrawan, personal communication

that in 2021 BPDPKS would lack about IDR 40 trillion to support the B30 program (Hasan & Hidayat, 2020). Even with an increased palm oil export levy, the fund would still lack about IDR 11.8 trillion.

Figure 3.6.
Price gap
between
biodiesel and
petroleum
diesel
reference
price. Data
from MEMR.



04.

Techno-economic analysis (TEA)



This chapter aims to provide an economic evaluation of biofuel production technologies. As described in Chapter 2, there are different biofuel production technologies with different product characteristics and feedstocks. This chapter's focus is drop-in biofuels since they are expected to play a more important role in the future in Indonesia. FAME biodiesel has now reached a 30% blend ratio. While it could potentially be increased to 40-50%, it would be technically difficult to be increased to 100% due to its oxidation stability problem. Ethanol utilization has never taken off, and with the price gap and blending wall limitation, it might never be. Moreover, biodiesel and bioethanol prices are already determined by the formula from MEMR.

Jong et al. (2015) performed a techno-economic analysis of various advanced biofuels, including HVO, gasification, and pyrolysis, based on existing process modeling data and techno-economic framework following Standardized Cost Estimation for New Technologies (SCENT) developed by Ereev and Patel (2012). This techno-economic analysis follows the method employed by Jong et al. (2015). The capital investments are obtained from existing literature, taking only the total purchased equipment cost (TPEC) and multiplied with the factors used by Jong et al. (2015). The prices for raw materials, labor, and

utilities are adapted to the Indonesian context. The currency is adjusted to USD₂₀₁₉ using the exchange rate in the reference year (*Euro Dollar Exchange Rate (EUR USD) - Historical Chart*, n.d.) and CEPCI index for the capital cost or Consumer Price Index (CPI) for operational expenditures (e.g. raw material, utilities).

Landälv et al (2017) estimated the production cost of various advanced biofuels (utilizing waste materials) based on literature and already established plants, which incorporated comments from stakeholders, including developers and producers. According to the study, the production cost of drop-in biofuels ranges from USD 0.68 per kg (lower range of HVO liquids) to USD 1.9 per kg (higher range of FT liquids). Unfortunately, the study provides no details on the cost breakdown, and therefore it is impossible to adapt to the Indonesian context.

Table 4.1 showed the economical parameters of several recent literature on techno-economic analysis of drop-in biofuels. The production cost of drop-in biofuels ranges from USD 0.81 per kg fuel to USD 3.2 per kg, although most fall below USD 1.5 per kg. These costs are calculated using different methodologies and assumptions, which make them difficult to be compared directly.

Table 4.1. Summary of several recent existing literature on techno-economic analysis of drop-in biofuel production (since 2016).

Technology	Feedstock	Capacity (ton/h)	Capex (million)	Opex (million/y)	Feedstock (million/y)	Production cost (USD/kg)	Capex (USD/kg)	OPEX (USD/kg)	Feedstock (USD/kg)	Currency	Base year	Location	Reference
HVO coprocessing	Waste oil	12,50	27,50	22,70	41,90	0,81				USD	2015		Glisic 2016
HVO Stand alone	Waste oil	12,50	56,80	33,90	41,60	1,00				USD	2015		Glisic 2016
HVO Stand alone	Palm oil	0,99	5,53	1,77	6,02	1,13	0,14	0,23	0,77	USD	2016		Martinez-Hernandez 2019
HVO Stand alone	Palm oil	1,17	13,8	4,77	14,98	2,44	0,32	0,51	1,61	USD	2016		Martinez-Hernandez 2019
HVO Stand alone	CPO	17,40	19,5	155,19	161,80	1,36				USD	2017	Taiwan	Hsu 2018
Gasification -FT	Biomass	17,93	422,00	25,70	37,30	0,79	0,35	0,18	0,26	EUR	2014		Dimitriou 2018
Gasification -FT	Biomass	2,90				3,20	1,30	1,90		EUR	2014		Albrecht 2017
Gasification -FT	Biomass	1,04	67,99	10,31	2,04	1,94				USD	2017	Australia	Ramirez 2019
Liquefaction	Biomass	2,44	72,79	12,53	2,04	0,98				USD	2017	Australia	Ramirez 2019
Pyrolysis	Biomass	1,40	52,05	4,12	2,04	1,19				USD	2017	Australia	Ramirez 2019
Pyrolysis	Red oak	20,18	317	73,92	31,08	1,39				USD			Hu 2016

Capital Expenditure (Capex)

The most important aspect in Capex estimation is the equipment cost. Other costs, such as installation, engineering, and construction, are estimated using the ratio factor as a percentage of the equipment cost. The equipment cost is obtained from existing literature based on process simulation, adjusted to the USD₂₀₁₉ currency using CEPCI index and plant size of 20 thousand barrels of fuel product per day, or equal to 100 ton of fuel product per hour. When the reference uses a currency other than USD, it is converted to USD with the base

year's average exchange value prior to CEPCI adjustment. Since recent references are used, no learning curve is assumed for the equipment cost. The equipment costs are then multiplied by ratio factors of 4.69 used by Jong et al (2015) to obtain the fixed capital investment (direct and indirect capital cost). Working capital is assumed to be 5% of the total capital investment as used by Jong et al (2015). Total capital investment is the sum of fixed capital investment and working capital.

Operational expenditures (OPEX)

Operational expenditures consist of raw materials, utilities, labor, maintenance, insurance, taxes, overhead, and administrative costs. The amount of labor required is calculated using the formula used by Ereev and Patel (2012). Labor cost is calculated by multiplying the amount of labor and the annual salary. The annual salary is assumed to be USD 4,000, based on the monthly salary for operators in Pertamina of IDR 4.2 million (Putri, 2020) and 14 months

salary payment per annum. Utility consumption is obtained from the process modeling data in existing literature, adjusted to the plant capacity of 100-ton fuel product per hour, assuming that the utility requirement per ton of product is constant. The prices for utilities (i.e. electricity, water, natural gas) use the Indonesian price. Other operational expenses are calculated using the factorial method with the ratio factors as used in Jong et al. (2015).

Fuel production cost

The fuel production cost is estimated by adding up the annual operational expenditure (including feedstock purchase) and annual capital recovery, divided by the volume of fuel produced per annum. The annual capital recovery is calculated using a simplified method of capital recovery factor (CRF). This assumes that loan is the sole source of funding for the capital expenditure. The interest rate is assumed to be 10% and the repayment period as well as plant lifetime is 25 years. No depreciation and amortization are assumed in this calculation.

All capital expenditure is assumed to be paid in year 1, as well as the first loan repayment.

Table 4.2 shows the result of techno-economic assessment using the methodology described above. Since several references with different process modeling parameters are used, the results vary and are presented in ranges. For HVO technology, there are two feedstock options used, CPO and UCO. For both feedstocks, only feedstock cost is different, assuming that both employ similar technology. The feedstock

$$\text{Annual capital recovery} = \text{Total capital investment} \times \text{CRF}$$

$$\text{CRF} = \frac{r(1+r)^N}{(1+r)^N - 1}, \text{ Where } r \text{ is the interest rate and } N \text{ is the loan period.}$$

price is assumed to be USD 586 per dry ton for CPO (based on 2020 price by World Bank Group (2020) adjusted to domestic KPNB price) and USD 327 per dry ton for UCO (based on Kharina et al., 2018). For biomass gasification

and biomass pyrolysis, the feedstock price uses the wood processing mill residue in Indonesia from Simangunsong (2019), USD 19 per ton, with 17 GJ/ton energy content.

Table 4.2. Result of techno-economic calculation

Technology	HVO	HVO (UCO)	Gasification-FT	Pyrolysis
Fuel production cost per kg fuel	USD 0.92-1.06	USD 0.54-0.64	USD 0.67-0.82	USD 0.68-1.07
Share of:				
- feedstock cost	66-68%	51%-55%	17%	13-14%
- capital recovery	3-11%	5-15%	36%	16-36%
- operational cost	21-31%	30%-44%	46-47%	51-71%
Total capital investment	USD 0.2-0.8 billion	USD 0.2-0.8 billion	USD 1.2-2.2 billion	USD 0.8-1.8 billion
Feedstock cost per year	USD 480-578 million	USD 261-315 million	USD 71-117 million	USD 90-113 million
Operational cost per year	USD 178-229 million	USD 178-229 million	USD 253-305 million	USD 277-560 million
Reference basis	Jong et al. (2015)*, Glisic et al. (2016)	Jong et al. (2015)*, Glisic et al. (2016)	Jong et al. (2015), Dimitriou et al. (2018)	Jong et al. (2015), Hu et al. (2016), Carrasco et al. (2017)

* using the total capital investment for Neste Singapore (available in its supplementary document) instead of Neste Rotterdam used in the main document

Fuel production cost is the most important parameter to be assessed. In general, the estimated biofuel production costs are higher than the current selling price of conventional petroleum fuel, ranging from USD 0.54 to USD 1.60 per kg fuel. The reference price for petroleum diesel in Indonesia was USD 0.57 per kg over 2019 on average. Only the lower range of UCO based HVO falls below that price. However, when the oil price drops, such as in 2020, the petroleum diesel price was only USD 0.38 per kg (January-November average), making the biofuel even less competitive.

For HVO technology, the feedstock cost is the main contributor to the production cost, especially for the CPO-based one. For CPO-based HVO, feedstock contributes to about 66-

68% of the production cost, while for UCO-based one, the feedstock contributes to 51-55% due to lower feedstock price. This means that the fluctuation of feedstock price would significantly influence the fuel production cost. Capital cost is the least significant share in HVO production cost for both types of feedstock, ranging from 3-15%.

In contrast to HVO, for the thermochemical processes, since biomass waste is used as the feedstock, the feedstock cost is the least significant component of the production cost, ranging from 13%-17%. Opex (excluding feedstock) is the most important contributor to the production cost, both for the gasification process and pyrolysis process. The costs of utilities, catalyst/solvent, and maintenance are

the main contributors to the high opex. The capital costs for thermochemical processes are also higher than for HVO, resulting in a higher share in the production cost.

However, it is important to note that this analysis assumes the utilization of unprocessed waste biomass, which could be difficult to collect at high amounts. The transportation cost of unprocessed biomass could also pose additional

costs. When a more commercially available biomass is used, e.g. in the form of wood pellet, the feedstock price could increase to almost USD 110 per ton and becomes a significant contributor to the biofuel production cost. The biofuel production cost via gasification and pyrolysis using wood pellets (USD 109.5/ton as in Simangunsong (2019)) would be USD 1.08-1.33 and USD 1.00-1.60 per kg, much higher than the palm oil HVO.

Sensitivity analysis

This sensitivity analysis is performed to observe how the parameters influence the production cost. Parameters analyzed are yield, feedstock price, interest rate, total capital investment, project lifetime, and plant capacity. The sensitivity of each parameter to the production cost of different biofuel technologies is presented in Figure 4.1 and Table 4.3. The figure presents the average production cost of each technology for the sake of simplicity.

For all technologies, the fuel yield is the most influential parameter. It should be noted that the change of yield is assumed not to require any change in other parameters (capex, opex, and raw materials). This will not be the case in reality. Improvement of yield would require modification on the process, which would alter the other parameters. However, since this study does not perform any process modeling, it is not possible to assess the interaction between the yield and the other process parameters.

The next most sensitive parameter is different for each technology. For the thermochemical technologies (gasification and pyrolysis), the total capital investment is the second most important parameter. This is due to the high portion of annual capital recovery in the production cost component. A change in plant capacity and interest rate influences the production cost of both technologies to a less extent. The least sensitive parameter is the feedstock price and plant lifetime.

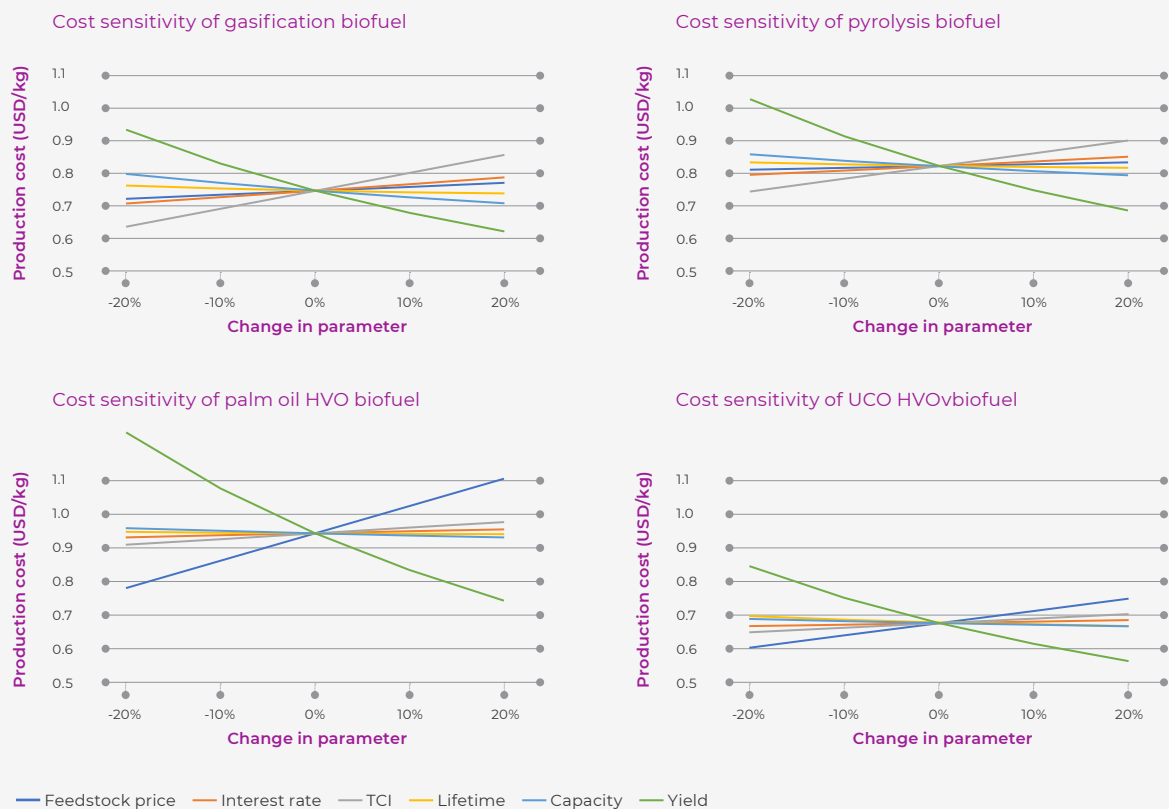
In contrast, for HVO technology, the next most important parameters are feedstock price. Indeed, feedstock cost is the major production cost component in CPO-based HVO and UCO-based HVO. A change of total capital investment much less significant compared to the yield and feedstock price. Changes on the other parameters almost have no influence on the production cost since these parameters mainly interact with the total capital investment.

Table 4.3. The effect of different parameter changes to biofuel production cost in different technologies

% parameter change \ parameter	Feedstock price	Interest rate	TCI	Lifetime	Capacity	Yield
Gasification						
-20%	-3.5%	-5.4%	-14.8%	2.4%	7.1%	25.0%
-10%	-1.7%	-2.7%	-7.4%	1.0%	3.3%	11.1%
0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10%	1.7%	2.8%	7.4%	-0.8%	-2.8%	-9.1%
20%	3.5%	5.7%	14.8%	-1.3%	-5.3%	-16.7%

% parameter change \ parameter	Feedstock price	Interest rate	TCI	Lifetime	Capacity	Yield
Pyrolysis						
-20%	-1.6%	-3.5%	-9.7%	1.6%	4.6%	25.0%
-10%	-0.8%	-1.8%	-4.8%	0.7%	2.1%	11.1%
0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10%	0.8%	1.8%	4.8%	-0.5%	-1.9%	-9.1%
20%	1.6%	3.7%	9.7%	-0.9%	-3.5%	-16.7%
Palm oil HVO						
-20%	-13.6%	-1.1%	-2.9%	0.5%	1.4%	25.0%
-10%	-6.8%	-0.5%	-1.5%	0.2%	0.7%	11.1%
0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10%	6.8%	0.6%	1.5%	-0.2%	-0.6%	-9.1%
20%	13.6%	1.1%	2.9%	-0.3%	-1.1%	-16.7%
UCO HVO						
-20%	-10.9%	-1.5%	-4.2%	0.7%	2.1%	25.0%
-10%	-5.4%	-0.8%	-2.1%	0.3%	1.0%	11.1%
0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
10%	5.4%	0.8%	2.1%	-0.2%	-0.8%	-9.1%
20%	10.9%	1.6%	4.2%	-0.4%	-1.6%	-16.7%

Figure 4.1. The effect of different parameter changes to biofuel production cost in different technologies



Pioneer plants

As noted by Jong et al. (2015), these numbers assume the cost for a commercial plant with mature technology. They do not include the potential technological risk and additional cost posed by the problems during start-up. Meanwhile, among the drop-in biofuel production technologies, only HVO is currently available at a commercial scale (Witcover & Williams, 2020). Jong et al. (2015) estimated the

increase in capital investment and decrease of plant performance for pioneer plants using the methodology developed by Merrow et al. (1981). For gasification-Fischer Tropsch fuel, the total investment cost for pioneer plants is estimated to be 2.2 times the investment required for commercial plants, while for pyrolysis fuel, the ratio is 2.7.

Summary

In summary, the cost of drop-in biofuel production will still be higher than the petroleum fuel for all technologies considered (i.e. HVO, gasification-FT, pyrolysis). HVO is already a mature technology and should be able to be implemented in the short term. However, the high feedstock price will be the main challenge for large deployment, causing the cost of palm oil HVO to be about twice as high as petroleum diesel. Using UCO could reduce the cost, but the

collection process might pose some difficulties. The production cost through thermochemical routes could be lower than palm oil HVO, but the technology is still in development, causing the high investment risk for these technologies. In addition, when commercial feedstock such as wood pellets are used, the cost of the thermochemical route could rise to USD 1.6 per kg, or about three to four times the petroleum counterpart.

Second generation biofuels from waste feedstock offer more significant GHG emissions reduction than the first generation biofuels.

05.

Social and environmental analysis



The discussion of social and environmental analysis begins primarily with the current condition of the biofuel industry in Indonesia, especially biodiesel. Discussions are also conducted on several types of biofuel feedstocks. The most discussed environmental and social issues in Indonesia are the upstream side, namely

oil palm plantations. However, keep in mind that the oil palm commodity in Indonesia is not only intended for the biofuel industry but also for food and chemical industries. Environmental and social impacts are discussed qualitatively, primarily based on literature reviews.

5.1 Potential environmental impacts and issues

The environmental impact and issues of biofuel development will be discussed in this section through several indicators considered most relevant by Ackom et al. (2010), namely: life-

cycle greenhouse gas (GHG) emissions, water requirements, land-use change, and energy balances. In addition to those indicators, air pollutant emissions are also discussed.

Life-cycle GHG emissions

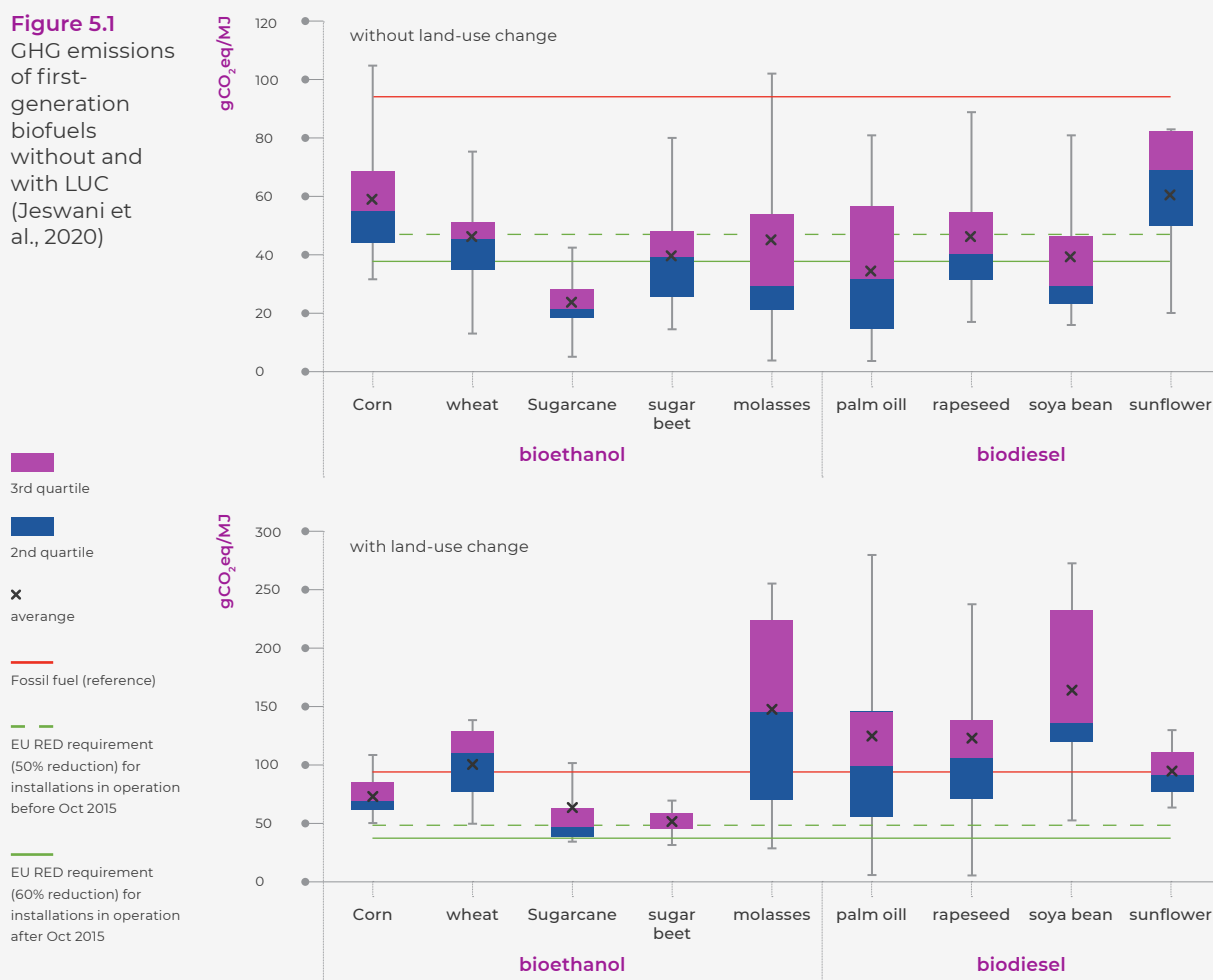
GHG emissions are one of the environmental impacts that arise at various stages of the biofuel industry. Globally, research related to the use of several types of biofuels shows the reduction of GHG emissions to varying degrees compared to the use of fossil-based fuels due to various factors such as differences in production routes and data variations, methodological choices, etc. Biofuel based on palm oil (the most widely used feedstock in Indonesia) can reduce 50-85% of GHG emissions compared to fossil-based fuels without considering the effect of land-use change (FAO, 2008). This achievement of GHG emission reduction is better than several other feedstocks such as sugar beet, rapeseed, and maize. Another review study also shows a similar thing: palm-oil-based biofuel has lower GHG emissions than rapeseed, soybean, and sunflower (Jeswani et al., 2020). However, the GHG emissions of palm-oil based biofuel (and all other first generation biofuel) will be much higher when considering the land-use change (LUC) as shown in Figure 5.1. The study also shows that second-generation biofuels can generally reduce GHG emissions due to the absence of LUC. In contrast, third-generation biofuels have higher GHG emissions than fossil fuels at the present state of development.

Previously, based on research conducted by US EPA and EU, the reduction of GHG emissions

from palm-oil based biodiesel does not meet the minimum threshold as a renewable fuel under the US renewable fuel standard (RFS) and the EU renewable energy directive (RED) program (Siregar, 2014). However, in its progress, this has not become an obstacle, as trade to these countries can continue. In its development in EU-RED II, biofuels derived from palm oil are categorized as having high indirect land use change (ILUC) risk, which can cause an increase in GHG emissions. Therefore, based on RED II, the use of palm oil based biofuels in the EU will be reduced and phased out by 2030.

Indonesia itself is still developing the life cycle inventory (LCI) database, but the inventory of data related to the impact of biofuels at each stage has been carried out by several studies. Research conducted by Siregar (2014) compared the reduction in GHG emissions from palm oil and *Jatropha curcas* in Indonesia, which shows a reduction value of 49.27% and 73.06%, respectively, from the sum before and after stable production. Another study on palm-oil based biodiesel in Indonesia shows that the largest GHG emissions are produced by land use change especially if planted on peatland, followed by the industrial phase, fertilizer production, agricultural production activities, milling, and transportation (S. S. Harsono et al., 2012). The study estimates

Figure 5.1
GHG emissions
of first-
generation
biofuels
without and
with LUC
(Jeswani et
al., 2020)



the production of palm-oil based biodiesel emits 1.7 to 4.9 kgCO₂eq/liter, including emission from LUC. Another study shows that for independent smallholders the FFB transportation stage is the largest source of GHG emissions; while several processing industries have attempted to reduce GHG emissions by installing methane capture from the POME produced (Traction Energy Asia, 2019). This study estimates the GHG emissions from palm-oil based biodiesel ranges from 0.7 to 22.9 kgCO₂eq/liter.

The government reports that the use of biodiesel in Indonesia has succeeded in reducing GHG emissions by 22.3-23.3 million tons of CO₂eq in 2020 (DGNREEC MEMR, 2021; Hartanto, 2021). However, this figure uses a very low biodiesel emission factor which may not have been analyzed by life cycle. By using GHG emission factors without LUC from several sources (Ackom et al., 2010; Jeswani et al., 2020), the achievement of GHG emission reduction for the biodiesel program in 2020 is around 9.8-12.9 million tons of CO₂eq.

The future development plan for mandatory biodiesel programs needs to consider whether the achievement of large emission reductions will actually be achieved and consider GHG emissions from LUC in the event of a wider expansion of land.

Second-generation biofuels feedstock, especially waste, can be used as an alternative with a higher reduction in GHG emissions. For example, on average, biodiesel from UCO emits only about half the GHG emitted by CPO biodiesel without LUC (Jeswani et al., 2020). However, this type of biodiesel has not been utilized properly. The initial study of the National Team for the Acceleration of Poverty Reduction (TNP2K) and Traction Energy Asia (2020) conveyed the potential of UCO for biodiesel in Indonesia. In 2019, the national consumption of cooking oil reached 16.2 million kL, with an average UCO produced in the range of 6.46 - 9.72 million kL (40-60%). Of this, only about 570 thousand kL are converted for biodiesel and other needs, while the rest are not collected or used for recycling and export (Mulyana & Rahmawati, 2020).

Water requirements

The biofuel production chain requires a fairly large amount of water, especially in terms of feedstock production, namely plantations. This is especially important if the plantation is located near a densely populated community, allowing conflicts / competition for domestic and industrial water use. In some regions with high rainfall, the need for the amount of water is not an issue. However, several other issues are the use of pesticides and fertilizer that can carry over to water bodies, which can impact water quality (Ackom et al., 2010; Obidzinski et al., 2012). On the other hand, liquid waste management is also one of the important environmental risks that need to be managed to not threaten the local water ecosystem (Dharmawan et al., 2020).

In more detail, the water requirements of plants are usually seen from the evapotranspiration value, which reflects the amount of water absorbed by plants to be evaporated through evaporation and transpiration. Various studies show that the evapotranspiration value of oil palm plants in Indonesia ranges from 1100-1700 mm/year. The evapotranspiration value shows that oil palm plants are water-efficient compared to many other agricultural and plantation crops, let alone forestry crops. This can also be seen in other indicators, namely the efficiency of water use. To produce 1 gigajoule

of bioenergy, oil palm plants only need about 75 m³ of water, much lower than rapeseed plants which require 184 m³, as well as several other plants (Leens, et al. al, 2008; Baskoro, 2017).

However, an oil palm plant is a plant that has shallow roots (fibrous roots), so it is prone to drought stress. This causes oil palm plants to require evenly distributed rainfall throughout the year so that they can produce maximally. In addition, this causes oil palm plants not to have the ability to store water as well as other plants. When the rain comes, the water is not retained but escapes to move to the soil layer below the root zone. If the land is flat land with a shallow groundwater level, it is easier to cause inundation and flooding, whereas if the water is drained, more water is lost and less water is stored. It is coupled with the condition of oil palm plantations which are equipped with harvest roads that are generally hard and dense. This harvest road has a very low infiltration capacity and can act as a drainage path for water during rain so that the waste water flows as surface runoff becomes high. The decrease in water availability in the area of oil palm plantations needs to be addressed with adequate water management (Baskoro, 2017).

Land-use change

Several projection scenarios show that the demand for biofuel plantation land areas continues to increase in order to respond to the increasing demand for biofuels in the future. In Indonesia, the mandatory biodiesel policy will increase the need for new oil palm land unless it is balanced by an increase in productivity or reduced export. The land area of oil palm plantations in Indonesia was 16.4 million ha in 2019 (MoA, 2019). A study shows that with the enactment of the B30 policy in 2020, the need for productive land is projected to reach 18.6 million ha in 2025 (LPEM FEB UI, 2020). So there will be land deficits for the plantation expansion that needs to be ensured in order to overcome the risk of deforestation that will occur.

Oil palm expansion is suspected as one of the most important drivers of deforestation because it occurs at the expense of Indonesia's tropical forest cover. A study based on spatial data shows that around 23% of deforestation in Indonesia between 2001-2016 was driven by the development of oil palm plantations, higher than other drivers (Austin et al., 2019). However, to show the relationship between biofuel development and tropical deforestation is complex and difficult to pin down in spatial terms, due to various things, including limited complete data and multipurpose of these feedstocks (Gao et al., 2011).

Other studies mention that its land clearing activities are also presumed partly responsible for forest and land fires as well as peatland degradation (Nurrochmat et al., 2020; Malins, 2017). The study conducted by Purnomo et al. (2017), shows these forest and land fires are caused by a diversity of actors (including farmer group organizers) which were involved and gaining benefits from fires. To mitigate the risk of recurring forest and land fires, the

government has focused on fire suppression, biophysical and technological issues (such as canal blocking and early warning systems). On the other hand, efforts on the underlying causes of fires (such as providing economic incentives for land preparation without burning) are still rare (Purnomo et al., 2017). In addition, the government has also issued policies related to a moratorium on new licenses for oil palm plantations to improve its governance.

Pollutants emission during combustion

Ethanol generally produces less pollution than gasoline and diesel, since it has a tolerance for combustion with excess air, allowing a more complete burn with lower CO and PM emissions. However, the investigation discovered that biodiesel pollutant's impacts varied depending on the type of biodiesel (soybean, rapeseed, etc.) and on the type of conventional diesel to which the biodiesel was added (Guarrieiro & Guarrieiro, 2013). Analysis conducted by the US EPA (2002), as cited by Guarrieiro & Guarrieiro (2013) shows that particularly heavy-duty highway engines show that increasing the level of biodiesel in the fuel blend increased NO_x while reducing PM. Proportionally, the PM reduction was slightly more than the increase in NO_x, on a percentage.

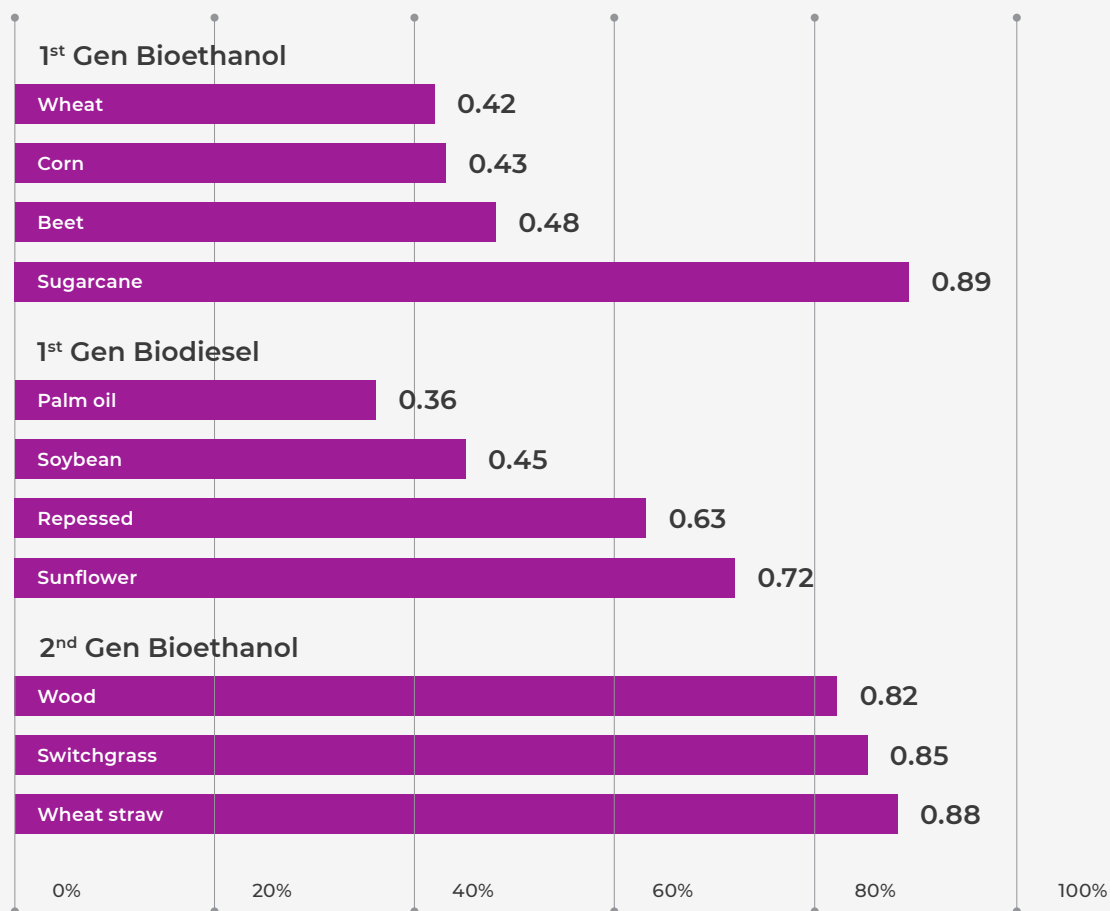
A laboratory and road test conducted using Indonesian B20 in a Euro 2 passenger vehicle also exhibited similar results (Reksowardojo et al., 2020). Increasing the cetane number of biodiesel could result in NO_x emission reduction instead of an increase, although at the expense of increased smoke and CO emission (Zhu et al., 2016). The NO_x emission increase is less significant in palm oil biodiesel compared to other vegetable oils such as rapeseed, soybean, and UCO, due to the higher cetane number (O'Malley et al., 2021). However, O'Malley et al. also noted that the NO_x emission increase is more notable when low sulfur diesel fuel instead of high sulfur diesel fuel is used as the baseline. This is important as Indonesia is soon moving to the lower sulfur diesel fuel following the latest MoEF regulation (No. 20/2017).

Another environmental indicator: energy balance

In addition to the environmental impact that has been mentioned earlier, energy balance is one of the environmental performance indicators that is commonly used in life cycle analysis for comparisons. Energy balance takes into account the flow of energy in the process of consumption and production of materials throughout the industry. There are various indicators to analyze it, one of which is energy efficiency when comparing several types of biofuels with the use of fossil energy. Palm oil is considered to provide the smallest energy efficiency compared to other types of biofuel as shown in Figure 5.2 (Ackom et al., 2010).

Another main indicator that can be measured is the net energy ratio (NER) which compares the output energy with the input energy. If only compare the output in the form of biodiesel fuel crude, NER of jatropha is greater than NER of palm oil (Siregar et al., 2019). If the produced biomass energy is calculated, the NER value of palm oil biodiesel production in Indonesia ranges from 3.19 to 3.46, with the highest value in plantation companies, followed by dependent and independent smallholders' plantations. This is still lower than the NER in Brazil (Harsono et al., 2012).

Figure 5.2. Reduction of fossil energy use,
% total fossil energy savings relative to
reference fossil system (Ackom et al., 2010)



5.2. Potential social impacts and issues

The social impact of biofuel development will be discussed in this section by adopting the social life cycle assessment (S-LCA) method framework. S-LCA focuses more on additional information on organization related aspects along the chain which is categorized by the United Nations Environment Program / Society

of Environmental Toxicology and Chemistry (UNEP/SETAC Life Cycle Initiative, 2009). The discussion was carried out through several main impacts and issues of related stakeholder actors, namely value chain actors, workers, consumers, local community, and society.

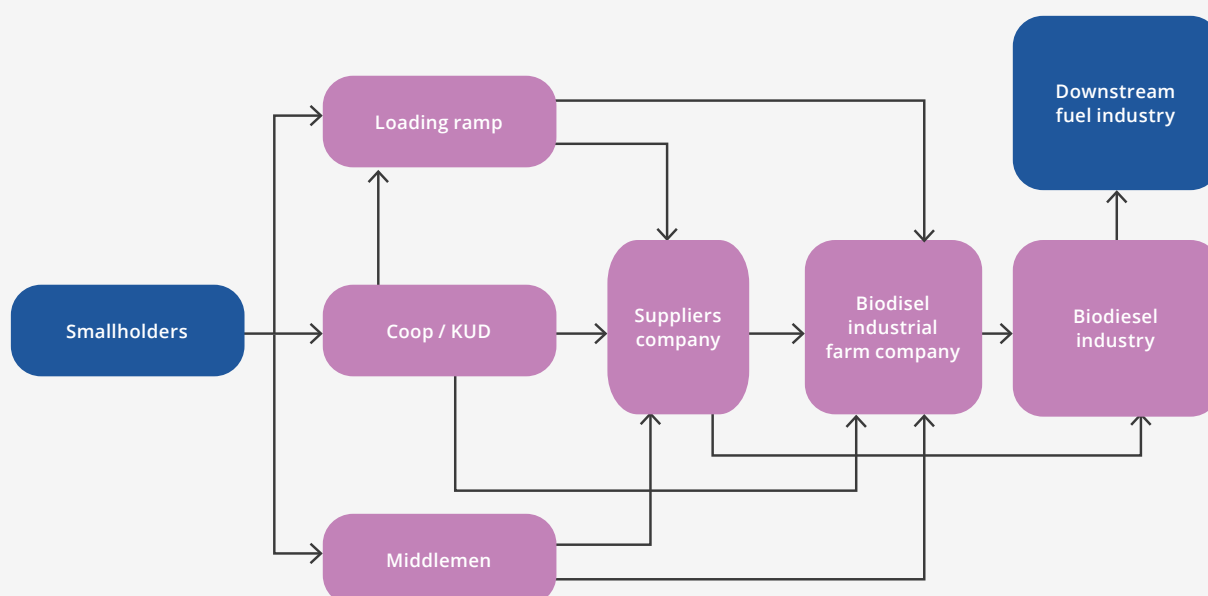
The weak position of independent smallholders in the value chain

The development of biofuels in Indonesia raises various actors along the value chain from upstream, especially in the palm oil commodity, to its downstream. On the upstream side of the palm oil feedstock, there are plantations owned by the smallholders, private companies, and also the state. As for the palm oil feedstock from smallholders, which can be summarized in the scheme in Figure 5.3., the plantation product will be collected for processing by the biodiesel industry either directly collected, or collected through loading ramp companies, village unit cooperatives (KUD), and middlemen. The biodiesel industry products will be distributed to PT. Pertamina for the downstream side of biofuels to reach consumers.

On the upstream side of the feedstock, of the total oil palm plantations area in 2019, 41.35% is managed by smallholders' farmers while 54.42% by private and the rest is managed by state companies (BPS, 2020a). As for the smallholder farmers' land area, around 79% is managed by independent smallholders' farmers, while the rest are plasma smallholders' farmers who partner with companies (InfoSawit, 2019). Apart from smallholders that supply feedstock to biofuel industries, there are also industries that are vertically integrated from upstream to downstream.

Along the supply chain of this industry, there are several problems and issues that do not stand

Figure 5.3. Indonesia palm oil - biodiesel value chain actors (modified from SPKS, 2020)



alone but are related between actors/institutional levels (Raharja et al., 2020). On the government side, there are limitations in regulating the existence of middlemen, prices at the actor level, and limitation of providing capacity building. This has an impact on remaining gaps in the quality and price of Fresh Fruit Bunches (FFB). Independent smallholders are one of the actors experiencing these issues, including:

- The formula used by the government to determine the FFB reference price does not consider the actual production cost borne by the smallholders. Instead, it focuses on the production cost of the palm oil mills. In addition, the palm oil mills or middlemen often paid the farmers less than the reference price due to lower fruit quality, in which case the price is determined unilaterally by the buyers (Madani Berkelanjutan, 2021).
- Their supply chain is quite long, where there are intermediaries who accommodate the products. Independent farmers sold their FFB products to middlemen at low prices, even lower than farmers who partnered with the company. Unfortunately, independent smallholders also have limited access to direct sales of FFB to palm oil mills. Madani Berkelanjutan (2021) found that the price cut borne by the farmers could reach 2.5%.
- There is still an imbalance in oil palm productivity and production quality between smallholder plantations and large plantations, both state and private companies. One of the reasons for the low productivity of smallholder oil palms is the production technology applied. In 2019, smallholder palm oil productivity was only 3,436 kg per ha of mature area. This number is lower than the productivity of large state plantations, which reached 4,417 kg per ha mature area and large private plantations, which reached 4,445 kg per ha mature area (BPS, 2020a).
- Based on December 2019 data, the BPD PKS fund allocation for the rejuvenation of smallholder palms plantation is only around 6.9% of the total revenue, while the biodiesel subsidy reaches 61.82%. This shows that there is a lack of intention to strengthen smallholder farmers, based on the Indonesian oil palm workers union perspective (SPKS, 2020). In addition, the majority (81.8%) of the BPD PKS funds used for the biofuel subsidy program only target several large industries from August 2015 - April 2016 data (KPK, 2016).

Several labor issues in the upstream sector

The Indonesia palm oil industry chain has provided 16.2 million jobs from the plantations all the way to the factories, based on the estimation results of Bappenas in 2018. With the details of 4.2 million being direct labor and 12 million being indirect labor (Hidayat & Anggraeni, 2018). With such a large number of workers, these palm oil plantations and factories have often been accused of irresponsible labor practices and charged with human rights violations (Saragih, 2019).

In terms of freedom of association and collective bargaining in the industrial relation process, the situation in Indonesia is quite facilitating where there are various palm oil workers' unions. This includes the formation of Japbusi (Indonesian Palm Oil Workers Union Network) at the end of 2018 as a consolidation of several confederations and trade unions that collectively have 2.2 million workers in the field. The Indonesian Palm Oil

Association (Gapki) has also created task forces to solve the labor issues identified by the ILO. The Gapki teams will be working closely with Japbusi (Saragih, 2019).

As for other labor issues, there are still things that need to be fixed due to various findings. On the health and safety issues, the oil palm industry in Indonesia still lacks this culture; workers did not always wear personal protective equipment (PPE), especially on the mill, estate, and collection sites (DIHR, 2018). On child labor issues, according to several reports by media and non-governmental organizations (NGOs), child labor is prevalent in this sector, particularly among smallholder estates that may supply to larger companies (UNICEF, 2016). One report even shows various findings of other labor problems, including forced labor and gender discrimination which were not isolated incidents but due to systemic business practices (Amnesty International, 2016).

Conflicts over land and resources with the local community

The biofuel industry is closely related to local communities in relation to the upstream sector (oil palm as a biofuel feedstock), which are generally located in the community and part of which is managed by the community. However, in terms of oil palm utilization, conflicts often occur both with regard to land and natural resources, which burden the company and the local community itself.

Before the development of the biofuel industry, oil palm plantations had developed quite a bit in Indonesia, especially since the 1970s with the aim of population redistribution through resettlement schemes or transmigration to stimulate the development of the outer islands (Budidarsono et al., 2013). With its development to date regarding the increasingly modern nature of the palm oil industry, there are several issues related to migrant populations, namely disappointment over the number of job opportunities available to local people and preferential use of non-local labor, although the numbers are not significant.

One of the serious issues related to local communities is land conflicts. This is because some of the smallholder palm oil land covers has not been registered with permits, and some

of it is in protected forest areas (Raharja et al., 2020). On the other hand, there are also common tenure conflicts between oil palm companies and communities, both in the form of disputed land claims / property rights and inadequate compensation for land use. Based on the study of Barreiro et al. (2016), land conflicts are even the most common (62%) compared to other social conflicts in the palm oil industry.

The various conflicts that exist in the palm oil industry, especially the local level, burden not only the palm oil companies, but also local government, and, most notably, the communities or individuals involved in the conflict (Barreiro et al., 2016). In terms of access to resources, the loss of most forest functions has resulted in dramatic changes in the basket of goods consumed at the household level, as these goods had previously been obtained free of cost prior to the conflict over oil palm plantations. Survey results indicate that people spend 36.79% of their current consumption to purchase goods freely available in the past (Zakaria et al., 2017). The survey also shows that local people bear the other costs of conflict with their lack of access to water, medical plants, and social harmony compared to pre-conflict conditions.

Economic contribution for society

Palm oil contributes significantly to the country's economic development of Indonesia, with a total production of 42.88 million tons of CPO and 8.57 million tons of palm kernel oil (PKO) in 2018. Of this production, around 57.7% or 29.69 million tons were exported with a value of 18.3 billion USD (Directorate General of Estate Crops, 2019). Some of the biggest export destinations include China, India, Pakistan, Bangladesh, and the United States (BPS, 2020). Besides that, there is also state revenue from taxes, export levies, and job creation.

At the regional level, palm oil is a strategic commodity for several regions such as West Kalimantan, North Sumatra, South Sumatra, Central Kalimantan and Riau. Palm oil plantations contribute significantly to Indonesia's rural

economy by a sustained boost to the value of agricultural output, manufacturing output, and district GDP (Edwards, 2015). Nevertheless, among the top palm oil producer provinces, four have a higher poverty rate than the national average and seven have lower non-food consumption than the national average (Andriarsi, 2021).

The development of the biodiesel industry is also considered to reduce oil imports, which in turn will reduce Indonesia's trade deficit. The utilization of B20 in 2019 amounting to 6.36 million kL has succeeded in saving foreign exchange of USD 2.92 billion or the equivalent of IDR 42.05 T, creating jobs for 801,000 people (DGNREEC MEMR, 2020). But this is also doubted by some parties who think that this program will

actually cause the trade balance to deficit due to lost opportunities in the form of CPO and biodiesel exports plus an increase in imports of capital goods for the construction of new biodiesel plants because capacity after 2020 certainly needs to be increased. Besides, there are also other risks of loss in the future, such as the risk of increasing subsidies, land expansion, etc. (Basri & Putra, 2020; LPEM FEB UI, 2020).

In addition to the current economic contribution and future macroeconomic risks, the management of the palm oil industry in Indonesia is still unfortunately prone to corruption (EIA International, 2014; KPK, 2016). Some of the main findings from the study conducted by the KPK include:

- The plantation business licensing control system is not accountable to ensure the compliance of business actors. There are several permits that need to be carried out by the companies, including the Plantation Business Permit (IUP), Environmental Permit, Forest Clearance, Timber Utilization Permit (IPK), which need to be obtained from various institutions both at the local government level, namely the city / district / province, the National Land Agency, to Ministry of Environment and Forestry. A major aspect of corruption occurs through the allowance of companies to skip or bypass certain laws. Several cases of bribery have even been proven, including the hand catch operation (OTT) of the Buol Regent's case in 2012, the Riau Governor's case in 2014, the Central Kalimantan DPRD members' case in 2018, etc (CNN Indonesia, 2019; Schütte & Syarif, 2020).
- There is ineffective control of palm oil commodity export levies and collection of palm oil sector taxes. However, this has continued to improve with the formation of the BDPKS. In 2020, the issuance of the Minister of Finance Regulation (PMK) Number 57 / PMK.05 / 2020 concerning the Service Tariff for the Public Service Agency for the Oil Palm Plantation Fund Management Agency.

Impacts and issues on consumers

Indonesia has entered the use of B30 since 2020, where before its implementation, a road test was carried out to ensure the quality of its use. Some of the results from the road test show various impacts on vehicle engines that are still at the threshold of measurement. It should be noted that new vehicles or those that did not previously use biodiesel tend to experience fuel filter replacement faster at the start of using B30 due to the blocking effect, but went back to

normal afterward. In addition, another significant problem lies in the supply chain process, where there is a potential high increase in water containment (BPPT, 2020; P3TKEBT ESDM, 2019). Not only does it require extra handling in the storage and transport process, but this water content can also potentially affect consumer vehicle engines if it is formed due to being stored in the vehicle's fuel tank for a long time (GAIKINDO, 2020; GridOto, 2020).

5.3. Current responses to mitigate impacts

In response to various environmental and social issues and impacts, there have been several certification programs built to encourage palm oil producers to be more sustainable. The Roundtable on Sustainable Palm Oil (RSPO), initiated in 2004 by the global environmental NGO, is currently the largest actor in palm oil certification. Although it is quite supportive of the progress of sustainability, this certification has also received criticism from various activists regarding several unclear criteria, minimal penalties, and weak audit processes (Tanuwidjaja, 2020). The 2018 RSPO Principles and Criteria (P&C) have also been supported through national level interpretations in Indonesia.

Apart from the RSPO, there are several standards/certifications that also apply at the global level, including the International Sustainability & Carbon Certification (ISCC), the Sustainable Agriculture Network (SAN), and the Roundtable on Sustainable Biomaterials (RSB). ISCC is generally used in Indonesia to meet the needs of the European market because the ISCC EU certification scheme complies with the EU RED and the Fuel Quality Directive (FQD) requirement. As for the SAN and RSB standards/certifications are still rarely used in Indonesia in the context of palm oil and biofuels.

In Indonesia itself, the Indonesian Sustainable Palm Oil System (ISPO) guidelines were issued through Minister of Agriculture Regulation no 19/2011, which was later amended in 2015. ISPO has standards that are more attainable and less exclusive so that they can better support smallholders. In 2020, Presidential Regulation 44/2020 was issued, which complements the previous ISPO guidelines. As of September 2020, there have only been 668 out of 2,056 oil palm plantation businesses (about 30%) that have obtained ISPO certificates, including 419 companies that are members of GAPKI (about 60% of all members). In terms of plantation area, only 5.45 million ha out of 16.38 million ha are ISPO certified.

The President issued Presidential Instruction No. 8/2018 regarding Postponement and Evaluation of Oil Palm Plantation Permits and Increasing Productivity of Oil Palm Plantations. When it was published, this moratorium policy was appreciated by various parties related to efforts to improve forest and land governance as a result of the oil palm industry. From the team formed based on this policy, it has also succeeded in providing several achievements, including informing the oil palm area cover in Indonesia in 2019 of 16.38 million ha (MoA, 2019), after previously there were always different data from various government agencies, as well as several other achievements. However, several notes on its implementation, especially related to the aspects of socialization, data openness, and process transparency. The NGO coalition demanded the government to extend the implementation period of this instruction so as to achieve improved management of Indonesian oil palm plantations (ELSAM, 2020).

Apart from the government's policies, some private sectors have also adopted No Deforestation, No Peat, No Exploitation (NDPE) commitments. These various companies are committed that all operation run sustainably along their supply chain. In more detail, 'No Deforestation' was obtained by protecting High Conservation Value (HCV) and High Carbon Stock (HCS) areas, 'No Peat' by avoiding planting on peat, and 'No Exploitation' by protecting human rights, workers' rights and the rights of local communities and indigenous peoples (EFECA, 2020). However, the details of this policy vary between companies and do not qualify as certification. These NDPE policies have been key in transforming the sector to stop deforestation, although the implementation has been inconsistent (Chain Reaction Research, 2021). As of April 2020, 83% of palm oil refining capacity in Indonesia and Malaysia have adopted this NDPE commitment, with an effectiveness of 78% due to weak implementation (Chain Reaction Research, 2020).

The future potential of biofuel demand is highly uncertain due to rapid development and the disruptive potential of alternative low carbon technologies.

06. Policy implication



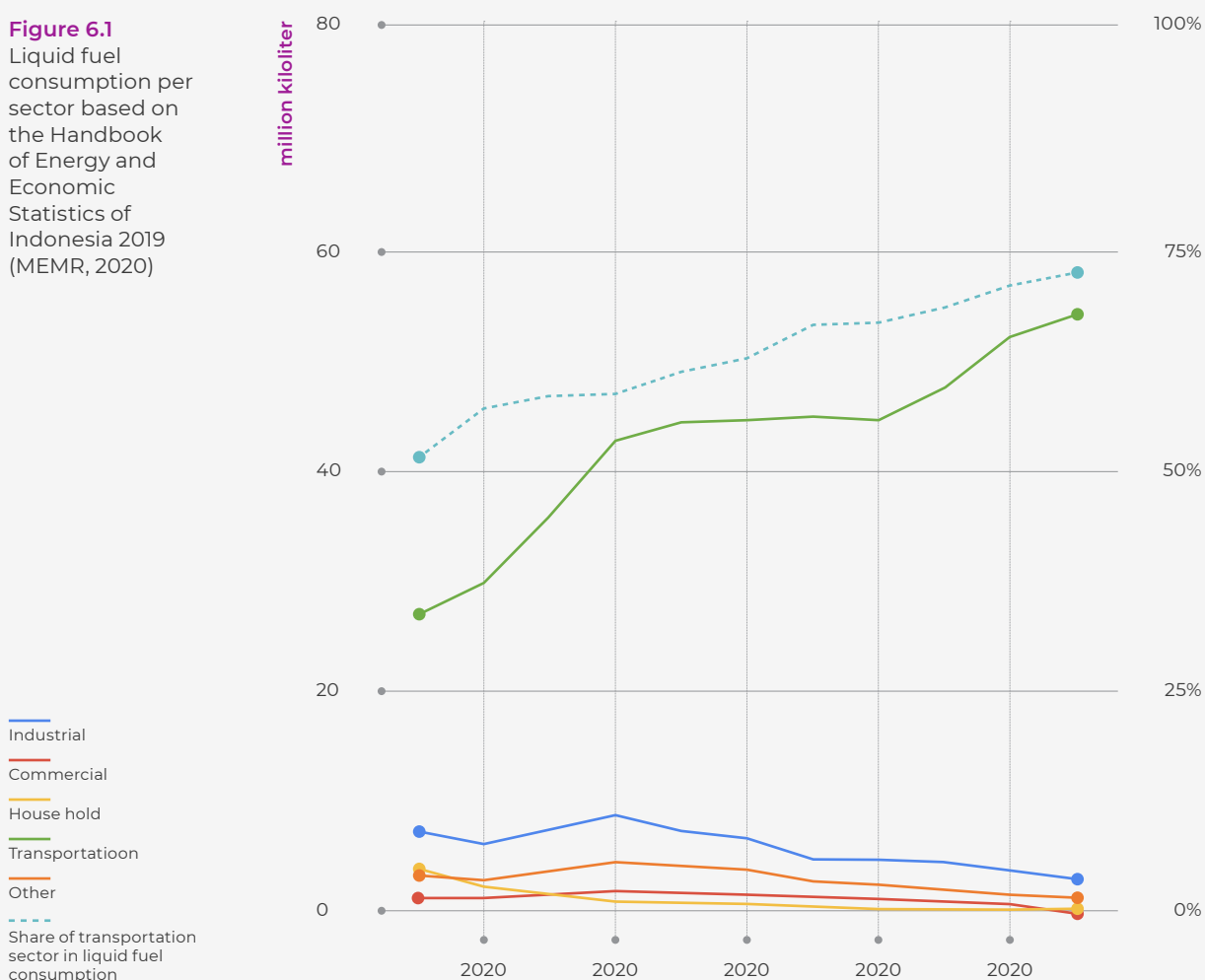
6.1. Potential impact of the recent biofuel program

6.1.1 Potential future demand

Liquid fuel is mostly consumed in the transport sector. In 2019, 91% of the final liquid fuel consumption was from transportation, followed by industry (5.4%), household (0.6%), commercial (0.5%), and other sectors (2.5%). In sectors other than transportation, the consumption rate declines over the years. On the other hand, the share of the transportation sector in liquid fuel consumption has increased from 65.9% in 2009 to 91% in 2019. The distribution of liquid fuel consumption per sector is shown in Figure 6.1. Following this trend, the transportation sector is expected to be the main driver of future liquid fuel consumption.

RUEN projection estimates that the share of petroleum fuel consumption in the industry sector would increase from 7.5% in 2020 to 9.2% in 2050. In the other sectors, including construction, agriculture, and mining, RUEN expects that liquid fuel (petroleum and biofuel) would supply all the energy required. The share of biofuel in these sectors is estimated to increase from 5% in 2020 to 27% in 2050. Since the energy demand projection in RUEN is not attainable due to unrealistic macroeconomic assumptions (IESR, 2020), the absolute energy demand (in MTOE) cannot be used in this analysis. Instead, other energy demand projections should be used.

Figure 6.1
Liquid fuel
consumption per
sector based on
the Handbook
of Energy and
Economic
Statistics of
Indonesia 2019
(MEMR, 2020)



Transportation sector

In the 2019 energy outlook, National Energy Council projects that the energy demand from the transportation sector would almost triple under the Business as Usual (BAU) scenario, from 50.2 MTOE in 2020 to 146.4 MTOE in 2050 (Suharyati et al., 2019). IESR (2020) also estimated a similar trend, with transportation energy demand increasing from 59.4 MTOE in 2020 to 160.7 MTOE in 2050 based on the current realization. BPPT's 2020 energy outlook projects that transportation energy demand would increase from 59.9 MTOE in 2019 to 172 MTOE in 2050, under the BAU scenario (Pusat Pengkajian Industri Proses dan Energi, 2020).

The liquid fuel demand in the transportation sector is also influenced by the penetration rate of other technologies. Most notably, the penetration of electric vehicles in road transport has been growing rapidly, driven by a steep decline in battery cost. Since 2010, the battery cost has been slashed by 85%, from USD 1,160 per kWh to USD 176 per kWh in 2018. It is expected to further drop to USD 62 per kWh by 2030 (Goldie-Scot, 2019). There are several studies that estimate the penetration rate of electric vehicles in Indonesia.

The BAU scenario projections by IESR (2020) and Suharyati et al. (2019) assume a very pessimistic outlook on electric vehicle penetration rates. IESR

(2020) assumes no electric vehicles until 2050 in its realization (BAU) scenario. In its electric vehicle intensification scenario, 56% and 100% of the car and motorcycle population in 2050 is electric. Consequently, the fuel demand in this scenario would decline by 48 MTOE in 2050, compared to the BAU scenario. The liquid fuel demand in the electric vehicle intensive scenario would only reach 112 MTOE in 2050 and only 22 MTOE from passenger cars and motorcycles.

Suharyati et al. (2019) assume that electric car and motorcycle shares would only reach 0.07% and 1.5% of the vehicle population by 2050 in the BAU scenario. Even in the low carbon scenario, only 1.18% and 3% of the car and motorcycle population is electrified. As a result, liquid fuel will still dominate the energy demand in the transportation sector, according to the projection. However, the transportation energy consumption is projected to decrease to only 131 MTOE by 2050.

Wehling et al. (2020) from Bloomberg New Energy Finance (BNEF) projected the electric vehicle penetration in Indonesia for all transport modes, as shown in Table 6.1. They estimated that the penetration rates of electric two-wheelers and electric buses are faster than other modes. The penetration rate of electric cars and trucks is expected to be slower.

Table 6.1.
Projection
of electric
vehicles share
in total sales
by Wehling
et al. (2020)

	Indonesia		Global		
	2025	2040	2025	2030	2040
Two-wheeler	<21%	69%-85%	31%	43%	77%
Car	<9%	<39%	13%	31%	58%
Light truck	<5%	20%-27%	8%	17%	30%
Med truck	<1%	13%-17%	2%	6%	19%
Heavy truck	<1%	7%-9%	1%	4%	10%
Bus	<41%	52%-69%	61%	70%	77%

ERIA (2018) also made a projection of electric vehicle shares in road transportation. In the BAU scenario, the share of electric (battery and plug-in hybrid) cars, motorcycles, trucks, and buses are 10.5%, 29.9%, 8.7%, and 3.5% of the total fleet in 2040. In the advanced EV scenario, the share of electric cars, motorcycles, trucks, and buses are 80.8%, 88.4%, 69.6%, and 81.0% of the total fleet in 2040.

A decarbonization scenario from New Climate Institute (2020, unpublished) estimated that the non-electricity energy demand from passenger transport (cars, motorcycles, trains, and buses) would decrease from 28.9 MTOE (540 tbopd) in 2020 to 7.5 MTOE (140 tbopd) in 2050. This scenario assumes that the penetration rate of electric vehicles follows China's example as the Asian best practice (reaching 69% of the total fleet in 2050) and an enhanced modal shifting to public transport following South Korea policy (reaching 58% of total passenger transport in 2050).

The Ministry of Industry targets 30% of the cars and motorcycles produced in 2035 will be low emission. If that target is fulfilled, there will be 6.5 million electric cars and 32 million electric motorcycles will be on the road in 2035 (Adiatma, 2020). If extrapolated, by 2050, there will be about 26 million electric cars (34% of the total fleet) and 138 million electric motorcycles (62% of total fleet). Meanwhile, the National Energy Agency plans to have 2.2 million electric cars and 13 million electric motorcycles on the road by 2030, which is estimated to reduce about 77 tbopd fuel consumption, or about 4.8 billion liters per year (Siswanto, 2020).

It is also important to note that the total cost of ownership of electric vehicles is expected to be lower than conventional vehicles by 2020 for motorcycles, 2025 for cars and trucks, and 2035 for buses (ERIA, 2018). The cost parity for buses could even be reached earlier for buses traveling longer distances since the electric vehicles operational cost is lower than the conventional ones.

Industry sectors

For the industry sector, IESR (2020) estimated that the energy demand would grow from 49.8 MTOE in 2020 to 184.3 MTOE in 2050. Assuming the share of liquid fuel is similar to RUEN, the fuel demand would grow from 3.7 MTOE in 2020 to 17 MTOE in 2050. The BAU scenario in Suharyati et al. (2019) projected that fuel demand in the industry would increase from about 2.5 MTOE in 2020 to 12.3 MTOE in 2050. In the low carbon scenario, they projected that the fuel demand growth in the industrial sector would be slower, increasing only to 5.4 MTOE in 2050.

Siagian et al. (2015) modeled a decarbonization scenario with a structural economic change in which the energy intensive industrial activity is reduced, energy efficiency and electrification are intensified, resulting in reduced energy consumption. In that scenario, the industrial energy demand in 2050 is only 2.2 times the demand in 2010, resulting in only 115 MTOE in 2050, a significant reduction compared to IESR (2020) projection.

Other sectors (construction, agriculture, mining - CAM)

For the other sectors, the IESR (2020) estimated the energy demand grew from 4.1 MTOE in 2020 to 12.5 MTOE in 2050, all supplied by liquid fuel. Suharyati et al. (2019) estimate the energy demand increases from 1.4 MTOE in 2020 to 3.9 MTOE in 2050 in the BAU scenario and 1.5 MTOE in 2020 to 4.6 MTOE in 2050 in the low carbon scenario. In the projection by Suharyati et al., liquid fuels compose about half of the energy

demand. The actual energy demand from other sectors has declined from 4.9 MTOE in 2012 to 1.7 MTOE in 2019, all supplied by liquid fuel (MEMR, 2020). Moreover, alternative technologies such as electric vehicles in construction, agriculture, and mining sectors are also growing, which could further reduce energy consumption, especially liquid fuel consumption in these sectors.

Power generation

Apart from the direct consumption as final energy, petroleum fuel and biofuel are also used in power generation, although the current policy aims to reduce its share. RUPTL 2019-2028 expects that diesel and biodiesel use in power generation will decrease from 3.3

million kiloliters (3.2 MTOE) in 2019 to 0.6 million kiloliters (0.5 MTOE) in 2028. As there is no plan to build a new diesel power plant, it can be assumed that the liquid fuel demand in power generation will further decline to insignificant amounts.

Potential domestic biofuel demand

Looking at the wide range of fuel demand projections listed above, it is not possible to precisely estimate the future biofuel demand. For further analysis, two liquid fuel demand scenarios are constructed, as presented in Table 6.2. The liquid fuel demand scenarios only include demand from transportation, industry, and other sectors, as well as power generation. The demands from commercial and household are neglected due to their small share in the total demand.

The high demand scenario comprises transportation and industry demand based

on IESR (2020) realization scenario; other sector demand based on Suharyati et al (2019), all supplied by liquid fuel; and power generation based on RUPTL 2019-2028. The low demand scenario comprises transportation demand based on analysis by New Climate Institute for passenger road transportation and IESR (2020) realization scenario for freight, aviation, and marine transportation; industry demand based on Siagian et al. (2015); other sector based on Suharyati et al (2019) with liquid fuels share declines to 50% in 2050; and power generation based on RUPTL 2019-2028.

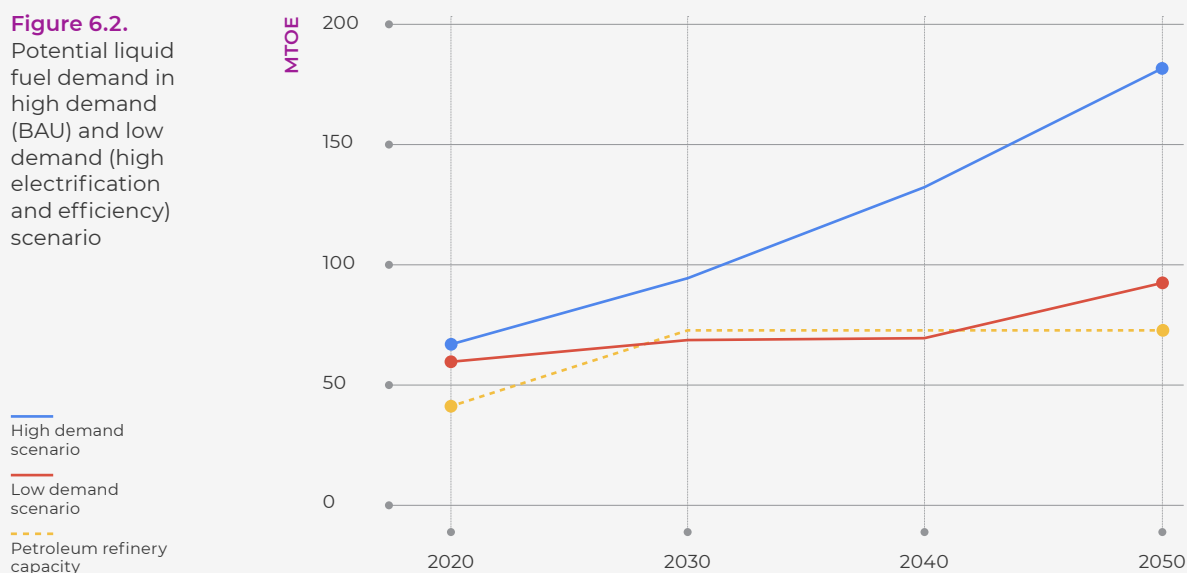
Table 6.2.
Long-term liquid
fuel demand
projection from
transportation,
industry, and other
sectors in BAU
scenario and high
EV penetration
scenario (MTOE).

Feedstock price	2020	2030	2040	2050
High demand scenario				
Industry	3.7	5.4	9.8	17
Transportation	59.3	86.6	119.7	160.5
Other	1.5	2.5	3.4	4.6
Power	3.2	0.5	0	0
Total	67.2	98.2	138.5	189.9
Low demand scenario				
Industry	3.7	6.1	8.4	10.6
Transportation	52.0	60.5	59.5	79.7
Other	1.5	2	2.2	2.4
Power	3.2	0.5	0	0
Total	60.4	69.1	70.1	92.7

A part or all of the liquid fuel demand in Table 6.2 could be fulfilled by biofuels. If the aim is to reduce petroleum fuel import, the biofuel share will depend on the existing petroleum refinery capacity. According to RUEN, the existing refinery capacity is 786 tbpd or about 42 MTOE per year (excluding other refinery products). The capacity is planned to increase by 575 tbpd by 2026, according to MEMR Strategic Plan (excluding the cancelled 300 tbpd Balikpapan refinery project). The annual petroleum fuel production capacity will reach about 72.6 MTOE by 2026. This capacity is already more than sufficient to cater to the current demand and the low demand scenario until 2040, but far from sufficient to cover the 2030 high demand scenario.

In the high demand scenario, there is still more than 20 MTOE fuel demand in 2030 up to 115 MTOE in 2050 that can be fulfilled by biofuel. Meanwhile, in the low demand scenario, there will be no liquid fuel demand left for biofuel by 2030 if all the planned additional refinery capacity is running. Then, the potential biofuel demand could vary from nothing to 115 MTOE per year in the next 30 years. While these two scenarios are extreme cases and might not occur, it still indicates the high uncertainty regarding the future potential of biofuels, as illustrated in Figure 6.2. This will be important when planning for new biofuel infrastructure, especially those with long-term economic lifetimes and no alternative purpose, such as the production plant.

Figure 6.2.
Potential liquid
fuel demand in
high demand
(BAU) and low
demand (high
electrification
and efficiency)
scenario



6.1.2 Current biofuel demand targets

Over the past few years, there have been different biofuel targets mentioned in different policy documents and public statements. RUEN targets an increasing biofuel consumption from 7.6 MTOE in 2020 to 32.3 MTOE in 2040, in the form of biodiesel and bioethanol. The National Energy Council (DEN), in its Energy Grand Strategy draft (December 2020), targeted biofuel consumption to increase from 8.5 MTOE in 2020 to 13.7 MTOE in 2040 (Siswanto, 2020), all coming from biodiesel. The Directorate General New Renewable Energy

and Energy Conservation (DJEBTKE), planned for an increased biofuel consumption from 9.5 million kiloliters (9 MTOE) in 2020 to 17.8 million kiloliters (16.9 MTOE) in 2035, partly from drop-in biofuels. Another number was earlier set in the national mid-term development plan (RPJMN), targeting 10 million kiloliters (9.5 MTOE) in 2020 to 17.4 million kiloliters (16.5 MTOE) in 2024. However, it is not clear which type of biofuel is considered in the target.

Table 6.3. Different biofuel targets set in different national documents (MTOE)

Policy	2020	2030	2040	2050
RUEN	7.6	13.2	19.7	32.3
Grand energy strategy (DEN)	8.5	11.2	12.7	13.7
Biofuel roadmap (DJEBTKE)	9.0	11.7	15.2	
RPJMN (BAPPENAS)	9.5	16.5 (2024)		

The biofuel target set in RPJMN is the most aggressive among the 3 recent policy documents, while the grand energy strategy by DEN is the least aggressive. The grand energy strategy looks to keep the B30 blending rate until 2030. In contrast, the RPJMN target numbers suggest a rapid implementation of B50 by 2025.

In addition to these targets, the government has also issued other biofuel plans in public statements, although they were never

materialized in policy documents. In mid-2019, the president publicly announced the plan to start B50 by the end of 2020 and further increased it to B100. Later in the year, the target was revised to B40 in 2020 and stopped at B50 in 2021, citing the lack of palm oil supply will limit the biodiesel blending rate at that level (Thomas, 2019). Entering 2021, the government has confirmed that the biodiesel blending rate will remain at 30% for the year and is expected to increase to 40% in 2022 (IESR, 2021).

6.1.3 Infrastructure requirement

New biofuel refineries are obviously needed to fulfill the targeted demand and the potential demand. However, which type of biofuels and how much should be produced is not as obvious. The current government plan prioritizes biodiesel and HVO, which are substitutes for diesel-type fuel mostly used in freight transportation, industry, and other sectors. Looking at the potential demand projection, those sectors are likely to keep increasing until 2050 due to the lack of alternative technologies penetration, especially in freight transportation.

For avtur substitute, the domestic demand is expected to keep increasing since there is no alternative technology available yet. In fact, there could be some fuel demand reduction from efficiency measures and shifting to rail transportation. However, the export potential for aviation biofuel is high since the International Civil Aviation Organization has designated biofuel as the sustainable alternative fuel for aviation (Malins, 2017a).

For gasoline substitutes such as ethanol and biogasoline, the demand might increase in case of no penetration of EV or decrease in the high penetration of EV. In the low demand scenario, the gasoline demand will already peak before 2030, then declining substantially to almost zero by 2040. This would mean that in the high EV scenario, only about 2 MTOE per year (37 tbopd) gasoline substitute biofuel refinery could last more than 20 years.

Since there is high uncertainty for the potential domestic demand of biofuels, it is necessary to plan for the worst case scenario (i.e. low demand scenario). If the domestic biofuel demand contracts, one option is to find an export market. Various long-term modeling studies indicate that the global biofuel demand will still significantly increase from the current 3.8 EJ per year until 2050 and even 2100 (Ahlgren et al., 2017). It is noteworthy that some of those studies consider second generation biofuels, especially FT biofuels, to be important in the future.

Table 6.4.
Potential liquid
fuel demand by
the type of fuel
substituted.

Feedstock price	2020	2030	2040	2050
High demand scenario				
Gasoline substitute	30.6	43.1	56.2	71.1
Diesel substitute	27.1	41.1	60.6	86.8
Avtur substitute	5.0	7.6	11.4	16.3
Fuel oil substitute	5.0	3.2	4.7	7.9
Total	67.8	95.0	132.8	182.1
Low demand scenario				
Gasoline substitute	25.3	19.6	2.3	1.8
Diesel substitute	25.1	38.5	52.5	69.8
Avtur substitute	5	7.6	11.4	16.3
Fuel oil substitute	5.0	3.4	3.9	4.9
Total	60.4	69.1	70.1	92.7

However, while in general, biofuel demand will still increase, the gasoline demand might cease much faster, with high electric vehicle adoption expected to occur globally. IEA (2017), in the beyond two degrees scenario (B2DS) projects that the total fleet of gasoline ICE cars, the main gasoline consumer, will peak in 2025 at about 1 billion units, then dropping to less than 100 million units by 2060. Even when hybrid cars are included, the total gasoline consuming cars would be significantly less than the current level. This means that the export potential of gasoline substitute biofuels will also be very limited.

In this case, prioritizing co-processing in the existing refinery could be part of the solution for the gasoline demand uncertainty. Co-processing could utilize the existing petroleum refinery capacity, and therefore reduce the potentially stranded assets if the high electric vehicle penetration occurs while still reducing the oil import. It is important to note that co-processing in the existing refinery means that the domestic gasoline production capacity will stay the same. Therefore this strategy will only reduce crude oil import instead of gasoline import.

6.1.4 Subsidy requirement

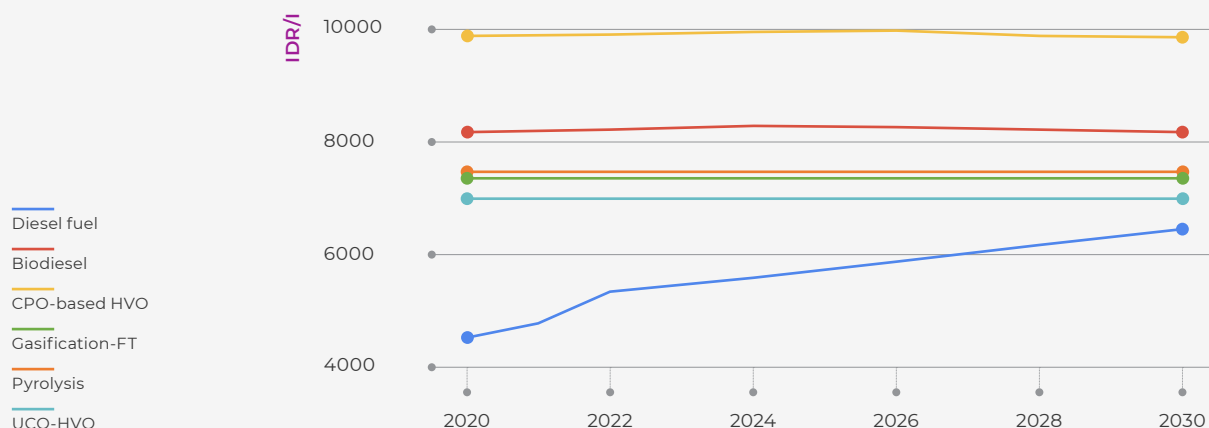
As discussed in chapter 3 and 4, biofuel costs are higher than petroleum fuel. Since 2015, the biodiesel price has been higher than the petroleum diesel reference price most of the time (Figure 3.4). Bioethanol price is generally higher than biodiesel, consistently above IDR 10,000 since 2017. On the other hand, gasoline prices are generally lower than petroleum diesel.

The drop-in biofuels, as estimated in chapter 4, are generally more expensive than biodiesel, depending on the assumptions. In the default assumptions, the price of drop-in biofuels ranges from IDR 6,971-7,946 (UCO-based

HVO), IDR 9,876-11,446 (CPO-based HVO), IDR 7,363-9,046 (gasification), and USD 7,454-11,794 (pyrolysis) per liter fuel, using 2019 exchange rate. These prices are higher than the petroleum diesel reference prices, which, most of the time since 2015, are below IDR 7,000, except for a few months in 2018. During those few months, the crude oil price spiked above USD 70/bbl.

However, the crude oil price is projected to remain below USD 60/bbl (constant USD 2019) until 2030, according to the latest World Bank projection (World Bank Group, 2020), as shown in Figure 6.3. With this crude oil price, the diesel

Figure 6.3. Price projection of petroleum diesel reference price and several biofuel types based on the crude oil and CPO price projection by the World Bank. The price of biofuels in this figure uses the lower value obtained from techno-economic analysis in Chapter 4.



reference price is estimated to remain below IDR 7,000 per liter. As indicated in Figure 6.3, the price of diesel fuel will be lower than even the cheapest type of biofuel, the UCO-based HVO.

With the price difference between petroleum fuel (represented by petroleum diesel) and biofuel, it is clear that biofuel would require financial support to be able to access the market. As described in Chapter 2, the technology for biodiesel and HVO production is already mature, and therefore, a further cost decline due to technological development should not be expected. Moreover, as already shown in Chapter 4, the main contributor to the production cost of HVO and biodiesel is the feedstock, meaning that any change in feedstock price would significantly affect the biofuel cost.

Based on the estimated prices in Figure 6.3 and the biofuel consumption target in Table 6.3, the potential subsidy required could be calculated.

The potential subsidy required for each biofuel target scenario is shown in Table 6.5. It only considers the subsidy needed to cover the price gap between biofuel and petroleum fuel but does not consider the subsidy provided for other purposes as described in Section 3.2. Table 6.5 shows that the required subsidy is the lowest in the DEN scenario since it targets the lowest biofuel utilization.

For the RPJMN consumption target, as the document does not specify the technology used to fulfill the biofuel target, two subsidy scenarios are considered. The first scenario assumes all biofuel used is biodiesel, while the other scenario assumes that a part of the biofuel used is HVO.

The cost of palm oil-based biodiesel and HVO is highly influenced by the CPO market price. Hence, the potential subsidy requirement is also subject to CPO price. As shown by the sensitivity analysis (Section 4), a 10% increase in

Table 6.5.
Potential
subsidy
required for
biofuel (IDR
trillion)

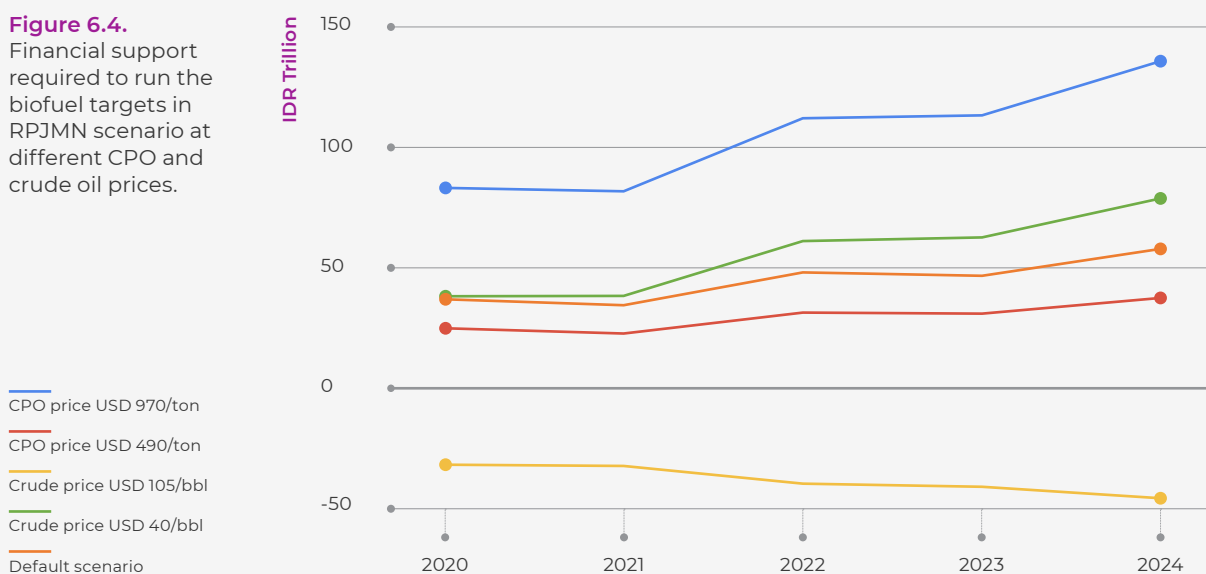
Scenario	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
DEN	32.7	29.2	29.4	29.5	29.5	28.5	27.4	26.2	24.9	23.6
EBTKE	33.3	30.9	31.0	34.8	34.2	33.5	32.4	31.2	30.0	35.8
RPJMN	35.0	47.4	47.0	56.9						
RPJMN (biodiesel only)	35.0	41.0	40.3	45.7						

palm oil price would result in a 6.8% increase in HVO price and about 8.8% in biodiesel price. In terms of subsidy, that would mean an increase of 20-40% for biodiesel and 13-19% for HVO at a petro diesel price of IDR 4,500 - 6,400.

As indicated in Figure 6.3, palm oil-based biofuel needs financial support to compete with petroleum fuel simply due to the high feedstock price. This required financial support will last for long periods of time, most probably for more than another ten years as indicated in Table 6.5. Historical data in the past ten years shows that the annual average CPO price could increase and decrease by 65% and 16% from the assumed price. On the other hand, the highest and lowest annual average crude oil price in the past ten years could reach as high as USD 105/bbl and as low as USD 40/bbl.

Figure 6.4 illustrates the sensitivity of the subsidy requirement to changes of crude oil and CPO prices. At the highest CPO price level (USD 970/ton), the subsidy could increase to more than double compared to the baseline scenario. Meanwhile, at a low CPO price (USD 490/ton), the subsidy required could be reduced by 30-35%. These two scenarios assume crude oil price follows the World Bank projection. On the other hand, if the crude oil price remains at the current level instead of following the World Bank projection, the subsidy requirement could increase by about 37% in 2024. However, if the crude oil price soars to USD 105/bbl, the highest in the past ten years, the biofuel program would be profitable and requires no subsidy. These scenarios assume CPO price follows World Bank projection.

Figure 6.4.
Financial support
required to run the
biofuel targets in
RPJMN scenario at
different CPO and
crude oil prices.



6.1.5 Potential land requirement for palm oil plantation

The current biofuel program has exclusively utilized palm oil as feedstock. The MEMR 2020-2024 Strategic Plan explicitly mentioned that the biofuel utilization in the next 5 years will still be based on palm oil. The document even specifically targets an increase of palm oil production from 43.7 million ton CPO in 2020 to 50.4 million ton CPO in 2024. Meanwhile, as described in Section 5, the current practices of

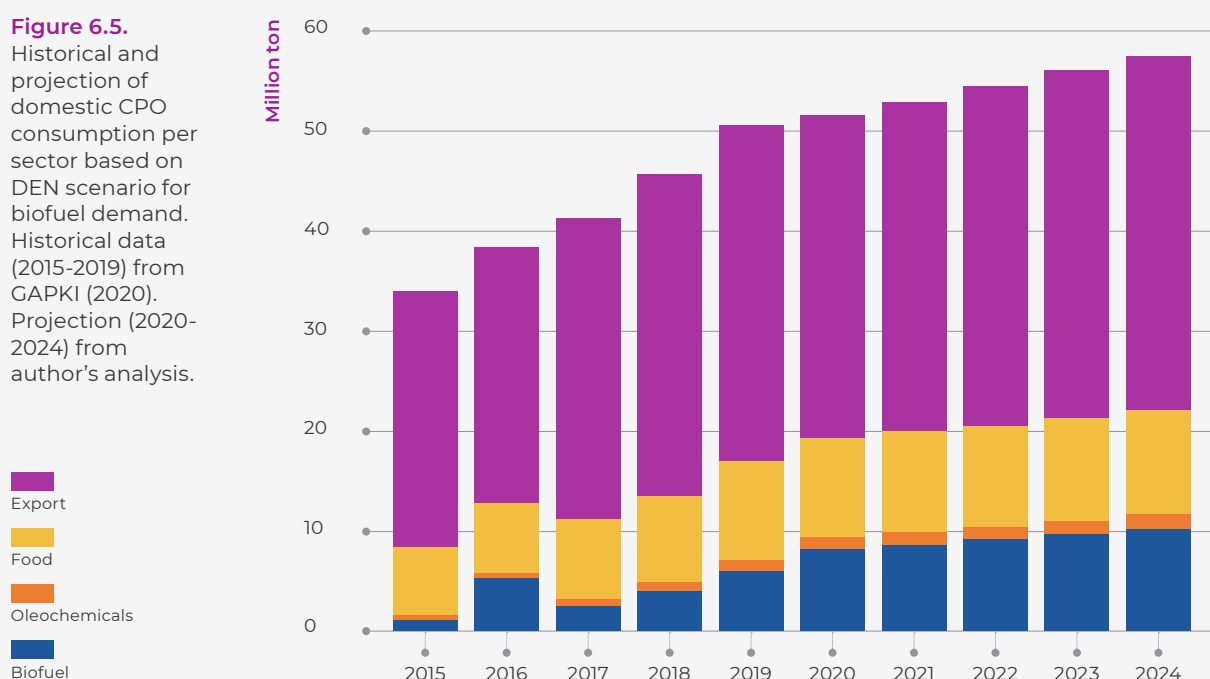
palm-oil plantations have brought social and environmental impacts.

One of the most pressing implications of the biofuel program is the potential land-use change, as it could drive other issues such as deforestation, GHG emission, and social conflict. Currently, palm oil plantations coverage is 16 million hectares. Based on the

biofuel demand targets provided in Table 6.1.3, and assuming that all the biofuels are coming from palm oil (except for RUEN scenario), as the government plans, the necessary CPO could be calculated. Assuming that 1 kg of CPO could produce 1.1 liter biodiesel or 1 liter HVO, by 2024, the CPO demand for domestic biofuel consumption would be between 10.1 million tons (DEN scenario) and 16.3 million tons (RPJMN scenario). In 2019, the CPO consumption for domestic biodiesel was only 5.8 million tons (GAPKI, 2020).

In addition to biofuel, domestic CPO consumption will also be driven by the food and chemical industry. Kurniawan et al. (2018) as well as Khatiwada et al. (2021), assume that the annual growth of CPO consumption by the food industry is 1.1% and by the chemical industry is 5.1%. The actual palm oil consumption in 2019 was 9.86 million tons in the food industry and 1.06 million tons in the chemical industry (GAPKI, 2020). Following the same assumption and using the consumption rate in 2019 as the basis, the CPO consumption in both industries in 2025 is estimated to reach 12 million tons.

Figure 6.5. Historical and projection of domestic CPO consumption per sector based on DEN scenario for biofuel demand. Historical data (2015-2019) from GAPKI (2020). Projection (2020-2024) from author's analysis.



While domestic CPO consumption will increase significantly, the export potential is also expected to grow. This increased export is driven by increasing global demand, mainly for food and oleochemical products. OECD/FAO (2020) projected the world vegetable oil consumption would increase by almost 30 million tons in the next 10 years. The traded vegetable oils are projected to increase from 85 million tons in 2019 to 97 million tons in 2029, while Indonesia contributes 37-40% of that amount. The report projects that the export of palm oil products from Indonesia will increase from an average of 31.8 Mt in 2017-2019 to 39.5 Mt in 2029. In the long term,

Afriyanti et al. (2016) estimated that global CPO demand could even increase to 264-447 Mt/year by 2050. Looking at the global vegetable oil demand growth projection, it will be unlikely that Indonesia will reduce its CPO export to fulfill the domestic demand. Data from 2017-2019 also indicates that palm oil export has kept increasing despite the additional domestic demand from the successful biodiesel program (GAPKI, 2020).

Based on the above projections, the CPO production would need to increase from 51.8 million tons in 2019 to 57.5-63.7 million tons in 2024, depending on the biofuel blending

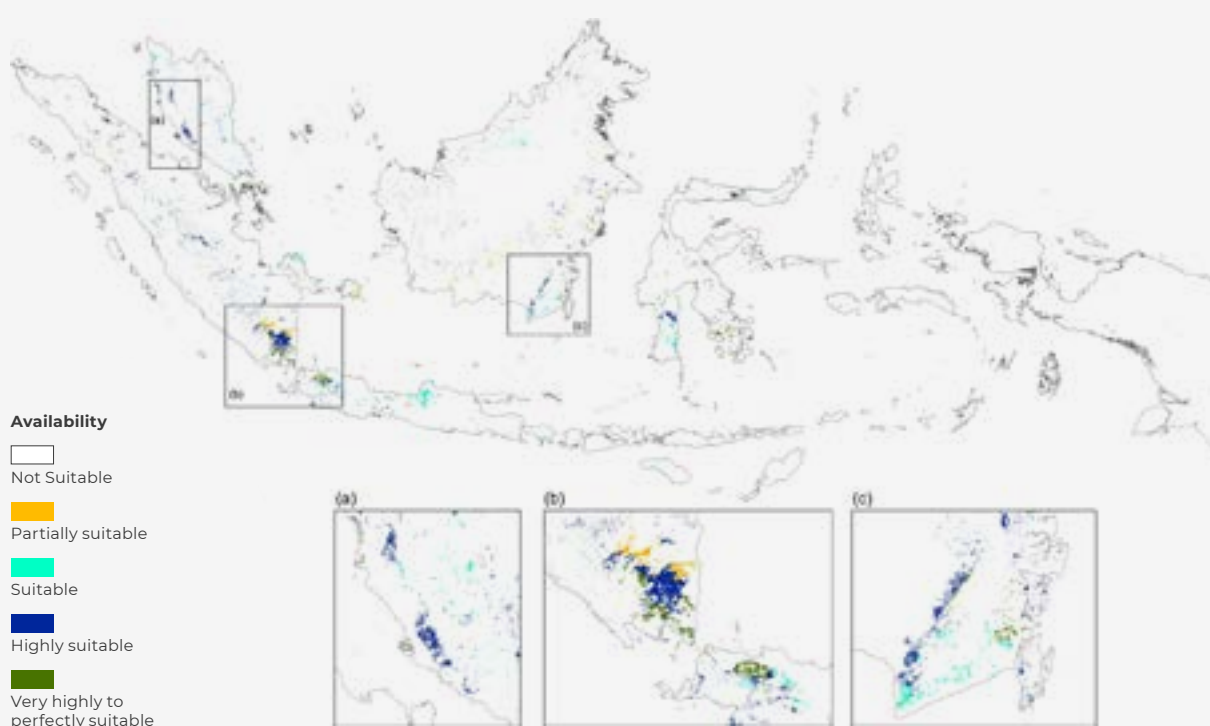
ratio scenario (B30-B50 scenario), as shown in Figure 6.5. If the plantation productivity stays at the current level at about 2.8 ton/ha total area (including immature area), the land required for palm oil production will reach 20.5–22.8 million hectares by 2024. The existing oil palm plantation area was 16.4 million hectares in 2019. This means that another 4–6 million hectares need to be converted into palm oil plantations to fulfill the domestic and export demand.

The oil palm productivity has not improved substantially in past years, and extrapolation from historical records will only see a slight increase of yield to 4 tons CPO per hectare by 2050 (Adiatma, 2020). Similarly, Wiebe et al. (2019), in their baseline scenario, also expects the global palm oil productivity will only increase to 4 tons per hectare by 2050. The statistics from the Ministry of Agriculture noted that the productivity of palm oil plantations since 2014 has only increased slightly at about 0.34% per year on average (Directorate General of Estate Crops, 2019). This productivity is way lower than the potential yield of 8–10 tons per hectare in low elevation areas in Indonesia

under optimum water and soil nutrients (Woittiez et al., 2017).

Several studies tried to estimate the availability of lands for palm oil plantations in Indonesia. Afriyanti et al. (2016) found that without deforestation and peat conversion, only 16.8 million hectares of land available for palm oil plantation, excluding 9.5 million hectares currently used for other agricultural commodities. Another study by Tapia et al. (2021) indicates that there are almost 4 million hectares suitable for new sustainable palm oil plantations in Indonesia, although are mostly scattered throughout the country, making it not suitable for largescale plantations. Figure 6.6 shows the available area suitable for palm oil plantations, with the least fragmented areas (covering about 700 thousand hectares in Lampung, the western part of Java, and South Kalimantan) are magnified. Pirker et al. (2016) found wider areas available for new oil palm plantations, 18 million hectares. However, they also include the moderately suitable and marginally suitable, which is excluded by Tapia et al. (2021).

Figure 6.6. Available area for new oil palm plantations in Indonesia and Malaysia. Source: Tapia et al. (2021).



6.2. Recommended actions

The biofuel utilization policy should be a part of the broader energy transition towards a net-zero emission energy system. As already seen in the power sector transition, the technological advancement of renewable energy has disrupted the established power generation and distribution model. This might also happen in the transportation sector, the current main petroleum fuel, and the potential future biofuel consumer. Rapid development of electric and autonomous vehicle technologies, shared mobility, and digitalization have the potential to revolutionize the mobility pattern and behavior, which could significantly reduce future fuel consumption. Many studies try to explore this disruption phenomenon in the transportation sector (Arbib & Seba, 2017; Fulton et al., 2017; Sprei, 2018). While these studies do not necessarily agree on how close the disruption

is, they acknowledge the uncertainty of the mobility future.

On the other hand, the current biofuel production is shadowed by various social, environmental, and economic issues that are not aligned with the broader energy transition and sustainable development agenda. One most notable criticism is the potentially high GHG emission of palm oil as the only biofuel feedstock utilized in Indonesia. According to many studies, the GHG emission of biofuel could be even higher than petroleum fuel when the emission from land use change is taken into account.

Considering those two major problems, there are several things that the government needs to do to ensure that the biofuel program will provide more benefits to society.

Develop a long-term strategy of biofuel role in the energy transition, aligned with the development of alternative technologies

The future potential of biofuel demand is highly uncertain, especially with the rapid development and the disruptive potential of alternative technologies. If the biofuel mandate is increased too aggressively, the built infrastructures might end up as stranded assets in the future. The infrastructures include the biofuel refineries and the biofuel crop plantations that are opened to fulfill the increasing biofuel demand in the short term. This would require the government to be more prudent in planning for an increased biofuel mandate and putting it under the broader energy transition plan.

This needed prudence has not been reflected well with the recent changes of biofuel targets in only a short period of time. In only 3 years since RUEN, the government has already stipulated several other plans for biofuel development with varying blending rates. These also include verbal announcements to aggressively increase the blending rate up to 100%, which have never materialized into actual policy documents. This inconsistency needs to stop since it creates unclear signals to the market players, both in biofuels and alternative technologies supply

chains, which will only increase the already high uncertainty on the future biofuel potential. Nevertheless, the most recent plan in the Grand Energy Strategy is already much better than the previous plans by integrating the biofuel planning with the electric vehicle adoption and petroleum refinery development. It also targets a more ambitious electric vehicle adoption rate, although still significantly lower than the global best practices.

One possible solution to reduce the risk of stranded assets is by minimizing new investments in biofuel production plants, for example, by implementing co-processing in the existing petroleum refineries instead of building new stand-alone production plants. By implementing co-processing, no new refinery needs to be built, minimizing the potential of stranded assets when the biofuel demand ceases. Another option is to develop a more resilient biofuel production system that could absorb future disruption. This resiliency could be achieved, for example, by using process technologies that can accommodate flexible product portfolios (e.g. fuels, chemicals, electricity, hydrogen)

or even transformable to non-fuel products when the demand drastically changes (Mu et al., 2011). The waste-based thermochemical process technologies are considered to have high flexibility and potential for transformation

to other industries, although the flexibility will require additional investment, which needs to be justified in further studies (Kou & Zhao, 2011b; Mu et al., 2011).

Set clear and transparent criteria to measure economic, social, and environmental benefits of biofuel program

The biofuel program in Indonesia was initiated as an alternative to reduce dependence on petroleum fuels and fuel import (Caroko et al., 2011), increase tax revenues, reduce fossil fuel subsidies, provide an alternative market for palm oil farmers, job creation, rural development, decentralized energy system, smallholder inclusion (Hunsberger et al., 2017), and climate change mitigation (Government of Republic of Indonesia, 2016). However, the existing social, environmental, and economic issues have undermined the achievement of these goals. The government needs to set better-articulated goals for the biofuel program and more robust parameters to measure its success (German et al., 2017). As Hunsberger et al. (2017) argued, many of the goals set for biofuel programs in many countries have been too narrow. For example, on job creation, policy goals focus only on how many jobs have been created while overlooking the quality of jobs created, the employment intensity, who gets the jobs, which part of the supply chain employs the most, etc. Hunsberger et al. (2017) also provides several criteria that might need to be evaluated, such as energy security at the local level, the quality of jobs created, preferential employment for impacted communities, etc.

The criteria could be adapted to the existing certification scheme, ISPO. ISPO certification could be designed as a measurement and

improvement program rather than the only certification of complying plantations. It could be designed as multiple achievement levels, adapting from other schemes such as the PROPER program. It should have the minimum standards, which all plantations are required to fulfill. However, it should also have the higher-level standards and the certified plantations are required to move towards the higher standards over time. This way, more plantations could join the certification program due to its lower entry barrier, but they need to improve the practices over time. Other certification schemes, such as the Cradle to Cradle certification, awards certifications based on increasing level of achievement, thus encouraging the participants to improve their practices (Cradle to Cradle Products Innovation Institute, n.d.). The level of certification awarded to each plantation should also be publicly accessible.

In addition, ISPO only covers the oil palm industry, not the biofuel industry itself, as well as the industry of other feedstocks. Sustainability criteria for other feedstocks or a more general biofuel industry need to be established. At the global level, there is already RSB certification that covers the whole biofuel industry supply chain. This kind of general criteria will be useful especially to compare the impact and benefits of different biofuel feedstocks and technologies.

Diversify the biofuel feedstock

As stated in policy documents, current biofuel relies and is expected to keep relying only on palm oil as the feedstock. However, other resources could be utilized as biofuel feedstock and studies indicate that diversifying the feedstock could serve important benefits. Utilizing other feedstock, either non-food crops or waste, could

reduce the environmental impact and arable land requirement. More diversified feedstock could also minimize the impact of feedstock disruption on biofuel production's economic sustainability.

One modeling study found that feedstock diversification could minimize the risk of

feedstock price volatility (Gülşen et al., 2014). Even for waste-based biofuel production plants, utilization of multiple waste feedstock could improve the economic performance (higher NPV, higher IRR, and lower bankruptcy probability) during feedstock disruption such as extreme weather conditions (Kou & Zhao, 2011a). Moreover, biofuel crops grown in large industrial monoculture, as practiced in most oil palm plantations in Indonesia, are susceptible to the attack of specialist pathogens and the rapid evolution of the pathogens, which could disrupt the feedstock supply for biofuels production (Smith et al., 2015). Having more diverse feedstock could also buffer the risk posed to the biofuel industry when outbreaks occur.

The utilization of non-food biofuel crops might have more benefits by reducing the pressure on arable land by oil palm plantations while using otherwise unproductive land. Bappenas identified some crops that do not compete with food use and could grow in degraded lands with relatively high oil productivity, such as jarak (*Jatropha curcas*), nyamplung (*Calophyllum inophyllum*), kemiri sunan (*Reutealis trisperma*), and malapari (*Pongamia pinnata*) (Bappenas, 2015). However, the availability of degraded land suitable for those plants might be limited, as one study estimated that only about 250,000 hectares of degraded lands are suitable for the cultivation of oil crops with less than 10

PJ per year (about 280,000 kl biodiesel) (Jaung et al., 2018). Besides, some crops, such as *R. trisperma*, produce oil composition that is less suitable for biofuel production (i.e. high share of polyunsaturated fatty acid) (Soerawidjaja, 2021), meaning that it will require more processing and consequently higher cost. Nevertheless, the potential of these crops as alternative biofuel feedstock deserves to be further investigated.

The utilization of waste material as a biofuel feedstock is even more potential. The available waste feedstock is highly abundant, including 4 million tons of waste fat/oil that can be converted to biodiesel or HVO (Zhou et al., 2021) and 260 million tons of agricultural and plantation residue that can be converted into ethanol or drop-in biofuel through thermochemical processes (Zhou et al., 2020). The biofuel from waste feedstock also has a higher GHG emission reduction potential and could provide other benefits, such as avoiding improper waste disposal (Zhou et al., 2021). Moreover, as indicated in the techno-economic analysis, biofuel from waste feedstock could cost less than the biofuel from palm oil in the long term due to cheaper feedstock. Biofuels produced by gasification and pyrolysis of lignocellulosic biomass waste is less sensitive to feedstock price change. The use of waste material as biofuel feedstock should be incorporated in the policy documents and regulations, as suggested by Zhou et al. (2020, 2021).

Establish policy support to incentivize the production of second and further generation biofuels

The share of the second and further generation (advanced) biofuels have to grow to comply with IEA's sustainable development scenario and Paris Agreement. Their use will minimize the negative implication due to land use change, and they generally perform better in GHG emissions reduction than first-generation biofuels (IEA, 2020). However, globally the progress of these biofuels is slow, and there is virtually no production of the advanced biofuel in Indonesia. Thus, policy support is deemed important in accelerating the development of second and further generation biofuels. Financial incentive and research and development support are considered the most impactful instruments. There are different policies implemented in other countries that intend to drive the production

of advanced biofuels. Some countries impose specific mandates for advanced biofuels (in percentage or volume), on top of general biofuel mandates (Ebadian et al., 2020). However, as Indonesia's experience with biofuel mandates since 2008, mandates alone could not establish the market without other policy supports. Costantini et al. (2015) conclude that for spurring innovation in advanced biofuels, research and development spending (technology push) and price-based incentive (market pull) are the most impactful instruments, while biofuel mandate (market pull) seems to have no impact.

For the technologies that are ready to commercialize, such as biodiesel and HVO from waste oil or lignocellulosic ethanol, IRENA

suggests government support such as public procurement initiatives, loan guarantee, and soft loans alongside specific mandate and fiscal incentives (in the form of price premium or tax exemption) to create the market (IRENA, 2016). Financial incentives could also be provided as an upfront grant to reduce capital investment or as an annual subsidy (Zhou et al., 2020). For less-ready technologies such as the gasification and pyrolysis of lignocellulosic biomass, government support could be provided in the form of public-funded research and demonstration projects, as well as public-private partnerships to reduce the risk for technology development (IRENA, 2016). The OPPF could also be directed for the research and development of second-generation

biofuels utilizing the biomass waste from palm oil production.

For third and fourth-generation biofuels, the government needs to prepare a development pathway. The barrier is currently in the high cost of feedstock production, i.e. the microalgae cultivation and harvesting. However, microalgae cultivation technologies are already commercially feasible to produce specialty chemicals that have a higher value than biofuels. The support should first focus on the microalgae cultivation for chemicals, which is expected to encourage further research and drive down future costs. When microalgae could be produced cheaply, its use for biofuel production could be pushed.

Transform the incentive scheme to encourage innovation and sustainability

The existing incentive scheme needs to be transformed to accommodate the sustainability aspects as part of the requirements. One example is the low carbon fuel standards (LCFS) implemented by California and Oregon in the US, and British Columbia in Canada, which provide incentives for carbon intensity reduction in transportation fuels instead of stipulating quantity-based mandates. In this scheme, biofuel with lower carbon intensity generates higher carbon credit that translates to higher market value. This type of policy is touted to encourage more efficient production of conventional biofuel and stimulate the production of advanced biofuels (Ebadian et al., 2020). It should be noted that the LCFS policy is a market-based mechanism, which might not be suitable to be directly adopted in Indonesia. Nevertheless, the basic idea of giving more incentive to the lower carbon intensity biofuels should be driving the biofuel development policy in Indonesia.

The existing incentive scheme based solely on the price difference between fossil fuel and biodiesel does not incentivize the innovation towards more sustainable biofuel production nor towards the achievement of the government's goals. For example, it does not distinguish between biofuel produced from palm oil grown in peatland or not, or whether smallholders produce the biofuel or not. Consequently, the public fund given for the incentive would fund social and environmental problems rather than solving them, and as Gomiero (2015) suggests,

become perverse subsidies. The incentive should only be directed for biofuel production that fulfills certain sustainability criteria set by the government, such as life cycle carbon intensity or working conditions. The incentive could also be designed to be different for each type of biofuels, depending on their sustainability performance. This might put the second-generation biofuels at an advantage compared to palm oil biofuel since they generally have less carbon intensity and environmental and social impacts.

Similarly, it could be used to incentivize sustainable practices on the upstream side and improve the smallholders' participation. For example, utilizing OPPF to support farmers in the replanting process, land legalization, and certification could double the smallholder oil palm productivity to 5-6 tons per hectare per year. Land legalization is especially important to increase the farmers' access to certification, government programs, and loans from formal financial institutions. In addition, requiring the smallholders to comply with certain sustainability criteria to be able to receive the incentive could also help improve the farming practice (Nurfatriani et al., 2019).

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