Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Complexities Of Biofuel Implementation In South-East Asia: A Policy Review

Loso Judijanto

IPOSS Jakarta
losojudijantobumn@gmail.com

The rising energy requirements and global concern over climate change have accelerated the search for renewable sources of energy in Southeast Asia. One of the most promising is biofuels, developed from organic renewable resources as a way of reducing carbon emissions and dependence on fossil fuels. This study reviews the policies that cover the opportunities and challenges in implementing biofuels within Southeast Asia with special reference to the palm oil industry in Indonesia and Malaysia. The paper brings out the current status of biofuel production, infrastructure, and policy framework within the region calling for more investments, improvement in technology, and the issue of sustainability. It further raises the issue related to food security, land use changes, and biodiversity conservation that ushers the need to strike a good balance between production and environmental protection. The paper, through a review of successful biofuel programs in other regions, brings out the key lessons and policy recommendations that can facilitate the uptake of biofuels in Southeast Asia. The findings underline the enormous potential that the use of biofuels brings to sustainability of the energy future, economic growth and environmental preservation within the region.

Keywords: Biofuels, Southeast Asia, Palm oil, Sustainability, Policy review

INTRODUCTION

The rapid growth of the global energy demand is a more reason behind the search for sustainable sources of energy. Organic biomass, which is basically biofuel, is a source that has gained more attention in reducing greenhouse emissions and lessening the use of fossil fuels (Rai et al., 2022). The abundance of biomass resources and growing energy needs in Southeast Asia thus make a potential pathway for biofuel production(Mofijur et al., 2015). Besides, diversified agriculture, including massive palm oil plantations, provides a sustainable feedstock meant for biofuel production in the region(Statista, 2024). Indeed, the Biofuel implementation in Southeast Asia is challenged by a host of issues from technological limitations to insecurity of food and environmental sustainability(Brinkman et al., 2020; Soam and Börjesson, 2020; Ahmed et al., 2021).

As one of the major sources for greenhouse gas emissions, the transport sector gives an immense opportunity to blend biofuels within it (IRENA, 2022; Hassan et al., 2024). Biodiesel and bioethanol could either be blended with petrol or diesel or can be used directly in petrol- and diesel-powered vehicles, respectively, to substitute fossil fuels with greener alternatives

(Zuurbier and van de Vooren, 2008; Cherwoo et al., 2023). Furthermore, biofuels are invigorators of economic development because the sector creates employment, increases rural earnings via feedstock supply, and reduces reliance on imported fossil fuels (Hendy, Firmansyah and Wahyu, 2018). But then, expanded biofuel value chains pose the issue of encroaching into food crops' territory in terms of land and resource competition, hence inflating food insecurity as well as prices(Searchinger et al., 2008; Brinkman et al., 2020; Ahmed et al., 2021). On the other hand, the sustainability of the production of biofuel feedstocks especially oil palm has been challenged because of the apparent linkage with the activities of deforestation and habitat destruction(Gaveau et al., 2019).

Challenges and coherent policies — that is, policies for sustainability, economic viability, and social inclusivity — are two fundamental requirements to ensure successful implementation of biofuels in Southeast Asia. The former should be viewed from a multifaceted approach, including technology development, regulatory framework, and stakeholder collaboration and public awareness campaigns, while the latter should be obtained through the lesson learned from other countries. Best practices facilitate the southeastern country in developing the complexity of biofuel development to make it flourish(IRENA-ACE, 2022; Susilowati et al., 2023).

Multi-dimensional approach of technological advancement, regulatory framework, stakeholders' collaboration and public awareness campaign(Boestami, 2020). By learning from past experiences and best practices from around the world, Southeast Asian countries can navigate the complexities of biofuel development and unlock its full potential(HumasEBTKE, 2023).

Objective

This paper will provide a review of the prospective policy framework for the implementation of biofuels in the Southeast Asian countries. It will discuss the opportunities as well as the challenges related to the production and use of biofuels and potential feedstocks along with technological developments and policy interventions.

Research Method

The study would use the qualitative research method and therefore an extensive review of the literature on existing policies regarding the development of biofuels in the region to case studies and expert opinions (Creswell and Creswell, 2018; Pawar, 2020). Having critically assessed the present landscape, with policies as well as identifying the key policy gaps, this research is perceived to be adding inputs into the development of effective and sustainable biofuel policies in Southeast Asia.

RESULTS AND ANALYSIS

The Southeast Asian region is witnessing a significant rise in energy consumption, primarily driven by factors such as population growth, urbanization, and industrial expansion. This trend is evident as the region's energy demand has increased by about 3% annually over the past two decades and is expected to continue growing(IEA, 2024). The reliance on fossil fuels to satisfy this increasing demand has led to concerns about energy security, environmental degradation, and climate change. The Southeast Asia energy sector is primarily reliant on fossil fuels, this has led to a significant increase in carbon dioxide emissions (IEA, 2019). This dependency poses risks to the region's energy security and climate goals(Ock, 2024).

Biofuels present a viable alternative to fossil fuels, offering a sustainable solution that can reduce greenhouse gas emissions, create jobs, and stimulate economic growth(Fitzherbert et al., 2008; Phalan, 2009; Cherwoo et al., 2023). Derived from renewable biomass resources, biofuels have the potential to contribute significantly to energy security and environmental sustainability. Indonesia and Malaysia, as the world's largest palm oil producers, are pivotal in the Southeast Asian biofuel landscape. Palm oil serves as a versatile feedstock that can be processed into various biofuels such as biodiesel, bioethanol, and biogas(Papilo et al., 2022a). The production of palm oil-based biofuels is particularly significant in these countries due to their extensive palm oil industries(Coca, 2020; Cahayani, Pertiwi and Nihayati, 2023).

While the transition to biofuels offers numerous benefits, it also requires careful consideration of sustainability practices to mitigate potential environmental impacts associated with palm oil production(Papilo et al., 2022a).

Biofuel Production in Southeast Asia

The production of biofuels in Southeast Asia is primarily derived from palm oil, the two countries there are significant producers of this oil. The region's rich biomass supply, beneficial climate, and long history of agriculture make it ideal for producing biofuels (Mukherjee and Sovacool, 2014). Biodiesel, produced through the transesterification of palm oil, is the most common biofuel in the region. It is blended with conventional diesel fuel at varying ratios, depending on the country's regulations(Papilo et al., 2022b). Bioethanol, produced from sugarcane or cassava, is also gaining traction as a biofuel option, particularly in Thailand and the Philippines(Elder and Hayashi, 2018a). The production of biofuels in Southeast Asia has witnessed significant growth in recent years, driven by government policies, rising fossil fuel prices, and increasing environmental awareness. However, the industry faces several challenges, including sustainability concerns, competition for land and resources, and technological limitations(Tharakan et al., 2011; Elbehri, Segerstedt and Liu, 2013).

Feasibility of Biofuel Implementation in Southeast Asia

The potential for Southeast Asia's biofuel policies to be realized is high, primarily because of the region's biomass resources that are plentiful and the growing demand for environmentally friendly energy solutions. Countries like Indonesia and Malaysia, which produce large quantities of palm oil, have a readily available source of biodiesel. The existing infrastructure dedicated to fossil fuels can also be utilized to distribute biofuels, this diminishes the cost of implementation (IEA, 2011). Additionally, this paper highlights that technological advancements have made biofuel production more efficient and cost-effective, further enhancing its feasibility(Jazi and Sangroudi, 2020).

Several Southeast Asian countries have already demonstrated the feasibility of biofuel implementation through successful policy initiatives. Indonesia's mandatory biodiesel program, which has progressively increased the blending mandate to B35, showcases the practical application and positive outcomes of such policies(McCormick et al., 2006; Lopes et al., 2014). The program has resulted in increased renewable energy usage, reduced CO2 emissions, job creation, and income growth for smallholders(Boestami, 2020). Malaysia's B20 mandate and Thailand's B20 mandate with a target of 20-25% biofuel share by 2037 further exemplify the region's commitment to biofuel adoption(ACE, 2024).

The potential for biofuels in the policy dynamics of Southeast Asia is rather high because of the potential for biomass resources with sustained demand for clean energy solutions in the region. Being among the largest palm oil producers, Indonesia and Malaysia are favored to venture into biofuel production. Besides that, existing fossil fuel facilities shall reduce the constructions of distribution facilities for biofuels drastically, thus reducing the implementation costs(Rahmadi, 2018; Veza et al., 2022). This paper will also refer to the achievement of biofuel policies in Indonesia, as well as in Brazil, which is indicative of the workability and efficiency of such policies. These programs have turned out to be effective not only in decreasing greenhouse emissions but also in creating new job opportunities and economic stimulation(Sahara et al., 2022).

The feasibility of biofuel usage depends on whether several huge challenges are first dealt with. One of the major issues is that it requires a technological breakthrough to make efficiency and economy-related features of producing biofuels better. Many are at present based on existing technologies that have large implementation barriers due to limitations and will further require more research and development towards improving the process of production and reducing the cost(Rodionova et al., 2017; Trung, 2023)

Another important factor is the sustainable way to produce feedstock. Biofuel production often seeks to occupy land that is similar to food crops, this can lead to deforestation and increased costs of food. Sustainable practices are crucial to preventing the negative effects of biofuels on food security or the environment (Naylor et al., 2007; Babcock, 2008; Stromberg et al., 2010; Brinkman et al., 2020; Ahmed et al., 2021). For example, the utilization of non-food biomass or waste materials as a feedstock can mitigate these issues by decreasing the competition for land that is arable and minimizing the release of greenhouse gases associated with land utilization changes (Trung, 2023).

A further requisite, however, for successful policy implementation is the building of proper infrastructure. This covers all logistics, storage facilities, and distribution networks, both in investment and economically adequate for the proper handling of biofuels. Infrastructure inadequacy harms market development because it deals directly with the availability and access of biofuels by consumers(Rabago, 2008). The key, Rabago argues, lies in overcoming the numerous and very real infrastructure challenges to a sustainable, economically viable biofuel industry(Rabago, 2008).

Benefits and Costs Analysis

Benefits of Biofuel Implementation

Implementation of biofuel policies in Southeast Asia will also provide some other co-benefits of reducing greenhouse gas emissions and contributing to climate change actions. It has also reported that the carbon emissions from biofuels produced from non-food crops and agricultural waste are very low compared to carbon emissions from fossil fuels(Cherwoo et al., 2023). These second-and third-generation biofuels might reduce greenhouse gas emissions significantly since their renewable feedstocks and wastes are used to produce more biofuels with no added pressure on agricultural land use (EPA, 2024). IEA estimates that biofuels could offer a sustainable possibility to reduce approximately 2.1 GtCO2 automobile emissions per year (Fairley, 2011; InternationalEnergyAgency, 2021).

IIn Southeast Asia, countries like Indonesia, Malaysia, and Thailand have dedicated their efforts to biofuels derived from palm trees. These initiatives are part of a larger effort to increase energy security and promote sustainable development (Mukherjee and Sovacool, 2014). Despite these challenges, the potential for biofuels to contribute to significant reductions in greenhouse gas emissions remains a key driver for their adoption in the region(Tharakan et al., 2011; Kumar, Shrestha and Abdul Salam, 2013; Elder and Hayashi, 2018b).

Another of the most important advantages is that it has the potential for economic growth and the creation of new jobs. The emergence of the biofuel sector attracts economic activities through employment opportunities in production, distribution as well as research and development. In 2019, the palm oil industry in Indonesia employed approximately 16 million workers. Furthermore, biofuel policies can contribute to national energy security due to reduced dependency on fossil fuel imports. Official data assert that Indonesia has saved a total of US$8.34 billion in foreign exchange as of the year 2022 by using B30 biofuels (Heo and Choi, 2018; Sahara et al., 2022).

The implementation of biofuel policies in Southeast Asia offers a multitude of benefits, spanning environmental, economic, and social dimensions.

Environmental Benefits: Non-food-based biofuels also have tech to sharply cut emissions of greenhouse gases compared with fossil fuels(Soam and Börjesson, 2020). In this paper, references are made to studies asserting that the use of biofuels can lead to an avoidance of some 2.1 gigatonnes of CO2 emissions every year and reduce particulate matter emissions by as much as 50% (Fairley, 2011; Karin et al., 2022). The use of biofuels resonates with the region's initiatives geared toward fighting climate change and building a sustainable energy future.

Economic Benefits: Biofuel strategies can have a positive economic effect by creating new jobs, increasing the income of farmers, and reducing the dependency on foreign oil in Southeast Asia, specifically in the context of the developing countries (Hendy, Firmansyah and Wahyu, 2018; Sahara et al., 2022; Wirawan et al., 2024). The Indonesian palm oil sector, for instance, created approximately 16 million jobs in 2019, with a significant portion located in rural areas (Hendy, Firmansyah and Wahyu, 2018; Wirawan et al., 2024). Moreover, the implementation of B30 biofuels in Indonesia saved USD 8.34 billion in foreign exchange in 2022 (Sahara et al., 2022; Wirawan et al., 2024). Biofuel policies can also enhance energy security by diversifying the energy mix and reducing reliance on volatile fossil fuel markets.

Social Benefits: Biofuel strategies can reduce poverty and increase the well-being of rural communities, specifically in regards to reducing the prevalence of poverty. The cultivation of palm trees in Riau, Indonesia, had a significant effect on decreasing the poverty rate (Hendy, Firmansyah and Wahyu, 2018). Biofuels can also empower smallholder farmers by providing them with additional income sources and promoting sustainable agricultural practices(Peskett et al., 2007; Zapata, Vazquez-Brust and Plaza-Úbeda, 2010; Mudombi et al., 2021).

Costs of Biofuel Implementation

On the other side of the coin, however, are the costs related to the implementation of biofuels. One main issue that has been of concern relates to the impact on food security (Brinkman et al., 2020; Ahmed et al., 2021). Basically, the use of food crops for biofuel production normally competes with food production thereby raising the price of food(Tenenbaum, 2008; Chakravorty et al., 2015) . This paper agrees with the statement and suggests that the focus should be on non-food crops and agricultural waste for biofuel production (Awogbemi and Kallon, 2022). Other costs include those related to the initial investment in research and development, infrastructure, and setting up the unit for biofuels production (Malik et al., 2024).

There are also notable associated costs and challenges that need to be addressed as the following:

Infrastructure Development: The biofuel supply chain requires adequate infrastructure, including production facilities, storage tanks, and transportation networks. The development and upgrading of this infrastructure can entail significant investments (ACE, 2024).

Feedstock Availability and Competition: Feedstock is the lifeblood of any biofuel production process and, more than anything else, secures its sustainability and dependability. Such tensions and insecurities arise between food and biofuel crops, often termed as potential threats to food security and subsequent price increases (Shrestha, Staab and Duffield, 2019; Brinkman et al., 2020; Ahmed et al., 2021).

Technological Advancements: The creation of advanced biofuels, such as those derived from cellulosic biomass or algae, is often complicated by additional technological development and is more expensive than conventional biofuels, such as those derived from oil-palm (C.N. Hamelinck and Faaij, 2006; Carlo N Hamelinck and Faaij, 2006; Nelson and Reddy, 2018).

Sustainability Concerns: The sustainability of biofuel production, specifically regarding palm oil, has been a topic of discussion. Concerns regarding deforestation, habitat loss, and social consequences need to be addressed through rigorous criteria for sustainability and certification (Mohajan, 2013; Jeswani, Chilvers and Azapagic, 2020).

Opportunities and Challenges

The implementation of biofuel policies in Southeast Asia indeed presents both opportunities and challenges.

Opportunities for Biofuel Expansion

The implementation of biofuel strategies in Southeast Asia has several benefits. The region's rich biomass resources, increasing energy needs, and existing infrastructure promote the development of biofuels (IRENA, 2017; Beňová et al., 2021). Advancements in technology and supportive policies can further increase the economic viability and environmental sustainability of biofuels (Wu et al., 2023). Technological advances can further enhance the efficiency and effectiveness of biofuel production, making it more similar to fossil fuels in terms of cost (Carlos and Ba Khang, 2008; Cherwoo et al., 2023). The successful endeavors of countries like Indonesia and Brazil provide important lessons and superior methods for other Southeast Asian countries (Veza et al., 2022). Additionally, biofuel policies can have a role in rural development by creating employment and increasing the income of farmers (Zhou and Thomson, 2009; Sahara et al., 2022).

This article also describes the possibility of cooperation between regions in the development of biofuels. ASEAN countries can collaborate to promote the sharing of successful practices, methods, and experiences in the production of biofuels. This partnership can facilitate the rapid adoption of biofuels and help with the region's efforts to transition to energy (Kumar, Shrestha and Abdul Salam, 2013; Mofijur et al., 2015; Silitonga, Anh and Abdullah, 2024; Sorooshian, Ahadi and Zainul Abideen, 2024; Subkhi, 2024).

Southeast Asia's potential for increasing its biofuel production is enormous. The region's vast agricultural land, diverse biomass resources, and increasing energy needs, all of which are beneficial to biofuel development. The expansion of biofuel production can contribute to several key objectives:

Reducing greenhouse gas emissions: Biofuels, when cultivated sustainably, have the potential to significantly lower greenhouse gas emissions than other fuels. This can facilitate the achievement of climate change mitigation goals in Southeast Asia and contribute to the global fight against climate change (Khanna, Crago and Black, 2011; Mukherjee and Sovacool, 2014; Xu et al., 2022; Hasan et al., 2023; Prasad et al., 2024).

Enhancing energy security: Biofuels can diversify the energy source and reduce the dependency on foreign oil, thus increasing the region's energy security. This is of special significance to countries that rely heavily on oil for their economies (Kung et al., 2014; Jeswani, Chilvers and Azapagic, 2020; Yoon, 2022; Nibedita and Irfan, 2024).

Stimulating economic growth: The biofuel industry can create jobs, earn income, and promote economic development in rural areas. This can reduce poverty and improve the livelihoods of small-scale farmers in Southeast Asia (Tharakan et al., 2011; Hought et al., 2012; Mukherjee and Sovacool, 2014; Sahara et al., 2022; IRENA, 2023).

Improving air quality: Biofuels have the potential to reduce pollution in the air by emitting less harmful substances than other fuels. This can have a positive impact on public health and the environment, as it has already been successful in multiple locations **(Lee, Iraqui and Wang, 2019; Huy, Winijkul and Kim Oanh, 2021; Amnuaylojaroen and Parasin, 2023).**

Challenges and Sustainability Concerns

Addressing infrastructure gaps, ensuring sustainable feedstock supply, and promoting technological advancements are key challenges(Yazdanparast et al., 2022; Suhara et al., 2024). Balancing food security and biofuel production, along with mitigating the environmental and social impacts of biofuel feedstock cultivation, requires careful planning and implementation(German, Schoneveld and Pacheco, 2011; Kline et al., 2017; Brinkman et al., 2020; Kurowska et al., 2020; Ahmed et al., 2021).

Despite the opportunities, there are also challenges associated with biofuel implementation in Southeast Asia. One major challenge is ensuring the sustainability of biofuel production. This paper emphasizes the need to avoid deforestation and competition with food crops. This requires careful planning and the implementation of strict sustainability criteria(Mukherjee and Sovacool, 2014; Elder and Hayashi, 2018a; Ramadhan, Mori and Abdoellah, 2023)

Another obstacle is the requirement for technological improvements and infrastructure. The biofuel industry is characterized by significant spending on research and development in order to enhance efficiency and reduce costs. The creation of appropriate infrastructure, including storage and logistics facilities, is also of paramount importance in the implementation of biofuel strategies (IRENA, 2017; Junginger, Koppejan and Goh, 2020; Khan et al., 2021).

Additionally, consumers should be addressed regarding the performance and dependability of biofuels. This article suggests that car manufacturers should support the effort and conduct proper engine testing in order to ensure compatibility and minimize any potential problems (Tharakan et al., 2011; Mukherjee and Sovacool, 2014; Elder and Hayashi, 2018a; Sovacool, 2019).

While biofuels offer numerous opportunities, their implementation also faces several challenges and sustainability concerns.

Deforestation and land-use change: The increase in plantation size of palm trees for biofuel production has been associated with deforestation, habitat loss, and biodiversity loss. This has prompted concerns about the environmental viability of biofuels derived from palm trees (Papilo et al., 2018, 2022a; Yasinta and Karuniasa, 2021).

Competition for land and resources: The creation of biofuels can conflict with agriculture for land, water, and other resources. This can cause food prices to increase and food insecurity to occur, primarily in countries that are net importers of food (Tenenbaum, 2008; Schoneveld, 2010; Tharakan et al., 2012).

Social impacts: The biofuel industry can have indirect effects, such as the displacement of communities, land issues, and labor rights violations. It's crucial to make sure that biofuel production is socially responsible and honoring the rights of local communities (Sheil et al., 2009; German et al., 2010; Obidzinski et al., 2012; Mukherjee and Sovacool, 2014).

Technological limitations: The creation of advanced biofuels, such as cellulosic alcohol and algae-based biofuels, is still at the early stages of development and has technical issues. These obstacles include high production expenses, low yields, and the requirement for additional research and development (Tharakan et al., 2011; Balan, 2014; Kim and Kim, 2014).

Policy Development Frameworks and Technological Advancements

Policy frameworks and technological advances have a significant role in the sustainable development of biofuels in Southeast Asia. Regional governments have enacted various laws and regulations to promote the biofuel industry, these include mandates regarding blending, tax breaks, and standards for sustainability. These strategies attempt to promote a beneficial environment for the production and consumption of biofuels while also ensuring environmental and social responsibility. The advances in technological science in the production of biofuels, such as the development of advanced biofuels and the enhancement of production methods, can mitigate some of the issues and concerns associated with the field. Research and development initiatives should concentrate on enhancing yields, reducing expenses, and minimizing environmental consequences (Mukherjee and Sovacool, 2014; Elder and Hayashi, 2018b).

collaboration between government agencies, industry participants, and civil society organizations is crucial to the development of biofuels in Southeast Asia. Governments can endorse policies, subsidize products, and regulate the industry's growth (Malik, 2012; Kumar, Shrestha and Abdul Salam, 2013; Varkkey, 2021). Industry stakeholders can invest in research and development, adopt sustainable practices, and ensure social responsibility(Elder and Hayashi, 2018a). Civil society organizations can play a crucial role in monitoring the industry, advocating for sustainable practices, and raising awareness about the potential impacts of biofuels(Chakib, 2014; PWYP-Indonesia, 2023).

The policy development advocates the sustainable development of biofuels in Southeast Asia. It focuses on the crucial importance of precise policy rules regarding biofuel integration mandates and the necessity of extensive research and development. It also advocates for the promotion of the utilization of non-food crops and farm waste for the production of biofuels instead of competing with food crops.

Furthermore, this paper recommends strengthening regional cooperation among ASEAN countries to share best practices and technologies. It also highlights the importance of addressing consumer concerns and providing support from vehicle manufacturers.

The implementation of biofuel strategies in Southeast Asia has the potential to serve as a promising path towards a sustainable energy future. The region's rich biomass resources, growing demand for environmentally friendly energy, and the successful implementation of biofuels in some countries demonstrate the potential benefits and feasibility of these policies. However, it's essential to address the issues associated with sustainability, technology, infrastructure, and consumer acceptance in order to ensure the successful and sustainable implementation of biofuels in the region.

By taking a comprehensive approach that includes detailed policy guidelines, extensive research and development, sustainable production of feedstocks, and regional cooperation, Southeast Asian countries can unleash the full potential of biofuels and contribute to a more environmentally friendly energy future. The benefits of reduced greenhouse gas emissions, economic growth, job creation, and enhanced energy security far exceed the costs and challenges, as a result, biofuels are likely to become a viable and attractive policy for the region.

To maximize the benefits and address the challenges of biofuel implementation in Southeast Asia, the following policy development aspects are proposed:

Strengthen Regional Cooperation: Enhance collaboration among ASEAN countries to share knowledge, best practices, and technology in biofuel development. Harmonize regulations and standards to facilitate trade and investment in the biofuel sector.

Invest in Research and Development: Support research and development efforts to improve biofuel production technologies, develop advanced biofuels, and optimize feedstock utilization.

Promote Sustainable Feedstock Production: Encourage the cultivation of biofuel feedstocks that have minimal impact on biodiversity and food security. Implement strict sustainability criteria and certification schemes to ensure responsible production practices.

Develop Supportive Policies and Incentives: Provide financial incentives, tax breaks, and other supportive measures to encourage investment in the biofuel industry. Implement clear and consistent policies on blending mandates and feed-in tariffs.

Address Infrastructure Gaps: Invest in the development and upgrading of biofuel infrastructure, including production facilities, storage tanks, and transportation networks.

Engage Stakeholders: Facilitate the discussion and collaboration between government, industry participants, and civil society organizations regarding concerns and the sustainable development of biofuels in the region.

Monitor and Evaluate: Regularly monitor and evaluate the impacts of biofuel policies and production on the environment, economy, and society. Use this information to inform policy adjustments and improvements.

The implementation of biofuel strategies in Southeast Asia has the potential to serve as a promising path towards a sustainable energy future. By utilizing the region's rich biomass resources, promoting technological advances, and addressing environmental concerns, biofuels can have a significant role in decreasing greenhouse gases, promoting economic growth, and enhancing energy security. The successful stories of countries like Indonesia demonstrate the potential and benefits of biofuel adoption. However, it's crucial to address the associated costs and issues through supportive policies, investments in research and development, and shared efforts between stakeholders. By taking a comprehensive and integrated approach, Southeast Asian countries can unleash the full potential of biofuels and have a more positive impact on the region's prosperity and environment.

CONCLUSION AND RECOMMENDATION

Conclusion

Biofuels have a promising route towards a more environmentally friendly and secure energy source for Southeast Asia. The region's rich biomass resources, beneficial climate, and increasing energy demand all contribute to the potential for biofuels. However, it's essential to address the issues and concerns associated with the industry. By implementing supportive policy frameworks, spending money on technological improvements, and encouraging collaboration between stakeholders in Southeast Asia, the countries can promote the sustainable development of biofuels, and contribute to global efforts to address climate change. The successful implementation of biofuels in the region can lead to a decrease in greenhouse gas emissions, an increase in energy security, economic growth, and increased well-being for millions of people.

The investigation of Southeast Asian biofuels via this policy analysis, demonstrates a complex relationship between opportunities and challenges. The region's rich biomass resources are coupled with an increasing demand for energy and a commitment to environmental sustainability, all of which are paramount to the strategic importance of biofuels. Indonesia and Malaysia, who are leading producers of palm oil, have a significant impact on the biofuel industry, they offer a significant opportunity for economic growth and renewable energy development. However, the route to successful biofuel integration is not free of obstacles. Concerns regarding the sustainability of the system, land utilization, food security, and technological development necessitate a complex and detailed policy approach.

Key Policy Recommendations

Prioritize Sustainability: Establish and enforce stringent sustainability criteria for biofuel production, encompassing responsible land use, biodiversity conservation, and social impact mitigation. Encourage the adoption of certification schemes like ISPO, MSPO, ISCC, and RSPO to ensure adherence to international standards and promote market access.

Foster Technological Innovation: Invest in research and development dedicated to the advancement of biofuels, the optimization of feedstock utilization, and the enhancement of production efficiency. Support the exploration of second and third-generation biofuels to reduce competition with food plants and minimize environmental effects.

Strengthen Regional Cooperation: Facilitate knowledge sharing, technology transfer, and collaborative initiatives among ASEAN countries to harmonize biofuel policies, standards, and best practices. Establish a regional platform for dialogue and cooperation to address common challenges and leverage collective expertise.

Enhance Infrastructure Development: Invest in biofuels infrastructure, including production facilities, storage, distribution and blending, as these facilities are prioritized. Allow private sector participants to participate and incentivize investments in infrastructure dedicated to the biofuel industry.

Promote Public Awareness and Engagement: Conduct extensive public awareness campaigns to inform stakeholders about the benefits and drawbacks of biofuels. Foster open communication and participate in local communities in order to ensure social acceptance and address potential issues.

Additional Recommendations

Develop Integrated Policies: Design and implement policies that consider the interconnectedness of the biofuel and agriculture sectors, ensuring food security and promoting sustainable land use practices.

Enhance Resource Efficiency: Improve resource efficiency in both sectors through technological advancements, optimized farming practices, and the utilization of marginal lands for biofuel feedstock production.

Foster International Collaboration: Engage in partnerships with international organizations and research institutions to access expertise, funding, and technology transfer opportunities.

Monitor and Evaluate: Establish effective monitoring and evaluation processes that assess the environmental, social, and economic consequences of the implementation of biofuels in Southeast Asia.

Support Smallholders: Create targeted assistance and capacity for all of the impacted smallholder farmers in the region, this will enhance their productivity, sustainability, agricultural methods and the profitability of their farms.

By following these policy suggestions, Southeast Asian countries will have the capacity to deal with the complexity of implementing biofuels, while also utilizing their potential for sustainable development while avoiding associated problems. A holistic and collective approach that is grounded in sustainability, technological innovation, and stakeholder participation, will serve as a precursor to a resilient and decarbonized energy future in the region.

REFERENCES

1. ACE (2024) The 7th ASEAN Energy Outlook (AEO7). Jakarta. Available at: https://aseanenergy.org/publications/asean-energy-in-2024/.
2. Ahmed, S. et al. (2021) ‘Systematic review on effects of bioenergy from edible versus inedible feedstocks on food security’, npj Science of Food, 5(1), p. 9. Available at: https://doi.org/10.1038/s41538-021-00091-6.

3. Amnuaylojaroen, T. and Parasin, N. (2023) ‘Perspective on Particulate Matter: From Biomass Burning to the Health Crisis in Mainland Southeast Asia’, Toxics, 11(7), p. 553. Available at: https://doi.org/10.3390/toxics11070553.
4. Awogbemi, O. and Kallon, D.V. Von (2022) ‘Valorization of agricultural wastes for biofuel applications’, Heliyon, 8(10), p. e11117. Available at: https://doi.org/10.1016/j.heliyon.2022.e11117.
5. Babcock, B.A. (2008) ‘Breaking the link between food and biofuels’, Iowa Agriculture Review, 08-BP 53(3), pp. 1–12. Available at: https://www.card.iastate.edu/iowa_ag_review/summer_08/IAR.pdf.
6. Balan, V. (2014) ‘Current Challenges in Commercially Producing Biofuels from Lignocellulosic Biomass’, ISRN Biotechnology, 2014, pp. 1–31. Available at: https://doi.org/10.1155/2014/463074.
7. Beňová, D. et al. (2021) ‘Energy Potential of Agri Residual Biomass in Southeast Asia with the Focus on Vietnam’, Agronomy, 11(1), p. 169. Available at: https://doi.org/10.3390/agronomy11010169.
8. Boestami, D. (2020) Sumbangan Pemikiran untuk Perkembangan Sektor Kelapa Sawit Indonesia 2017 -2020. 1st edn. Lembaga Kemitraan Pembangunan Sosial. Available at: https://books.google.co.id/books/about/Sumbangan_Pemikiran_untuk_Perkembangan_S.html?id=OjbeDwAAQBAJ&redir_esc=y.
9. Brinkman, M. et al. (2020) ‘The distribution of food security impacts of biofuels, a Ghana case study’, Biomass and Bioenergy, 141, p. 105695. Available at: https://doi.org/10.1016/j.biombioe.2020.105695.
10. Cahayani, I., Pertiwi, E.A. and Nihayati, A. (2023) ‘Analysis of Energy Transformation Through Biofuel Energy Downstream to The National Economy’, JEJAK: Jurnal Ekonomi dan Policy, 16(2), pp. 323–342. Available at: https://doi.org/10.15294/jejak.v16i2.43179.
11. Carlos, R.M. and Ba Khang, D. (2008) ‘Characterization of biomass energy projects in Southeast Asia’, Biomass and Bioenergy, 32(6), pp. 525–532. Available at: https://doi.org/10.1016/j.biombioe.2007.11.005.
12. Chakib, A. (2014) ‘Civil society organizations’ roles in land-use planning and community land rights issues in Kapuas Hulu regency, West Kalimantan, Indonesia’, CIFOR Working Paper, p. 100. Available at: http://search.ebscohost.com/login.aspx?direct=true&db=lah&AN=20153419987&site=ehost-live%5Cnhttp://www.cabi.org/cabdirect/showpdf.aspx?PAN=http://www.cabi.org/cabdirect/showpdf.aspx?PAN=20153419987%5Cnhttp://www.cifor.org/library/5426/civil-society-organi.
13. Chakravorty, U. et al. (2015) ‘The Long-Run Impact of Biofuels on Food Prices’, Resources for the Future Discussion Paper [Preprint], (October). Available at: https://media.rff.org/documents/RFF-DP-15-48.pdf.
14. Cherwoo, L. et al. (2023) ‘Biofuels an alternative to traditional fossil fuels: A comprehensive review’, Sustainable Energy Technologies and Assessments, 60, p. 103503. Available at: https://doi.org/10.1016/j.seta.2023.103503.
15. Coca, N. (2020) As palm oil for biofuel rises in Southeast Asia, tropical ecosystems shrink, Dialogue Earth: Energy. Available at: https://dialogue.earth/en/energy/11957-as-palm-oil-for-biofuel-rises-in-southeast-asia-tropical-ecosystems-shrink/ (Accessed: 14 September 2024).
16. Creswell, john W. and Creswell, J.D. (2018) Research Design: Qualitative, Quantitative, and Mixed-Methods Approaches. 5th edn. Thousand Oaks, CA: SAGE Publications Ltd.
17. Elbehri, A., Segerstedt, A. and Liu, P. (2013) Biofuels and the sustainability challenge: A global assessment of sustainability issues, trends and policies for biofuels and related feedstocks. FAO. Available at: https://doi.org/ISBN 978-92-5-107414-5.

18. Elder, M. and Hayashi, S. (2018a) 'A Regional Perspective on Biofuels in Asia', in K. Takeuchi et al. (eds) Biofuels and Sustainability: Holistic Perspectives for Policy-making. Tokyo: Springer Japan, pp. 223–246. Available at: https://doi.org/10.1007/978-4-431-54895-9_14.
19. Elder, M. and Hayashi, S. (2018b) 'A Regional Perspective on Biofuels in Asia', in H. Takagi, T. Takahashi, and N. Suzuki (eds) Welfare Effects of the US Corn-Bioethanol Policy. 1st edn, pp. 33–51. Available at: https://doi.org/10.1007/978-4-431-54895-9_5.
20. EPA (2024) Economics of Biofuels, Environmental Economics. Available at: https://www.epa.gov/environmental-economics/economics-biofuels (Accessed: 14 September 2024).
21. Fairley, P. (2011) 'Introduction: Next generation biofuels', Nature, 474(7352), pp. S2–S5. Available at: https://doi.org/10.1038/474S02a.
22. Fitzherbert, E.B. et al. (2008) 'How will oil palm expansion affect biodiversity?', Trends in Ecology and Evolution, pp. 538–545. Available at: https://doi.org/10.1016/j.tree.2008.06.012.
23. Gaveau, D.L.A. et al. (2019) 'Rise and fall of forest loss and industrial plantations in Borneo (2000–2017)', Conservation Letters, 12(3). Available at: https://doi.org/10.1111/conl.12622.
24. German, L. et al. (2010) 'The local social and environmental impacts of biofuel feedstock expansion A synthesis of case studies from Asia , Africa and Latin America', CIFOR InfoBrief, (34), p. 12. Available at: www.cifor.cgiar.org.
25. German, L., Schoneveld, G. and Pacheco, P. (2011) 'The social and environmental impacts of biofuel feedstock cultivation: Evidence from multi-site research in the forest frontier', Ecology and Society, 3(16), pp. 1–24. Available at: https://hdl.handle.net/10568/20887.
26. Hamelinck, Carlo N and Faaij, A.P.C. (2006) 'Outlook for advanced biofuels', Energy Policy, 34(17), pp. 3268–3283. Available at: https://doi.org/10.1016/j.enpol.2005.06.012.
27. Hamelinck, C.N. and Faaij, A.P.C. (2006) 'Production of advanced biofuels', International Sugar Journal, 108(1287), pp. 168–175. Available at: https://www.cabidigitallibrary.org/doi/full/10.5555/20063048370.
28. Hasan, M. et al. (2023) 'Sustainable biofuel economy: A mapping through bibliometric research', Journal of Environmental Management, 336, p. 117644. Available at: https://doi.org/10.1016/j.jenvman.2023.117644.
29. Hassan, Q. et al. (2024) 'The renewable energy role in the global energy Transformations', Renewable Energy Focus, 48, p. 100545. Available at: https://doi.org/10.1016/j.ref.2024.100545.
30. Hendy, A.H., Firmansyah, F. and Wahyu, W. (2018) 'The Intra-Industry Trade of Palm Oil Commodity Between Indonesia and Malaysia', E3S Web of Conferences. Edited by Hadiyanto, Maryono, and B. Warsito, 73, p. 10011. Available at: https://doi.org/10.1051/e3sconf/20187310011.
31. Heo, S.J. and Choi, J.W. (2018) 'Biofuel Utilization and Implications in ASEAN Based on Case Analysis of Developed Countries', Journal of the Korean Wood Science and Technology, 46(5), pp. 577–596. Available at: https://doi.org/10.5658/WOOD.2018.46.5.577.
32. Hought, J. et al. (2012) 'Biofuels, land use change and smallholder livelihoods: A case study from Banteay Chhmar, Cambodia', Applied Geography, 34, pp. 525–532. Available at: https://doi.org/10.1016/j.apgeog.2012.02.007.
33. HumasEBTKE (2023) Era Baru BBN, Indonesia Siap Implementasikan B35, Ditjen EBTKE Artikel Detail. Available at: https://ebtke.esdm.go.id/post/2023/02/01/3413/era.baru.bahan.bakar.nabati.indonesia.siap.implementasikan.b35#:~:text=JAKARTA - Kementerian Energi dan Sumber Daya Mineral,secara nasional mulai 1 Februari 2023%2C esok hari. (Accessed: 14 September 2024).

34. Huy, L.N., Winijkul, E. and Kim Oanh, N.T. (2021) 'Assessment of emissions from residential combustion in Southeast Asia and implications for climate forcing potential', Science of The Total Environment, 785, p. 147311. Available at: https://doi.org/10.1016/j.scitotenv.2021.147311.
35. IEA (2011) Technology Roadmap Biofuels for Transport. Paris. Available at: https://iea.blob.core.windows.net/assets/0905b11e-53d4-417a-a061-453934009476/Biofuels_Roadmap_WEB.pdf.
36. IEA (2019) Southeast Asia Energy Outlook 2019 – Analysis, IEA Energy Outlook. Available at: https://www.iea.org/reports/southeast-asia-energy-outlook-2019#.
37. IEA (2024) Southeast Asia Energy Outlook 2022: Key Findings, IEA Statistics. Available at: https://www.iea.org/reports/southeast-asia-energy-outlook-2022/key-findings (Accessed: 14 September 2024).
38. InternationalEnergyAgency (2021) Global Energy Review 2021. Paris: IEA Publications.
39. IRENA-ACE (2022) Renewable energy outlook for ASEAN: Towards a regional energy transition. Abu Dhabi and Jakarta. Available at: www.irena.org.
40. IRENA (2017) Biofuel Potential in Southeast Asia. Available at: http://www.irena.org/DocumentDownloads/Publications/IRENA_Biofuel_Potential_SE_Asia_2017.pdf.
41. IRENA (2022) Renewable Energy Statistics 2018. The International Renewable Energy Agency. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jul/IRENA_Renewable_Energy_Statistics_2018.pdf.
42. IRENA (2023) Socio-economic footprint of the energy transition: Indonesia. Abu Dhabi. Available at: www.irena.org.
43. Jazi, E.M. and Sangroudi, H.A. (2020) 'Designing a hybrid first/second generation biofuel supply chain with reliable multimodal transport: a mathematical model', International Journal of Industrial Engineering \& Production Research, 31, pp. 101–113. Available at: https://api.semanticscholar.org/CorpusID:216287566.
44. Jeswani, H.K., Chilvers, A. and Azapagic, A. (2020) 'Environmental sustainability of biofuels: a review', Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 476(2243). Available at: https://doi.org/10.1098/rspa.2020.0351.
45. Junginger, M., Koppejan, J. and Goh, C.S. (2020) 'Sustainable bioenergy deployment in East and South East Asia: notes on recent trends', Sustainability Science, 15(5), pp. 1455–1459. Available at: https://doi.org/10.1007/s11625-019-00712-w.
46. Karin, P. et al. (2022) 'Influence of ethanol-biodiesel blends on diesel engines combustion behavior and particulate matter physicochemical characteristics', Case Studies in Chemical and Environmental Engineering, 6, p. 100249. Available at: https://doi.org/10.1016/j.cscee.2022.100249.
47. Khan, M.A.H. et al. (2021) 'Investigation of Biofuel as a Potential Renewable Energy Source', Atmosphere, 12(10), p. 1289. Available at: https://doi.org/10.3390/atmos12101289.
48. Khanna, M., Crago, C.L. and Black, M. (2011) 'Can biofuels be a solution to climate change? The implications of land use change-related emissions for policy', Interface Focus, 1(2), pp. 233–247. Available at: https://doi.org/10.1098/rsfs.2010.0016.
49. Kim, Tae Hoon and Kim, Tae Hyun (2014) 'Overview of technical barriers and implementation of cellulosic ethanol in the U.S.', Energy, 66, pp. 13–19. Available at: https://doi.org/10.1016/j.energy.2013.08.008.
50. Kline, K.L. et al. (2017) 'Reconciling food security and bioenergy: priorities for action', GCB Bioenergy, 9(3), pp. 557–576. Available at: https://doi.org/10.1111/gcbb.12366.

51. Kumar, S., Shrestha, P. and Abdul Salam, P. (2013) 'A review of biofuel policies in the major biofuel producing countries of ASEAN: Production, targets, policy drivers and impacts', Renewable and Sustainable Energy Reviews, 26, pp. 822–836. Available at: https://doi.org/10.1016/j.rser.2013.06.007.
52. Kung, C.-C. et al. (2014) 'Biofuel for Energy Security: An Examination on Pyrolysis Systems with Emissions from Fertilizer and Land-Use Change', Sustainability, 6(2), pp. 571–588. Available at: https://doi.org/10.3390/su6020571.
53. Kurowska, K. et al. (2020) 'Food Security in the Context of Liquid Biofuels Production', Energies, 13(23), p. 6247. Available at: https://doi.org/10.3390/en13236247.
54. Lee, H.-H., Iraqui, O. and Wang, C. (2019) 'The Impact of Future Fuel Consumption on Regional Air Quality in Southeast Asia', Scientific Reports, 9(1), p. 2648. Available at: https://doi.org/10.1038/s41598-019-39131-3.
55. Lopes, M. et al. (2014) 'Emissions characterization from EURO 5 diesel/biodiesel passenger car operating under the new European driving cycle', Atmospheric Environment, 84, pp. 339–348. Available at: https://doi.org/10.1016/j.atmosenv.2013.11.071.
56. Malik, A.Q. (2012) 'Potential and Use of Bioenergy in The Association of Southeast Asian Nations (ASEAN) Countries – A Review', in Sustainable Energy - Recent Studies. 1st edn. InTech. Available at: https://doi.org/10.5772/51917.
57. Malik, K. et al. (2024) 'Biofuels Production: A Review on Sustainable Alternatives to Traditional Fuels and Energy Sources', Fuels, 5(2), pp. 157–175. Available at: https://doi.org/10.3390/fuels5020010.
58. McCormick, R.L. et al. (2006) Effects of Biodiesel Blends on Vehicle Emissions: Fiscal Year 2006 Annual Operating Plan Milestone 10.4. Golden, CO. Available at: https://doi.org/10.2172/894987.
59. Mofijur, M. et al. (2015) 'Energy scenario and biofuel policies and targets in ASEAN countries', Renewable and Sustainable Energy Reviews, 46, pp. 51–61. Available at: https://doi.org/10.1016/j.rser.2015.02.020.
60. Mohajan, H. (2013) 'Present and future of biofuels production for sustainability', Int. J. Eco. Res., 3(3), pp. 12–23. Available at: https://mpra.ub.uni-muenchen.de/50678/1/MPRA_paper_50678.pdf.
61. Mudombi, S. et al. (2021) 'Fuelling rural development? The impact of biofuel feedstock production in southern Africa on household income and expenditures', Energy Research & Social Science, 76, p. 102053. Available at: https://doi.org/10.1016/j.erss.2021.102053.
62. Mukherjee, I. and Sovacool, B.K. (2014) 'Palm oil-based biofuels and sustainability in southeast Asia: A review of Indonesia, Malaysia, and Thailand', Renewable and Sustainable Energy Reviews, 37, pp. 1–12. Available at: https://doi.org/10.1016/j.rser.2014.05.001.
63. Naylor, R.L. et al. (2007) 'The Ripple Effect: Biofuels , Food Security , and the Environment', Agronomy & Horticulture - Faculty Publication [Preprint], (386). Available at: https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1386&context=agronomyfacpub.
64. Nelson, E.S. and Reddy, D.R. (2018) Green Aviation: Reduction of Environment Impact through Aicraft Technology and Alternative Fuels. 1st edn. CRC Press. Available at: https://books.google.co.id/books?hl=en&lr=&id=1tFfDwAAQBAJ&oi=fnd&pg=PT18&dq=Emily+S.+Nelson,+Dhanireddy+R.+Reddy.+%22Green+Aviation:+Reduction+of+Environmental+Impact+Through+Aircraft+Technology+and+Alternative+Fuels%22,+CRC+Press,+2018&ots=dEoPcC8jOd&si.
65. Nibedita, B. and Irfan, M. (2024) 'Energy mix diversification in emerging economies: An econometric analysis of determinants', Renewable and Sustainable Energy Reviews, 189, p. 114043. Available at: https://doi.org/10.1016/j.rser.2023.114043.

66. Obidzinski, K. et al. (2012) 'Environmental and Social Impacts of Oil Palm Plantations and their Implications for Biofuel Production in Indonesia', Ecology and Society, 17(1), p. art25. Available at: https://doi.org/10.5751/ES-04775-170125.
67. Ock, H.L. (2024) Reliance on fossil gas risks climate goals and energy security in Southeast Asia: Experts, CASEforSEA. Available at: https://caseforsea.org/reliance-fossil-gas-risks-climate-energy-security-southeast-asia/ (Accessed: 14 September 2024).
68. Papilo, P. et al. (2018) 'Sustainability index assessment of palm oil-based bioenergy in Indonesia', Journal of Cleaner Production, 196, pp. 808–820. Available at: https://doi.org/10.1016/j.jclepro.2018.06.072.
69. Papilo, P. et al. (2022a) 'Palm oil-based bioenergy sustainability and policy in Indonesia and Malaysia: A systematic review and future agendas', Heliyon, 8(10). Available at: https://doi.org/10.1016/j.heliyon.2022.e10919.
70. Papilo, P. et al. (2022b) 'Palm oil-based bioenergy sustainability and policy in Indonesia and Malaysia: A systematic review and future agendas', Heliyon, 8(10), p. e10919. Available at: https://doi.org/10.1016/j.heliyon.2022.e10919.
71. Pawar, N. (2020) '6. Type of Research and Type Research Design', Social Research Methodology, 8(1)(December 2020), pp. 46–57. Available at: https://www.kdpublications.in.
72. Peskett, L. et al. (2007) 'Biofuels, Agriculture and Poverty Reduction', Africa, 107(March), p. 6. Available at: http://www.odi.org.uk/resources/download/2574.pdf.
73. Phalan, B. (2009) 'The social and environmental impacts of biofuels in Asia: An overview', Applied Energy, 86, pp. S21–S29. Available at: https://doi.org/10.1016/j.apenergy.2009.04.046.
74. Prasad, S. et al. (2024) 'Review on biofuel production: Sustainable development scenario, environment, and climate change perspectives – A sustainable approach', Journal of Environmental Chemical Engineering, 12(2), p. 111996. Available at: https://doi.org/10.1016/j.jece.2024.111996.
75. PWYP-Indonesia (2023) Regionel Meeting of Civil Society Organizations for a Just Energy Transition: 'ASEAN Energy Landscape', PWYP Policy Dialog. Available at: https://pwypindonesia.org/en/regional-meeting-of-civil-society-organizations-for-a-just-energy-transition-asean-energy-landscape/ (Accessed: 14 September 2024).
76. Rabago, K.R. (2008) 'A Review of Barriers to Biofuel Market Development in the United States', Environmental and Energy Law and Policy Journal, 2(211). Available at: https://digitalcommons.pace.edu/cgi/viewcontent.cgi?article=1945&context=lawfaculty.
77. Rahmadi, A. (2018) Effectiveness of biofuel development for Indonesia. The University of Melbourne. Available at: https://core.ac.uk/download/pdf/162234046.pdf.
78. Rai, A.K. et al. (2022) 'Recent Developments in Lignocellulosic Biofuels, a Renewable Source of Bioenergy', Fermentation, 8(4), p. 161. Available at: https://doi.org/10.3390/fermentation8040161.
79. Ramadhan, R., Mori, A. and Abdoellah, O.. (2023) 'Biofuels Development and Indirect Deforestation', in A. Triyanti et al. (eds) Environmental Governance in Indonesia. 1st edn. Springer, pp. 135–150. Available at: https://doi.org/10.1007/978-3-031-15904-6_8.
80. Rodionova, M.V. et al. (2017) 'Biofuel production: Challenges and opportunities', International Journal of Hydrogen Energy, 42(12), pp. 8450–8461. Available at: https://doi.org/10.1016/j.ijhydene.2016.11.125.
81. Sahara et al. (2022) 'Economic impacts of biodiesel policy in Indonesia: a computable general equilibrium approach', Journal of Economic Structures, 11(1), p. 22. Available at: https://doi.org/10.1186/s40008-022-00281-9.
82. Schoneveld, G.C. (2010) Potential land use competition from first-generation biofuel expansion in developing countries, CIFOR Occasional Paper. Available at: https://www.cifor-icraf.org/publications/pdf_files/OccPapers/OP-58.pdf.

83. Searchinger, T. et al. (2008) ‘Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change’, Science, 319(5867), pp. 1238–1240. Available at: https://doi.org/10.1126/science.1151861.
84. Sheil, D. et al. (2009) The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know?, CIFOR Occasional Paper. Available at: https://doi.org/10.17528/cifor/002792.
85. Shrestha, D.S., Staab, B.D. and Duffield, J.A. (2019) ‘Biofuel impact on food prices index and land use change’, Biomass and Bioenergy, 124, pp. 43–53. Available at: https://doi.org/10.1016/j.biombioe.2019.03.003.
86. Silitonga, R.J.P., Anh, V.T.D. and Abdullah, A. (2024) Optimising biofuels and energy efficiency in complementing the EVs towards carbon neutrality in ASEAN, ACE Report. Available at: https://aseanenergy.org/post/optimising-biofuels-and-energy-efficiency-in-complementing-the-evs-towards-carbon-neutrality-in-asean/ (Accessed: 14 September 2024).
87. Soam, S. and Börjesson, P. (2020) ‘Considerations on Potentials, Greenhouse Gas, and Energy Performance of Biofuels Based on Forest Residues for Heavy-Duty Road Transport in Sweden’, Energies, 13(24), p. 6701. Available at: https://doi.org/10.3390/en13246701.
88. Sorooshian, S., Ahadi, N. and Zainul Abideen, A. (2024) ‘Leading countries and research networks advancing clean production and environmental sustainability in Southeast Asia’, International Journal of Development Issues, 23(1), pp. 84–105. Available at: https://doi.org/10.1108/IJDI-06-2023-0165.
89. Sovacool, B.K. (2019) ‘Competing Dimensions of Renewable Energy Policy: Challenges of the “Energy Trilemma”’, Energy Research & Social Science [Preprint].
90. Statista (2024) Palm oil land use worldwide 2000-2022. Available at: https://www.statista.com/statistics/1328496/palm-oil-land-use-worldwide/.
91. Stromberg, P.M. et al. (2010) Impacts of Liquid Biofuels on Ecosystem Services and Biodiversity. Available at: http://collections.unu.edu/eserv/UNU:2930/Biofuels_e_ver21.pdf.
92. Subkhi, S. (2024) Sustainable Production of Biofuels in the ASEAN Region from Oil Palm Residues, Resilience Development Initiative Report. Available at: https://rdi.or.id/project/sustainable-production-of-biofuels-in-the-asean-region-from-oil-palm-residues-2/ (Accessed: 14 September 2024).
93. Suhara, A. et al. (2024) ‘Biodiesel Sustainability: Review of Progress and Challenges of Biodiesel as Sustainable Biofuel’, Clean Technologies, 6(3), pp. 886–906. Available at: https://doi.org/10.3390/cleantechnol6030045.
94. Susilowati, I. et al. (2023) ‘Nexus Between Economic Growth, Renewable Energy, Industry Value Added and CO2 Emissions in ASEAN’, Jurnal Ekonomi Pembangunan: Kajian Masalah Ekonomi dan Pembangunan, 24(2), pp. 265–281. Available at: https://doi.org/10.23917/jep.v24i2.23165.
95. Tenenbaum, D.J. (2008) ‘Food vs. Fuel: Diversion of Crops Could Cause More Hunger’, Environmental Health Perspectives, 116(6). Available at: https://doi.org/10.1289/ehp.116-a254.
96. Tharakan, P. et al. (2011) Biofuels in Asia: An Analysis of Sustainability Options, Polity. Available at: https://digital.lib.washington.edu/dspace/handle/1773/15601%0Ahttp://dx.doi.org/10.1057/pol.2012.12%0Ahttp://www.unicef.org/sowc04/files/AnnexB.pdf%0Ahttp://rsb.epfl.ch/.
97. Tharakan, P. et al. (2012) ‘Biofuels in the Greater Mekong Subregion: Energy Sufficiency, Food Security, and Environmental Management’, ADB-Southeast Asia Working Paper Series [Preprint], (8). Available at: https://www.adb.org/sites/default/files/publication/29516/biofuels-gms.pdf.
98. Trung, N. (2023) Moving toward sustainable biofuel production: evaluating economic and environmental trade-offs, EcoPress Colorado State University. Available at:

https://www.nrel.colostate.edu/toward-sustainable-biofuel-production-evaluating-economic-and-environmental-trade-offs/ (Accessed: 14 September 2024).
99. Varkkey, H. (2021) 'Transboundary Environmental Governance in the EU and South-East Asia: Contesting Hybridity in the Biofuels and Palm Oil Regimes', JAS (Journal of ASEAN Studies), 9(2). Available at: https://doi.org/10.21512/jas.v9i2.7757.
100. Veza, I. et al. (2022) 'Lessons from Brazil: Opportunities of Bioethanol Biofuel in Indonesia', Indonesian Journal of Computing, Engineering and Design (IJoCED), 4(1), p. 8. Available at: https://doi.org/10.35806/ijoced.v4i1.239.
101. Wirawan, S.S. et al. (2024) 'Biodiesel implementation in Indonesia: Experiences and future perspectives', Renewable and Sustainable Energy Reviews, 189, p. 113911. Available at: https://doi.org/10.1016/j.rser.2023.113911.
102. Wu, B. et al. (2023) 'Economic and environmental viability of biofuel production from organic wastes: A pathway towards competitive carbon neutrality', Energy, 285, p. 129322. Available at: https://doi.org/10.1016/j.energy.2023.129322.
103. Xu, H. et al. (2022) 'Life Cycle Greenhouse Gas Emissions of Biodiesel and Renewable Diesel Production in the United States', Environmental Science & Technology, 56(12), pp. 7512–7521. Available at: https://doi.org/10.1021/acs.est.2c00289.
104. Yasinta, T. and Karuniasa, M. (2021) 'Palm oil-based biofuels and sustainability in Indonesia: Assess social, environmental and economic aspects', IOP Conference Series: Earth and Environmental Science, 716(1), pp. 0–11. Available at: https://doi.org/10.1088/1755-1315/716/1/012113.
105. Yazdanparast, R. et al. (2022) 'A resilient drop-in biofuel supply chain integrated with existing petroleum infrastructure: Toward more sustainable transport fuel solutions', Renewable Energy, 184, pp. 799–819. Available at: https://doi.org/10.1016/j.renene.2021.11.081.
106. Yoon, S.-M. (2022) 'On the interdependence between biofuel, fossil fuel and agricultural food prices: Evidence from quantile tests', Renewable Energy, 199, pp. 536–545. Available at: https://doi.org/10.1016/j.renene.2022.08.136.
107. Zapata, C., Vazquez-Brust, D. and Plaza-Úbeda, J. (2010) 'Productive inclusion of smallholder farmers in Brazil's biodiesel value chain: Programme design, institutional incentives and stakeholder constraints', International Policy Centre for Inclusive Growth Working Paper [Preprint], (73). Available at: https://www.econstor.eu/bitstream/10419/71825/1/637817559.pdf.
108. Zhou, A. and Thomson, E. (2009) 'The development of biofuels in Asia', Applied Energy, 86, pp. S11–S20. Available at: https://doi.org/10.1016/j.apenergy.2009.04.028.
109. Zuurbier, P. and van de Vooren, J. (eds) (2008) Sugarcane Ethanol: Contribution to Climate Change Mitigation and the Environment. Brill | Wageningen Academic. Available at: https://doi.org/10.3920/978-90-8686-652-6.