NAVIGATING THE FUTURE:
Opportunities, Challenges and Strategies of Biofuel Development in South East Asia

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Executive Summary

Renewable energy, particularly bioenergy, offers a sustainable alternative to fossil fuels and can play a significant role in mitigating climate change. Bioenergy is derived from organic biomass and can be converted into various usable energy forms, such as heat, electricity, and biofuels. Biofuels, a specific type of bioenergy, are produced from organic materials and emit significantly less carbon dioxide compared to fossil fuels. ASEAN countries, with their abundant biomass resources and growing energy demands, are well-positioned to exploit bioenergy and biofuels.

Currently, the ASEAN region is facing a pressing challenge in meeting its escalating energy demands, with projections indicating a substantial increase in energy consumption to 1186 Mtoe by 2040. To address the growing energy demand, ASEAN countries need to explore diverse and sustainable energy sources. Bioenergy and biofuels, utilizing biomass resources like wood residue, rice husk, and palm oil, can offer an attractive option for reducing fossil fuel dependence, lowering carbon emissions, and meeting the region's energy needs.

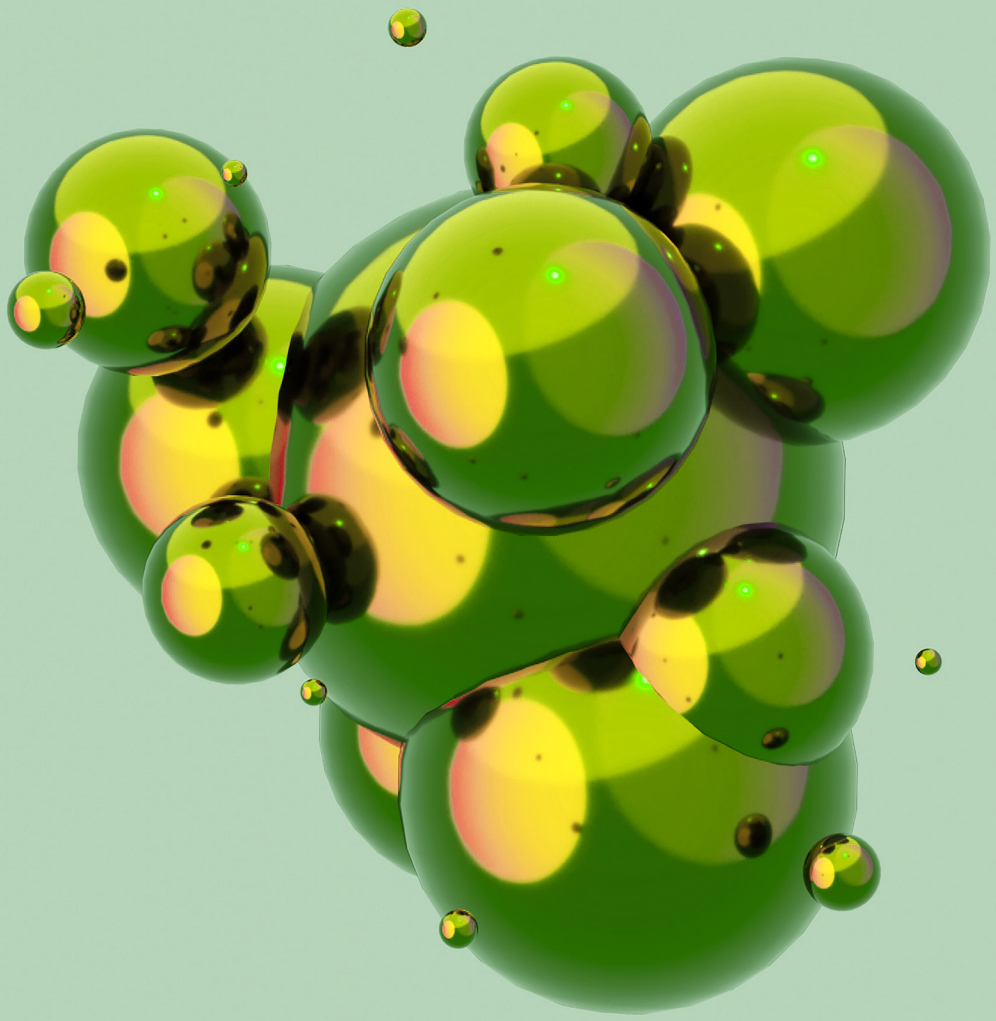
Indonesia and Malaysia, as the world's largest palm oil producers, have made significant contributions to biofuel production. However, despite biofuel policies in place, the overall contribution of biofuels to the regional energy mix remains minimal. This policy brief focuses on analyzing the biofuel sector in ASEAN, with a specific emphasis on the potential of Indonesia and Malaysia's palm oil industry and its crucial role in the region's biofuel agenda.

Biofuels have emerged as a promising solution to reduce dependence on fossil

fuels. However, to enhance biofuel production and achieve economic growth and a sustainable renewable energy supply, it is essential to address productivity disparities in the palm oil sector. Adopting modern technologies and practices, can optimize palm oil yield, reduce the need for land expansion, and promote sustainability. Technology improves palm oil productivity by optimizing harvests, assessing sustainability, automating image analysis, increasing yield, and minimizing human error.

The palm oil sector can significantly reduce emissions through renewable energy usage and the application of palm oil mill effluent (POME). Efficient design and management of the biofuel supply chain, including biomass storage, transportation, and infrastructure development, are vital for the growth and viability of the biofuel sector in ASEAN. Leveraging existing infrastructure, such as distribution channels, and attracting private sector investments are key factors in enhancing the competitiveness of biofuels.

This policy brief recommends sustainable biofuel development, strengthening regional cooperation, and supporting ASEAN's renewable energy goals. It emphasizes the importance of biofuels in fostering a more sustainable energy future, addressing poverty reduction, promoting economic growth, and enhancing energy security. By implementing these policy recommendations, ASEAN can unlock the full potential of biofuels and accelerate the transition to a low-carbon and sustainable energy landscape.

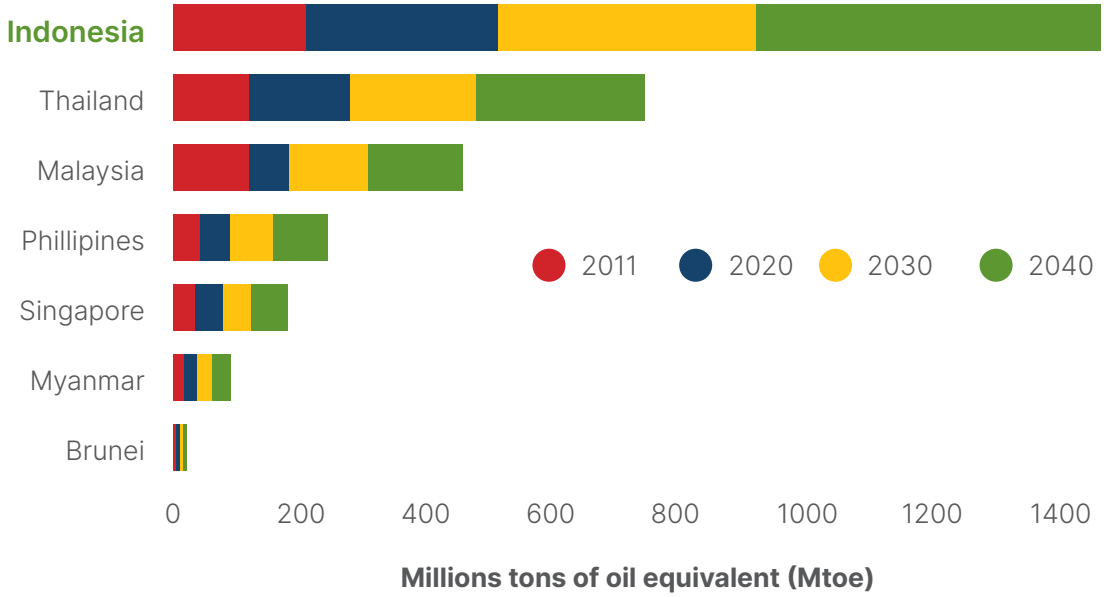


1. Beyond fossil fuels, towards sustainable energy in Southeast Asia

Climate change and the increasing demand for energy have intensified the search for sustainable and renewable energy sources. Among the various options available, renewable energy, particularly bioenergy, has emerged as a promising solution to mitigate the adverse impacts of fossil fuel consumption on the environment. Bioenergy is derived from organic biomass, like plants, animals, microorganisms, and agricultural waste which then converted into usable energy forms, such as heat, electricity, and biofuels. Biofuels, a specific bioenergy type, are produced from various organic materials which makes them renewable by nature. They also emit significantly less carbon dioxide when burned compared to fossil fuels, thereby contributing to reduced greenhouse gas emissions. Their sustainable characteristics, coupled with their potential on long-term energy security, makes biofuels a compelling energy source.

In 2020, the global pandemic caused a substantial contraction and slowdown in the economy in the ASEAN region, leading to a decline in energy demand from various sectors. Specifically, the transport and industrial sectors experienced a significant drop in energy demand, with reductions of 13 Mtoe (8.8%) and 11 Mtoe (6.8%), respectively, compared to 2019. This decline was primarily attributed to the mobility restrictions imposed by governments across the AMS (ASEAN Member States). While the commercial and agriculture sectors also saw decreases in energy consumption, they were not as pronounced. Surprisingly, residential energy demand bucked the trend, experiencing a 0.8% increase in 2020 compared to the previous year. The pandemic's impact on energy consumption varied across sectors, with stringent restrictions affecting certain industries more significantly than others, while the residential sector saw an upswing in demand.

Given the region's vast biomass resources and the growing energy demands forecasted for ASEAN countries, are well-positioned to capitalize on the potential of bioenergy. According to a study, ASEAN's energy consumption is predicted to increase to 1186 Mtoe by 2040, with an annual growth rate of 3.1%, driven by factors such as population growth and expanding industrial activities in the region (Mojifur et al., 2015). As ASEAN countries address the challenges posed by this escalating energy consumption, they must explore and embrace diverse and sustainable energy sources to ensure a secure and resilient energy future. Biofuel has a great potential role to play in fulfilling the ASEAN region's energy needs.



Adapted from Mofijur et al. (2015)

Figure 1. ASEAN primary energy consumption (2011-2040)

For instance, ASEAN's significant production of wood residue, rice husk, and palm oil, which can generate around 41,000 MW of power (Rai et al., 2022, Parnphumeesup & Kerr, 2011). The region's abundant biomass resources and commitment to renewable energy make bioenergy and biofuels an attractive option for the future of energy in Southeast Asia. These renewable energy sources could help ASEAN countries reduce their fossil fuel dependence, lower carbon emissions, and address the increasing energy demand.

The ASEAN region has various other resources with great potential for use as biofuels. These resources include fuel derived from palm kernel oil, corn, cassava, sugarcane, agricultural waste, and other organic materials. Through advanced

processing techniques, these materials can be transformed into different types of biofuels, such as biodiesel, bioethanol, and biogas, offering diversified and sustainable energy resources. Leading the production of biofuels in the region are Indonesia and Malaysia, both prominent palm oil producers on a global scale. However, in 2023, palm oil production in these countries is anticipated to remain tight due to increasing demand from key markets like China and a surge in domestic processing within Indonesia. As of 2021, Indonesia produced a substantial 46 million tons of crude palm oil, securing its position as the world's largest palm oil producer, with Malaysia following closely behind with approximately 20 million tons of production (Chu, 2023; Ritchie & Roser, 2021). The utilization of these abundant biofuel resources holds the potential to address energy demands sustainably while fostering economic growth within the ASEAN region.

This policy brief aims to analyze the ASEAN biofuel sector, focusing on the potential of Indonesia and Malaysia's palm oil industry and its crucial role in the region's biofuel agenda. These nations can notably boost biofuel production, impacting their economic growth and renewable energy supply positively. Through policy recommendations, the brief will promote sustainable biofuel development, strengthen regional cooperation, and contribute to ASEAN's renewable energy goals. It will underscore the role of biofuels in fostering a more sustainable energy future, emphasizing their importance in poverty reduction, economic growth, and energy security.

2. Biofuel sector foundations

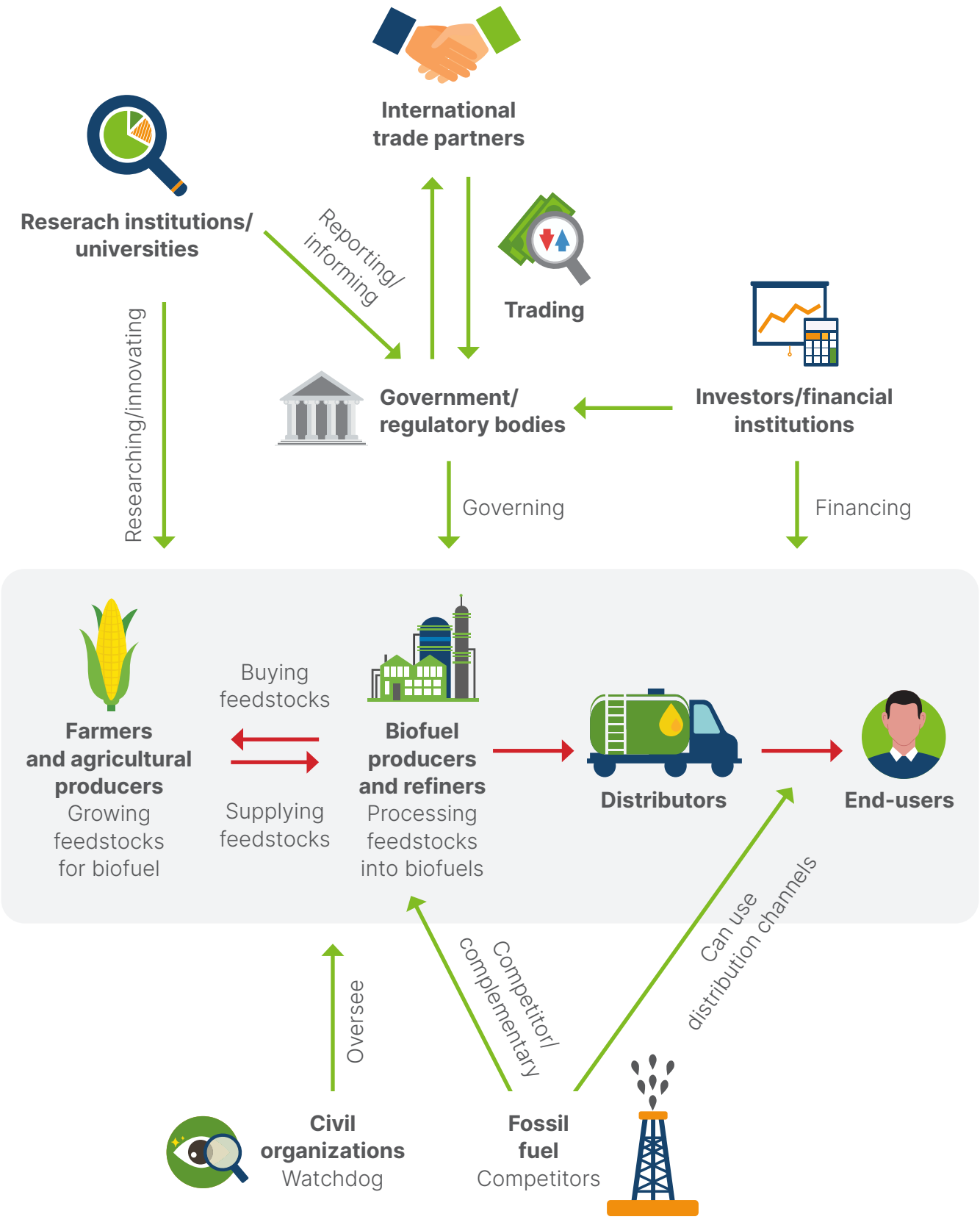
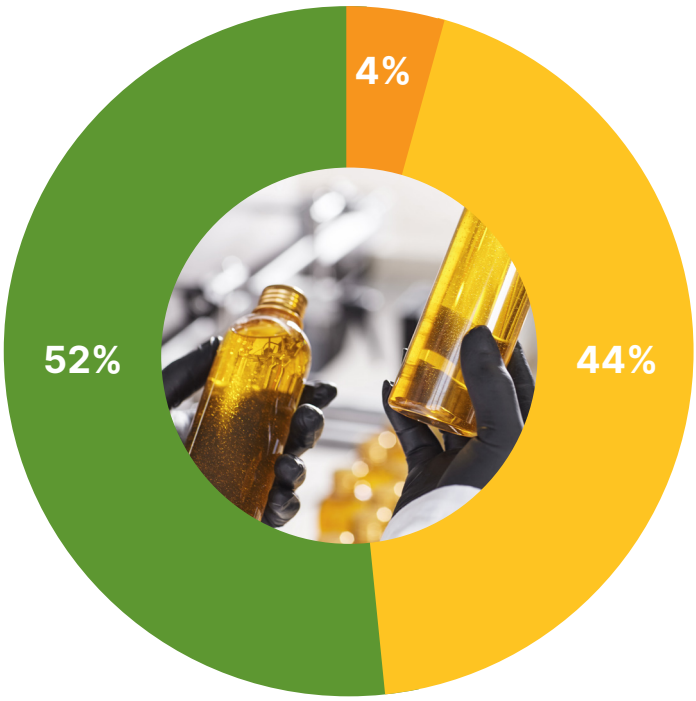


Figure 2. Biofuel sector stakeholder map

Biofuels have gained significant attention in recent years due to the growing demand for alternative energy sources. In the ASEAN region, biofuels primarily stem from the palm oil sector, with 21 million hectares dedicated to palm oil plantations (Statista, 2022).

However, it is worth noting that these plantations only represent a small fraction (4.7%) of the region's vast land area, which spans around 452 million hectares. The majority of ASEAN's land area, approximately 245 million hectares, is still covered by forest (RECOFTC, 2016). With such a significant forested area, there is a need to strike a balance between the expansion of palm oil plantations for biofuel production and preserving the region's valuable forest ecosystems. Agronomists recommend an optimal planting density of around 140 palms per hectare, aligning with the 5-year average of 4.38 tons of crude palm oil (CPO) per hectare in Southeast Asia (Ritchie & Roser, 2021).



Palm oil plantation
(21 million hectares)

Other land area
(207 million hectares)

Forest area
(245 million hectares)

Source: BPS, 2022

Figure 3. Palm oil plantation coverage

The Indonesian government had implemented an palm oil moratorium since 2018, which was intended to address environmentally-related concerns. However, palm oil production in the country has experienced a significant surge. The production has escalated 70 times since 1980, during the same period outpacing the 48 times increase in land area (Ritchie & Roser, 2021), and there is still more room for productivity increase. However, this growth comes with a disparity in productivity. Statistics Indonesia (Badan Pusat Statistik, BPS) reported that while smallholders control 41.24% of the total plantation area, they contribute to just 34% of total output. In contrast, corporations manage 58.76% of the land but account for a much larger 65.64% of the overall yield (BPS, 2021). Concurrently, a study estimated that the current yield of Fresh Fruit Bunch (FFB) palm oil in Indonesia and Malaysia still falls short of its potential (Khiabani & Takeuchi, 2020). Addressing this disparity and elevating productivity necessitates the adoption of modern technologies and practices, exemplified by corporations like Asian Agri and many others. This organization leverages advanced technology to optimize tree harvesting, resulting in enhanced fruit quality and consequently, improved palm oil yield.

AI technology, combined with advanced remote sensing and satellite imagery, offers a powerful tool for sustainable palm oil management. By leveraging AI algorithms, palm oil plantations can precisely monitor and assess land use changes, allowing for early detection of any potential deforestation activities (Akhtar et al., 2023). This proactive approach helps eliminate deforestation and ensures responsible land management practices. Moreover, AI-driven precision agriculture techniques enable farmers to optimize their plantation operations, leading to increased productivity and reduced environmental impact. By analyzing vast amounts of data from soil conditions to weather patterns, AI can provide valuable insights to farmers, helping them make informed decisions on irrigation, fertilization, and pest control, ultimately enhancing palm oil yield while minimizing resource wastage (Ibrahim, 2022). The adoption of AI technology in the palm oil sector holds immense potential to transform the industry into a more sustainable and productive domain, addressing environmental concerns and meeting the growing demand for biofuels without compromising valuable forest resources.

In the context of addressing climate change, the palm oil sector plays a crucial role in reducing emissions through the adoption of renewable energy usage and the effective utilization of plantation waste. Indonesia, as indicated in its Enhanced Nationally Determined Contribution (ENDC) for the year 2022, has made ambitious commitments to significantly reduce national emissions, targeting a 31.89% reduction and a more substantial 43.2% reduction with international support.

Biofuel supply chain

In the context of ongoing transition towards a sustainable fuel, biofuels emerge as a lucrative alternative due to their compatibility with the existing infrastructure originally designed for fossil fuels. The physical resemblance between biofuels and fossil fuels, which permit them to utilize the same transportation pipelines and distribution channels, is often overlooked.

Leveraging existing infrastructure such as distribution channels can be a significant way to enhance the cost competitiveness of biofuels. According to a report by the International Energy Agency (IEA), in 2019, the use of existing fossil fuel pipelines for transporting biofuels in the United States saved around $150 million in transportation costs compared to using trucks (IEA, 2021). The same report also stated that the use of existing infrastructure for biofuels is not yet fully exploited globally, highlighting the potential for further cost savings.

Logistics and supply chain infrastructure are vital components for the success of the biofuel sector in the ASEAN region. The biofuel supply chain encompasses both downstream and upstream processes, involving various stages from biomass production to bioenergy utilization. These stages include biomass production, biomass pretreatment, feedstock storage, bioenergy conversion, distribution, and the ultimate utilization of bioenergy. Efficient design and management of the biofuel supply chain network can address the complexities of biofuel conversion processes and supply chains, making the commercialization of biofuels more appealing.

The primary objective in designing a biofuel supply chain is to enhance the value added for biofuel producers, while considering practical constraints such as biomass supply, facility capacity, storage, Greenhouse Gas (GHG) emissions, and transportation limitations. These stages are essential for the transformation of biomass resources, such as palm oil, into biofuels that can be utilized for energy production.

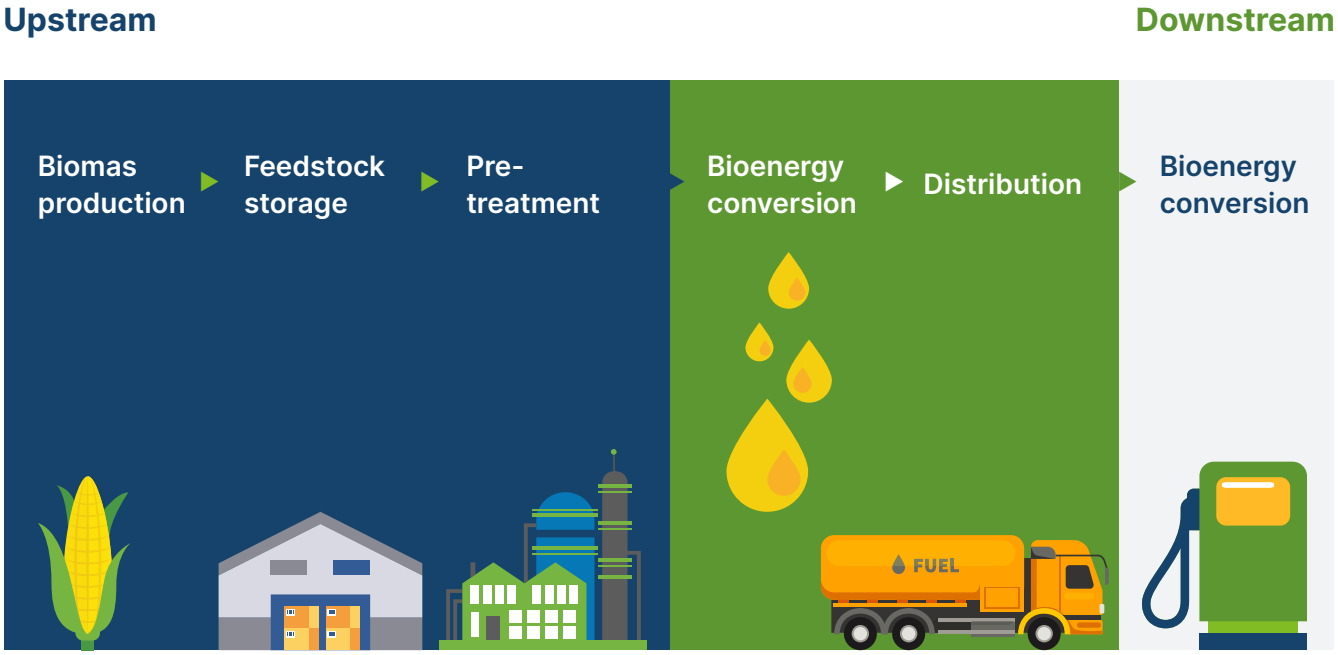


Figure 4. Biofuel supply chain (adapted from Ying et al., 2020)

The growth and viability of the biofuel sector in the ASEAN region depend on the efficiency and effectiveness of the biofuel supply chain. Technological advancements in biotechnology, fermentation, and process engineering have made biofuel production more efficient and cost-effective (Jazi & Sangroudi, 2020). According to a report by the International Renewable Energy Agency (IRENA), Southeast Asia's bioenergy potential is estimated to be around 70 exajoules (EJ) per year, with the majority of the potential coming from biomass residues, wastes, and energy crops. However, inadequate infrastructure can increase the costs of production and transportation, making biofuels less competitive compared to fossil fuels. In Indonesia, for example, the high cost of transporting biomass feedstocks can add up to 60% to the cost of producing biofuels (IRENA, 2018).

In the biomass feedstock logistics supply chain, biomass storage plays a critical role. It enables biorefineries to operate consistently throughout the year, despite variations in feedstock availability on a daily, monthly, and seasonal basis (Wendt & Zhao, 2020). Effective storage approaches are essential to prevent uncontrolled biomass loss caused by microbial degradation. When storage conditions are not optimized, biomass degradation can lead to challenges in handling, size reduction, preprocessing, and conversion processes.

To address these challenges, the ASEAN region needs to invest in pretreatment, storage and processing facilities, as well as transportation and distribution networks, and other infrastructure to support the biofuel supply chain. A study by the ASEAN Centre for Energy found that Indonesia, the Philippines, and Thailand have significant

potential for bioenergy development, but the lack of infrastructure is hindering growth. For example, in the Philippines, a lack of pre-processing facilities and storage capacity for feedstocks is a major challenge for the biofuel industry (ACE, 2017).

Finally, private sector support and investments are crucial for the growth of the biofuel sector. According to a report by the Asian Development Bank (ADB), in 2017, the global investment in biofuels was around $7.6 billion, with the majority of the investment coming from private sources (ADB, 2018). The private sector can provide funding, technology, and expertise to support biofuel projects and help to commercialize biofuels, creating new markets. Governments in the ASEAN region need to create an enabling environment for private sector investments by providing incentives, regulations, and policies that support the growth of the biofuel sector.

3. Unlocking biofuel potential in ASEAN

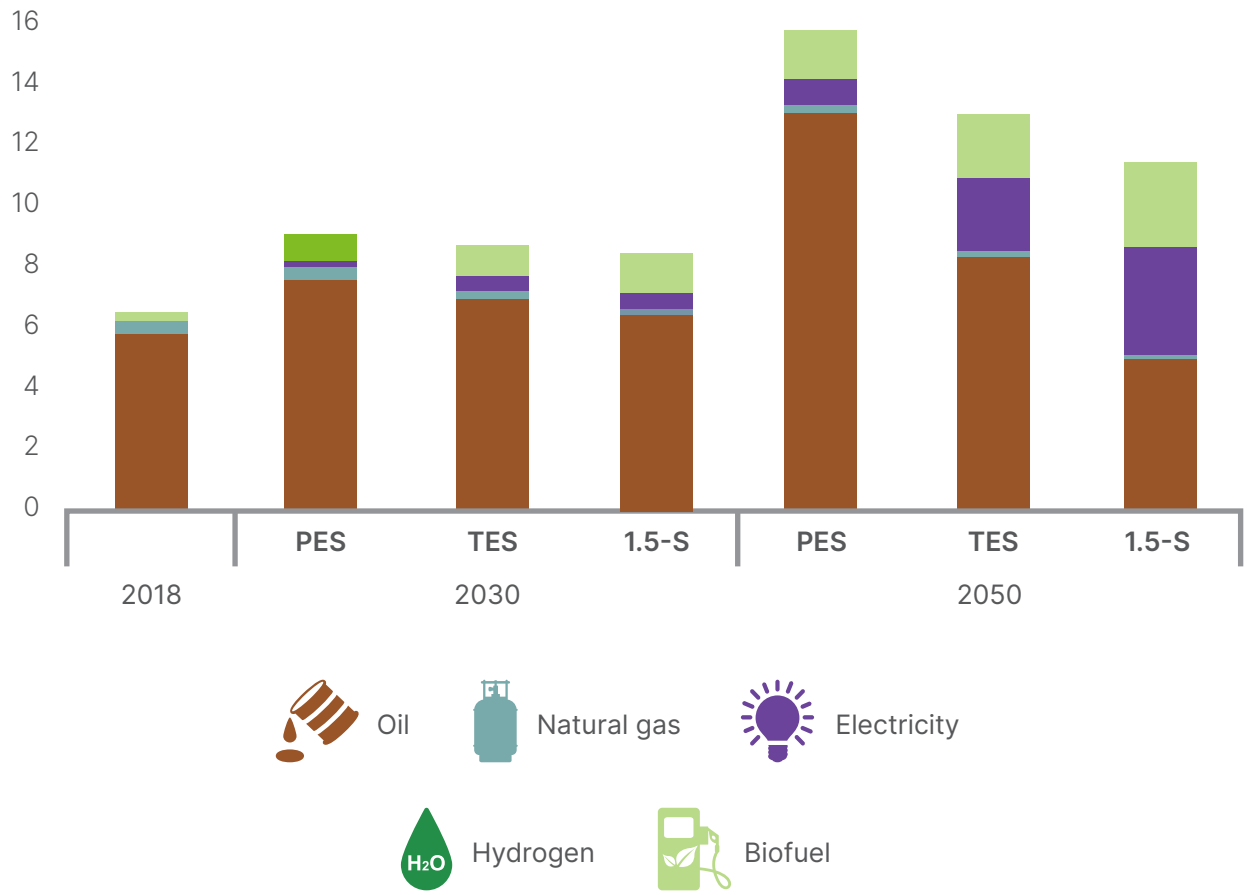
Biofuels have emerged as a promising substitute for fossil fuels in the fight against climate change. These biofuels can be broadly categorized based on their source: food crops and non-food crops. Food-crop biofuels, derived from plants such as corn, sugarcane, and soybeans, have been a dependable energy source (Macedo et al., 2008). However, the use of food crops for fuel production has been criticized for causing the rising food prices, changes in land use, and increased deforestation (Searchinger et al., 2008).

Conversely, non-food crop biofuels, produced from agricultural waste and residues, are being recognized for their superior sustainability profile. These non-food crop biofuels do not compete with food resources, thereby averting the food-security concerns linked with the food crop biofuels. Additionally, biofuels derived from non-food crops yield more significant greenhouse gas reductions, further enhancing their environmental advantages (Soam & Börjesson, 2020). Despite these advantages, they are currently constrained by higher production costs and energy inputs, which limit their immediate widespread adoption.

These characteristics illustrate that food crop biofuels and non-food crop biofuels are not adversaries but rather collaborators in the pursuit of a sustainable energy future. Each offers unique advantages and faces distinct challenges. Biofuels from food crops have provided a stepping stone, demonstrating the potential of biofuel technology, and contrary to some concerns, have managed to do so without significantly jeopardizing food security. Meanwhile biofuels from non-food crops represent an evolution of this technology, aiming to address some of the shortcomings of their predecessors. Serving the same purpose, both food crop and non-food crop biofuels helps reduce our reliance on fossil fuels.

3.1 The Potential of Biofuel Usage in the Transportation Sector

The use of biofuels in transportation offers numerous advantages, prominently serving as a more environmentally friendly alternative energy source. Biofuels are considered greener than fossil fuels because of their ability to significantly reduce carbon emissions and produce fewer harmful pollutants. The IEA suggests a sustainable and significant increase in global biofuel consumption. The assessment projects a substantial increase in global biofuel consumption, from 55 Mtoe currently to 750 Mtoe by 2050. This growth would boost the global biofuel share in total transport fuel from 2% to 27%, while ensuring environmental benefits and food security. The use of sustainable biofuels can help avoid approximately 2.1 gigatonnes (Gt) of CO2 emissions per year, (IEA, 2011). The use of biofuels in diesel engines can reduce particulate matter emissions by up to 50% (Karin et al., 2022).



Note: Planned Energy Scenario (PES) considers current and planned policies, 1.5°C Scenario (1.5-S) aims to reach net-zero emissions globally by 2050, Transforming Energy Scenario (TES) considers readily available technologies with slightly higher emissions around 1 Gt vs 0.7 Gt for 1.5-S.

Source: IRENA, 2022

Figure 5. Energy Consumption in Transportation Sector

IRENA (2022) reports a strong commitment to reducing oil fuel consumption by over 60% by 2050 under the 1.5-S scenario, despite the persistent use of oil products in the transportation sector. Presently, the sector is experiencing a significant and proactive transition towards the widespread adoption of EVs and biofuels and this trend is expected to continue growing. The report also predicts that biofuels will account for approximately 25% of the transportation sector's energy consumption by 2050. This prediction suggests a significant shift towards the adoption of biofuels as an alternative to conventional fossil fuels in the transportation industry. The demand for biofuel is expected to continue to rise, with the increasing adoption of sustainable biofuels and the implementation of supportive policies by governments worldwide. Several countries, including India and Brazil, have implemented higher blending

requirements to promote and enhance the utilization of biodiesel. Mirroring the efforts seen in other parts of the world, the same trend is observed in ASEAN countries as well. However, it is important to note that the biofuel blending rate varies across countries within the ASEAN region, primarily depending on the availability of biofuel resources in each country. Therefore, in order to boost biofuel adoption several countries have established increased biofuel blending targets as part of their energy policies. These targets are expected to have a significant impact on biofuel consumption, driving it to grow nearly tenfold by mid-century from 2018 levels, reaching an estimated 1.6 EJ (Exajoules).

	2018	2030			2050		
		PES	TES	1.5-S	PES	TES	1.5-S
Total energy consumption (PJ)	6.444	8.933	8.708	8.362	15.583	12.835	11.353
Electrification of transport (%)	-	2%	5%	7%	5%	18%	30%
Biofuels in transport (million kilo litres)	10	39	48	57	65	93	112
Biofuel share in transport fuels (%)	4.8%	11%	13%	15%	10%	16%	25%

Note: Planned Energy Scenario (PES) considers current and planned policies,1.5°C Scenario (1.5-S) aims to reach net-zero emissions globally by 2050, Transforming Energy Scenario (TES) considers readily available technologies with slightly higher emissions around 1 Gt vs 0.7 Gt for 1.5-S

Source: IRENA, 2022

Figure 6. Projection of transport sector summary, by scenario, 2018-2050

According to IRENA, in 2018, the transport sector accounted for the largest proportion of the region's end-use energy demand, with road transport alone constituting 90% of the sector's energy consumption. In the PES scenario, final consumption in Southeast Asia is projected to grow 2.5 times from 2018 to 2050. Additionally, the share of biofuel is expected to increase to one-quarter, as it plays a crucial role in decarbonizing heavy-duty road transport. One of the significant advantages of using biofuels is their ability to help vehicles meet the stringent emission standards of Euro 4, 5, and 6 by significantly reducing the number of pollutants released from the tailpipe (Lopes et al., 2014; McCormick et al., 2006).

In striving towards reduced reliance on fossil fuels and carbon neutrality, Electric Vehicles (EVs) play an imperative role in ASEAN's transportation sector. Nevertheless, alongside promoting EVs, the exploration of alternative, complementary options is equally critical. Given IRENA's projection that at least 20% of vehicles in ASEAN will not be electrified by 2050 (IRENA, 2022), this necessity becomes clear. Heavy freight vehicles, in particular, pose significant challenges for electrification due to issues such as battery weight, required range, and the need for extensive recharging infrastructure. Given this scenario, immediate attention must be accorded to the advancement of strategies for the implementation of biofuels in transportation. Such measures, coupled with accelerated progress towards electric power and increased biofuel adoption, have the potential to profoundly influence ASEAN's transport sector. This holistic approach, leveraging both EVs and biofuels, holds promise for achieving substantial reductions in carbon emissions, further reinforcing the role of innovative, diverse energy solutions in a sustainable future.

Driving the Adoption of Biodiesel in Indonesia's Transportation Sector

The mandatory biodiesel program in Indonesia mandates the blending of a certain percentage of biodiesel with petroleum diesel for use in the transportation and industrial sectors since 2015. The program has undergone expansions, with the blend requirement currently set at B35. The transportation sector assumes a pivotal role in the effective enforcement of the mandatory biodiesel policy. As the government has officially announced the implementation of B35 at the beginning of 2023, this sector becomes even more integral to the success of the policy. The early implementation of B35 in 2023 signifies

a remarkable achievement in the biodiesel program, surpassing the initial target of reaching B30 by 2025. This accomplishment showcases the program's effectiveness and the accelerated progress made towards sustainable biodiesel utilization.

Table 1. Mandatory B35 in Indonesia (Initial target)

Sectors	April 2015	January 2016	January 2020	January 2025
Small-scale enterprise, fishery, agriculture, transportation and public service obligation (PSO)	15%	20%	30%	30%
Transportation non-PSO	15%	20%	30%	30%
Industry and commercial	15%	20%	30%	30%
Power plant	25%	30%	30%	30%

Source: Minister of Energy and Mineral Resources (MEMR) Regulation No. 12 of 2015

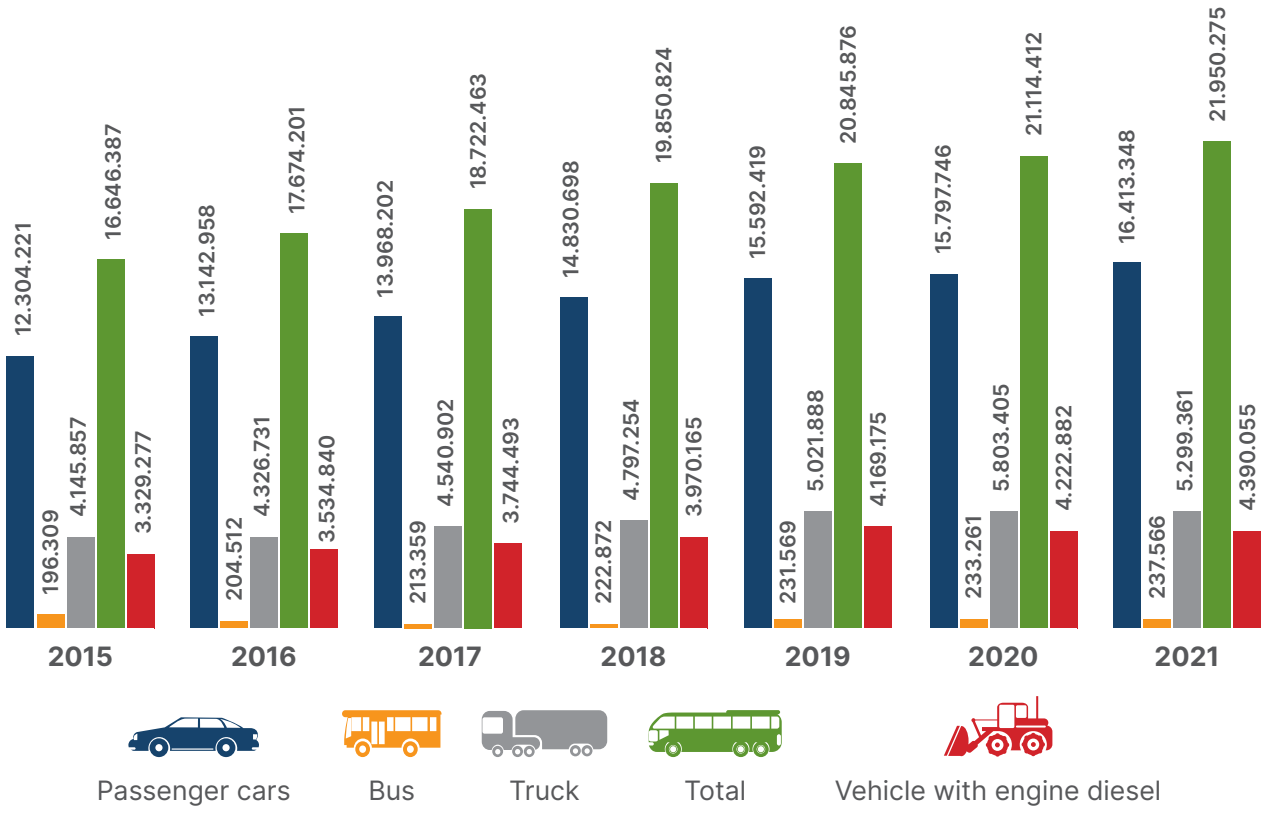
Table 2. Mandatory B35 in Indonesia (Realization)

Sectors	April 2015	January 2016	January 2020	January 2023*
Small-scale enterprise, fishery, agriculture, transportation and public service obligation (PSO)	15%	20%	30%	35%
Transportation non-PSO	15%	20%	30%	35%
Industry and commercial	15%	20%	30%	35%
Power plant	25%	30%	30%	35%

Source: *Update MEMR Decree Number 205.K/EK.05/DJE/2022

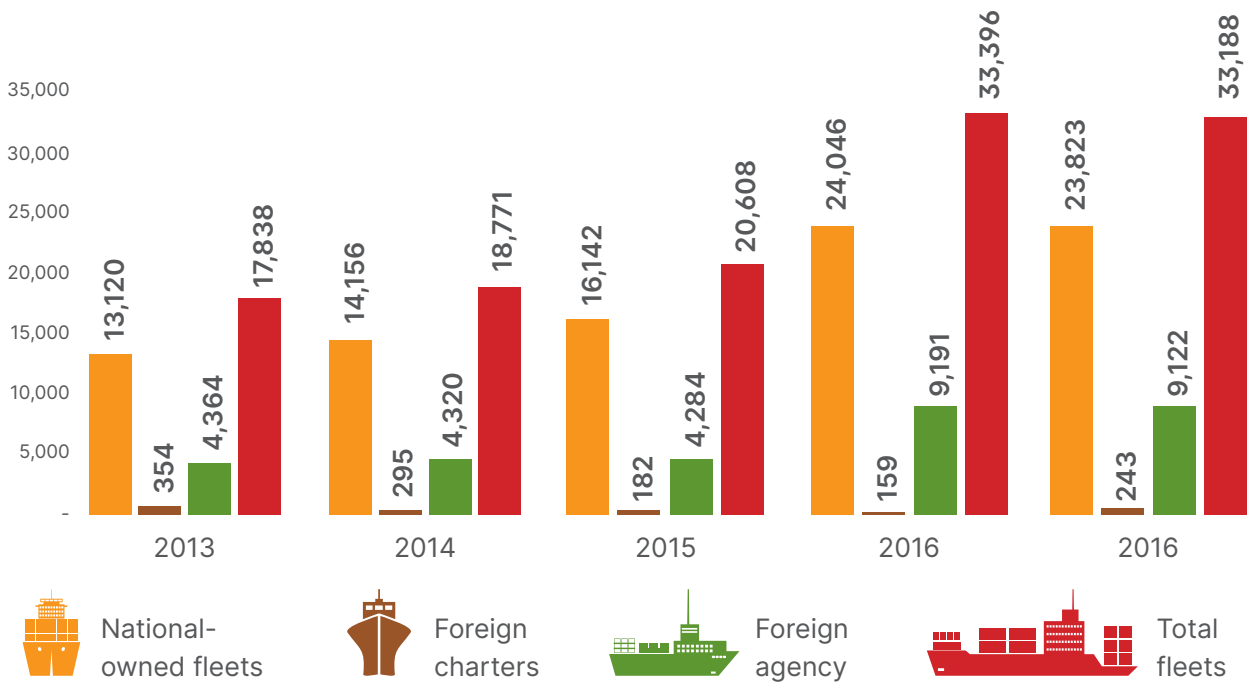
Based on data provided by the Indonesian Ministry of Energy and Mineral Resources, there was a substantial 10% increase in transportation-related diesel consumption in Indonesia between 2013 and 2018. This growth indicates a significant rise in the utilization of diesel fuel for transportation purposes during that five-year period. In 2017, the non-PSO land transportation sector alone encompassed over four million vehicles that could potentially utilize biodiesel. Considering that Indonesia has a total of 21.9 million vehicles, of which 20% rely on diesel engines, the potential for incorporating biodiesel into the country's transportation sector is both significant and promising. The potential utilization of biodiesel in the sea transportation sector is also highly promising, particularly for fleets such as ASDP and PELNI, which encompass more than 33,000 vessels, with approximately 90% of them relying on diesel fuel. The total sea transport fleet in Indonesia was recorded at 33,188 vessels in 2017. The combined annual fuel consumption for the PELNI fleet, ASDP, and the Directorate General of Transportation (Inter-Island Ships) amount to 505,200 KL on average. However, the biodiesel demand in this sector, which includes ASDP and PELNI, surpasses 700 thousand KL. As a result, there is a substantial opportunity for biodiesel, with a potential yearly demand of 175,000 KL.

Number of motor vehicle by type (unit) 2013-2017



Source: BPS (2022)

Number of sea transport fleets categorized by ownership 2013-2017



Source: Ministry of Transportation, 2017

Indonesia has been focusing on the development of aviation biofuel, known as bio aviation turbine fuel (Bioavtur), as part of its broader biofuel ambitions. Sustainable Aviation Fuel (SAF) has been predicted to account for 5.8% of worldwide jet fuel consumption by 2050 (IATA, 2019). This translates to an annual supply of 66.2 million kL equivalent needed for all varieties of sustainable aviation fuels, including both biofuels and synthetic fuels. Interest in bioavtur in Indonesia started in 2015, but concrete action only emerged in 2020 when various energy players collaborated on a biofuel plant in South Sumatra. PT Pertamina, the state-owned energy company, conducted a trial on bioavtur derived from refined, bleached, and deodorized palm kernel oil (RBDPKO) in December 2020, with satisfactory result.

Indonesia needs to shift towards alternative biogasoline options like methanol-ethanol fuel blends. Biogasoline presents opportunities for domestic businesses and transportation end-users, as it doesn't require engine modifications and has environmental advantages such as lower greenhouse gas emissions and costs. PT Pertamina is experimenting with methanol and ethanol in gasoline and plans to build a biogasoline refinery. The government has inaugurated PT Katalis Sinergi Indonesia to manufacture specialized chemical catalysts for biofuel production, previously imported.

3.2 Producing Biofuels

Biofuels present themselves in various forms, including biodiesel and bioethanol. Bioethanol, often referred to as ethanol, is a form of biofuel produced primarily through the fermentation of sugar or starch-rich crops like corn or sugarcane. Ethanol is mainly used as an additive in gasoline. On the other hand, biodiesel is produced from vegetable oils, cooking oil waste, animal fats, through a process called transesterification.

The primary methods currently used for biodiesel production is the creation of Fatty Acid Methyl Esters (FAME) (European Biofuels Technology Platform, 2011). FAME is produced via transesterification, a process involving the reaction of a glyceride with an alcohol in the presence of a catalyst (European Biofuels Technology Platform, 2011). The outcome is a renewable, non-toxic, and biodegradable biofuel sharing physical characteristics with conventional diesel (McGill et al., 2008). However, FAME has several limitations, including high viscosity, poor cold properties, and high boiling point (McGill et al., 2008). Moreover, FAME biofuels require blending with fossil fuels, with the biofuel content capped at 35%.

Biohydrocracking offers a promising alternative to FAME, capable of producing a wide variety of biofuels, including Sustainable Aviation Fuel (SAF) and B100 biodiesel. Importantly, B100 biodiesel can be utilized directly in diesel combustion engines, enhancing its practical appeal. This process, employed by companies like Neste, involves the decomposition of plant and vegetable oils in the presence of hydrogen gas and a catalyst, resulting in fuels rich in hydrocarbon-based compounds (Asaoka et al., 2014). Biohydrocracking can also be used to create ethanol which can also be used directly in the combustion.

Biohydrocracking provides several advantages over FAME, such as the ability to handle a more diverse range of feedstocks, produce higher quality fuel, and yield fuels with lower oxygen content (Asaoka et al., 2014; Lin et al., 2022; Žula et al., 2022). One critical distinction is that biohydrocracking allows for 100% renewable fuels, eliminating the need for fossil blends. The flexibility of biohydrocracking extends to the production of other fuels like biodiesel, underlining its extensive potential in the renewable energy and transportation sectors.

Apart from the potential of biofuels in the transportation sector, there is also interest in using bioenergy for power generation. Biomass power generation is a form of renewable energy that uses organic matter, such as wood chips, agricultural waste, and municipal solid waste, to produce electricity. This technology has the potential to reduce greenhouse gas emissions from power generation and provide decentralized energy solutions in rural areas. In ASEAN, several countries, such as Thailand and the Philippines, have implemented policies and programs to promote biomass power generation.

Navigating through the intricate landscape of biofuels reveals their considerable potential in combating climate change, particularly within the transportation sector. These renewable energy sources present both opportunities and challenges, with different types offering unique advantages and facing distinct hurdles. Policies and innovations, such as the mandatory biodiesel program in Indonesia and the evolving biohydrocracking technology, further influence biofuel consumption and quality. However, alongside these advancements, concerns for the sustainability of biofuels persist. With the right policies and investments in research and development, biofuels can play a crucial role in the ASEAN region's efforts to mitigate climate change and achieve a sustainable energy future.

Case Study

Neste’s Commitment Towards Sustainable Aviation

Neste is a Finnish oil refining and marketing company that produces and sells a variety of petroleum and renewable products. The company’s products include gasoline, diesel fuel, aviation fuel, heating oil, light and heavy fuel oil, base oils, gasoline components, specialty fuels, solvents, liquid petroleum gas (LPG), bitumen, renewable diesel, and renewable aviation fuel. Neste is also the world's largest producer of renewable diesel and renewable jet fuel refined from waste and residues.

Neste MY Sustainable Aviation Fuel (SAF) is a cleaner, direct replacement for fossil jet fuel that reduces greenhouse gas emissions by up to 80% compared to its fossil counterpart. Produced from 100% renewable waste and residue raw materials, such as used cooking oil and animal fat waste, it is both sustainable and environmentally responsible.

Currently, Neste produces 100,000 tons of SAF annually, with plans to increase production to 1.5 million tons by the end of 2023. To advance the use of SAF in the aviation sector, the company has partnered with Airbus, focusing on technical development, fuel approval, and testing of current and future production technologies. Neste has also signed deals with Boeing and Wizz Air to supply SAF for their operations.

The fuel is produced through a hydrotreatment process, which removes impurities and yields a high-quality, drop-in fuel that can be used in existing aircraft engines

without any modifications. This process involves heating the raw materials to high temperatures and pressures in the presence of hydrogen, breaking down long-chain hydrocarbons into shorter chains and removing impurities such as sulfur and nitrogen. Neste's commitment to sustainability and responsibility is reflected in its production process, which is designed to minimize waste and emissions.

To ensure the sustainability of its raw materials, Neste sources them from sustainably-sourced, 100% renewable waste and residue materials. The company collaborates with partners across the value chain to promote the use of renewable fuels in the aviation industry and employs established life cycle assessment methodologies, such as CORSIA methodology, to calculate the greenhouse gas emissions reduction achieved by using its SAF.

Using Neste MY Sustainable Aviation Fuel is a key solution to help reduce greenhouse gas emissions in air travel. The fuel is already in use worldwide, with companies like Finnair purchasing 750 tons of Neste MY SAF for flights departing Helsinki Airport. Neste and Air Canada have also expanded their collaboration with an additional supply of 9.5 million liters (2.5 million gallons or 7,500 tons) of Neste MY SAF. As Neste continues to forge partnerships and increase global availability of SAF, the aviation industry moves closer to a more sustainable future.

Source: Asian Aviation (2023); BP (2019); Neste (2022a; 2022b)

4. Sustainability aspects of biofuels: addressing the concerns

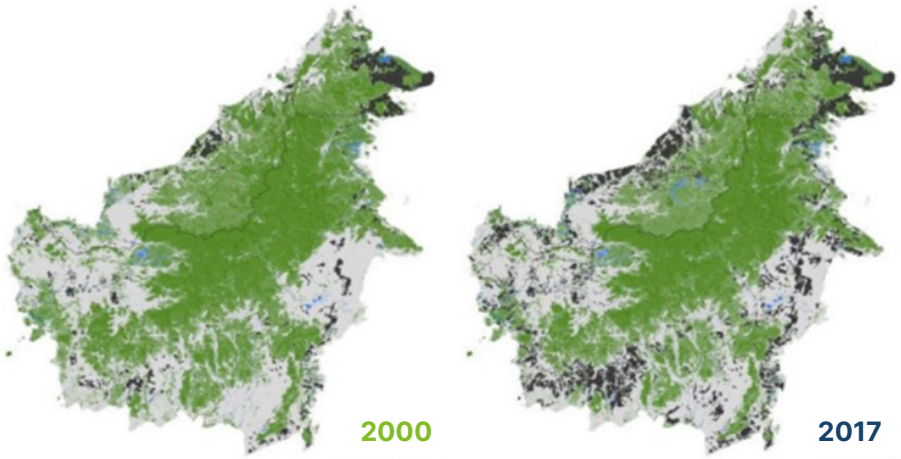
Biofuels are produced from renewable feedstocks, making their production and use theoretically sustainable. However, the production of these feedstocks comes with environmental impacts such as land use, water consumption, and effects on biodiversity. Therefore, the sustainability of biofuels depends on the consideration of various social and environmental aspects.

The main crop for biofuel in the ASEAN region is palm oil. Palm oil has been viewed with critics especially regarding to land conversion in Indonesia and Malaysia.

The environmental impact of palm oil production for biofuels is a topic of concern. Despite facing controversies, palm oil remains a major source of bioenergy in regions like Indonesia and Malaysia, largely due to the already existing palm oil plantations. However, the governments in these countries have not remained passive. They have implemented measures to ensure the sustainability of the palm oil industry.

Indonesia, for instance, has taken significant strides towards enhancing the sustainability of its palm oil sector. The government implemented a moratorium on new palm oil plantations and the expansion of existing ones, aiming to halt the conversion of natural forests into palm oil production areas. In 2017, they initiated replanting programs for smallholder palm oil plantations to bolster productivity and sustainability. In line with the Indonesian Sustainable Palm Oil (ISPO) certification, both the government and the palm oil industry have committed to achieving 100% sustainable palm oil production. While the action of the palm oil industry in the 1980s and 1990s may have led to deforestation when opening land for palm oil plantations, the scenario has shifted significantly post-2000. The expansion of palm oil plantations during this period mainly involved the conversion of degraded, unproductive lands. By transforming these lands into palm oil plantations, they are now actively contributing to carbon absorption and subsequently reducing overall carbon emissions.

A significant portion of the plantations are established on lands previously subjected to enviromental degradation due to historical deforestation.



Green to white
forest loss

White to black
cleared forest replanted by palm oil

Green to blue
forest permanently flooded by hydropower dams

Source: Gaveau et al., 2019

Figure 7. Palm oil expansion in Borneo, Indonesia, over the years

Similarly, palm oil is also a leading contributor of biomass in Malaysia. The Malaysian government has also promoted palm oil biodiesel as a sustainable and eco-friendly fuel alternative. The launch of the National Biofuel Policy in 2006 marked the major efforts from the country towards ensuring the sustainability of its biofuel and palm oil sector. The policy was designed with a threefold objective: to discover green renewable energy sources, strengthen the country's palm oil industry, and reduce dependency on rapidly depleting fossil fuels. The Malaysian government is devoted to ensuring that palm oil remains a sustainable and competitive alternative fuel for global markets. As part of this commitment, the government has pledged to preserve half of Malaysia's total land areas as forests.

In a pioneering move, Malaysia became the first and only country globally to mandate sustainability certification for its oil palm industry, actively defending its sustainable standing. This commitment extends to regional efforts as well, with the Sabah government in Malaysia implementing innovative measures to protect forests, end labor abuses, and improve agricultural practices.

4.1 Certification as a way to address sustainability issues

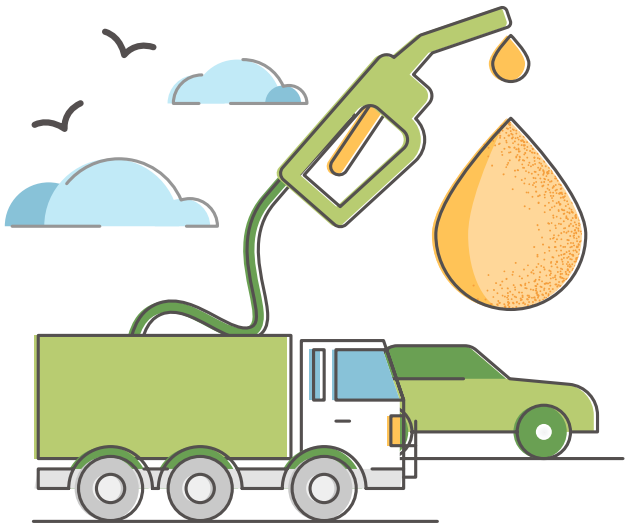
The palm oil industry has faced significant scrutiny due to its environmental and social impacts, including deforestation, habitat destruction, and labor rights issues. In response to these concerns, several certification schemes have been established to promote sustainable palm oil production. These certification initiatives aim to address the complex challenges associated with the palm oil supply chain and ensure that the production of this widely used commodity aligns with stringent environmental and social standards.

The Roundtable on Sustainable Palm Oil (RSPO) is the leading certification standard for the use of palm oil that establishes sustainability standards for palm oil production, encompassing environmental, social, and economic aspects. The certification process requires companies to demonstrate adherence to RSPO Principles and Criteria for Sustainable Palm Oil Production, which cover responsible land use, biodiversity conservation, greenhouse gas emission reduction, and protection of workers' rights and community interests. The International Sustainability and Carbon Certification (ISCC), on the other hand, is a certification scheme that covers a wide range of biofuels and biomaterials, including palm oil. RSPO and ISCC certifications are increasingly crucial for accessing international markets and gaining the trust of stakeholders in the palm oil industry, especially in the EU and other developed countries. These certifications are essential to maintaining the competitiveness of this commodity and protecting its safety in trade.

In response to concerns over the sustainability of palm oil production, the governments of Indonesia and Malaysia have developed guidelines to help the industry meet international sustainability standards. The Indonesian Sustainable Palm Oil (ISPO) standard, introduced by the Government of Indonesia in 2011, aims to ensure that all Indonesian oil palm growers, regardless of whether they export to foreign markets, adhere to higher standards. In 2013, Malaysia introduced the Malaysian Sustainable Palm Oil (MSPO) certification scheme, which became a mandatory requirement in January 2020, covering even independent smallholders. Similarly, as per the latest regulations, it is now mandatory for all oil palm growers, including smallholders, to obtain ISPO certification by November 2025. These standards align closely with national legal and regulatory requirements and cover the entire palm oil supply chain, from independent and organized smallholders to plantations and mills.

RSPO, ISCC, ISPO and MSPO are currently the dominant certification systems in Indonesia and Malaysia. RSPO and ISCC the certification systems identified are voluntary while ISPO and MSPO are mandatory. The stringent standards enforced by RSPO and ISCC are implemented with the primary objective of promoting responsible and sustainable palm oil production on a global scale. ISPO and MSPO play a crucial role in establishing alternative frameworks that cater to smallholders who may lack the capacity or resources to participate in the RSPO (Higgins and Richards, 2019). These national sustainability standards provide a means to reframe sustainable palm oil practices, allowing the palm oil sector in Indonesia and Malaysia to address the perceived challenges of RSPO certification.

In addition, ISPO and MSPO certifications have significantly evolved from their initial versions, continuously updating their requirements. This signifies the integration of various important aspects, including environmental thresholds, smallholder inclusion, protection of indigenous peoples and labor rights, governance and decision-making, monitoring and verification, as well as traceability. These updates ensure that the certifications meet the same high standards as other international certifications. Therefore, considering the significant importance and relevance of the ISPO and MSPO certifications in promoting sustainable practices, it is crucial and highly desirable that these certifications be universally accepted and recognized on a global scale.



	National		International	
INDICATORS/SCHEME	ISPO Indonesian Sustainable Palm Oil	MSPO	ISCC International Sustainability & Carbon Certification	RSPO Certified Sustainable Palm Oil
SCHEME				
Prerequisites for certification	☑	⊗	☑	☑
Certification scheme	☑	☑	☑	☑
Accreditation body	☑	☑	☑	☑
Funding incentives	☑	☑	⊗	☑
Suppy chain system	☑	☑	☑	☑
Labelling scheme	⊗	☑	☑	☑
SOCIAL/ENVIRONMENTAL				
Social development	☑	☑	☑	☑
Gender discrimination	☑	☑	☑	☑
No child labor	☑	☑	☑	☑
No forced labor	☑	☑	☑	☑
Enviromental management and protection	☑	☑	☑	☑
Industrial waste management	☑	☑	☑	☑
Greenhouse gas emissions	☑	☑	☑	☑
SMALLHOLDERS				
Addressed in standard	☑	☑	☑	☑
Fair treatment in supply contracts	☑	☑	⊗	☑
Provision of financial support	☑	☑	⊗	⊗
Smallholder accessibility programs	☑	☑	☑	☑
PETLANDS/FOREST LAND				
Peatland planting ban	☑	☑	☑	☑
Primary forest clearance ban	☑	☑	☑	☑
Addresses High Conservation Value	☑	⊗	☑	☑
LAND TENURE				
Complaint system	☑	☑	☑	☑
Conflict resolution	☑	☑	☑	☑

Figure 8. Comparison of ISPO with Other Palm Oil Certification Schemes

4.2 Regulation, focus on Sustainability

The regulatory frameworks for biofuels in ASEAN countries exhibit variations due to the differing policies, regulations, and targets set by each country. Nonetheless, collaborative efforts are being made to foster harmonization and cooperation within the region, aiming to establish unified standards and guidelines that align with the regulations of ASEAN countries for the production and utilization of biofuels.

IRENA emphasizes the crucial role played by national and regional regulatory frameworks in ensuring the sustainability of biofuels in the ASEAN region. These frameworks establish specific conditions and requirements during the project licensing process, while also monitoring post-project performance to ensure compliance. It is of utmost importance for the regulatory framework to define sustainability criteria that are specifically tailored to the ASEAN context.

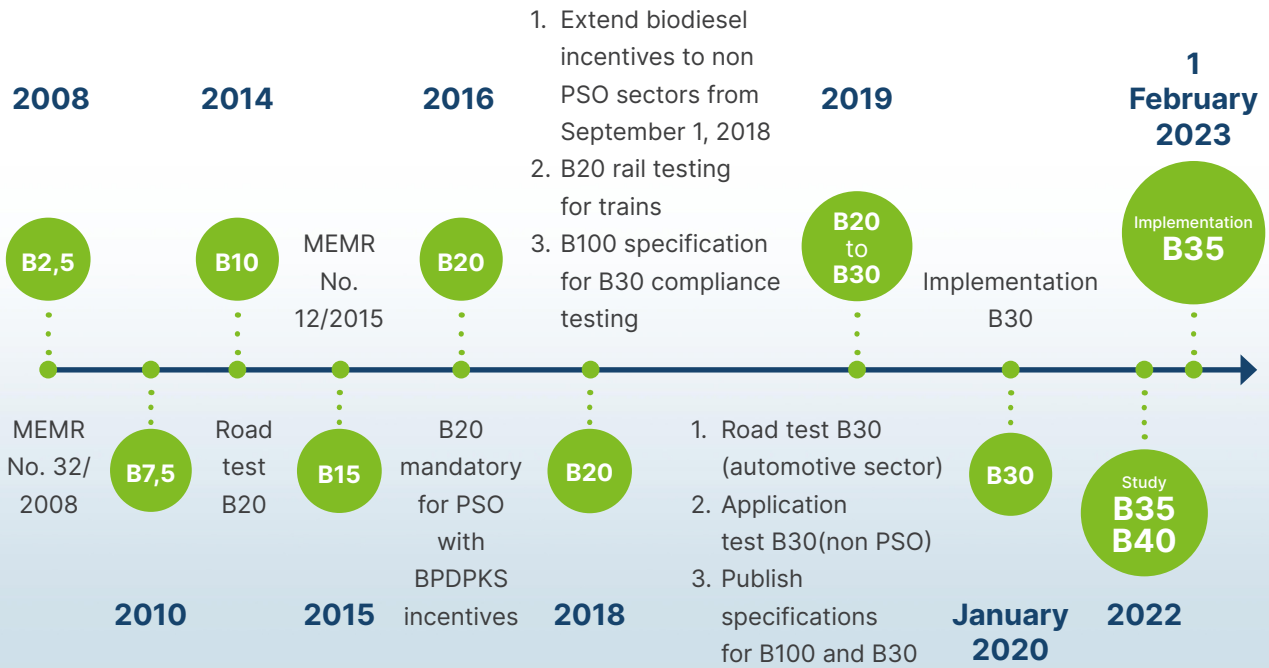
Policy for Biofuel Development: A Case Study of Indonesia

The National Energy Management Blueprint for 2005-2025 is a plan crafted by the Indonesian government that aims to foster the development of alternative energy sources and enhance the exploration of renewable energy. This plan includes the use of palm oil-based biodiesel as a renewable source of energy in Indonesia. The use of biofuels, such as palm oil-based biodiesel, is seen as a means to reduce the nation's dependence on fossil fuels and promote sustainable energy practices. The government is committed to implementing different programs and initiatives to support the growth of the biofuel industry, and to encourage the production and use of biodiesel. The end goal of these efforts is to achieve a sustainable energy future for Indonesia, while also contributing to global initiatives aimed at combating climate change.

The Indonesian government has taken significant steps to support the growth of the biofuel industry, which serves as a sustainable alternative to traditional fossil fuels. This commitment by the government is aimed at promoting the use of renewable energy sources and reducing the nation's reliance on non-renewable ones. The current policies and regulations provide a nurturing framework for the development of the biofuel sector in Indonesia, and this includes the use of biodiesel.

Biofuel development in Indonesia has undergone progressive implementation starting in 2006 with Presidential Regulation No. 5 of 2006, followed by the Regulation of the MEMR No. 41 of 2018. The government has consistently encouraged the gradual increase of biodiesel content in fuel, with targets set at 7.5% in 2010, 10% in 2011, 15% in 2015, 20% in 2016, 30% in 2020, and now mandating 35% in 2023. The nationwide implementation of B35 is scheduled to take place in February 2023, as outlined in the MEMR Decree Number 205.K/EK.05/DJE/2022. The adoption of B35 signifies Indonesia's leading position as pioneers in the utilization of biodiesel, particularly in the transportation sector. This commitment showcases Indonesia's dedication to sustainable energy practices and further establishes the nation as a global leader in the use of biodiesel. Figure below shows the development of regulation supporting biodiesel in Indonesia.

Biodiesel Mandatory Program in Indonesia



Source: MEMR (2022)

The Indonesian government has recently enacted new regulations that make it mandatory for the transportation sector to adopt Biodiesel B35, with the implementation slated to commence in February 2023. Furthermore, President Joko Widodo during his presidential speech on August 16th 2019 expressed his optimistic vision for the future, aiming to expand the use of biofuels to higher blends such as B40, B50, and potentially even B100 or biofuel 100% (MEMR, 2022). This signifies Indonesia's commitment to promoting the use of biofuels as a sustainable alternative to fossil fuels.

Table 3. Program value from mandatory biodiesel program in Indonesia

Benefits	Program Value				
	B20 2018	B20 2019	B30 2020	B30 2022	B35 Targets for 2023
Volume used	**3,75 million kL** 23,59 million barrels/year 64,62 thousand barrels/day	**6,62 million kL** 41,68 million barrels/year 114,21 thousand barrels/day	**9,59 million kL** 60,31 million barrels/year 165,24 thousand barrels/day	**10,5 million kL** 66,04 million barrels/year 180,93 thousand barrels/day	**13,15 million kL** 82,70 million barrels/year 226,56 thousand barrels/day
Savings in foreign exchange	USD 1,89 billion	USD 3,54 billion	USD 5,13 billion	USD 8,34 billion	USD 10,75 billion
GHG emission reduction and environmental quality improvement	5,61 million tonnes CO_2	9,91 million tonnes CO_2	14,25 million tonnes CO_2	27,8 million tonnes CO_2	34,9 million tonnes CO_2

Source: Ministry of Energy and Mineral Resources Republic of Indonesia

4.3 Collaboration

Collaboration and partnership among governments, industry stakeholders, and civil society organizations is critical in disseminating information and addressing concerns surrounding biofuel development. Through these partnerships, stakeholders can work together to promote sustainable practices and share their knowledge and expertise in the development and implementation of biofuel programs. Productivity can be enhanced through collaboration, thereby negating the need to expand land usage.

Government

Establish regulatory frameworks and incentives to fosterthe growth of the industry

Industry and Academia

Contribute technical know-how and resources

Civil society organization

Function as watchdogs, advocating for environmental and social responsibility in biofuel production and flagging any issues or concerns that arise

Collaborative efforts can also address potential concerns related to biofuel development, such as land use change, deforestation, and social impacts. For instance, a successful collaboration between the Bandung Institute of Technology (ITB) and the Oil Palm Plantation Fund Management Agency (BPDPKS) has resulted in the development of catalyst technology and the establishment of a pilot unit for producing biohydrocarbon gasoline using palm oil as the primary raw material. The importance of this research lies in its aim to create downstream opportunities for smallholder oil palm plantations, addressing both food and energy security. This is achieved through the application of the circular economy concept, which focuses on premium palm oil production, edible oil, and palm gasoline on a technological scale that can be readily implemented in smallholder oil palm plantations. The study's outcomes will not only lead to the production of recommended institutional models for small-scale palm oil processing but also yield two essential products: healthy edible oil and bio-hydrocarbon vegetable gasoline. These innovations hold significant promise for advancing sustainability and enhancing the overall viability of smallholder oil palm operations.

By engaging with local communities and other stakeholders, concerns and issues can be identified and resolved through dialogue and cooperation. Furthermore, partnerships can establish trust and understanding among different groups, supporting a common vision for sustainable biofuel development.

5. Prosperity through biofuels

Increasing income and employment through biofuels can be an effective solution to enhance the well-being of ASEAN societies, such as Indonesia and Malaysia. The palm oil sector in Indonesia created approximately 16 million jobs in 2019, with over 4 million jobs located in rural areas (Stikkers, 2019). Another success story can be found in Riau Province, where the development of palm oil plantations successfully reduced the poverty rate from 33% in 2002 to 8% in 2016 (Hendy, Firmansyah, & Wahyu, 2018).

Similarly, in Malaysia, the palm oil sector generated around 2 million jobs by 2019. The palm oil industry directly provides employment opportunities for about 570,000 people and indirectly benefits approximately 3.5 million individuals in Malaysia (Goh & Potter, 2022). Despite facing criticism concerning its environmental impact and effects on indigenous communities in both countries, the palm oil sector remains a significant contributor to employment and the economy in Indonesia and Malaysia.

By sustainably developing palm oil-based biofuels, both nations can harness this potential to improve the well-being of their societies and achieve sustainable development goals.the sustainability of the palm oil industry.

The production and use of biofuels not only have the potential to increase income and employment but also provide economic opportunities to farmers and reduce fossil fuel dependence. This, in turn, can accelerate the transition to a petroleum-free transportation system. Furthermore, the development of the biofuels industry in Indonesia is considered a means to reduce oil imports and subsequently decrease the country's trade deficit. For instance, in 2022, the utilization of B30 biofuels amounting to 6.36 million kL successfully saved foreign exchange of USD 8.34 billion (MEMR, 2020).

On a global scale, the United States, Canada, Brazil, and India play a significant role in the expansion of biofuel use, accounting for 80% of the global biofuel adoption from 2019- 2022 due to their comprehensive policies (IEA, 2022).

In conclusion, biofuels offer a promising solution to increase income, employment, and sustainable development in ASEAN societies such as Indonesia and Malaysia. By leveraging the success and potential of the palm oil sector and implementing sustainable practices, both countries can achieve economic growth, reduce dependence on fossil fuels, and contribute to a more sustainable future. Additionally, the development of the biofuels industry presents opportunities to smallholders and can lead to a petroleum-free transportation system, ultimately benefiting society and the environment as a whole.

6. Learning from the past

Success Story of B30 Implementation: Indonesia's Transition to Higher Blend Biofuel

In Indonesia, the implementation of a Mandatory Biodiesel Policy has yielded a range of positive outcomes, including the increase in renewable energy usage, reduction of CO2 emissions, job creation, and income growth for smallholders. This policy has not only fostered the development of the biodiesel industry but also generated employment opportunities in the oil palm plantation sector. According to MEMR, the mandatory biodiesel policy implemented from 2015 to 2020 had the following impacts:

1. A substantial reduction of 23.17 million tonnes of carbon dioxide equivalent (CO_2e) in GHG emissions was achieved.
2. The domestic utilization in 2018-2020 of biodiesel reached an impressive volume of 19.96 million KL.
3. In 2018-2020, significant savings amounting to US$10.56 billion in foreign exchange were realized due to a reduction in the importation of fossil fuels.

Additionally, the implementation of this policy has led to job creation within the biodiesel industry and the oil palm plantation sector. The increased demand for biodiesel has spurred investment and expansion of biofuel production facilities, resulting in new employment opportunities. The policy also has significantly increased the demand for CPO. This, in turn, has stabilized CPO prices and improved the income of smallholders, who benefit from higher prices of FFB, the primary input for CPO production. Thus, the implementation of B30 in Indonesia has sparked significant growth in the domestic biodiesel industry.

Furthermore, the successful implementation of B30 in Indonesia has demonstrated the country's commitment to sustainable energy practices and its achievements in the biofuel sector. This milestone showcases the positive impacts of B30 on the environment, energy security, and economic growth.

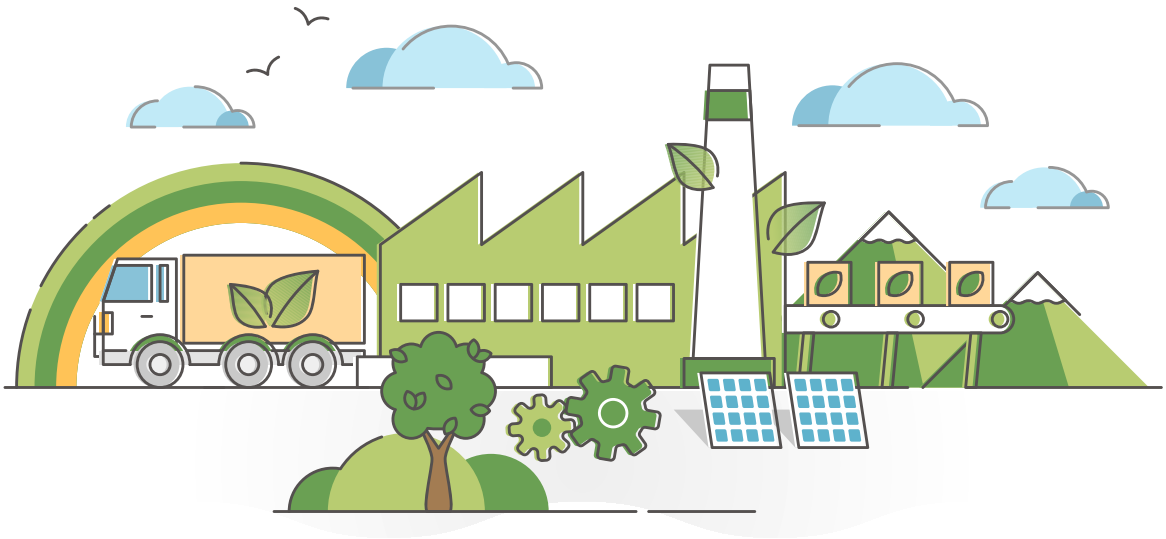
Challenges in Expanding the Mandatory Biodiesel Program.

Expanding the mandatory biodiesel program to encompass B100 (100% biodiesel) presents specific challenges that require careful consideration. According to Boestami (2020), the expansion of the program poses several key challenges, which can be clarified as follows:

1. One of the key challenges in expanding the mandatory biodiesel program from B35 to B100 lies in ensuring the quality of biodiesel products, particularly during the blending process. It is essential to enhance the overall quality of biodiesel products, focusing on improvements in both processing and blending stages. Thus, new technology is crucial to ensure consistent and high-quality production of B100 and its direct usage in existing diesel combustion engines.

2. Despite some interchangeability with existing fossil fuel infrastructure, several logistics and infrastructure issues still pose significant concerns. Adequate logistics and storage facilities, as well as efficient transportation distribution systems, must be in place to ensure equal distribution of biodiesel. Moreover, there is a need to address the issue of limited mixing facilities, which can hinder the smooth implementation of the program. To overcome these challenges, it is necessary to establish and prepare additional logistics and blending facilities.
3. Another critical aspect to consider is the perspective of consumers, particularly those in the transportation sector. These consumers harbor concerns regarding the performance, reliability, and durability of their vehicles when using biodiesel, specifically higher than B35. To address their concerns and promote consumer confidence, various measures can be taken. Firstly, support from the vehicle manufacturers should be provided, along with incentives for consumers to use higher blend biodiesel products. Additionally, proper engine testing should be conducted specifically to ensure compatibility and mitigate any potential issues.
4. Furthermore, it is crucial to recognize that not all stakeholders may be interested in supporting the implementation of the mandatory biodiesel program. Therefore, a more intensive outreach and public education campaign should be undertaken. This initiative will help create awareness among stakeholders, addressing any misconceptions or reservations they may have, and garnering their support for the program.

Therefore, effectively addressing these challenges necessitates the adoption of a multi-faceted approach that entails collaborative efforts among government agencies, industry stakeholders, and research institutions. Comprehensive policies, incentives, and regulations, along with ongoing research and development efforts, can help overcome these challenges and facilitate the successful expansion of the mandatory biodiesel program to B100.



Lessons from Biofuel Programs in Brazil

Brazil has a long history of supporting biofuels, including the proliferation of flex-fuel vehicles (FFVs), that can operate on gasoline and any blend of gasoline and ethanol up to 83%, with only a few modifications to the engine and fuel system. In the 1970s, the country launched Proálcool, a program that promoted the use of ethanol as a fuel, paving the way for the adoption of FFVs. In 2004, Brazil established the National Program of Production and Use of Biodiesel (PNPB). And in 2019, Brazil launched RenovaBio, a comprehensive biofuel program aimed at reducing greenhouse gas emissions.

Brazilian flex-fuel vehicles have been present in the automotive market since March 2003, marking a significant increase in their mass production and commercialization. By March 2018, Brazil boasted the world's largest fleet of flexible-fuel vehicles, with 30.5 million cars and light-duty trucks, and over 6 million flexible-fuel motorcycles registered in the country. These vehicles are optimized to run on any mix of E20-E25 gasoline and up to 100% hydrous ethanol fuel (E100), making Brazil a frontrunner in the transition to biofuels.

RenovaBio has been successful in boosting the biofuel industry and reducing reliance on imported fossil fuels. The program has also faced some challenges, such as the COVID-19 pandemic and the oil price war in 2020. Despite these challenges, Brazil's biofuel programs and FFV integration have been a success and offer valuable insights for other countries. Some of the key insights that can be learned from Brazil's biofuel and FFV programs are:

- Government support is essential for the growth of the biofuel industry. Brazil's biofuel programs have all been supported by the government, through subsidies, tax exemptions, and other measures. This support has been essential for the development of the biofuel industry and its ability to compete with fossil fuels.

- Technological innovation, such as the introduction of FFVs, is key to increasing the utilization of biofuels. Brazil's programs have also been supported by investments in research and development, leading to the development of new technologies which have made biofuels more widely available and affordable.

- A multi-stakeholder approach is essential for success. Brazil's biofuel programs have been successful because they have involved a wide range of stakeholders, including the government, private companies, research institutions, and non-governmental organizations. This approach has helped to ensure that the programs are aligned with the needs of all stakeholders and that they are sustainable in the long term.

- Flexible and adaptable policies are needed to manage the biofuel sector. Brazil's biofuel programs have been successful because they have been flexible and adaptable. The government has been willing to adjust the programs as needed to address changing market conditions and strategic objectives. This flexibility has helped to ensure that the programs remain effective and relevant.

Brazil's biofuel programs and the adoption of FFVs are a valuable example for other countries that are looking to reduce their reliance on fossil fuels and transition to a cleaner energy future. By following the insights from Brazil's experience, other countries can increase their chances of success in developing their own biofuel programs.

7. Recommendations for the Long-Term ASEAN Energy Strategy

7.1 Biofuel Target and Policy in ASEAN Countries

Biofuels are widely recognized as a pivotal instrument for diversifying the energy mix within the ASEAN region, presenting an essential solution to decarbonize energy systems. According to the ASEAN Energy Outlook report in 2020, several ASEAN countries have made significant progress in implementing blending mandates for biofuels. Indonesia has set ambitious targets, aiming to achieve B40 by 2030. Malaysia has already implemented blending mandates of B20 and E10. Similarly, Thailand has adopted blending mandates of B20, with a target of achieving a 20 to 25 percent biofuel share in total energy demand by 2037. The Philippines has set targets of B10 by 2040 and E20 by 2040. Lastly, Vietnam aims to increase biofuel energy mix in the transport sector's fuel demand with B10 and E10 by 2050. These initiatives reflect the commitment of ASEAN countries to promote biofuels and diversify their energy sources.

Table 4. Biofuel target and policy in ASEAN countries

Country	Biofuel Target and Policies
Cambodia (ERIA, 2019)	Initiative program from the General Department of Petroleum is seeking business opportunities for biofuel (E3 gasoline will be possible by 2025)
Indonesia (ACE, 2022; MEMR, 2023)	Biodiesel blending ratio target 30% by 2025; Bioethanol blending ratio 20% by 2025 and 50% by 2050
Lao PDR (ACE, 2022)	10% biofuel share (blending ratio 5%-10%)
Malaysia (MPIC, 2023)	• Targeted B20 biodiesel programme implementation started in 2020 • B30 biodiesel programme is planned for implementation by 2030
Philippines (ACE, 2022; FAFD, 2021)	• Implement 5% blending for biodiesel starting in 2022 • Target biofuel blends B20 and E20/85 by 2030

Country	Biofuel Target and Policies
Thailand (ACE, 2022)	20%–25% biofuel share in TFEC
Vietnam (Mofijur et al., 2015)	• Increase production E5/ B5 since 2015 • Ethanol and vegetable oil output will reach 1.8 million MT, satisfying some 5% of the whole country's gasoline and oil demand, vision to 2025

Source: Adapted from ACE (2022)

Through policy frameworks, such as blending mandates and feed-in tariffs, ASEAN countries are incentivizing the production and consumption of biofuels. Blending mandates require a certain percentage of biofuels to be mixed with conventional fuels, ensuring a market for biofuel producers and increasing the overall share of biofuels in the energy sector. Feed-in tariffs provide financial incentives for bioenergy projects, encouraging investment, and development in the biofuel industry.

The implementation of clear policy guidelines for biofuel blending mandates is of great importance for ASEAN countries. By accelerating the adoption of biofuel blending mandates, particularly up to B35 and E35, in more countries within the region, significant progress can be made towards achieving the regional renewable energy target. However, to fully capitalize on the potential of biofuels, extensive research and development (R&D) efforts are crucial. Thus, R&D activities should focus on advancing technologies, processes, and infrastructure to enhance the production of high-quality biofuels. This includes optimizing feedstock selection, improving production efficiency, and ensuring cost-effectiveness and environmental sustainability throughout the entire biofuel value chain.

	Short-term	Mid-term	Long-term
Upstream	• Improvement of feedstock pretreatment • Efficiency of oil crop plantation • Yield improvement of oil crop by genetic modification	• Adoption of bio-hydrocracking technology • Transesterification using heterogeneous catalyst • Transesterification using heterogeneous ethanol	New feedstock development
Midstream	• Value added process of by product from conventional process • Upgrading conventional biodiesel for higher blend • Utilization of existing fossil fuel infrastructure	Development of production, storage, and distribution facilities	Expansion and integration of production, storage, and distribution facilities
Downstream	• Emission treatment system modification to accommodate >B7 (beyond Euro 4) • Emission treatment system modification to accommodate >B20 (beyond Euro 4)	• Engine modification to accommodate the use of B100 E100 • Adoption of B100	Expansion of B100

Source: ASEAN Energy Outlook, 2022

Figure 9. ASEAN Biodiesel R&D RoadMap

ASEAN countries are witnessing a rising interest in biofuels, leading them to establish policies and targets aimed at progressively increasing the adoption of biofuels as an alternative to conventional fuels. Through active promotion and support for biofuel utilization, ASEAN countries have the capacity to make a positive impact on global energy transition endeavors, thereby forging a path towards a more sustainable future.

"Advancing Sustainable Energy: The Development of Palm-Based Green Fuels in Indonesia"

The development of renewable energy has garnered significant recognition and has been designated as a critical national strategic project, as explicitly stated in the Presidential Decree. The primary aim of establishing a renewable energy program is to make substantial contributions towards the national target of achieving 23% renewable energy in the overall energy mix by the year 2025. In this context, biofuels, including biodiesel, along with other variants of palm-based biofuels like Bio-hydrocarbon and Green Fuel, assume a pivotal role as integral components of the renewable energy sector.

President Joko Widodo envisions Indonesia achieving the usage of B100, including the possibility of exporting products like bio-Avtur. This goal is supported by several factors:

1. Indonesia holds the distinction of being the largest producer of palm oil globally, with projections indicating that palm oil production will surpass 50 million tons in the coming years.
2. A significant portion of Indonesia's palm oil is sourced from independent smallholder plantations. Consequently, the implementation of policies that promote domestic consumption of palm oil can concurrently contribute to the welfare improvement of smallholders.
3. Indonesia has made notable advancements in Catalyst technology, developed by its own experts, which enables the conversion of palm oil into bio-hydrocarbon fuel or Green Fuel. This technology encompasses various types of Green Gasoline, Green Diesel, and Green Avtur.

Despite the successful implementation of the mandatory biodiesel program, which has already reached B35 as of the beginning of 2023, there are several potential scenarios for the future utilization of palm oil-based biofuels. The first scenario involves further promoting the use of biodiesel, potentially increasing it to the B50 level. This approach aims to continue capitalizing on the benefits of biodiesel while increasing its overall contribution to the energy mix. Alternatively, the second scenario entails maintaining

the use of biodiesel at the B35 level and compensating for the remaining portion with green fuel products. This strategy seeks to diversify the renewable energy portfolio and potentially achieve the usage of B100 through the incorporation of other sustainable fuel alternatives. The chosen scenario will be determined based on careful considerations, taking into account various factors and considerations discussed earlier. These include the country's energy needs, sustainability goals, agricultural sector development, and technological advancements.

However, the successful implementation of higher advanced biofuels hinges on the application of new technologies across the value chain. Technological advancements in feedstock pre-processing, conversion processes, refining, and infrastructure development are vital for achieving superior fuel quality, maximizing energy output, and ensuring compatibility with existing infrastructure. Consequently, the development of new technologies for advanced biofuels holds significant potential in boosting sustainable biofuel production in the future.

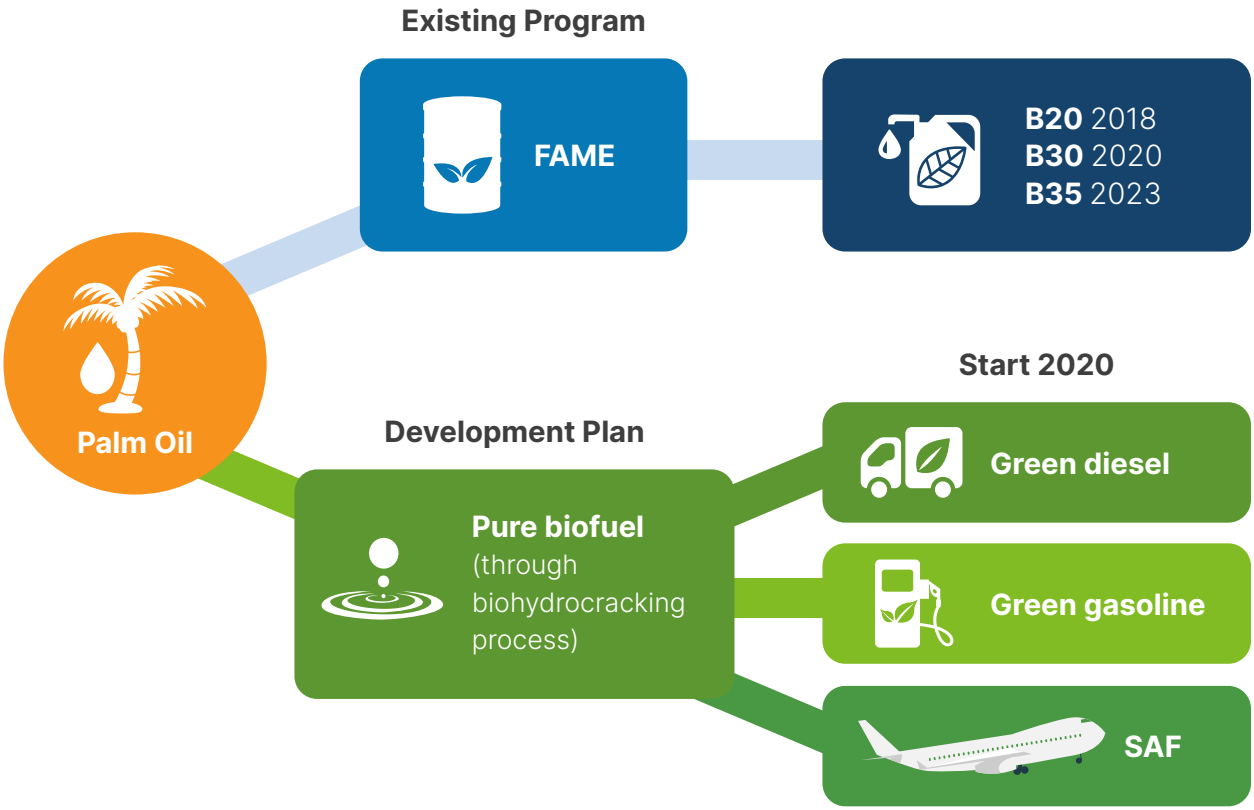


Figure 10. Potential scenario for the future utilization of palm oil-based biofuels

Thorough preparation throughout the entire process chain for the further development of palm-based biofuels, including green fuel, is essential. This encompasses readiness in the upstream sector, preparatory measures in refineries, logistics planning for storage and distribution, and preparedness in downstream sectors to engage the public as biofuel consumers. Moreover, the establishment of appropriate policies and fostering effective collaboration and coordination among stakeholders are key factors essential to achieving successful outcomes in this endeavor.

7.2 Balancing food security and biofuel production

The data on food prices and land use over an extended period of time has been examined to identify potential correlations between biofuel production and food prices or changes in land use. Economic models predict that biofuel will increase food prices. A study was conducted in the United States, comparing the food price index, biofuel prices, and land use. The average comparison of commodity price index (CPI) increases did not provide evidence of higher food CPI levels before and after the biofuel boom in 2000. The inflation rate of food prices from 1991 to 2000 (prior to significant biofuel production) and from 2000 to 2016 (following the biodiesel surge) did not differ significantly from the average inflation rate of 2.6% across the entire range. Despite an increase in biofuel production, US exports of corn and soybeans did not decline. In summary, our findings indicate that there have been no significant changes in US food prices due to biofuel, and biofuel has not led to significant changes in agricultural land use. The study concluded that satellite-based land use classification imagery does not currently possess the necessary accuracy for use in land use change analysis (Shrestha et al., 2019).

The balance between food security and biofuel production is an important issue with competition for resources. To address this, it is necessary to improve national policies and guidelines for the biofuels and agriculture sectors. Increasing crop yields and expanding agricultural land are a key focus, while research and development can reduce direct competition between biofuels and food through the development of high quality seeds and second and third generation biofuel technologies.

In Japan, it is necessary to consider food safety in the criteria of sustainable biofuels, while China needs to diversify biofuel raw materials. Competition between biofuels and food can have significant impacts, including rising food prices which pose a threat to food importing countries. However, in the long term, increased demand for biofuels may also provide opportunities for agricultural and rural development.

In China, it is assumed that the current production of non-food and cellulosic based biofuels will not have a serious impact on food security at the national and sub-national level due to the limited use of raw materials. Likewise in Japan, the current production of biofuels from by-products, agricultural waste products and soft cellulose is not expected to have a significant impact on food security at the national and sub-national level due to the relatively small amount of raw materials used. Competition between biofuels and food in Japan does not always have a negative impact on food security. The increase in agricultural commodity prices due to this competition can provide opportunities to increase farmers' incomes and promote rural development.

To address the challenge of striking a balance between food security and biofuel production in the ASEAN region, policy makers need to consider several key factors:

1. **Integrated Policy**
   It is important to design and implement integrated policies that take into account the interests of the biofuels and agriculture sectors. This policy should aim to encourage sustainable production of biofuels while ensuring food security for the population.

2. **Research and Development**
   Increased investment in research and development is essential to explore new technologies, increase crop yields, and increase the efficiency of biofuel production. Research and development efforts should be focused on developing second and third generation biofuels that minimize competition for food resources.

3. **Resource Efficiency**
   Improving resource efficiency in both the agriculture and biofuels sectors can help

reduce competition for land, water, and other resources. This can be achieved through improved farming practices, technological innovation, and the use of marginal lands for the production of biofuel feedstocks.

4. **International Cooperation**

   Collaboration between ASEAN countries and international partners is essential for sharing knowledge, best practices and transfer of technology in the field of biofuel production. This cooperation must also consider the impact on food security and aim for sustainable development in the region.for the production of biofuel feedstocks.

Overall, striking a balance between food security and biofuel production in ASEAN requires a comprehensive approach that takes into account economic, social and environmental dimensions. By adopting unified policies, investing in research and development, promoting resource efficiency, and promoting international cooperation, ASEAN countries can address these complex challenges and promote sustainable development in both sectors.

7.3 Preserving biodiversity and biofuel production

Biodiversity is the variety of life on Earth, including plants, animals, fungi, and microorganisms. It is essential for human health and well-being, providing food, water, air, and other essential services. Biofuel production, when sustainably managed, can effectively balance energy needs and biodiversity. Cultivation of biofuel feedstock does not necessarily lead to deforestation, especially when responsible strategies are implemented, it is possible to mitigate the potential harm that could lead to biodiversity loss.

To preserve biodiversity in the context of biofuel production, ASEAN countries can consider the following recommendations:

1. **Promote sustainable feedstock production.**

   Encourage the cultivation of biofuel feedstocks that have minimal impact on biodiversity, such as non-food biomass sources and agricultural residues (IRENA, 2017). This can help reduce land-use changes and competition for resources needed for food production.

2. **Implement strict sustainability criteria.**

   Establish and enforce sustainability criteria for biofuel production, including guidelines on land-use changes, deforestation, and the use of fertilizers and pesticides (ASEAN Centre for Biodiversity, 2013). This can help minimize the negative

impacts of biofuel production on biodiversity and ecosystems.

3. **Support research and development of next-generation biofuels.**
   Invest in the research and development of advanced biofuels that use non-food feedstocks and waste materials, such as palm oil waste, cellulosic biomass and algae-based resources (Merdekawati et al., 2023). These next-generation biofuels can help reduce the pressure on biodiversity and ecosystems while meeting the growing demand for biofuels.

4. **Adopt landscape-level planning and management.**
   Implement landscape-level planning and management approaches that consider the needs of both biofuel production and biodiversity conservation (Hughes, 2017). This can help balance the competing demands for land and resources while maintaining ecosystem integrity.

5. **Strengthen regional cooperation.**
   Enhance regional cooperation among ASEAN countries to share best practices, technologies, and experiences in sustainable biofuel production and biodiversity conservation (Figueroa, 2023). This can help promote the adoption of sustainable practices across the region and minimize the negative impacts of biofuel production on biodiversity.

6. **Monitor and evaluate the impacts of biofuel policies.**
   Regularly monitor and evaluate the impacts of biofuel policies and production on biodiversity and ecosystems (Lee et al., 2012). This can help identify potential issues and inform the development of adaptive management strategies to address these challenges.

7. **Raise public awareness and promote stakeholder engagement.**
   Increase public awareness of the importance of preserving biodiversity in the context of biofuel production and engage stakeholders, including local communities, in the decision-making process. This can help ensure that the of all stakeholders are considered in the development and implementation of biofuel policies and practices.

8. Conclusion

ASEAN countries have abundant agricultural resources, such as palm oil, sugarcane, and cassava, which can be utilized as feedstock for biofuel production. This availability of biomass feedstock provides a sustainable and renewable source for biofuel production within the region. Biofuels serve as a sustainable energy source and play a crucial role in reducing reliance on petroleum-based diesel and mitigating greenhouse gas emissions.

Summary of the key findings:

1. **The biofuel sector in the ASEAN region, predominantly reliant on palm oil production**, has seen significant growth due to increased demand for alternative energy sources.

2. **The biofuel supply chain infrastructure is vital for the sector's success, but is often inadequate, raising production costs and hindering growth.** Therefore, investments are needed in infrastructure, particularly transportation and storage facilities. The private sector can also play a crucial role in the biofuel sector's growth, thus necessitating supportive governmental incentives, regulations, and policies.

3. **Extensive research provides clear evidence that the implementation of biofuels can have a substantial impact, not only in terms of reducing emissions but also in driving economic growth.** The benefits extend beyond emission reductions and include employment opportunities, economic stimulation, enhanced energy security, and reduced fuel consumption in Indonesia and other regions.

4. **Biofuel offers significant potential in reducing climate change impacts.** The more sustainable second-generation biofuels, derived from non-food crops and agricultural waste, can offer substantial greenhouse gas reductions. The International Renewable Energy Agency (IRENA) projects biofuels to make up 10% of energy used in transportation by 2050, largely due to increased biofuel blending targets in various countries. While the growth of electric vehicles is crucial for reducing fossil fuel reliance, promoting biofuel adoption is also important, as about 20% of ASEAN vehicles might not be electric by 2050. Together, electric vehicles and biofuels could significantly cut carbon emissions in ASEAN's transportation sector.

Bioenergy is also being explored for power generation in countries like Thailand and the Philippines. Thus, with the right investments and policies, biofuels can substantially contribute to mitigating climate change and achieving sustainable energy goals.

5. **Biofuels production can pose sustainability challenges such as impacts on land use, water consumption, and biodiversity, particularly in palm oil production.** However, Indonesia and Malaysia, major palm oil producers, have implemented measures like moratoriums on new plantations, rejuvenation programs, and sustainable certification schemes, transforming degraded lands into carbon-absorbing plantations. Certifications like the Roundtable on Sustainable Palm Oil (RSPO) and International Sustainability and Carbon Certification (ISCC) enhance industry competitiveness. Regulations and collaborative efforts between governments, industry, and civil society also support biofuel industry growth, transition to renewable energy, and address potential concerns, showing that while biofuels production has its issues, steps are being taken to ensure sustainability and contribute to the fight against climate change.

6. **Analyzing past efforts in biofuel programs, both successful and unsuccessful,** provides critical insights into the necessity of comprehensive governmental support, stakeholder cooperation, robust and adaptable policies, and continual technological innovation, which can be used to refine and optimize future biofuel initiatives. For example, Indonesia's mandatory Bioethanol program launched in 2006 faced challenges due to lack of targeted incentives for the ethanol industry, absence of stakeholder coordination, limited distribution channels, and inadequate infrastructure. The supply chain for bioethanol also presented problems, such as high feedstock prices, lack of available land for alternative feedstock, lack of government support for land acquisition, and inadequate support for upgrading from industrial to fuel grade ethanol. In contrast, Brazil's successful biofuel programs like Proálcool, PNPB, and RenovaBio benefited from governmental support through subsidies and tax exemptions, technological innovation including investments in R&D, a multi-stakeholder approach involving the government, private companies, research institutions, and NGOs, and flexible and adaptable policies. Brazil's success provides valuable insights for countries seeking to reduce their reliance on fossil fuels and transition towards cleaner energy alternatives.

7. **The analysis of data on food prices and land use** in relation to biofuel production reveals that there have been no significant changes in US food prices due to biofuel, and biofuel has not led to significant changes in agricultural land use. The study emphasizes that satellite-based land use classification imagery currently lacks the required accuracy for land use change analysis. In the ASEAN region, balancing food security and biofuel production necessitates improved national policies and guidelines, focusing on increasing crop yields, expanding agricultural land, and advancing research and development for high-quality seeds and advanced biofuel technologies. Japan and China also face the challenge of diversifying biofuel raw materials and considering food safety criteria in sustainable biofuel production. While competition between biofuels and food can impact food prices, it may also present opportunities for agricultural and rural development. Addressing this challenge in ASEAN requires integrated policies, research and development efforts, resource efficiency improvements, and international cooperation to promote sustainable development in both the biofuels and agriculture sectors.

8. **Biofuel is instrumental for diversifying the energy mix within the ASEAN region,** presenting an opportunity to decarbonize energy systems. The implementation of clear policy guidelines for biofuel blending mandates is of great importance for ASEAN countries. Moreover, balancing food security and biofuel production presents a challenge, necessitating integrated policies, enhanced R&D, resource efficiency, and international cooperation to strike a balance. Biodiversity conservation in the context of biofuel production is crucial, with strategies such as promoting sustainable feedstock production, stringent sustainability criteria, supporting next-generation biofuels, adopting landscape-level planning, strengthening regional cooperation, monitoring policy impacts, and raising public awareness being recommended.

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IPOSS
Indonesia Palm Oil Strategic Studies

Indonesian Palm Oil Strategic Studies (IPOSS) is an independent think-tank institution established in 2022. Our aim is to promote the sustainability of the palm oil industry, which has provided benefits for millions of people in Indonesia alone, while also fulfilling the world's demand for food, oleochemical, and energy products. We provide comprehensive and insightful analysis to support informed decision-making and drive positive transformation in the palm oil industry.

SBM ITB

The School of Business and Management (SBM) Bandung Institute of Technology (ITB) was established on December 31, 2003. SBM ITB is located at the Main Campus of Bandung Institute of Technology (ITB), the best science and technology institute in Indonesia. SBM ITB has a role as the hub and orchestrator to develop and grow technopreneurs in Indonesia. In 2018 SBM ITB won an international accreditation, ABEST, and in 2021 SBM ITB has become among the limited AACSB accredited schools.

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We believe that through shared commitments and coordinated efforts, we can establish a robust and environmentally friendly biofuel industry, contributing to the region's energy security and emission reduction goals.

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