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Research article

Palm oil-based bioenergy sustainability and policy in Indonesia and Malaysia: A systematic review and future agendas

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ABSTRACT

This paper reviews previous research on the sustainability and policies of palm oil-based bioenergy in Indonesia and Malaysia. A systematic literature review with a meta-analysis (PRISMA) methodology was performed to evaluate the related articles discussing sustainability and bioenergy policies. This study found 96 articles that mapped the sustainability and policies of bioenergy in Indonesia and Malaysia over the last decade. The sustainability studies were divided into two areas: the environment and socioeconomics. Researchers were more likely to examine environmental factors than socioeconomic factors, specifically focusing on the following environmental indicators: land use conversion, deforestation, and CO_2 emissions. Most policy studies concentrated on sustainability and energy security. Over the last two decades, the development of bioenergy policies in Indonesia and Malaysia has been comparable in terms of geographical position and palm oil production. However, Indonesia's bioenergy policy has tended to be more vigorous and dynamic than Malaysia.

1. Introduction

The increasing energy demand has forced the world community to search for alternative sources by expanding new and renewable energy sources. One of them is biomass, or what is known as bioenergy. However, this effort has a further impact on the environmental sustainability and social life of the community. In Europe and America, natural resources are used widely as alternative energy sources in forestry. The utilization of forest resources outside the control limits has triggered deforestation, which has resulted in increased CO_2 emissions and reduced biodiversity and may trigger global impacts in the form of climate change. Similarly, in Asian regions, such as Indonesia and Malaysia, agricultural products have become the primary source of bioenergy development, including palm oil plantations.

Over the past decade, Indonesia and Malaysia have become two countries that provide many palm oil products to the world [1]. Both countries produce around 85% of the world's palm oil [2, 3]. Palm oil, which produces crude palm oil (CPO), is a major source of bioenergy, particularly biofuels (biodiesel) [4]. In Southeast Asia, there has been a steep rise in the production of biodiesel owing to its high potential and yield. Palm oil plantations and processing byproducts, such as fiber, empty fruit bunches, shells, and liquid waste, can potentially be used as an alternative source of renewable energy, such as power plants (bioelectric) [5, 6]. Similarly, liquid waste, known as palm oil mill effluent, can be used as an alternative energy source for biogas and electricity generation [7].

Since 2005, Asia has become an important region for exporting world palm oil for biofuel. Palm oil, with its relatively small share (3.4%), was used as an alternative fuel in Indonesia in 2005. Asia's biodiesel production was 0.18 million m^3, with a biodiesel production rate of 6.47% per year and a consumption growth rate of 6.43% per year in 2006 [8]. Numerous studies on the development and analysis of palm oil-based bioenergy have been conducted since the 1980s. Indonesia and Malaysia officially started using palm oil as an alternative renewable energy source in 2006, which was marked by the issuance of National Energy Policy in both countries [9, 10]. The demand for bioenergy in Indonesia has also increased because of Ministerial Regulation 1212/2015, which was related to the mandatory blending of 202% biofuel into fossil fuel, later called B202.

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Implementing the bioenergy policy in Indonesia has produced advantageous outcomes for the gross domestic product (GDP) and national economy. According to the Directorate of Energy and Mineral Resources of Indonesia, in 2013, the policy could save 831 million dollars in foreign exchange (particularly biodiesel). In 2014, the Indonesian government, through the Minister of Energy and Mineral Resources (ESDM), revised the previous regulations by issuing ESDM Regulation No. 20/2014 [11]. This regulation has increased the proportion of biofuels to 20% for transportation and industry. With this regulation, the Indonesian government anticipated savings of up to US$ 3 billion [12].

However, the development of bioenergy-based palm oil faces challenges and negative campaigns in the international community. Palm oil smallholders and industry found hurdles because of concerns from the international community over issues related to sustainability, particularly regarding their impact on the environment and social aspects [13]. Therefore, there is a need to prove that the bioenergy from palm oil complies with sustainability standards that consider economic, social, and environmental balances.

In some countries, bioenergy development is considered a trigger for social problems and negative environmental sustainability. Deforestation for land expansion has been associated with deleterious impacts on biodiversity, organic matter in the soil, and greenhouse gas effects, increasing the Earth's surface temperature [14, 15]. Land availability and security are essential for many activities, including agriculture for food production, forest protection, and residences [16]. However, there is copious demand for food, leading to large-scale land conversion. Consequently, this activity adversely contributes to greenhouse gas emissions, increasing global temperatures [17]. Similarly, using palm oil as a raw bioenergy material led to deforestation and increased CO_2 emissions in some areas of Indonesia [18]. Socially, palm oil plantations and industry have caused land problems and further conflicts in the community. The expansion of land to meet the needs of palm oil plantations may increase land conversion, threatening settlements and other plantations. This has a high land price effect and increases conflicts among communities [19].

Considering all these factors, this article reviews various studies on bioenergy sustainability and policies in Indonesia and Malaysia that rely on palm oil as the primary raw material source. This study also examines bioenergy development in several other countries, exploring the use of palm oil as a potential resource for each country.

This study conducted a systematic literature review of sustainability and policy regarding bioenergy-based palm oil in Indonesia and Malaysia. This review focuses on the literature on the sustainability and policy dynamism in palm oil producer countries: Indonesia and Malaysia. The original contribution of this paper is to provide sustainability indicators for developing palm-oil-based bioenergy sustainability, which is important to consider in policy and regulations. The present work is expected to serve as foundational research and an evaluation for Indonesia to prepare and establish sustainability criteria and indicators suitable for the development and expansion of palm oil-based bioenergy.

2. Research methodology

2.1. Research framework

This study focused on two categories related to each other. The first part of the review focuses on articles on the sustainability of bioenergy, specifically oil palm-based bioenergy, in two comparison regions, Indonesia and Malaysia. The two aspects examined were the socioeconomic and environmental factors. In the second part, the review focuses on bioenergy policies based on the existing potential in the global scope or two observation regions, Indonesia and Malaysia. The policy aspects studied include energy security, sustainability, feed-in tariff, energy elasticity, and technology.

2.2. Systematic literature review flowchart and data analysis

This study systematically explored relevant peer-reviewed academic articles to collect data. In addition, data were obtained from government reports or national and international research institutions to determine the development of bioenergy production and consumption. In this study, the preferred reporting items for systematic reviews and meta-analysis (PRISMA) method were applied to complete a systematic literature review (SLR), as proposed in Ref [20]. The research flow following the PRISMA methodology is illustrated in Figure 1.

The SLR method using the PRISMA methodology evaluated 95 articles related to bioenergy sustainability and policy from various high-impact journals. Journal of Renewable and Sustainability Review, Journal of Energy Policy, Journal of Biomass and Bioenergy, Journal of Cleaner Production, Energy Procedia, Journal of Applied Energy, Journal of Land Use Policy, Energy Conversion and Management, Conservation Letters, and other relevant international journals. Figure 2 presents the distribution of articles according to the publisher.

In this study, a peer review analysis was conducted on all relevant articles obtained from the database. Some approaches applied included the selection, grouping, classification, and summarization of the entire article. The overview is presented in the form of a matrix showing the relationship between the various variables involved, which consists of the author, the year the article was published, the study area, bioenergy potential, sustainability aspects, and policy focus. Furthermore, the analysis results form the basis for recommendations of various possibilities that can be applied to meet energy needs by considering sustainability and policy aspects.

3. Results and discussion

3.1. Evaluation of the reviewed articles

This study conducted a SLR of 95 targeted articles to highlight two main aspects: bioenergy sustainability and bioenergy policy. First, 95 targeted articles published between 2000 and 2019 are described. The 95 reviewed articles were classified as follows: 42 articles discussed the aspects and indicators of bioenergy sustainability, while 27 articles were related to bioenergy policy. In addition, 10 articles and reports that discuss the exploration of palm oil-based bioenergy in both countries and 16 articles related to bioenergy development, sustainability, and policy in other countries, including European, America, and Asian countries, were reviewed.

The first group of articles was selected primarily according to the years of publication, country or region, bioenergy feedstock, and sustainability. The selection of policy related articles was based on the year, country, bioenergy feedstock, and policy focus. This study focused on studies from Asia because palm oil commodities are primarily planted in Indonesia and Malaysia. Regarding sustainability studies, the articles were grouped into two main categories: environmental and socioeconomic. Environmental articles had four indicators: 1) greenhouse gas (GHG) emissions; 2) land use/land use conversion and deforestation; 3) biodiversity; 4) soil, water, and carbon stock. The socioeconomic category of articles is organized by six indicators: 1) productivity, 2) net energy balance, 3) smallholder yield and income, 4) land tenure and conflict, 5) market share and price, and 6) food security. In terms of bioenergy policy, it was divided into six areas: (1) sustainability impact, (2) energy security, (3) feed-in tariff, (4) blending mandatory, (5) technology innovation and infrastructure, and (6) tax and incentive. Figure 3 shows the distribution of the articles according to this classification.

Based on Figure 3, of the 96 articles reviewed, 23 articles (24.05%) discussed the impact of land use change and deforestation; 21 articles (21.52%) were related to GHG emissions, and as many as 13 articles or 12, 66% discussed the issues related to the impact of oil palm bioenergy on the environment and biodiversity. Furthermore, related to the socioeconomic aspects, of the 96 articles that have been reviewed, most discussed the market share indicators, namely nine articles or 8.86%, while the other socioeconomic indicators, such as productivity, smallholder yield and income, land tenure, and conflict, and food security, an average of five to six articles or approximately 6%.

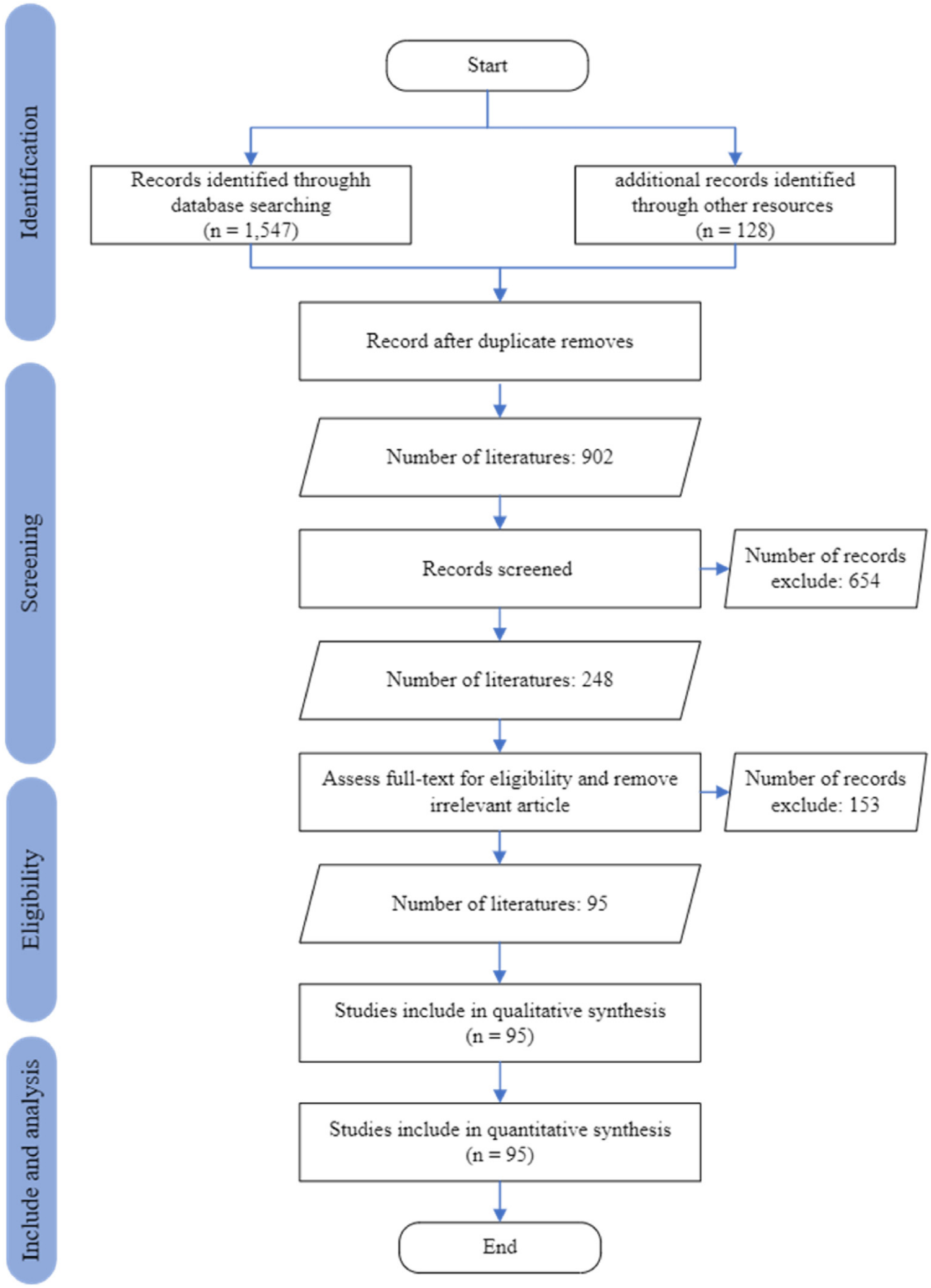

Figure 1. Systematic literature review flowchart, adapted from PRISMA [20].

Figure 3 shows that environmental indicators are the most considered factors in sustainability discussion. Land use changes, deforestation, and GHG emissions are the two most important factors discussed in the literature. The importance of these two factors in sustainability policies was also confirmed. For the socioeconomic indicators, market share and price and smallholder yield and income were the two most important indicators discussed in the literature. In the bioenergy industry, the raw materials produced by smallholders encourage scholars to discuss this aspect in research. Producing a fair market share and price with a reasonable smallholder yield and income may support business stability and sustainability. Therefore, incorporating these indicators into the sustainable development and policy of bioenergy-based palm oil is aimed at enhancing business stability and making further improvements.

For further explanation, Table 1 lists the context of the field of study and the indicators. Land use is the most important indicator discussed in the literature because it is related to many human activities. Applying land use as a sustainability indicator is important for monitoring and managing the current land use conversion status and providing further improvement. For the socioeconomic field, market share and smallholder income were the two indicators considered in the sustainability assessment of bioenergy. The socioeconomic field of sustainability, especially in bioenergy from palm oil, is related to smallholders and profit sharing [21]. Therefore, it is unsurprising that these indicators were primarily considered in the analysis.

A review of bioenergy sustainability identified the leading indicators considered in the literature. For bioenergy sustainability, four indicators

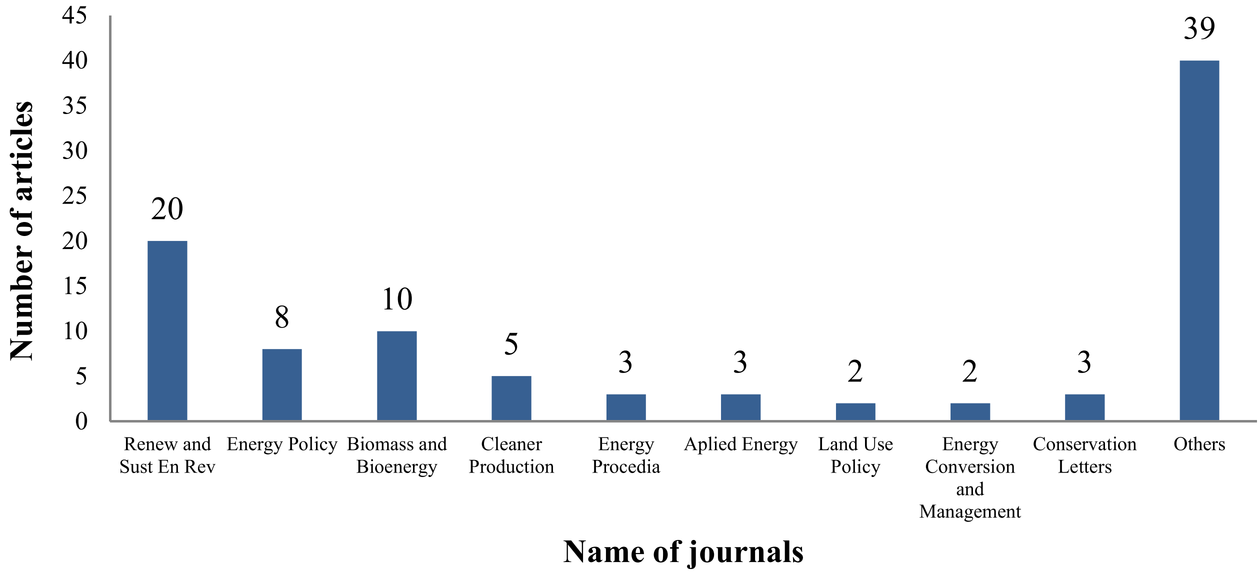

Figure 2. Distribution of articles by the publisher.

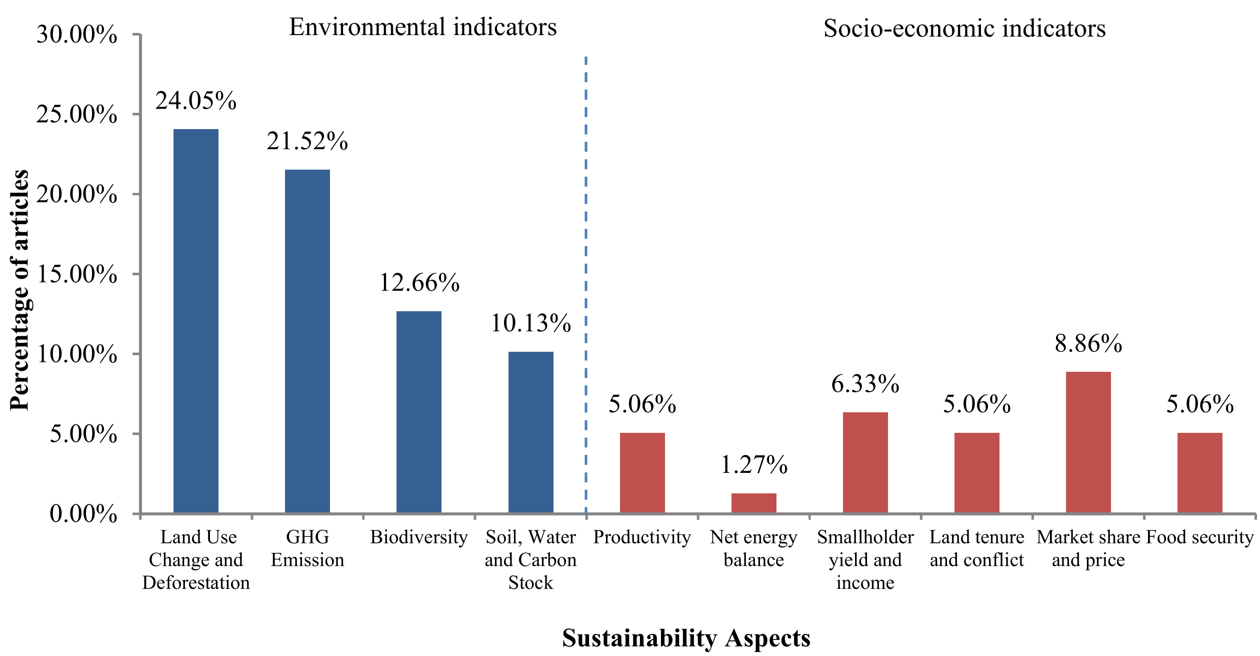

Figure 3. Distribution of articles according to the bioenergy sustainability indicators.

were found to be the most considered for assessing the bioenergy sustainability performance. These indicators are land use and greenhouse gas (GHG) for environmental aspects, market share, and smallholder yield for socioeconomic aspects, as shown in Table 2.

For the second focus of this SLR, we also identified articles that discussed bioenergy policy. This review found four main foci in the bioenergy policy in the literature: sustainability impact, energy security, technology innovation and infrastructure, blending mandatory, feed-in tariff (FiT), and tax and incentive. Sustainability impact and energy policy are the two foci of bioenergy policy found in the literature. Figure 4 presents the distribution of articles discussing bioenergy policy issues.

Table 3 lists a detailed description of the policy focus in the literature. Sustainability impact is the focus of developing bioenergy policy because this business is related to human and natural resource activities. The government understands the possible impact of a bioenergy explosion. Therefore, a sustainability impact policy is required to balance the social, economic, and environmental effects. Subsequently, energy security was also found to be the most policy focus in developing bioenergy policy. This is unsurprising because the main idea of proposing bioenergy as a new alternative energy source is to maintain energy security with renewable and low-cost resources resource.

A review of bioenergy policies in Malaysia and Indonesia has found that the main policy focus considered in the literature is to adopt regulations on bioenergy policies. Table 4 lists the key findings of the review of sustainability policies.

This section describes the slight information of the reviewed articles and their foci. The following section describes the detailed aspect of bioenergy sustainability, bioenergy policy, and its impact. Further policy recommendations are provided based on this SLR.

Table 1. Summary of papers discussing sustainability aspects and indicators.

Field of Study	Indicators	Description	Number of articles	References
Environmental Aspect	Land Use/Land Use Change and Deforestation	Land use is related to human activities related to agriculture. The accumulation of land area determines the land area to produce raw materials from bioenergy divided by the accumulation of surface area nationally and agricultural and forest areas utilized [22].	23	[4, 15, 16, 18, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35]
	GHG Emission	GHG emission of bioenergy is determined through the framework of GBEP. This approach is established nationally [22].	21	[15, 16, 17, 27, 28, 30, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44]
	Biodiversity	The percentage of national areas that have high biodiversity values [22].	13	[3, 4, 30, 39, 40, 45, 46, 47, 48, 49]
	Soil, Water, and Carbon Stock	• Percentage of land that maintains soil quality where bioenergy feedstocks are cultivated [22]. • Data from watersheds determined by the Indonesian government is taken as a reference to determine the volume of water associated with production activities and processing bioenergy raw materials [22].	8	[16, 31, 40, 44, 47, 48, 50, 51]
Socioeconomics Aspect	Productivity	Indicators represent resource utilization, production efficiency, and distribution of bioenergy [22].	4	[30, 47, 51, 52]
	Net energy balance	Energy inputs in the value chain for bioenergy production [22].	1	[52]
	Smallholder yield and income	Benefits impacting smallholder incomes related to bioenergy production [22].	5	[13, 28, 40, 53, 54]
	Land tenure and conflict	The percentage of land used for new bioenergy production is based on legal instruments and the current legal system for establishing rights and procedures for changing rights [22].	4	[19, 28, 54, 55]
	Market share and price	Prices and food supply nationally affect the use of bioenergy and domestic production.	7	[24, 30, 56, 57, 58, 59, 60]
	Food security	Combining bioenergy production with existing land use activities without changing food production.	4	[51, 56, 57, 60]

3.2. Bioenergy sustainability

Numerous studies have been conducted on the sustainability of palm oil and bioenergy. However, many researchers have focused only on one sustainability indicator that lies within one aspect of sustainability, whereas others have investigated the linkages between indicators on one particular sustainability characteristic. As a result, there has been an imbalance of research strategies, with researchers focusing on the issues related to technical facets rather than sustainability issues [32]. Ideally, sustainability studies should examine the linkages between the three features of sustainability, namely economic, social, and environmental aspects, as described previously by Mukherjee and Sovacool [30], Markevicius et al. [79], Hayashi et al. [80], Mikkila et al. [81], and Chong et al. [82].

Recently, there has been an increase in sustainability studies involving various aspects, not just the three traditional areas: social, economic, and environmental. Some recent studies have included additional aspects, such as technology [83, 84], and politics [85]. Closely related fields to sustainability, such as conceptual sustainability, have included management views [86]. In relation to research on palm oil-based bioenergy sustainability, especially on environmental aspects, several indicators have been studied, such as greenhouse gas emissions [4, 15, 18, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 56], land use change and deforestation [14, 15, 17, 18, 27, 30, 32, 33, 34, 35, 37, 38, 39, 41, 42, 43, 44, 87], biodiversity, soil, water, and air quality [18, 25, 44, 47, 48, 50, 51], and [56].

Other related indicators of socioeconomic factors have also been investigated, such as productivity [30, 47, 51, 52], net energy balance [52], smallholder yield and income [13, 18, 28, 53, 54], land ownership [19, 28, 54, 55], price and market share [16, 21, 24, 27, 30, 50, 51, 52, 53, 56, 57, 58, 59, 60], and food security [56, 57, 60, 88].This study assembled previous studies based on the time, area, methods, and sustainability indicators. In the subsections, the detailed indicators found most commonly in the literature are explored.

3.2.1. Impact of bioenergy-based palm oil development on environmental aspects

Related to sustainability issues, the development of bioenergy-based palm oil is considered the main factor that affects environmental impact and social influences in the community [13]. As a bioenergy source, palm oil plantations are a major cause of land conversion and deforestation [33, 38]. In Indonesia, palm oil plantations contributed to the reduction of 5,000 ha of mangrove forests, approximately 1,000 ha of forest in mountainous areas, 0.38 million hectares of peat land forest, and 0.29 million hectares of medium land forest from 2000 to 2010 [18]. Indeed, the rate of deforestation in Indonesia is almost double that of Brazil. According to Margono et al. [39], deforestation of primary forest in Indonesia reached 0.84 million hectares, while in Brazil, it was 0.46 million hectares.

In some countries, bioenergy development is considered the leading cause of environmental unsustainability. For example, expansion through logging activities (deforestation) affects biological diversity (biodiversity), reducing organic matter content in the soil and increasing the negative impact of greenhouse gases that increase the temperature of the Earth [14, 15]. Land is also important for other reasons, including food agriculture, forest protection, and accommodation for humans [56]. Therefore, analyzing bioenergy development in the land use aspect is required to ensure sustainability balances.

Turning toward Indonesia, bioenergy development from palm oil-based sources has not yielded satisfactory results on sustainability

Table 2. Key findings of the sustainability aspect.

Aspects	Most considered indicators
Environmental	1. Land Use/Land Use Change and Deforestation 2. GHG Emission
Socioeconomics	1. Market share and prices 2. Smallholder yield and income

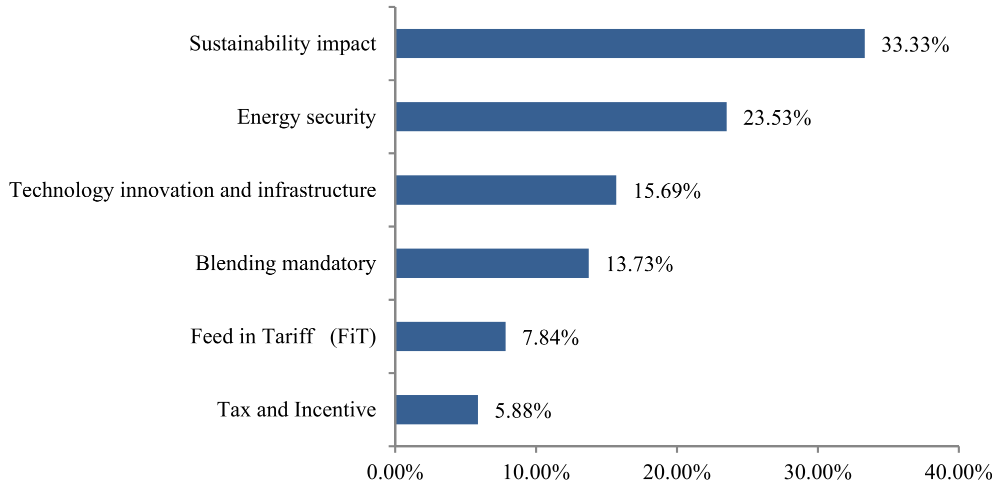

Figure 4. Distribution of articles on bioenergy policy focuses.

performance. According to Papilo et al. [89], from the three aspects studied (i.e., economic, social, and environmental aspects), are the worrying status. However, to overcome this disappointing result, the Indonesian government has organized policies, including the certification of plantation land policy, mandatory mixing of 30% of bioenergy with fossil energy, later known as B30, and improving institutional governance concerning the reform of coordination and policy. An overview of the bioenergy sustainability of the reviewed studies is provided in the appendix.

Global land conversion for agricultural activities to fulfill energy needs is the main factor increasing greenhouse gas emissions and global warming [17]. The utilization of agricultural products for bioenergy development has led to climate change, which is expected to continue until 2050 [25]. Similarly, the utilization of palm oil as the raw materials for bioenergy production has led to the expansion of land for palm oil plantations in Indonesia, which has greatly affected the preservation of forests, biodiversity, and the availability of carbon reserves. Over the last 30 years, palm oil plantations in Indonesia have been responsible for land use changes of up to 40 million hectares of land, resulting in the loss of 30% of forestland. This figure is much higher than in Malaysia, where only around 5 million hectares or 20% of forest land has been lost [37].

The results of this assessment were reinforced by Lee et al. [18]. Approximately 88.3% of the total land was damaged by fires committed by various large corporations, while 10.7% of the damage was caused by burning by the public. On the island of Sumatra, palm oil plantations, because of deforestation, have been releasing 756–1,043 MTT CO_2 [18].

Utilizing palm oil as a bioenergy raw material also affects global warming. Siregar et al. [90] discussed the impact of using palm oil and *Jatropa* for biodiesel production as part of a global warming potential policy. The results showed that biodiesel production from palm oil had the highest total environmental impact on global warming. Biodiesel production (in one million) using agrochemicals, such as fertilizers and crop protection, significantly contributed to the environmental impact of the production of palm oil- and *Jatropa*-based biodiesel by 50.46% and 33.51%, [90].

Over the last decade, palm oil plantations in Indonesia have penetrated carbon-rich lands, such as peatlands. Approximately 95% of palm oil plantations in Kalimantan and Sumatra are cultivated on peatlands [43]. This has had a profound effect on increasing CO_2 emissions [18, 33]. Regardless of the thresholds, the use of fertilizers has also decreased soil quality [44] and reduced food availability for animals in the soil [48].

3.2.2. Impact of bioenergy-based palm oil development on socioeconomic aspects

Economically, the Indonesian agricultural sector has played an essential role in improving livelihoods because it is donating the main contributor to national domestic products [53]. Similarly, palm oil has the potential to produce alternative renewable energy sources for various applications, including fuel for transportation and industry, power generation, and household energy [6]. Its availability is abundant; thus, palm oil has become an important source for increasing the economic level of Indonesian society [91]. Biodiesel produced from palm oil is recognized as a high-productivity commodity in the first generation of biofuels [52].

Socially, bioenergy development from palm oil-based has also affected the availability of land for both agricultural and residential purposes. According to Obidzinski et al. [19], palm oil cultivation for bioenergy raw materials has led to an increase in land prices, which has become a new source of conflict over land ownership, either between communities of people or companies and communities. In Indonesia, weak law enforcement and regulations on land use have caused the development of palm oil plantations, especially on indigenous land [30].

Moreover, there is still a significant gap in the awareness of land issues and revenue in the farming community [53]. Independent smallholder households commonly receive lower monthly gross incomes than schemes and managed smallholder households, whereas independent smallholders receive the lowest monthly gross income from palm oil cultivation [40]. In this case, the government must provide regulations in maintaining the negative impact and trade-off of palm oil expansions. The potential considered regulations are as follows: environmental management, the use of forest land for plantation, traditional land use, and land conversion in a transparent and legal manner [19].

3.2.3. Commercial aspect of bioenergy in Indonesia and Malaysia

The literature review shows two leading socioeconomic indicators to consider in bioenergy: market share and prices and smallholder yield and income. The bioenergy source for economic stability in Malaysia and Indonesia is promising because it contributes significantly to GDP. Indonesia and Malaysia have also been reported as the primary contributors of biodiesel from palm oil worldwide [92].

The contribution of bioenergy production to national economic stability has resulted in Indonesia and Malaysia proposing strong policies to strengthen domestic energy stability. Indonesia and Malaysia have focused on strengthening palm oil and bioenergy production by proposing policies since 2006 [9], [10]. In 2017, Malaysia proposed the B20 biodiesel program for the transportation sector to increase the advantage of biodiesel for energy. Indonesia proposed B30 for transportation, electricity, industry, and commerce. These two countries have responded seriously to the potential for bioenergy from palm oil as a renewable energy source.

In addition, to enhancing the domestic energy stock, biodiesel blending for fossil energy can potentially improve palm oil prices in domestic areas. Because biodiesel is produced mainly from palm oil,

Table 3. Summary of papers discussing bioenergy policies.

Field of Study	Policy Focus	Description	Number of articles	References
Bioenergy Policy	Sustainability impact	Related to developing bioenergy policies that consider the environmental impacts, especially on the environmental aspects.	17	[10, 13, 24, 31, 32, 41, 42, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70]
	Energy security	Bioenergy source as energy supply for geopolitical security, households, and communities—this source should be accessible, reliable, sustainable, and viable for national development and economic health.	12	[10, 26, 60, 61, 62, 69, 70, 71, 72]
	Feed-in Tariff (FiT)	Policies that offer fee-based compensation to produce renewable energy, providing detailed prices and long-term contracts that support a renewable energy investment.	4	[67, 73, 74] [55, 61, 69, 70]
	Blending mandatory	Policies that encourage the use of biofuels, especially biodiesel, reduce dependence on imported diesel oil through the mixing of fossil fuels with biofuels. This policy aims to save foreign exchange and support the macroeconomic.	7	[10, 24, 59, 68, 70, 75, 76]
	Technology innovation and infrastructure	Related to government and industry efforts to increase productivity, efficiency, and effectiveness of palm oil-based energy production and simultaneously attempts to minimize negative impacts on the environment by encouraging the development of technology advancement.	8	[9, 24, 59, 60, 77]
	Tax and Incentive	Related to government support to efforts of renewable energy development through the provision of subsidies, incentives, and tax breaks.	3	[13, 73, 78]

farmers are in a bargaining position to improve the market share and yield. This is also in line with the leading indicators considered in the socioeconomic aspects found in this study. The data is also shown in the global increase in palm oil prices. Figure 5 presents the palm oil prices of Indonesia and Malaysia based on processed data of CPOPC Palm Oil Database [93].

3.3. Bioenergy policy review

Several studies on bioenergy policies have been conducted by researchers from various countries. Policy recommendations generally refer to the potential commodities in each region or country. In general, the potential of biomass for bioenergy development comes primarily from residual agricultural and forest products.

The policies issued in the countries are directed into the following diverse considerations: 1) achieving energy security; 2) relationship among the economic, social, and environmental factors *(sustainability)*; 3) FiT; 4) elasticity of energy; 5) use of technology. In comparison, the European Union (EU) proposed a bioenergy policy to achieve the following objectives: 1) achieving green economic growth, 2) embodying the resilience of energy, 3) developing rural communities, and 4) reducing the impact of greenhouse gas emissions [94].

In the United States (US) and the EU, policies are frequently directed toward the development of bioenergy utilization of residual forest products, as reported by Scarlat et al. [60], Soderberg et al. [94], Evans [95], Guo et al. [96], Suttles et al. [97], Lindstat et al. [98], and Lossau et al. [99]. In some regions, bioenergy is directed primarily through agricultural byproducts in the form of biomass.

Bioenergy policy development in the EU has generally complied with forestry policy as a precaution due to the potential impact of bioenergy development on the environment. According to Lindstat et al. [98], there are several important instruments for determining the focus of bioenergy policy in the EU, particularly in Finland, Germany, Spain, Norway, and Slovenia. They found the following instruments to be important: 1) determination of FiTs procedure and the assurance of the electricity price sourced from renewable energy; 2) provision of incentives, such as tax reductions on various efforts to develop bioenergy; 3) provision of financial support to the farming business that supports the development and use of bioenergy in the form of soft bank loans; 4) supporting investment for efficient energy use and switching to renewable energy sources in the household; 5) other schemes that support the development of bioenergy and efficiency.

Table 4. Key findings of sustainability policies.

Aspects	Most considered focus on bioenergy regulations
Sustainability policies	1. Sustainability impact 2. Energy security

In addition to relying on forestry, biomass has been used and developed in the EU as a raw material for bioenergy. The existing biomass is expected to contribute to approximately half of the renewable energy sources in Europe. Hence, sustainability requirements should accommodate all biomasses, such as food, chemicals, biofuels, and bioenergy [60]. Table 5 lists previous studies on bioenergy development in some countries in accordance with potential commodities and policy targets.

An overview of the bioenergy policy in Indonesia and Malaysia shows some uniqueness. Malaysia has focused on FiTs, with some focus on energy security. Malaysia pays less attention to the sustainability impact of the bioenergy business. Indonesia, however, focused mostly on sustainability impacts with less attention on feed-in tariffs and energy security. Sustainability impact focused on the triple bottom line of sustainable development, which includes economic, social, and environmental factors. The differences between these countries indicate that they have different ways of taking positions to regulate bioenergy business development.

Using non-food materials, such as *Jatropa*, may be a promising option to suppress the disadvantageous effects of sustainability, particularly the conflict between food and energy. In some countries, such as South Africa, Uganda, and China, plants are cultivated as a new alternative to renewable energy materials. Amezaga et al. [113] reported that the major reason for using energy crops as a source of bioenergy feedstock rather than other sources is due to the lower risk of environmental damage; most of the initiatives for waste utilization of forests were not as expected, and other considerations that can have a positive impact on the social aspect, especially in the empowerment of rural communities. Sugarcane is another important material source for bioenergy business development. Although sugarcane is used as food for the community, it produces bioethanol as a byproduct and is a renewable alternative energy source.

In contrast, some ASEAN countries, including Indonesia and Malaysia, rely more on palm oil plantations as raw materials for

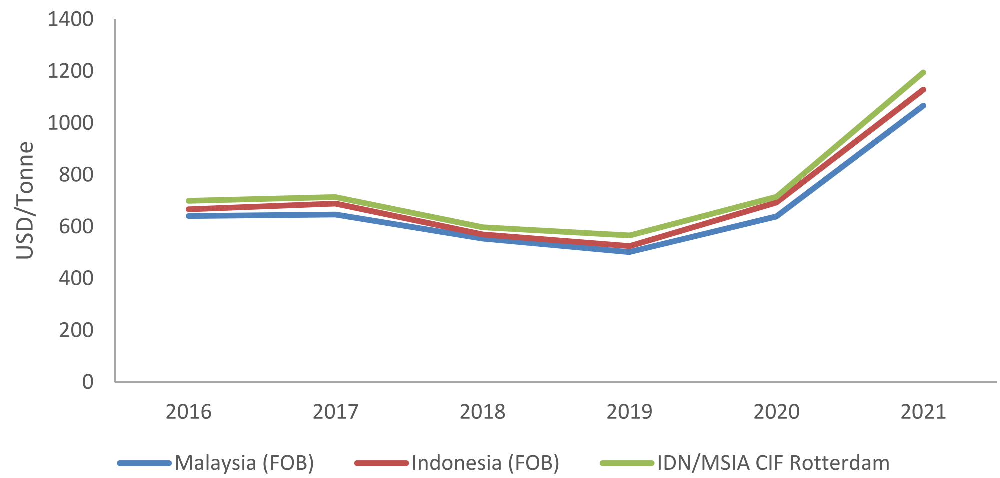

Figure 5. Crude palm oil price of Indonesia and Malaysia.

bioenergy explorations and development. These resources are major considerations in the establishment of bioenergy policies. This situation has been described in several studies, including those by Masjuki et al. [10], Mekhilef et al. [67], Hashim and Ho [73], and Umar et al. [74].

3.3.1. Bioenergy policy in Indonesia

Many studies have investigated the development of Indonesian bioenergy policies, including Singh and Setiawan [9], Caroko et al. [13], Kamahara et al. [52], Hasan et al. [114], Mujiyanto and Tiess [71], Handoko et al. [109], FAO [112], and Kumar et al. [107]. The research encompassed the palm oil-based bioenergy policy in Indonesia. Moreover, it did not cover the possibility of using other commodities for bioenergy.

In his study, Sadirsan et al. [111] established models for bioenergy policy, showing how biomass is applied for electrical purposes. The policy focused on setting the price of the feed-in tariff biomass Green

Table 5. Overview of the bioenergy policy from the reviewed studies.

Region/Country	Researchers	Bioenergy Sources	Policy Focused						
			Es	Si			Ft	Ee	T
				Ec	Sc	En			
America	Evans [95]	Forest biomass	-	X	X	X	-	-	-
	Guo et al. [96]	Forest biomass	-	-	-	X	-	-	-
Brazil	Lossau et al. [99]	Forest biomass	-	-	-	X	-	-	-
Uni Europe	Dandres et al. [100]	Forest biomass	-	X	-	X	-	-	-
	Soderberg et al. [94]	Forest biomass	-	-	-	X	-	-	-
	Kraxner et al. [101]	Forest biomass	-	-	-	X	-	-	-
	Suttles et al. [97]	Forest biomass	-	X	-	X	X	-	-
	Scarlat et al. [60]	Forest biomass	-	X	-	X	-	-	-
	Lindstat et al. [98]	Forest biomass	-	X	X	X	-	-	-
	Troost et al. [102]	Agriculture	-	-	-	X	-	-	-
UK and Germany	Purkus et al. [103]	Renewable energy	-	-	-	-	X	-	-
	Amezaga et al. [104]	Agriculture	-	X	X	X	-	-	-
Asian	Tongsopit et al. [69]	Renewable energy	X	-	-	-	-	-	-
China	Kahrl et al. [105]	Forest biomass	-	-	X	-	-	-	-
	Xingang and Pingkuo [106]	Forest biomass	X	-	-	-	-	-	-
Malaysia	Hashim and Ho [73]	Renewable energy	-	-	-	-	X	-	-
	Masjuki et al. [10]	Palm oil	X	-	-	-	-	-	-
	Mekhilef et al. [67]	Palm oil	-	-	-	-	X	-	-
	Umar et al. [74]	Palm oil	-	-	-	-	X	-	-
Indonesia–India	Singh and Setiawan [9]	Agriculture	X	-	-	-	-	-	-
Indonesia-Thailand	Kumar [107]	Renewable energy	X	-	-	X	-	-	-
Indonesia	Tampubolon [108]	Forest biomass	X	-	-	-	-	-	-
	Kamahara et al. [52]	Palm oil	-	-	-	-	-	X	-
	Caroko et al. [13]	Palm oil	-	X	X	X	-	-	-
	Handoko et al. [109]	Bioenergy	-	-	-	-	-	X	-
	Jupesta [110]	Bioenergy	-	-	-	X	-	-	X
	Mujiyanto and Tiess [71]	Renewable energy	X	X	-	X	-	-	-
	Sadirsan et al. [111]	Forest biomass	-	-	X	-	X	-	-
	FAO [112]	General	-	X	X	X	-	-	-

Notation: *Es*, energy security; *Si*, sustainability impact; *Ec*, economic; *Sc*, social; *En*, environmental; *Ft*, feed-in tariff; *Ee*, energy elasticity; *T*, technology.

Table 6. Evolution of bioenergy policy developments in Indonesia.

Year	Policy and Program	Purposes
2002	Energy and Mineral Ministerial Decree No. 1122 in 2002 related to the development of small-scale power generation and distribution	Providing incentives for developing power plants based on renewable energy sources distributed through a network of State Electricity Company (SEC) by manufacturers of non-SEC for projects with a capacity of up to 1 MW.
2004	Energy and Mineral Ministerial Decree No. 2 in 2004 about energy conservation	• Optimizing the utilization of renewable energy sources. • Efficient use of energy sourced from renewables and fossil energy and increase public awareness in implementing energy efficiency.
2005	Government Regulations No. 3 in 2005 on power plant development program	• Arranging relations of cooperation between the SEC and the private sector in developing electricity projects, an exception is granted to companies that produce electricity for its use or for companies that use renewable energy. This project can be done independently without the need to partner with SEC.
	Blueprint of the application national energy program 2005 to 2025	• To describe the steps on developing national energy security and providing energy development roadmap of each sector that is sourced from renewable energy and non-renewable energy. • Designing subsidy programs and energy efficiency improvement.
2006	Presidential Decree No. 1 in 2006 about the supply and use of biofuel	• Regulate the use of biofuels. • Regulate guidelines for cooperation on the development of biofuel.
	Presidential Decree No. 5 in 2006 of the National Energy Policy (NEP 2006)	• The energy policy related to the contribution of biofuels of 5% of its energy needs until 2025. • To set targets for energy savings of up to 1% per year.
	Presidential Decree No. 10 in 2006 on the establishment of the National Team for Biofuel Development,	Assignment to the relevant minister in implementing the objectives of the National Energy Policy to promote the use of biofuel as an alternative fuel.
	Directorate General of the Ministry of Energy and Mineral Resources issued a decree in 2006 on quality standard diesel oil (SNI 04-7182-2006)	This decree regulates the use of fatty acid methyl esters (FAME) up to a maximum of 10 percent in volume of diesel fuel blending. FAME for blended biodiesel must meet quality standards SNI 04-7182-2006.
	Ministry of Energy and Mineral Regulation No. 2 in 2006, on the development of medium-scale power generation, sourced from renewable energy	Extension of the program at the same price as the Ministerial Decree No. 1122 of 2002 for the construction of power projects with a capacity of 1 MW–10 MW.
2007	Law No. 30 in 2007 about energy	Policies governing renewable energy development and energy conservation, especially as efforts to increase the use of renewable energy and provide incentives for renewable energy development efforts within a certain period.
2008	Ministry of Energy and Mineral regulation No. 32 in 2008 concerning Supply, Utilization, and Marketing Biofuel as Alternative Energy	The government provides special incentives for biofuel investors, including in the form of the following: a) Reduction of stamp duty; b) Agreements with 50 countries to avoid double taxation; c) Manage import duties for goods in supporting biofuels productions; d) Reduction in taxable income with a value equal to up to 30%expansion of the realization of investment for six years (tax allowance); e) Accelerated depreciation and amortization; f) Income tax 10% per dividend, to the extent possible lower and regulated in the applicable tax treaty; and g) Exclusion of the value-added tax. A ministerial decree, which states that the agency is licensed for the consumption of biofuels, will be given a fiscal and non-fiscal incentive.
2009	Presidential Decree No. 45 in 2009	The government will ensure the provision and distribution of biofuel in Indonesia. The decree also states that the price of the biofuel market index will be determined by the Ministry of Energy and Mineral Resources.
2010	Ministry of Energy and Mineral regulation number 0219 in 2010 on pricing market index of biofuel	The benchmark price of biodiesel is the standard export price of fatty acid methyl esters. The reference price is the price of the meter bioethanol ethanol (FOB Thailand) plus 5 % (the bioethanol program was discontinued in 2010 because of a dispute in the formulation of the EDM market price index and producer of ethanol).
	Law No. 30 in 2010 on electricity	Regulate investment in electricity, giving priority to projects funded by renewable energy and clean technologies, encourage the development of power plants that rely on the biomass potential,

Energy National. It was suggested that the policy could support regulations related to the energy and mineral resources of the feed-in tariff. Based on research findings, several key elements influence the development of policy models for new and renewable energy: (1) human resources; (2) coordination among government agencies; (3) community participation; (4) funding and business investment; (5) micro-finance; (6) public figure; (7) forest land status; (8) local policy on forest plantation; (9) spatial and territory; (10) financial institutions/banking; (11) energy-based NGOs and associations.

The bioenergy policy in Indonesia has changed over time. The transformation of bioenergy-related policy in Indonesia aims to address the issues in the field. Singh and Setiawan [9] and FAO [22] described policy developments related to the use and expansion of bioenergy in Indonesia from 2000 to 2011, as summarized in Table 6.

Through National Energy Policy (NEP) No. 79/2014, the Indonesian government confirmed that energy management needs to be emphasized to reduce the dependence on petroleum energy use. This is related to using energy sources derived from bioenergy (biofuels and biomass). In 2025, the government has set the target of a 23% share of renewable energy, 7% of which is obtained from biofuels, and 5% is generated from other renewable sources, including solar, hydro, nuclear, wind, and solar.

The substance of National Energy Policy includes energy supply, energy utilization (efficiency and diversification), pricing, and environmental sustainability [100]. In addition, several other existing policies were related to basic electricity tariffs, where the Indonesian government, through Ministerial Decree No. 27/2014, established that the State Electricity Company (PLN) is obliged to buy electricity sources from power plants that utilize renewable energy with a capacity of 10 Megawatts or more for state and private enterprises, cooperatives, and NGOs.

A mandatory policy has been set through ESDM Ministerial Decree No. 25/2013, which is an amendment to the previous regulation No. 32/2008, to increase the use of biofuels. With the former regulation, there is growing demand for biofuel because it mandated the blending of 10% biodiesel into diesel, which is recognized as B10. In 2014, the Indonesian government revised a previous regulation by issuing ESDM Regulation No. 20/2014, which increased the blending portion of biofuels by up to

Table 7. Development of mandatory policy on biofuel use in Indonesia.

Sector	Regulation 25/2013			Regulation 20/2014			Regulation 12/2015			Purpose
	2015	2020	2025	2016	2020	2025	2016	2020	2025	
Transportation PSO	10	20	25	20	30	30	20	30	30	In total needs
Transportation Non-PSO	10	20	25	20	30	30	20	30	30	In total needs
Industry and Commercial	10	20	25	20	30	30	20	30	30	In total needs
Electrical Generate	25	30	30	30	30	30	30	30	30	In total needs

20% (for transportation and industry). This regulation has been implemented since 2016 (see Table 7) [12]. Figure 6 shows the changes in the Indonesian national energy mix targets from 2006 to 2014.

3.3.2. Bioenergy policy in Malaysia

Malaysia's renewable energy policy was proposed to enhance the utilization of potential renewable energy resources, which ensured the stability of the national electricity supply and sustainable socioeconomic development. The development of renewable energy in Malaysia aims to achieve five objectives: 1) enhance renewable energy contribution to electricity generation, 2) facilitate expansion and innovation in the renewable energy industry, 3) ensure reasonable costs for renewable energy generation, 4) conserve the environment for future generations, and 5) enhance public awareness of the renewable energy potential for future life.

Bioenergy development in Malaysia began after the introduction of the Fifth Fuel Policy under the Eighth Malaysia Plan (2001–2005), with the launch of the Small Renewable Energy Power (SREP) program. Through this program, Malaysia attempted to integrate renewable energy and fossil fuels. In 2000, the transportation sector accounted for the highest demand for energy, approximately 41% of the total energy needs in 29.70 MTOE (million tons of oil equivalent). Although the energy demand for the industry exceeded the needs of transportation in Malaysia in 2000, it had the largest energy demand in 2008, accounting for a substantial increase in energy demand by 32.7% in just eight years [91].

The Malaysian government focused on developing comprehensive bioenergy policies through efforts to emphasize the improvement of fossil energy needs, particularly for transportation purposes. One result was to provide biofuel sources from palm oil plantations. This was realized by establishing mandatory policies B2, B5, and B10 from 2002 to 2010 [10].

Mekhilef et al. [67] also asserted that the SREP Program, introduced in the 8th Malaysia Plan on May 11, 2001, aimed to foster the development of renewable energy projects and facilitate the wider use of renewable energy, particularly for the development of power generation in Malaysia. Through the SREP Program, small-scale renewable energy plants were allowed to sell their generated electricity to the grid. The energy sources covered in this program include solar, wind, biomass, mini-hydro, biogas, and other forms of energy.

Palm oil biomass power is a promising technological commodity contributing to a sustainable clean energy market. However, strong policies are needed to accelerate the development of renewable technologies. Unfortunately, the SREP Program appeared unsuccessful in increasing the share of biomass projects, which affected the overall national renewable energy capacity target. The weaknesses of past policies must be understood to formulate better energy policies in the future [74].

In the case of India, the evolution of the bioenergy policy occurred in gradual stages, starting from the establishment of institutions to the development of biomass energy. In addition, the strategy was allocated to developing and deploying more efficient technologies from inside and outside the country. This policy was also supported by tax incentives and subsidies. Consequently, an integrated strategy for bioenergy development has been developed [9].

Furthermore, bioenergy policies in both Indonesia and Malaysia have evolved over the years. Masjuki et al. [10] and Umar et al. [74] summarized the development of bioenergy policy in Malaysia, as listed in Table 8.

3.3.3. Policy contributions to bioenergy sustainability

The design of a bioenergy policy that satisfies the concept of sustainability requires serious attention from economic, social, and environmental dimensions. The development of bioenergy policy without considering other aspects will lead to new problems in the future. Therefore, there is a need to develop a comprehensive approach for assessing the status of these facets. Collaboration between stakeholders and institutions is necessary to ensure optimal use of existing resources to meet the growing national demand for bioenergy.

Meeting the energy demand is complicated and requires a comprehensive solution, particularly in terms of policy and institutional approaches. However, developing a bioenergy policy that aligns with sustainability principles is a significant challenge. The main problem of the National Energy Policy (NEP) still revolves around the phases of implementation, coordination, and regulation. There is a clear requirement to align policies across various levels: NEP, national general energy design (RUEN), and regional general energy designs (RUED). Policymakers must face uncertain factors, including policy sustainability, resources, cost, technology, and future energy market conditions. Information and conditions may change at any time, resulting in a high cost of policy adjustments [103].

The additional challenges caused by using agricultural commodities for bioenergy should be anticipated by considering all the leading factors (economic, social, and environmental). Achieving this will require the greatest focus and efforts on the use of second-generation and biomass energy [115] or the development of other bioenergy forms, such as biogas, thereby calculating and anticipating deleterious environmental outcomes [102].

Biofuels can help reduce LCA and GHG emissions globally by considering the technology and local conditions while applying sustainability screening [116]. Methane recovery and composting [27] and the development of second-and third-generation biofuels [16] appear to be the best methods for reducing GHG emissions. Furthermore, implementing the best management practices [35] and the National Biofuel Policy align with global efforts to reduce emissions [24].

Kazamia and Smith [117] asserted that the development of second-generation biofuels has attracted the attention of many researchers. This is because second-generation biofuels are considered a solution to reduce the conflict between the food and energy industries. Considering alternative energy sources and their impact on land use remains tremendously important. Using second-generation biomass may also be an acceptable strategy for conserving the environment. As reported in India, rice straw was used as a raw material for bioethanol production, which also contributed to reducing the potentially harmful environmental problems caused by fires in open lands [118].

Based on the discussion above, these recommendations should be considered to improve sustainability standards for bioenergy development related to environmental aspects: 1) the need to draft certification standards with more reliable and viable indicators and cost-effectiveness, at least covering the structure and process of key ecosystems and

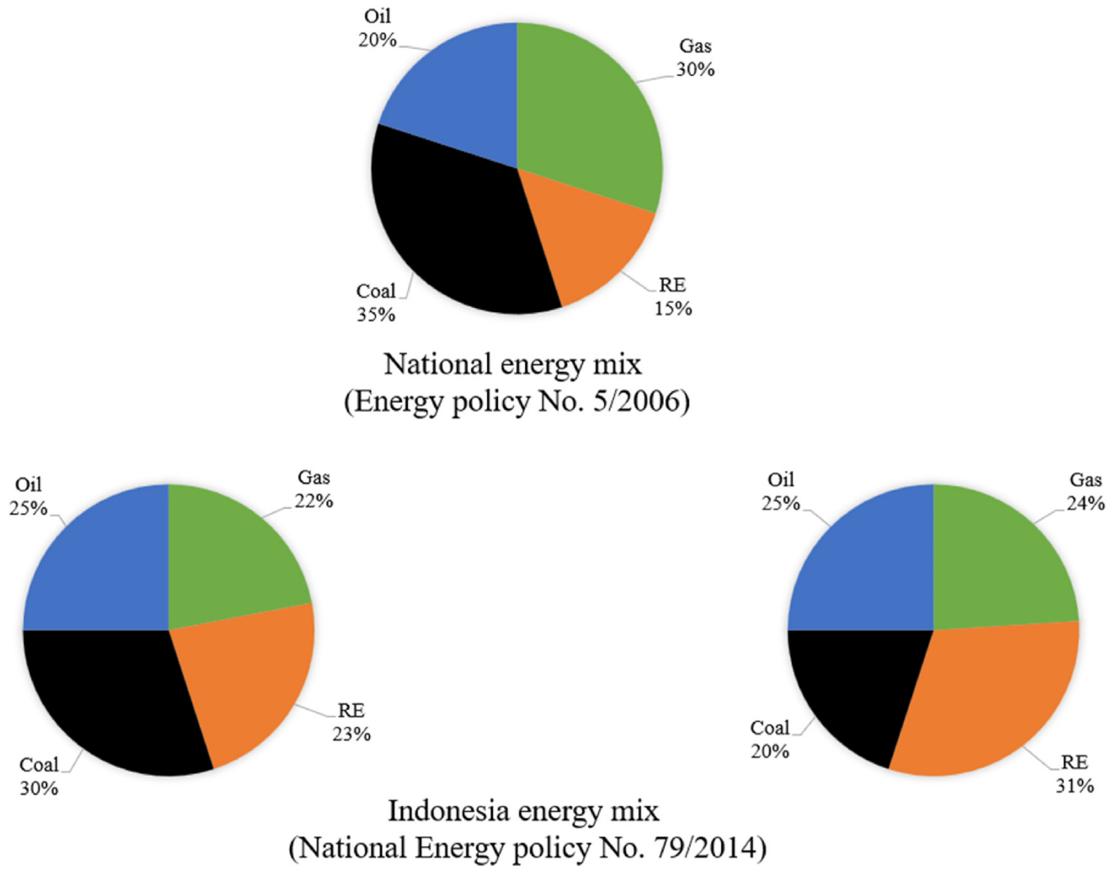

Figure 6. Pie chart of the national energy mix in 2006 and 2014.

fundamentals; 2) the need to consider methodologies for assessing the ecosystem capacity and determining the threshold value of sustainable bioenergy development. The indicators should benefit policymakers or actors moving toward bioenergy [119], while sustainability indicators should be easy to use, measurable, and relevant. Furthermore, the indicators must be broad in scope and predict changes through management measures [120].

To establish governance and better sustainability policy in the bioenergy sector, the government needs to focus on implementing policies related to the conservation values of biodiversity, the benefits for manufacturers when certified, and increasing engagement with stakeholders [121]. In addition, institutional strengthening is also expected to have a significant social value on independent smallholders in the supply chain, which is mutually beneficial and can substantially increase productivity, contributing to rural development and saving land use [122].

3.4. Future agendas

Based on research, the following recommend seven important agendas can be recommended for the future:

1. Determination of more appropriate sustainability indicators for the bioenergy potential. Further research needs to be performed,

Table 8. Evolution of bioenergy policy developments in Malaysia.

Year	Programs and purpose
2001	Using crude palm oil (CPO) and fuel oil blend to generate power and expand research in low-pour-point palm biodiesel.
2002–2005	Refined diesel oil (B2, B5, and B10) using a mixture of palm oil for vehicles in Malaysia. There was a transfer of technology to Lipochem (M), which came from vehicles in Malaysia by mixing palm oil and diesel (B5), which was purified, bleached, and deodorized (B5)
	Renewable share of 500 MW or 5% of Energy Mix 2005.
2006	Launching National Biofuel Policy as first commercial-scale biodiesel plant, launching envo Diesel, and approving 92 biodiesel licenses.
2007	Increasing the price of CPO due to many biodiesel projects that were suspended or canceled.
2008	Malaysian Biofuel Industry Act 2007 came into force. The use of Envo Diesel was scrapped and replaced with B5.
2009–2010	Using B5 blend for Government vehicles from selected agencies. The government announced that the B5 mandate for commercial use would be deferred to June 2011.
	Renewable share of 350 MW or 1.8% of Energy Mix 2010.
2011–2015	Renewable energy act 2011.
	Sustainable energy development authority 2011.
	Fit in Tariff (FiT).
	Renewable share of 985 MW or 5.5 % in Energy Mix 2015.

particularly to determine sustainability indicators that are more appropriate to the bioenergy potential of Indonesia and Malaysia.
2. To enhance the bioenergy potential, this research found that stakeholders and the government must pay attention to these important aspects: land use/land use change and deforestation, GHG emissions, market share and prices, smallholder yield and income, sustainability impact, and energy security.
3. Expanding the scope of the study on sustainability. Future studies should consider other important aspects, including political, technological, and institutional factors.
4. In the context of policies for bioenergy sustainability in Indonesia and Malaysia, the government may consider expanding B30 to B40 because it contributes to the countries' GDP, palm oil farmers' income, and strengthens energy stability.
5. Institutional Bioenergy Development. Institutional governance is the relationship among stakeholders directly involved in the supply of raw materials, processing and management, policy makers, and supervision. In the future, stakeholders need to pay attention to bioenergy supply chains from downstream to upstream to secure contribution and control price.
6. Harmonization in the bioenergy policy formulation that design and formulation of future bioenergy policies must involve various related institutions and consider the balance between aspects of sustainability.
7. Environmental considerations of converting forests to monoculture plantations (deforestation) cause major land use change (LUC), soil physical properties, hydrological cycle, and water resources at the site. One of the strategies that could minimize the negative impact of monoculture plantations through better plantation management is implementing a mixed cropping system (agroforestry).

4. Conclusions

Over the past two decades, the literature has generally highlighted the negative impacts of expanding palm oil-based bioenergy, especially on social and environmental aspects. The main environmental impacts include deforestation due to the conversion of land and forests to palm oil plantations. Further impacts from deforestation are increased CO_2 emissions, decreased air and water quality, and adverse impacts on biodiversity around oil palm plantations and production.

However, the important questions that need to be answered are as follows. ***First***, "are the environmental impacts that occurred during the previous two decades also still happening today in Indonesia and Malaysia?" ***Second***, "what are the negative impacts that still occur today and greatly influence environmental and social sustainability?" ***Third***, "if the various impacts still occur today, how effective are the policies set by the two countries to prevent and overcome plantation management practices and the development of palm oil-based bioenergy that do not meet sustainability principles?" Therefore, it is essential to conduct further research in the future, especially to review the development of various environmental and social impacts after two decades. For Indonesia and Malaysia, the sustainability of the development of palm oil bioenergy is very important. This has had a major impact on the views and responses of the international community toward oil palm development in both countries, now and in the future.

In addition, there are still very few studies on the development of palm oil bioenergy technology, especially technology that can have a positive impact on the environment. Although some researchers have offered various ideas on second-generation bioenergy utilization, the study is still not well developed for palm oil bioenergy. Similarly, the study reviewed the linkages between the development of palm oil bioenergy and its role among various organizations within the institutional context. Few researchers have examined the institutional and chain linkages supporting sustainability principles in developing palm-oil-based bioenergy. Therefore, it would be very useful to research the development of technology for processing palm oil as an energy source and institutional conditions in the future.

5. Recommendation

Bioenergy policy does not significantly influence the three main sustainability factors. Economic factors are more prevalent in preparing bioenergy policies in both countries, which may produce difficult circumstances for achieving sustainability goals. The orientation in which bioenergy is developed to meet economic needs should also be considered regarding its social and environmental aspects.

Furthermore, effective regulation is required. Regulations should cover land use for bioenergy production and law enforcement for forest clearance by burning, illegal logging, or both. Applying best practice management in plantation management and using environment-friendly technology to use second- and third-generation bioenergy should be essential in developing future bioenergy policies.

However, the need for the attention and awareness of all parties is more fundamental. Stakeholders, government, industry, and the public should understand the importance of sustainability. They must synergize in implementing various policies to realize bioenergy development efforts that meet sustainability principles. Similarly, the relationship between institutional governance and implementing good management in accordance with existing norms are vital for meeting all needs in implementing sustainable development.

Declarations

Author contribution statement

Petir Papilo, Marimin Marimin: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Erliza Hambali, Machfud Machfud, Muhammad Asrol: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mohamad Yani, Evanila Evanila, Hermawan Prasetya, Jaizuluddin Mahmud: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

No data was used for the research described in the article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Appendix

Overview of the bioenergy sustainability from reviewed studies

Authors	Year	Country			Environmental Indicator				Socioeconomic Indicators					
		Indonesia	Malaysia	Others	GHG emission	Deforestation LU/LUC	Biodiversity	Soil, Water & Carbon Stock	Productivity	Net Energy Balanced	Smallholder yield and Income	Land Tenure and Conflict	Market Share & Price	Food Security
Wicke et al. [23]	2008	-	X	-	X	-	-	-	-	-	-	-	-	-
Koh et al. [46]	2008	X	X	-	-	-	X	-	-	-	-	-	-	-
Fitzherbert et al. [3]	2008	X	X	-	-	-	X	-	-	-	-	-	-	-
Boons and Mandoza [123]	2010	-	-	X	-	-	-	-	-	-	-	-	-	-
Gao et al. [57]	2010	-	-	X	-	-	-	-	-	-	-	-	X	X
Kamahara et al. [52]	2010	X	-	-	-	-	-	-	X	X	-	-	-	-
Janaun and Ellis [78]	2010	-	X	-	-	-	-	-	-	-	-	-	-	-
Wicke et al. [124]	2011	X	X	-	-	X	-	-	-	-	-	-	-	-
Schmidt et al. [15]	2011	-	-	X	X	X	-	-	-	-	-	-	-	-
Haberl et al. [25]	2011	-	-	X	X	-	-	-	-	-	-	-	-	-
Havlık et al. [17]	2011	-	-	X	-	X	-	-	-	-	-	-	-	-
Lee et al. [125]	2011	-	-	X	-	-	X	-	-	-	-	-	-	-
Hirawan [54]	2011	X	-	-	-	-	-	-	-	-	X	X	-	-
Cramb and Sujang [55]	2011	-	X	-	-	-	-	-	-	-	-	X	-	-
Gingold et al. [47]	2012	X	-	-	-	-	X	X	X	-	-	-	-	-
Gamborg et al. [14]	2012	-	-	X	-	X	-	-	-	-	-	-	-	-
Obidzinski et al. [19]	2012	X	-	-	-	-	-	X	-	-	-	X	-	-
Agus et al. [27]	2013	X	X	-	X	X	-	-	-	-	-	-	-	-
Lee et al. [126]	2013	X	-	-	-	-	-	-	-	-	X	-	-	-
Chiew and Shimada [28]	2013	-	X	-	X	X	-	-	-	-	-	-	-	-
Geibler [58]	2013	X	X	-	-	-	-	-	-	-	-	-	X	-

(*continued on next page*)

(*continued*)

Authors	Year	Country			Environmental Indicator				Socioeconomic Indicators					
		Indonesia	Malaysia	Others	GHG emission	Deforestation LU/LUC	Biodiversity	Soil, Water & Carbon Stock	Productivity	Net Energy Balanced	Smallholder yield and Income	Land Tenure and Conflict	Market Share & Price	Food Security
Gunarso et al. [27]	2013	X	X	-	-	X	-	-	-	-	-	-	-	-
Bessou et al. [29]	2013	X	X	-	X	-	-	-	-	-	-	-	-	-
Ogbonna et al. [127]	2013	-	-	X	-	-	-	-	-	-	-	-	-	-
Mukherjee and Sovacool [30]	2014	X	X	-	X	X	X	-	X	-	X	X	X	-
Margono et al. [39]	2014	X	-	-	-	X	-	-	-	-	-	-	-	-
Popp et al. [56]	2014	-	-	X	X	X	-	X	-	-	-	-	X	X
Lee et al. [128]	2014	X	-	X	X	X	X	-	-	-	-	-	-	-
Djomo et al. [28]	2015	-	-	X	X	X	-	-	-	-	-	-	-	-
Alwarritzi et al. [35]	2015	X	-	-	-	-	-	-	-	-	X	-	-	-
Khasanah et al. [50]k	2015	X	-	-	-	-	-	X	-	-	-	-	-	-
Brad et al. [129]	2015	X	-	-	-	-	-	-	-	-	-	-	-	-
Peñarandaa et al. [31]	2015	X	-	-	X	-	X	X	-	-	-	-	-	-
Hansen et al. [32]	2015	-	-	X	X	X	X	-	-	-	-	-	-	-
Gatto et al. [41]	2015	X	-	-	-	X	-	-	-	-	-	-	-	-
Abood et al. [33]	2015	X	-	-	X	X	-	-	-	-	-	-	-	-
Souza et al. [51]	2015	-	-	X	X	-	X	X	X	-	-	-	-	X
Susanti and Maryudi [42]	2016	X	-	-	-	X	-	-	-	-	-	-	-	-
Petrenko et al. [34]	2016	X	-	-	X	X	-	-	-	-	-	-	-	-
Tao et al. [48]	2016	X	-	-	-	-	X	X	-	-	-	-	-	-
Afriyanti et al. [43]	2016	X	-	-	-	X	-	-	-	-	-	-	-	-
Goh et al. [44]	2016	X	-	-	-	X	-	X	-	-	-	-	-	-

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