ERIA Research Project Report FY2024, No. 30

# Analysis of the Water-Energy-Food Nexus for Sustainable Biomass Utilisation for Fuel, Fibre, and Food in Selected EAS Countries

## Phase I (2023–2024) Report

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Phase I (2023–2024) Report

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| | |
|---|---|
| APROBI | Indonesia Biodiesel Producer Association |
| APTRI | Indonesian People's Sugar Cane Farmers Association |
| ASEAN | Association of Southeast Asian Nations |
| BIOGEN | Biomass Power Generation |
| BPS | Badan Pusat Statistik (Indonesia) |
| CAT | Climate Action Tracker |
| CHP | Combined heat and power |
| CIFOR | Center for International Forestry Research |
| $CO_2$ | Carbon dioxide |
| $CO_2eq$ | Carbon dioxide equivalent |
| CPO | Crude palm oil |
| DA | Department of Agriculture (Philippines) |
| DAR | Department of Agrarian Reform (Philippines) |
| DOE | Department of Energy (Philippines) |
| EAS | East Asia Summit |
| EC | Energy consumption |
| EEP | Energy economic productivity |
| EFB | Empty fruit bunches |
| EFEW | Environment-food-energy-water |
| EJ | Exajoules |
| EMP | Energy mass productivity |
| FAO | Food and Agriculture Organization |
| FAOSTAT | Food and Agriculture Organization Corporate Statistical Database |
| FFB | Fresh fruit bunches |
| GDP | Gross domestic product |
| GFSI | Global Food Security Index |
| GHG | Greenhouse gas |

| | |
|---|---|
| GJ | Gigajoule |
| GR | Government regulation (Indonesia) |
| GW | Gigawatts |
| ha | Hectare |
| HB | House Bill (Philippines) |
| IEA | International Energy Agency |
| INDC | Intended Nationally Determined Contribution |
| IPCC | Intergovernmental Panel on Climate Change |
| IRENA | International Renewable Energy Agency |
| ISRP | Indonesia Sustainable Rice Platform |
| IWRM | Integrated Water Resources Management (Malaysia) |
| JAO | Joint Administrative Order (Philippines) |
| LCA | Life Cycle Assessment |
| LEP | Land economic productivity |
| LP | Land productivity |
| LU | Land use |
| MJ | Megajoule |
| MNRE | Ministry of New and Renewable Energy (India) |
| MSW | Municipal solid waste |
| MW | Megawatt |
| MyRER | Malaysia Renewable Energy Roadmap (Malaysia) |
| NAFMIP | National Agriculture and Fisheries Modernization and Industrialization Plan (Philippines) |
| NBAP | National Biomass Action Plan (Malaysia) |
| NCCP | National Climate Change Policy (Malaysia) |
| NEP | National Energy Policy (Malaysia) |
| NETR | National Energy Transition Roadmap (Malaysia) |
| NOAP | National Organic Agriculture Program (Philippines) |
| NWP | National Water Policy (India) |
| NWRB | National Water Resources Board (Philippines) |
| PAPSI | Indonesia Sharia Banking Accounting Guidelines |

| | |
|---|---|
| PDP | Philippine Development Plan (Philippines) |
| PKS | Palm kernel shells |
| POME | Palm oil mill effluent |
| PR | Presidential Regulation (Indonesia) |
| PSA | Philippines Statistics Authority |
| PUPR | Ministry of Public Works and Public Housing (Indonesia) |
| RA | Republic Act (Philippines) |
| REPAFS | Renewable Energy Program for the Agri-Fishery Sector (Philippines) |
| SAMARTH | Sustainable Agrarian Mission (India) |
| SDGs | Sustainable Development Goals |
| SRA | Sugar Regulatory Administration (Philippines) |
| SREP | Small Renewable Energy Power |
| TERI | The Energy and Resource Institute, India |
| UNEP | United Nations Environment Program |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| UNFCCC | United Nations Framework Convention on Climate Change |
| USDA | United States Department of Agriculture |
| UU | Law (Indonesia) |
| WEF | Water-energy-food |
| WEFL | Water-energy-food-land |
| WEFLC | Water-energy-food-land-climate |
| WEP | Water economic productivity |
| WFP | World Food Programme |
| WMP | Water mass productivity |
| WP | Water consumption |
| WRI | World Resources Institute |
| WST2040 | Water Sector Transformation 2040 (Malaysia) |
| WWF | World Wildlife Fund |

# Executive Summary

The increase in the world population has significantly impacted the environment and the global economy, exacerbating issues like poverty and hunger. In response, the United Nations released the 2030 Sustainable Development Goals (SDGs), considering the linkages between food production, water resources, and energy sources. The Water-Energy-Food (WEF) Nexus concept was introduced by the Food and Agriculture Organization (FAO) and considers the dynamic relationships and mutual influences between human and natural systems (Flammini, 2014). In this study, we include in the nexus the integration of land use and climate as part of the dynamic analysis of the impacts of biomass utilisation. This emphasises the interconnectedness of various resources, encompassing both physical and socio-economic aspects, that are essential for achieving social, environmental, and economic objectives related to water, energy, and food. These interactions occur within the broader framework of external global factors, such as demographic shifts, urbanisation, industrialisation, agricultural modernisation, international trade, market dynamics, technological advancements, dietary changes, and climate change. Additionally, internal drivers specific to particular contexts, such as governance mechanisms, vested interests, cultural norms, and societal behaviours, also play a significant role.

Biomass is becoming a prominent alternative to fossil fuels due to its renewable and eco-friendly nature. In some East Asia Summit (EAS) countries, biomass forms a small but growing part of energy production, with projections showing significant increases by 2030. These countries' strategies involve integrating biorefineries to convert agricultural residues and other biomass sources into biofuels and bio-based products. However, the sustainability and profitability of these projects hinge on government support and subsidies. The government is making efforts to issue various regulatory policies to adapt to and mitigate climate change and minimise its impacts on the security of food, water, and energy sources, land use, and climate change. Thus, the evaluation of Water-Energy-Food-Land-Climate (WEFLC) Nexus indicators underscores several key aspects:

1. Water quality and usage: Bioenergy crop cultivation can affect water quality. Effective management practices are necessary to mitigate the negative effects.
2. Energy production: Biomass energy production is a potential solution for reducing greenhouse gas emissions compared to fossil fuels. The environmental benefits from improving efficiency and lowering emissions depend significantly on the type of biomass and the conversion technology used.
3. Food security: Utilising food crops for bioenergy can impact food security.

4. Land use: Changing land use from traditional agriculture to bioenergy crops has mixed effects. It can reduce environmental impacts like soil erosion and nutrient runoff but may also alter carbon storage and biodiversity.
5. Climate impact: Bioenergy production can help mitigate climate change by reducing carbon dioxide ($CO_2$) and nitrous oxide ($N_2O$) emissions, especially with biomass from marginal lands.

Another notable impact is the anticipated 60% increase in renewable energy for global electricity generation between 2020 and 2026, reaching more than 4,800 gigawatts (GW). Biomass is currently garnering global attention due to its abundance, potential for decentralised production, carbon neutrality, and role in mitigating climate change. Some EAS countries have a high potential as significant producers of biomass from agricultural and plantation crops, such as oil palm, rice, cassava, and sugar cane. An assessment by the FAO and the Climate Action Tracker (CAT) refers to three pillars – water, food, and energy (WEF) – as an effort to increase bioenergy. In this study, the evaluation of the availability of biomass feedstock and sustainability governance is an important pillar.

Based on current market forecasts and trends, a long-term strategy is necessary to address biomass feedstock impacts on the competition between food and fuel, water and energy security, the conversion of land use, and climate change. The current biomass feedstock availability could restrict biofuel production growth in the coming years. Therefore, ensuring its sustainability by expanding feedstock production is a crucial step for bioenergy production. Thus, to promote sustainable growth in biomass production, it is crucial to maintain equilibrium in the WEFLC Nexus. Policies from the government become pivotal, as they can influence cropping patterns, regional disparities in development, and the availability of agricultural resources such as water and energy.

This document focuses on the ERIA Working Group's work on 'Analysis of the Water-Energy-Food (WEF) Nexus for Sustainable Biomass Utilisation for Fuel, Fibre, and Food in Selected EAS Countries' by sharing the policy lessons from the respective developing EAS countries that have a high potential for biofuel production and the role of sustainable biofuels in energy transitions. Learning from other countries, such as their existing policies and agricultural practices, can help promote technological innovation and deployment to expand the use of available and sustainable feedstocks.

This study discusses policies aimed at forming cross-sectoral committees or task forces to ensure coherent policies and the effective implementation of WEFLC-related initiatives. Resolving conflicting policies, such as land-use regulations and energy production targets, is necessary for integrated and sustainable outcomes. Additionally, it emphasises enhancing data sharing and collaborative planning amongst government agencies, the private sector, and other related organisations.

# Chapter 1
# Introduction on Biomass Utilisation

## 1.1 Background

The global population is projected to reach around 10 billion by 2050 (United Nations, 2019), which will likely intensify stresses on resources such as water, energy, and land due to the growing demand for food (SWITCH-Asia, 2022a). Sustainable agriculture is essential to addressing this increased demand for food and energy in an environmentally responsible manner. By improving agricultural yields, we can meet the rising need for food and also generate biomass as a by-product, which can be utilised to produce renewable energy (Igbeghe et al., 2024; Muscat et al., 2020). Biomass can be converted into various energy outputs, such as heat, electricity, and biofuels. The dual functionality of biomass, along with its renewable and sustainable attributes, underscores its importance in addressing sustainability challenges and combating climate change. Biomass can be used for clean energy to meet the growing demand, especially in the food sector.

Global production of primary crops rose by roughly 50% between 2000 and 2018 (FAO, 2020a). In a strong convergence scenario, the global demand for cereal equivalent food is projected to reach about 10.1 billion tonnes by 2030 and 14.9 billion tonnes by 2050 (Islam and Karim, 2019). Asia is a leading producer of cereal crops, especially rice (Farooq et al., 2023). To meet the increasing demand for cereal equivalent food, more agricultural land is necessary. Currently, agriculture occupies more than half of Asia's land area and continues to expand due to heightened agricultural activities.

In recent years, the growing global population has impacted the environment and the world economy. Issues of poverty and hunger have prompted the United Nations (UN) to release the 2030 Sustainable Development Goals (SDGs) Agenda to meet basic human needs such as water, energy, and food. Alexandratos and Bruinsma (2012) reported that to maintain food value in this era, the food supply chain must increase by 70%–100% (van Dijk et al., 2021). To achieve this, food production is interrelated with the consumption of water resources, energy, agriculture, and livestock.

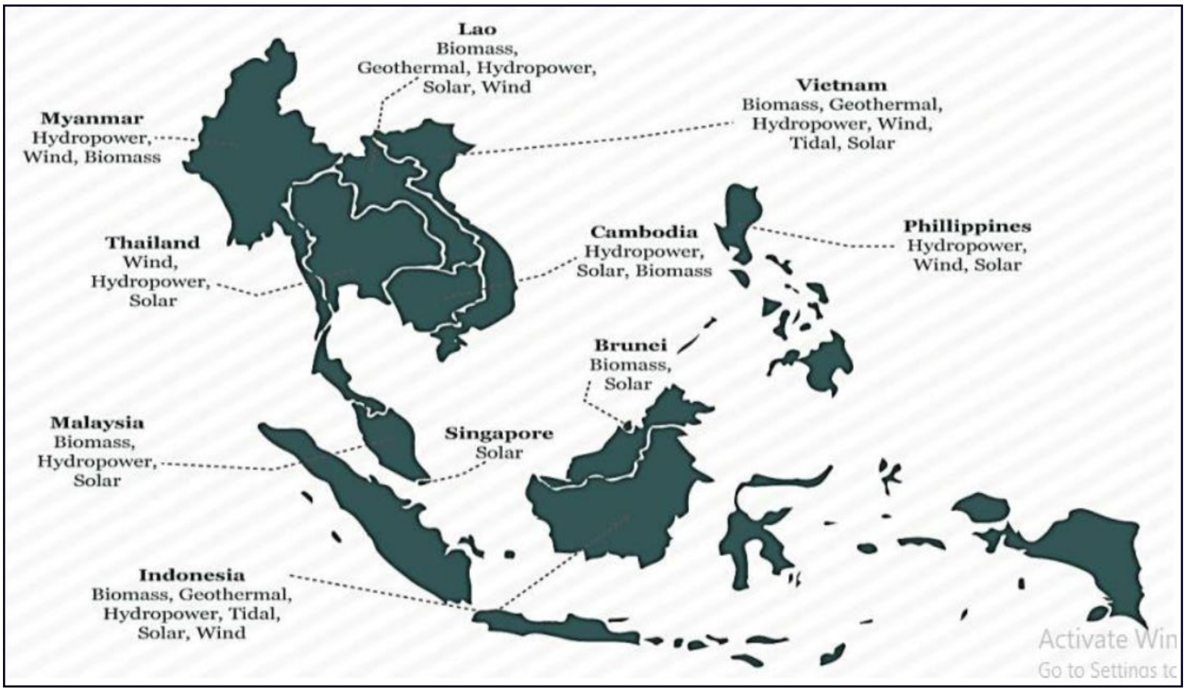
Climate and weather changes have the potential to cause drought, water shortages, and reduced plant productivity in dry subtropical regions. Despite the growing demand for food, energy, and water, their use needs to be more efficient, and the availability of these resources is often difficult to secure, leading to food, energy, and water scarcity. Increased conversion and expansion of cropland also impact water and food availability. This problem is significant and is faced by many countries.

The expansion of agricultural land leads to significant deforestation. The FAO reports that Southeast Asia lost 376,000 km$^2$ of forest between 1990 and 2020 (SWITCH-Asia, 2022a). Deforestation is a major contributor to greenhouse gas (GHG) emissions. By 2050, almost 1 billion hectares of land are expected to be cleared globally, resulting in GHG emissions of about 3 Gt $CO_2$-eq per year (Tilman et al., 2011). Additionally, agricultural activities have numerous environmental impacts, largely due to the use of fossil fuels, fertilisers, pesticides, and herbicides (Poore and Nemecek, 2018). The use of these chemicals in crop production can damage marine, freshwater, and terrestrial ecosystems (Tilman et al., 2011).

Farm operations have an even greater environmental impact, primarily due to the reliance on fossil fuels for groundwater irrigation. Groundwater depletion, which necessitates more energy to pump water as the water table drops, further amplifies these impacts (Siddiqi and Fletcher, 2015; Karimov et al., 2022). The topography of an area also influences energy consumption during land preparation (Diffendorfer and Compton, 2014). Fossil fuel use in crop production increases GHG emissions. Agriculture accounts for 70% of global freshwater withdrawals (SWITCH-Asia, 2022b) and this is expected to rise to meet increasing food demand (Dalstein and Naqvi, 2022). Global water withdrawals for irrigation are projected to grow by 10% by 2050 (FAO, 2011a), with groundwater currently providing about 40% of the world's irrigation needs (Siebert et al., 2010).

The potential of biomass as a renewable energy source has become a serious consideration for reducing dependence on conventional energy in recent years. Biomass is currently attracting global attention because of its abundance, potential for decentralised production and carbon neutrality, and role in mitigating climate change. In this study, biomass resources include waste or residue from agricultural and plantation crops. Countries in the Association of Southeast Asian Nations (ASEAN) have varying biomass resources (see Figure 1.1). These differences relates to how agricultural conditions, plantations, forestry, etc. can produce their products. Table 1.1 shows the potential for biomass energy resources in several ASEAN countries. However, the utilisation rate is still relatively low.

Figure 1.1. Potential Renewable Energy Sources in ASEAN Countries




Source: Shamasundari (2017).

Table 1.1. Potential Biomass Sources and Their Utilisation in Several ASEAN Countries

| Country | Potency | Utilisation |
|---|---|---|
| Indonesia | Technical potential: 49,810 MW | 302 MW |
| Philippines | Commercial potential: 120 MW | n.a. |
| Malaysia | Technical potential: 2,700 MW | 221 MW |
| Viet Nam | Technical potential: 400 MW | 50 MW |
| Thailand | Technical potential: 7,000 MW | 560 MW |
| Cambodia | Technical potential: 700 MW | n.a. |

Source: Saputra, Sriyono, and Pauling (2022).

## 1.2 Definition of the Water-Energy-Food Nexus

Agriculture is a multifaceted sector that involves various elements, such as land use, water and energy consumption, and fertiliser application. These activities are closely tied to climate change (Lynch et al., 2021), which underscores the interconnected nature of water, food, and energy, collectively forming what is known as the 'nexus'. Effective management of any of these components requires a holistic approach that considers the entire system (Cremades et al., 2019). Therefore, managing the nexus in an integrated manner is crucial for the sustainable and efficient use of resources, strategy development, and land suitability assessments (European Commission, 2021). This approach facilitates more comprehensive and effective policymaking, planning, monitoring, and evaluation across the various sectors involved (Botai et al., 2021).

The literature reported in Table 1.2 shows a close relationship between the availability of water, food, and energy.

Table 1.2. Relationship Related to the Availability of Water, Food, and Energy

| Source | Ties Between Water, Food, and Energy Sources |
|---|---|
| UNESCO (2012) | Food production and supply chains account for around 30% of global energy consumption. |
| UNESCO (2014) | Water plays an important role in 90% of electricity production. |
| UNESCO (2014) | In 2050, it is estimated that global water demand from industry will increase by 400%, and more than 40% of humans are expected to experience severe water scarcity. |
| UNESCO (2014) | By 2035, water consumption for energy production will reach 75%–85%, an increase of 20%, to produce higher power generation efficiency and better cooling systems, as well as increased biofuel production. |
| UNESCO (2014) | Damage to wetlands reduces the capacity of ecosystems to purify water, causing groundwater supplies to become depleted by around 20%. |
| WWF (2013) | The need for large water discharge is about 3,000–5,000 litres of water to produce food sources such as 1 kg of rice, 2,000 litres to produce 1 kg of soybeans, 900 litres to produce 1 kg of wheat, and 500 litres for 1kg of potatoes. |

Source: Nugroho (2020).

Based on Table 2.2, the three resources depend on each other to support human life. For example, in maintaining food security, the main target is to open agricultural land to increase the production of several agricultural commodities. Still, calculating the water and energy consumption required and the environmental impacts must be studied more deeply. For energy security, the main target is to increase renewable energy sources by utilising biomass/waste from food crops. Also, aspects of water need and estimates of the impact of energy development to support food and water security must be right on target. Finally, the main target for water security is to estimate the potential need for energy and food crops and their impact on food and energy security.

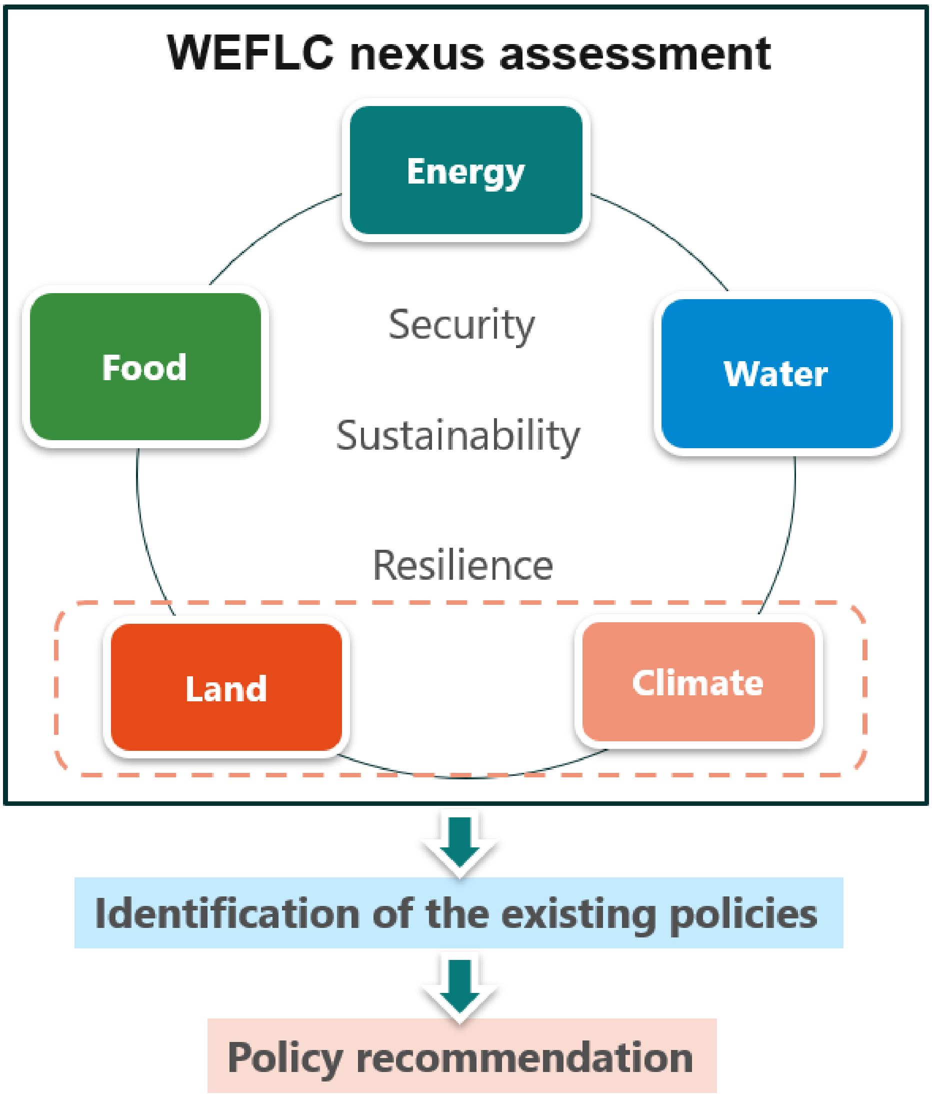
Using bioenergy as a source of new renewable energy, balanced with the WEF Nexus, is a solution to this scarcity problem. IRENA (2015) reports that the use of renewable energy globally is increasing, which is encouraging a reduction in the impact of climate change. It was added that energy capacity for renewable electricity generation globally will increase by 60% between 2020 and 2026 to reach more than 4,800 gigawatts (GW) (IEA, 2021). By assessing biofuels from the perspective of the WEF Nexus, this review addresses the sustainability of bioenergy production. Several countries use biomass from cultivated plants as their primary commodity for producing biofuels such as palm oil, sugar cane, cassava, rice, corn, etc.

### 1.3 Rationale of including land use and climate in the nexus

There are multiple methodologies available for nexus approaches, such as the El-Gafy method and the FAO-based method for nexus assessment, etc. (El-Gafy, 2017). The method developed by El-Gafy (2017) deals with the interlinkages amongst the different indicators and introduces economic and social factors (monetary value and labour involvement) as well along with resource consumption and productivity. To examine the interlinkages, El-Gafy (2017) developed a WEF Nexus approach. Further, Gazal et al. (2022) improved the WEF Nexus methodology by adding a land indicator. Then, Akbar et al. (2023) further enhanced the nexus methodology further by incorporating climate as an indicator.

Integrating land and climate into the WEF Nexus, as presented in Figure 1.2, is crucial for a comprehensive approach to resource management and sustainability. Land is fundamental in agriculture, energy production, and environmental conservation. Effective land use ensures optimised agricultural practices, which are essential for food security and sustainable water use. It also influences water management strategies and is critical for renewable energy initiatives, such as for biofuel crops. The competition between agricultural and energy uses of land necessitates a balanced approach to land allocation, supporting both sectors sustainably. Additionally, land provides essential ecosystem services like soil fertility, carbon sequestration, and biodiversity conservation. Degradation of land resources can impair these services, reducing agricultural productivity and affecting water resources. Thus, sustainable land management practices are vital for maintaining these ecosystem services and supporting the overall WEF nexus.

Figure 1.2. WEFLC Nexus Assessment on Biomass Production




Source: Authors.

Climate change, on the other hand, has a significant impact on water availability, energy production, and agricultural productivity. Variations in precipitation patterns and the frequency of extreme weather events due to climate change affect water resource management, agricultural water needs, and energy production. Including climate considerations in the WEF Nexus enables the development of adaptation and mitigation strategies that enhance resilience and sustainability. Both energy production and agricultural activities are major sources of GHG emissions.

Incorporating climate change into the WEF Nexus helps create strategies to reduce emissions from these sectors, contributing to broader climate change mitigation efforts. Promoting sustainable agricultural and energy practices, such as renewable energy use and conservation agriculture, can help mitigate climate change whilst ensuring water and food security. These practices reduce the carbon footprint of the WEF sectors and enhance their sustainability.

Integrating land and climate into the WEF Nexus promotes a holistic approach to resource management, ensuring the interdependencies between water, energy, food, land, and climate are considered. This integration leads to more comprehensive and effective policies and strategies, supporting the development of synergistic policies that align resource management goals with climate adaptation and mitigation strategies. By doing so, resource management policies are developed in a broader environmental and socio-economic context, promoting long-term sustainability and resilience. This integrated approach helps anticipate and mitigate risks associated with resource scarcity, environmental degradation, and climate variability, ensuring the robustness and adaptability of water, energy, and food systems. Integrating land and climate into the WEF Nexus is essential for developing sustainable and resilient systems capable of addressing the challenges posed by resource scarcity, environmental degradation, and climate change.

Thus, water, energy, food scarcity, land-use conversion, and climate change are problems that are linked to each other and are often called the Water-Energy-Food-Land-Climate (WEFLC) Nexus. These problems are expected to increase in several developing countries, especially countries with populations highly dependent on the agricultural sector. The role of the WEFLC Nexus is to consider plants' water needs so that water use is more efficient. Water is also needed on a large scale to produce energy so that it can drive electricity-generating turbines. Thus, the need for biomass and agricultural commodities also greatly influences the balance between water, energy, food security, efficient land-use, and climate mitigation. The existence of the WEFLC Nexus can increase energy efficiency in the process of converting biomass into bioenergy so that energy output can be optimised and the effects on the environment can be minimised (Gazal et al., 2022). The WEFLC Nexus approach has long been studied to overcome the problem of interconnected water, energy, and food resources. The relationship between these three sectors can be a solution, conflict, or trade-off. The more research there is regarding the connection between the WEFLC Nexus, the greater the world's attention on the problem of climate change will be. Borge-Diez et al. (2022) report on efforts to adapt, mitigate, and achieve food security and sustainable development for an environmentally friendly future.

## 1.4 Research Objectives

Phase I 'Analysis of the Water-Energy-Food Nexus for Sustainable Biomass Utilisation for Fuel, Fibre, and Food in Selected EAS Countries' aims to evaluate biomass utilisation in EAS countries across the entire biomass supply chain, focusing on bioenergy production and its effects on economic sectors, especially land use for food and water resources. The study examines the current state of biomass resources in selected EAS countries, aiming to understand the interconnections between water, energy, food, land, and climate policies and address these challenges in an integrated manner. Specifically, this project assesses the biomass utilisation process, from production to consumption, to produce energy and other biomaterials, with a particular emphasis on the impact on land use for food and energy, its associated water resources, and climate mitigation.

Figure 1.2 shows the nexus approach proposed in this study. It goes beyond the three common ways of the WEF Nexus to also include other sectors such as land and climate change. The nexus approach identifies synergies and trade-offs between the individual policy goals of each sector – e.g. climate and energy goals were both aligned. Based on the past trends and data collected, the present study can be used to project future short-term and long-term scenarios of linkages between individual policy goals. The analysis helps in understanding the nexus in the context of climate change. The study considers cooperation amongst six EAS countries – Malaysia, India, Thailand, Indonesia, the Philippines, and Viet Nam – to address issues of climate change, water, energy, land, and food security concerns towards resource efficiency and sustainable development in the region. The findings obtained from this study include sharing best practices and experiences between participating countries to tackle climate change through the nexus approach. The study has policy implications by analysing WEFLC Nexus variables on the SDGs and the impact of climate change.

The earliest phase of the methodology was the preparatory work for the methodology, often known as a desktop study. In this phase, a desktop study was conducted to obtain a literature review of the existing research on the biomass supply chain related to WEF Nexus assessment and its current policies for each selected EAS country. Its major goal was to undertake a thorough examination of the present policies, regulations, and frameworks governing biomass utilisation for biofuels. This research entailed a thorough examination of academic papers, research reports, governmental publications, and industry reports.

This study further utilised the comprehensive WEFLC Nexus index developed by Akbar et al. (2023). This index serves as a valuable tool for decision-makers to analyse and identify critical areas within the WEFLC Nexus of crop production systems holistically. It is also beneficial for policymakers aiming to achieve the SDGs, particularly by demonstrating the connection between GHG emissions in crop production and other indicators. One of the strengths of the WEFLC Nexus index is its versatility, as it can be applied to any type of crop without spatial or temporal limitations. Additionally, it can be used for future projections in quantifying the nexus for crop production systems (Akbar et al., 2023).

To estimate the impact of bioenergy production on the WEFLC Nexus in EAS countries, this study uses the methodology outlined by Akbar et al. (2023). The indicators considered include water use ($m^3$/ha), energy use (GJ/ha), land use (ha), GHG emissions during farm operations ($CO_2$eq/ha), water mass productivity (t/$m^3$), energy productivity (t/GJ), land productivity (t/ha), mass output per unit of GHG emission (kg/$CO_2$eq), and resource economics productivity indicators. In evaluating the nexus, all indicators were given equal importance. Additionally, factors unique to each country and their respective indicators were considered.

This report begins with a scoping study based on existing global and regional policies related to the bioenergy value chain, using the SDGs as an entry point or analytical lens at various levels. This involves establishing a hierarchical structure, starting from a global context and progressively narrowing down to the level of individual nations. The plan also highlights the availability of feedstocks in each country, alongside relevant data indicators. Initially, reliance will be placed on suggested WEF indices and Climate Action Tracker website indices for reference, including the WEF Nexus Index based on FAO indicators and resources from the Climate Action Tracker. Additionally, the plan will incorporate considerations for land use and innovative approaches.

# Chapter 2

# Current Status of Biomass Feedstock Availability and Challenges

This chapter provides a comprehensive overview of the current state of biomass utilisation in EAS countries, shedding light on the available feedstocks in each country and examining the challenges associated with biomass production that could impact various economic sectors. The report delves into the specifics of how different countries are leveraging their biomass resources and identifies the obstacles they face in maximising the potential of these resources. According to the IEA (2022), there are clear indications that feedstock availability might constrain the growth of some biofuels, particularly in the near future. This constraint poses a significant risk to the expansion of biofuel production and the broader goals of sustainable energy development.

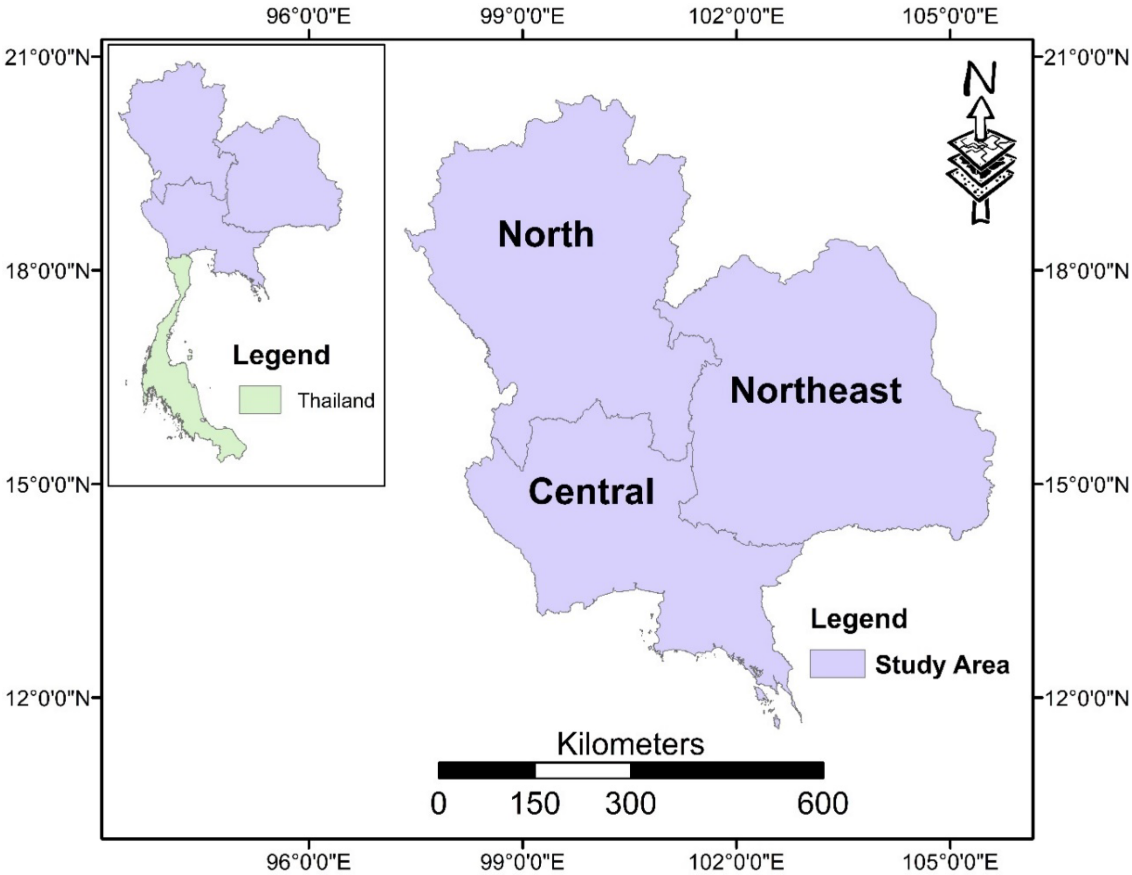
## 2.1 Thailand

Thailand is predominantly an agricultural nation, with a total land area of 513,120 $km^2$. According to the Food and Agriculture Organization (FAO, 2011a), out of this vast expanse, approximately 267,900 $km^2$ is dedicated to agricultural practices. This considerable portion of the country's land is used to cultivate its principal crops, which are sugarcane, cassava, and rice. These crops play a critical role in Thailand's economy, not only serving the domestic needs of its population but also contributing significantly to the global market through exports. Sugarcane is a key ingredient in both the sugar industry and for biofuel production, and cassava is crucial for food and industrial use.

Sugarcane farming in Thailand is primarily concentrated in the Central and Northeastern regions and parts of the Northern region. The northeastern region is responsible for about 36% of the country's average sugarcane output, with the northern region contributing 30%. The Central Plain also plays a crucial role, adding 34% to total sugarcane production. Together, these areas significantly dominate sugarcane cultivation in Thailand, which amounts to an annual production of 69.7 million tonnes (Kongboon and Sampattagul, 2012). Figure 2.1 shows the geographical boundaries of the North, Northeastern, and Central regions.

On the global stage, Thailand ranks as the third-largest producer of cassava, trailing behind Nigeria and Congo, and was responsible for 10.2% of the world's cassava production in 2019. By 2020, cassava cultivation occupied 8.9 million rai (approximately 1.42 million hectares) of Thai farmland, yielding about 29.0 million tonnes of the crop (Sowcharoensuk, 2023). The leading cassava-producing areas in Thailand are the Northeastern, Central, and Northern regions. Specifically, the Northeastern region accounts for 53% of the national output, the Central Plain contributes 30%, and the Northern region makes up 17% of the total cassava production (Kongboon and Sampattagul, 2012).

Figure 2.1. Geographical boundaries of the North, Northeastern, and Central Regions in Thailand




Source: Authors.

Sugarcane and cassava are the main crops in Thailand and have the potential to generate enormous amounts of biomass. The crop and biomass production of the main crops of Thailand is given in Table 2.1. Sugarcane generated approximately 74.2 million tonnes of biomass, with significant contributions from bagasse (22.4%) and tops and leaves (17.8%). In comparison, cassava's biomass production totalled 28.7 million tonnes, encompassing pulp (5.1%), peels (5.9%), stems and leaves (2.6%), and rhizome (7.3%) (Jusakulvijit et al., 2021). The high volume of residue is indicative of the crop's extensive cultivation and highlights the importance of sustainable residue management practices to leverage this biomass effectively.

Moreover, the availability of biomass resources presents a nuanced set of challenges and opportunities in contributing to energy security, given that biomass sources are finite. One significant obstacle is the dispersed nature of biomass, making it challenging to collect and, thus, limiting its potential for large-scale energy production deployment. The 'food versus fuel' debate further complicates the utilisation of biomass resources, as it raises concerns about the allocation of arable land for energy production rather than food cultivation. Despite these challenges, strategies such as diversifying biomass utilisation, enhancing feedstock collection and processing methods, and promoting the plantation of fast-growing trees offer promising avenues to overcome these hurdles and harness biomass more effectively for energy production (Mahakhant, 2018). 81% of farmers operate small landholdings (less than 1.6 hectares), which complicates efforts to mechanise farming operations and gather biomass. Over recent years, the farmgate price of cassava has experienced a decline from its peak in 2011. Consequently, the data indicate that the profit margins for numerous farmers in the area have somewhat decreased, given that production costs have stayed elevated. This is attributed to the rising costs of inputs and wage rates fuelled by inflation (Arthey et al., 2018).

Table 2.1. Crop Production and Residue in Thailand

| Crop | Crop Production (million tonnes per year) | Cultivation Area (ha) | Residue Type | Residue Generation (million tonnes per year) | Residue Production per Area (tonnes per ha) |
|---|---|---|---|---|---|
| Sugarcane | 131.72 | 1.85 | Bagasse | 41.3 | 22.4 |
| | | | Tops and leaves | 32.9 | 17.8 |
| | | | *Total* | 74.2 | 40.2 |
| Cassava | 29.37 | 1.38 | Pulp | 7.0 | 5.1 |
| | | | Peels | 8.1 | 5.9 |
| | | | Stems and leaves | 3.5 | 2.6 |
| | | | Rhizome | 10.1 | 7.3 |
| | | | *Total* | 28.8 | 20.9 |
| Rice | 32.36 | 11.42 | Straw | 25.8 | 2.3 |
| | | | Husks | 7.1 | 0.6 |
| | | | *Total* | 32.9 | 2.9 |

Source: Jusakulvijit et al. (2021).

## 2.2 Indonesia

The development of biofuel energy aims to save fossil energy (energy security), reduce emissions (climate change mitigation), and develop rural agriculture (FAO, 2008). Biofuel production in each country depends on the availability of raw materials (feedstock) in the country concerned. The availability of raw materials is also influenced by land area, so this research will further examine the increase or decrease in production results based on statistical data. Indonesia has extensive agricultural and plantation land and a relatively high fertility rate. Utilising palm oil, sugar cane, and rice as raw materials to produce renewable energy sources is an effort to save fossil energy that is more environmentally friendly. Apart from that, waste biomass or by-products from agriculture or industry can still be managed and used as bioenergy. Energy sources from biomass will not reduce this energy as a food provider for humans. For example, sugar cane bagasse and empty oil palm fruit bunches can be used. Table 2.2 shows the amount of potential biomass in Indonesia.

Table 2.2. Indonesia's Bioenergy Potential for Power Plants

| No. | Province | Potency (MW) | | |
|---|---|---|---|---|
| | | Waste Biomass for Biofuels | Biogas | Total |
| 1 | Riau | 4,157.4 | 37.7 | 4,195.1 |
| 2 | East Java | 2,851.3 | 569.6 | 3,420.9 |
| 3 | North Sumatra | 2,796.1 | 115.5 | 2,911.6 |
| 4 | West Java | 1,979.8 | 574.3 | 2,554.1 |
| 5 | Central Java | 1,885.1 | 384.3 | 2,269.4 |
| 6 | South Sumatra | 2,061.4 | 71.2 | 2,132.6 |
| 7 | Jambi | 1,821 | 18.9 | 1,839.9 |
| 8 | Central Kalimantan | 1,486.7 | 12.2 | 1,498.9 |
| 9 | Lampung | 1,407.6 | 84.5 | 1,492.1 |
| 10 | West Kalimantan | 1,279.3 | 28.9 | 1,308.2 |
| 11 | South Kalimantan | 1,266.2 | 23.6 | 1,289.8 |
| 12 | Aceh | 1,136.6 | 37.7 | 1,174.3 |
| 13 | East/North Kalimantan | 946.6 | 17.7 | 964.3 |
| 14 | South Sulawesi | 890.3 | 69.1 | 959.4 |
| 15 | West Sumatra | 923.1 | 34.7 | 957.8 |
| 16 | Bengkulu | 633 | 11.8 | 644.8 |
| 17 | Banten | 346.5 | 118.6 | 465.1 |
| 18 | West Nusa Tenggara | 341.3 | 52.8 | 394.1 |
| 19 | Central Sulawesi | 307.4 | 19.5 | 326.9 |
| 20 | East Nusa Tenggara | 192.5 | 48 | 240.5 |

| No. | Province | Potency (MW) | | |
|---|---|---|---|---|
| | | Waste Biomass for Biofuels | Biogas | Total |
| 21 | Yogyakarta | 183.1 | 41.1 | 224.2 |
| 22 | Bangka Belitung | 217.7 | 5.4 | 223.1 |
| 23 | West Sulawesi | 197.8 | 8.1 | 205.9 |
| 24 | Bali | 146.9 | 44.7 | 191.6 |
| 25 | North Sulawesi | 150.2 | 13.8 | 164 |
| 26 | Southeast Sulawesi | 132.8 | 17.7 | 150.5 |
| 27 | Gorontalo | 119.1 | 11.5 | 130.6 |
| 28 | DKI Jakarta | 0.5 | 126.1 | 126.6 |
| 29 | Papua | 81.4 | 15.1 | 96.5 |
| 30 | West Papua | 50.8 | 4.1 | 54.9 |
| 31 | North Maluku | 27.5 | 7 | 34.5 |
| 32 | Maluku | 23.6 | 9 | 32.6 |
| 33 | Riau Islands | 11.6 | 4.3 | 15.9 |
| Total | | 30,051.2 | 2,602.6 | 32,653.8 |

Source: Saputra et al. (2022); DEN (2019; 2020).

The National Energy Policy stipulated through Government Regulation (GR) No. 79/2014 is now the most important policy basis for the biofuel programme. The National Energy Council through national energy policy targets 23% economic use of renewable energy in 2025 and 31% in 2050 (Renewable Energy Indonesia, 2023). The contribution of biofuels to achieving this goal, indicated in Presidential Regulation (PR) no. 22/2017, roughly means biofuel use of 13.9 billion litres and 52.3 billion litres, respectively (USDA, 2022).

This study uses biomass from oil palm, sugar cane, and rice plants. According to the latest data from the Ministry of Energy and Mineral Resources, there is potential for biomass for renewable bioenergy based on waste from agro-industry in Indonesia. This study collected data from the literature regarding the possible use of biomass from palm oil, sugar cane, and rice industry waste to be processed into raw biofuel materials.

Table 2.3. Amount of Potential Agro-industrial Waste in Indonesia

| No. | Province | Agro-industrial Waste Results (MW) | | | | Potency Total (MW) |
|---|---|---|---|---|---|---|
| | | Palm Oil Mill Effluent Waste | Palm Oil Waste | Rice Industry Waste | Sugar Cane Industry Waste | |
| 1 | Aceh | 29.69 | 158 | 15 | 0 | 202.69 |
| 2 | North Sumatra | 119.3 | 627 | 4 | 6 | 756.3 |
| 3 | West Sumatra | 21.3 | 112 | 2 | 0 | 135.3 |
| 4 | Riau | 331.2 | 1,735 | 1 | 0 | 2,067.2 |
| 5 | Jambi | 57.7 | 303 | 0 | 0 | 360.7 |
| 6 | South Sumatra | 86.38 | 449 | 6 | 21 | 562.38 |
| 7 | Bengkulu | 15.4 | 87 | 0 | 0 | 102.4 |
| 8 | Lampung | 17.17 | 90 | 3 | 110 | 220.17 |
| 9 | Bangka Belitung Islands | 24.06 | 120 | 0 | 0 | 144.06 |
| 10 | West Java | 1.3 | 7 | 54 | 15 | 77.3 |
| 11 | Central Java | - | 0 | 11 | 51 | 62 |
| 12 | Yogyakarta | - | 0 | 0 | 5 | 5 |
| 13 | East Java | - | 0 | 125 | 209 | 334 |
| 14 | Banten | - | 8 | 10 | 0 | 18 |
| 15 | West Nusa Tenggara | - | 0 | 1 | 15 | 16 |
| 16 | West Kalimantan | 104 | 542 | 0 | 0 | 645.95 |
| 17 | Central Kalimantan | 123.2 | 635 | 1 | 0 | 759.2 |
| 18 | South Kalimantan | 40.5 | 213 | 0 | 0 | 253.5 |
| 19 | East Kalimantan | 102.2 | 534 | 0 | 0 | 636.24 |
| 20 | North Kalimantan | 4.5 | 24 | 0 | 0 | 28.5 |
| 21 | Central Sulawesi | 6.4 | 33 | 0 | 0 | 39.4 |
| 22 | South Sulawesi | 1.9 | 10 | 49 | 13 | 73.9 |
| 23 | Southeast Sulawesi | 2.8 | 15 | 0 | 0 | 17.8 |
| 24 | Gorontalo | - | 0 | 0 | 6 | 6 |
| 25 | West Sulawesi | 5.5 | 29 | 2 | 0 | 36.5 |
| 26 | Maluku | - | 0 | 0 | 0 | 0 |
| 27 | Papua | 14.4 | 75 | 0 | 0 | 89.4 |
| 28 | West Papua | 2.9 | 16 | 0 | 0 | 18.9 |
| **Total** | | **1,112** | **5,822** | **284** | **451** | **7,668.79** |

Source: Sektor Bioenergi Lintas EBTKE (2024).

a. Oil palm

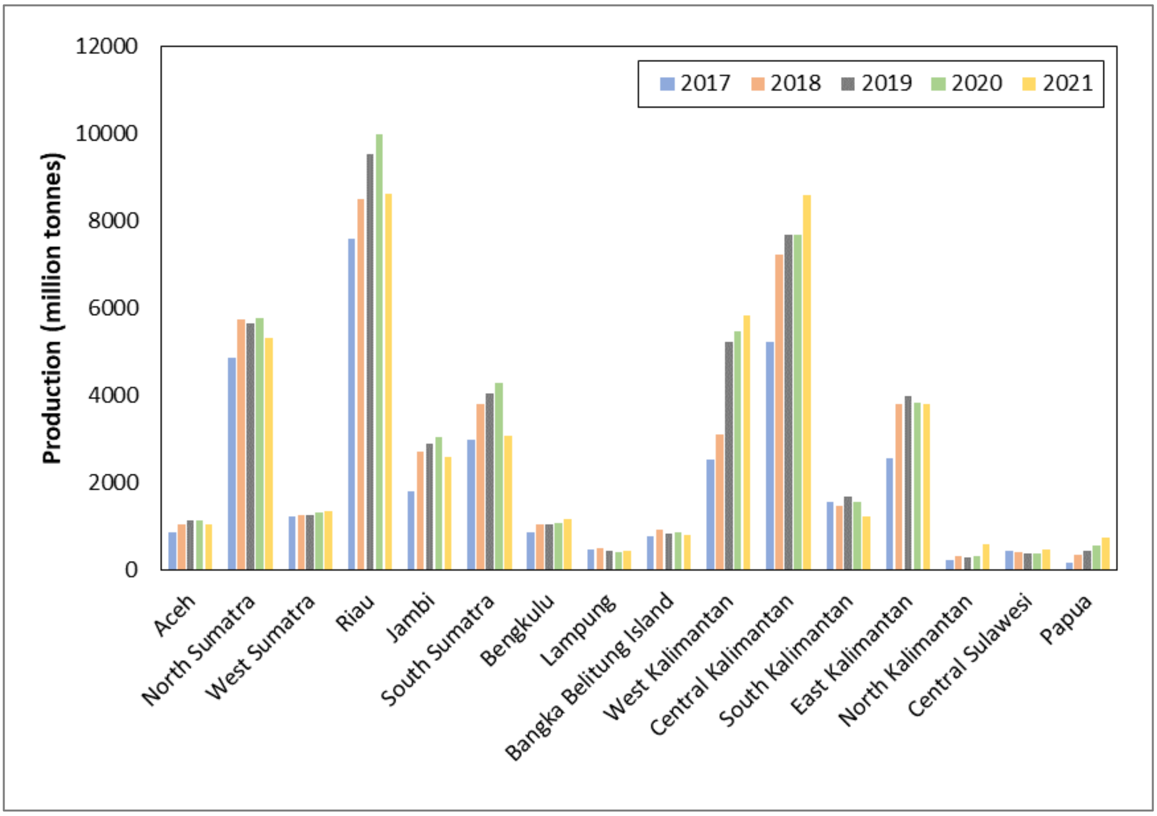
Palm oil is one of the types of biomass that has the potential to be developed into biofuel. A biofuel product that is being widely developed is biodiesel because of its fatty acid content. In 2023, Indonesia was the world's largest palm oil-producing country, with production more than double that of the country in second place, namely Malaysia. As land area increases, palm oil production continues to increase yearly. Table 2.4 and Figure 2.2 show data regarding land area and palm oil production in Indonesia.

Table 2.4. Development of Total Land Area and Amount of Palm Oil Production in Indonesia

| Year | Area of Oil Palm Land in Indonesia (million hectares) | Palm Oil Production in Indonesia (million metric tonnes) |
|---|---|---|
| 2017 | 14.05 | 34.94 |
| 2018 | 14.33 | 42.88 |
| 2019 | 14.46 | 47.12 |
| 2020 | 14.59 | 45.74 |
| 2021 | 16.83 | 45.12 |
| 2022 | 16.83 | 45.58 |
| 2023 | 16.83 | 48.23 |

Sources: Statista Research Department (2023); Ministry Of Agriculture Directorate General of Plantations (2023).

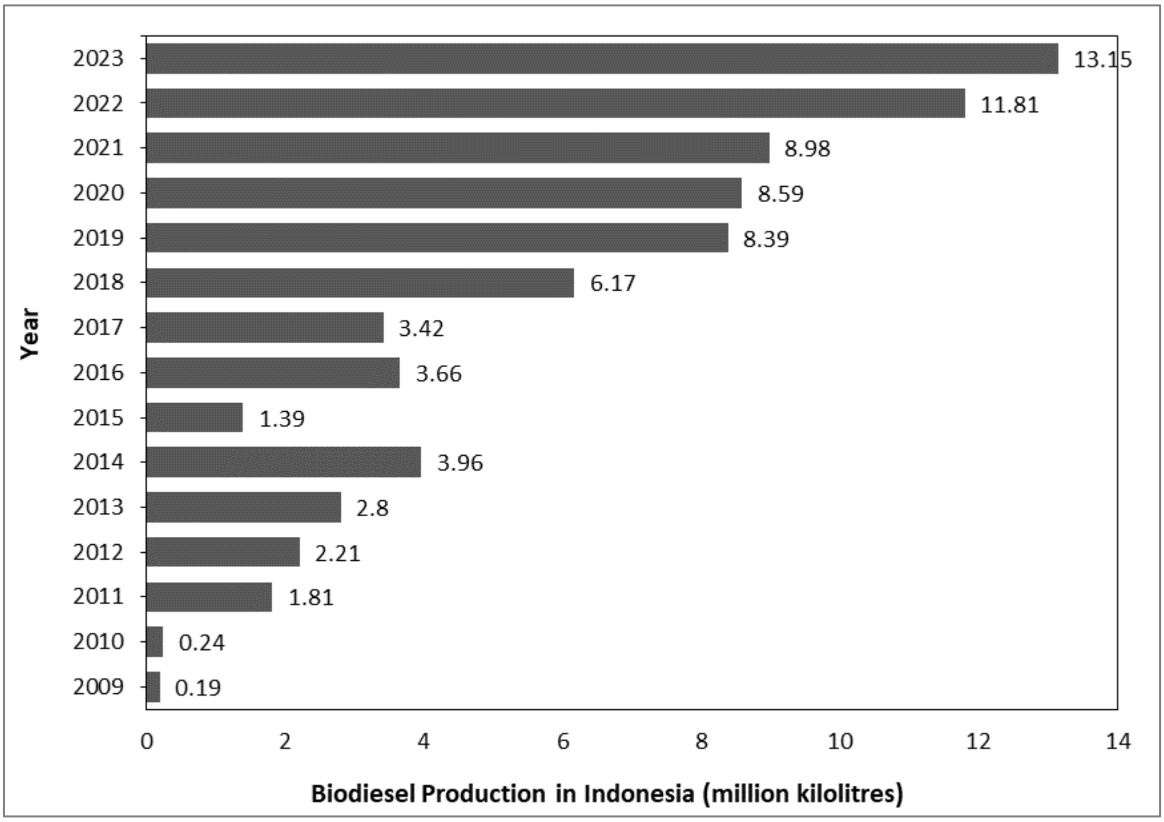
Figure 2.2. Palm Oil Production by Province in Indonesia




Source: Badan Pusat Statistik (2021).

Indonesia itself is one of the largest palm oil producers globally, and it has been exploring the use of biomass from palm oil for bioenergy. The island of Sumatra has the largest oil palm plantations in Indonesia, comprising 61% or 10.37 million ha, particularly in Riau province. The area of palm oil land in Riau province is around 3.49 million ha, or around 20.75% of the total area of national oil palm plantations in 2023. Oil palm biomass has been widely utilised to produce bioenergy through various processes, such as combustion, gasification, or anaerobic digestion. Not only utilising the biomass, the oil palm residues generated in the cultivation to harvesting process have also received attention to be applied as a source of bioenergy. One of the biofuel products that is being widely developed is biodiesel. Currently, Indonesia has become the largest biodiesel-producing country in the world with a much higher production capacity than other countries, according to United States Department of Agriculture (USDA). Figure 2.3 shows the development of palm oil biodiesel production in Indonesia until 2023.

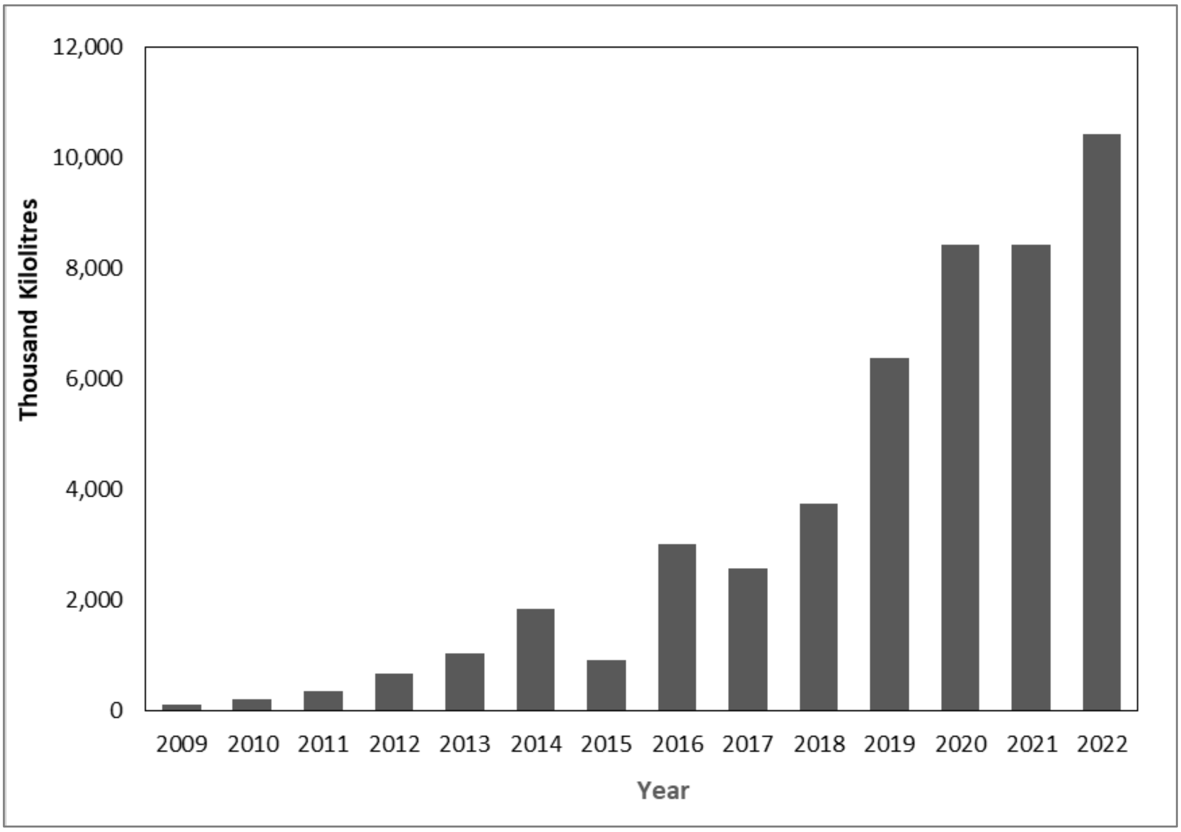
Figure 2.3. Development of Biodiesel Production from Palm Oil in Indonesia, 2009–2023




Source: Sipayung (2023).

According to Indonesia Sharia Banking Accounting Guidelines (PAPSI) data sourced from the Indonesia Biodiesel Producer Association (APROBI) regarding the development of the number and capacity of biodiesel companies in Indonesia in 2022, around 32 biodiesel companies have been developed in Indonesia with a total capacity of 17.14 million kilolitres. Even though the government was targeting a biodiesel volume allocation in 2023 of 13.15 million kilolitres, when compared with the installed biodiesel factory capacity of 17.14 million kilolitres, this means that the biodiesel production or allocation target is still below that capacity. This also shows that the Indonesian biodiesel industry still has great potential to produce biodiesel that can meet domestic needs and reduce dependence on imports. Meanwhile, biodiesel consumption in Indonesia increased from 119,000 kilolitres in 2009 to 10.42 million kilolitres in 2022 (Sipayung, 2023).

Figure 2.4. Biodiesel Consumption from Palm Oil in Indonesia




Source: Sipayung (2023).

In 2006, biodiesel consumption was still low and only for industrial purposes. As shown in Figure 2.4, Domestic biodiesel consumption has increased from 119,000 kilolitres in 2009 and has continued to increase following the launch of the B5 programme in 2010, which requires mixing 5% biodiesel with diesel. In 2020, biodiesel consumption increased by 98%, showing high dependence on biodiesel for domestic energy needs, and reached 10.42 million kilolitres in 2022. The proportion of domestic biodiesel consumption to production also shows an increase. The Indonesian government is targeting a national energy mix of 23% by 2025, and biodiesel is expected to contribute significantly to achieving this target. Several companies in Indonesia are developing technology to produce biodiesel from raw materials other than palm oil, such as lignocellulosic biomass (Sipayung, 2023).

Apart from biodiesel, bioethanol is also a renewable bioenergy that is being developed in Indonesia. However, to meet the need for mixed fuel supplies for government programmes, the existing bioethanol industry in Indonesia is still insufficient (Wirawan et al., 2024). The amount of fuel-grade bioethanol currently reaches 40,000 kL/year and is far below the requirement of 696,000 kL/year (Wahyudi, 2023). The supply amounts to 30,000 kL from PT Energi Agro Nusantara and 10,000 kL from PT

Molindo (Perdana, 2022). Several raw materials from agricultural and plantation crops can be alternative raw materials for bioethanol, such as sugar cane and rice plants.

b. Rice

Indonesia has great potential to develop bioethanol from paddy converted into rice. Compared to other countries, Indonesia has experienced a greater decline in rice production than other countries in ASEAN. Harder efforts and breakthroughs are needed to increase rice production and achieve food security. The factor of rice land area also influences rice production in Indonesia, as shown in Table 2.5.

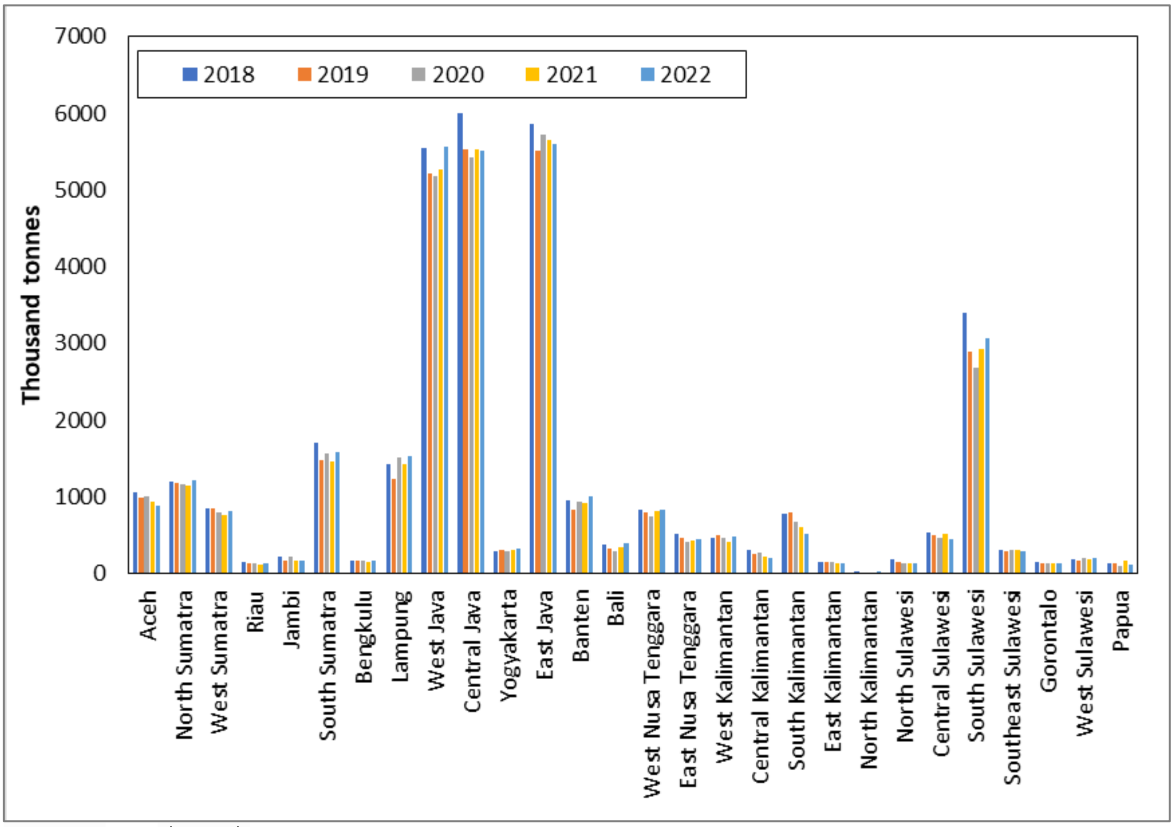
Table 2.5. Development of Land Area and Rice Production in Indonesia

| Year | Rice Plantation Area (million hectares) | Rice Production (million tonnes) |
|---|---|---|
| 2018 | 7.1 | 32.42 |
| 2019 | 7.45 | 31.3 |
| 2020 | 10.6 | 31.33 |
| 2021 | 10.4 | 31.4 |
| 2022 | 10.45 | 31.54 |
| 2023 | 10.21 | 31.10 |

Sources: Widyanto and Subanu (2023); Zuraina et al. (2023).

According to BPS No. 68/10/Th. XXVI dated 16 October 2023, rice production in Indonesia is expected to experience a significant decline in 2023, amounting to 31.1 million tonnes. According to the agricultural census, during the drought period (September–December) in 2023, the harvested area and rice production were expected to experience a relatively large decline compared to the same period in the previous year. Rice production was expected to decline in 2023 compared to 2022. The decline occurred in most production centre areas. Several factors, such as extreme weather, plant pests, land conversion, and increases in the prices of fertilisers and pesticides, have caused the decline in rice production in Indonesia. Based on data from BPS (2021a), the largest rice production is in the Java Islands. However, a significant decline in rice production has occurred in several production centre areas, such as West Java, East Java, South Sulawesi, and Central Java. The data of rice production in Indonesia by the province is shown in Figure 2.5.

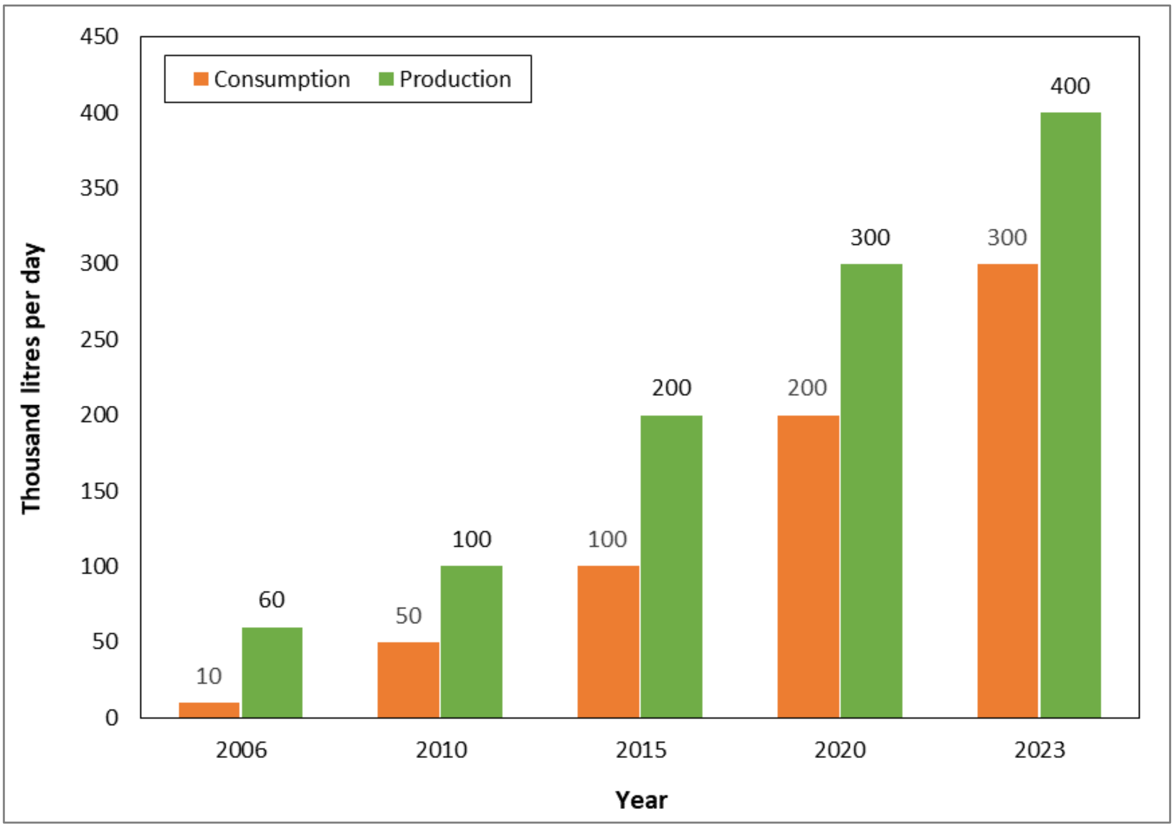
Figure 2.5. Rice Production in Indonesia by Province



Source: BPS (2024).

Rice production in Indonesia has the potential for bioethanol production. The Indonesian government continues to develop renewable energy sources, namely bioethanol as a gasoline mixture. The government targets an increase in the bioethanol mix in gasoline, requiring an increase in bioethanol production of up to 20% by 2025. Figure 2.6 shows the development of bioethanol consumption and production from rice raw materials in Indonesia according to the Ministry of Energy and Mineral Resources and BPS.

Figure 2.6. Bioethanol Production and Consumption from Rice Biomass in Indonesia



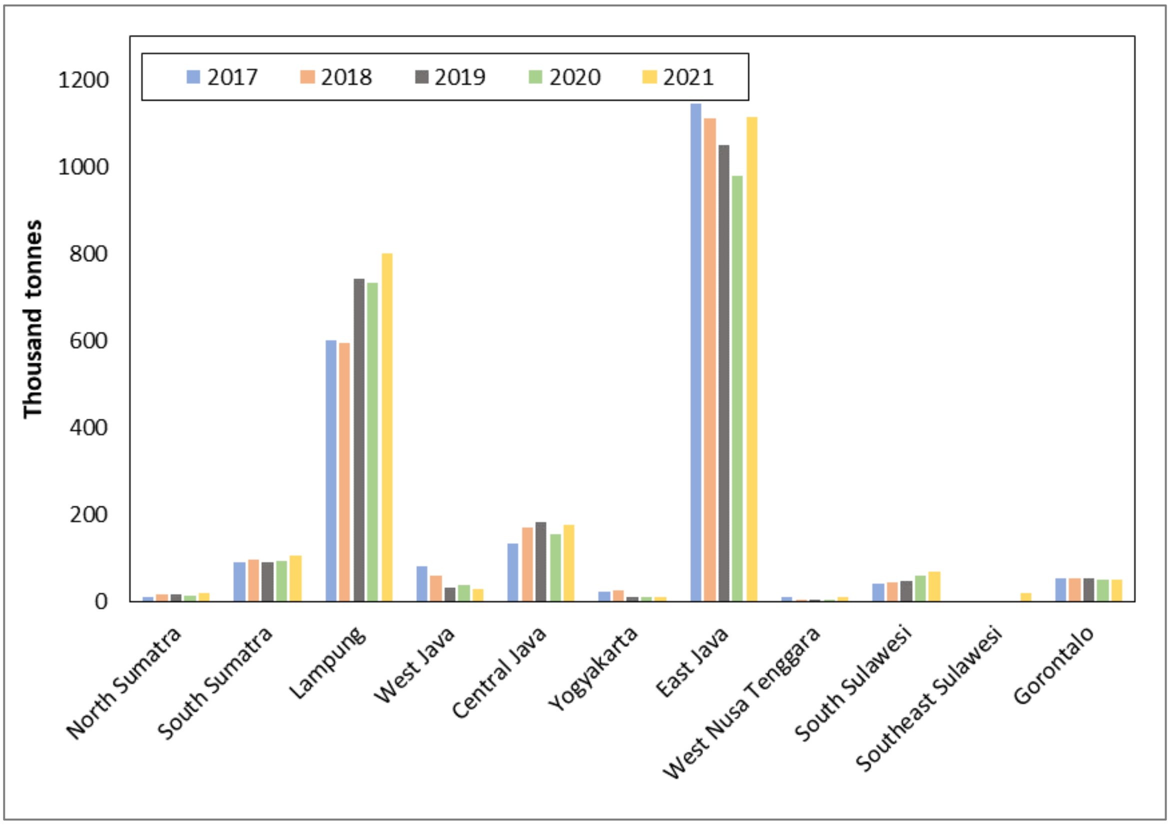

Source: Indonesian Ministry of Energy and Mineral Resources (2024).

## c. Sugarcane

Sugarcane is one of the main crops in Indonesia and is conventionally used to produce sugar.

Indonesia is one of the largest sugarcane-producing countries in the world, ranking sixth in 2023. BPS (2021a) details the amount of sugarcane production in each region of Indonesia, especially in Java and Sumatra, the largest sugarcane producers in Indonesia. Figure 2.7 shows the details amount of sugarcane production in each region of Indonesia.

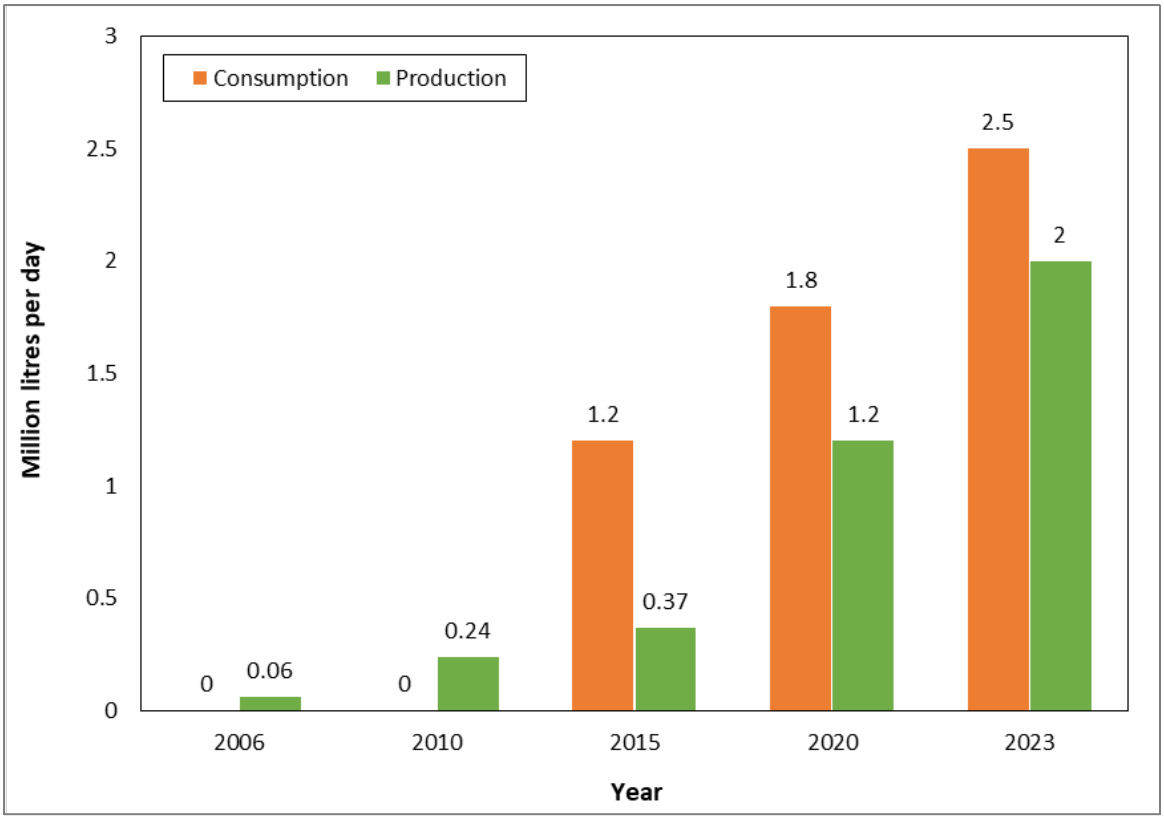
Figure 2.7. Sugarcane Production in Indonesia




Source: BPS (2021a).

Factors such as land area and sugarcane yield play a role in sugarcane production. The larger the land area with good conditions for cultivation, the higher the yield. The Indonesian People's Sugarcane Farmers Association (APTRI) (2022), details the comparison between total land area and total sugarcane and bioethanol productivity in Indonesia.

Figure 2.8. Bioethanol Production and Consumption in Indonesia from Sugarcane Biomass




Source: Taufani (2023).

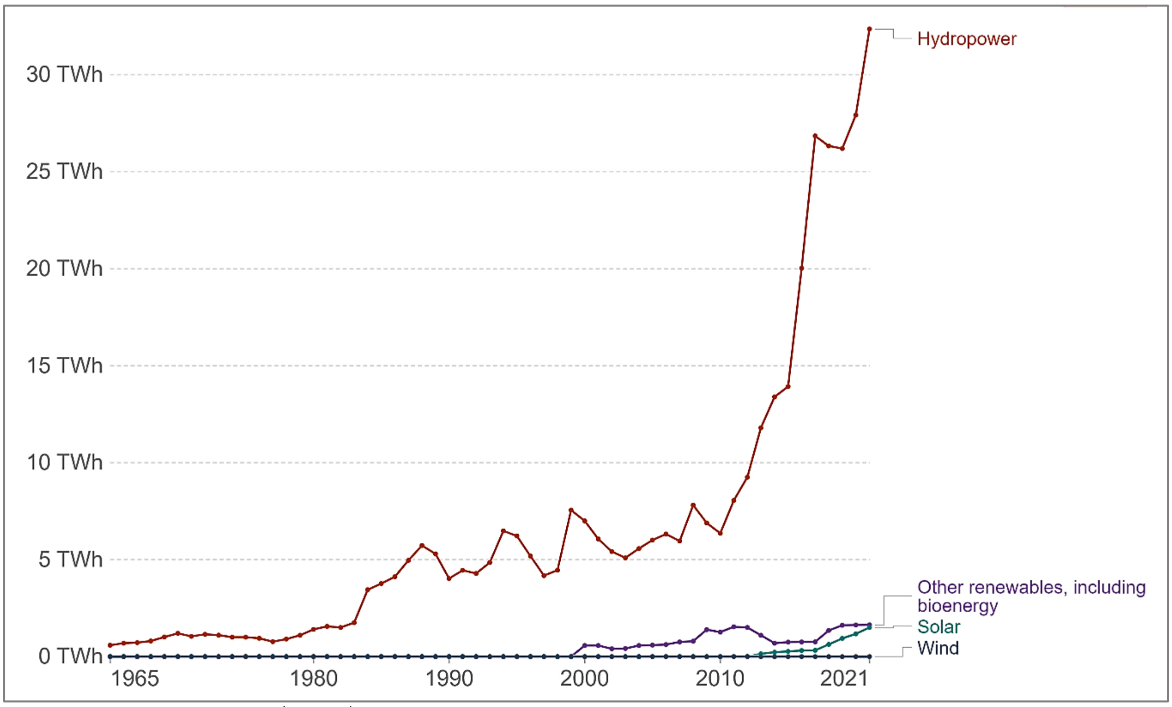
The Ministry of Energy and Mineral Resources reports that bioethanol production in Indonesia has only reached around 40,000 kilolitres (kl) per year (Wahyudi, 2023). The government's target for 2030 is to achieve production of 1.2 million kl, which is expected to reduce fuel imports by 60%, especially gasoline, which reached 35.8 million kl in 2022. Presidential Regulation Number 40 of 2023 concerning the Acceleration of Sugar Self-Sufficiency National and Provision of Bioethanol as Biofuel (Biofuel) (Presiden Republik Indonesia, 2023a). With this, the government hopes to increase the area of sugarcane land, productivity, and quality. One aspect that can be improved to maximise the sugarcane produced is the productivity of the land area. The Indonesian People's Sugarcane Farmers Association (APTRI) reported that the government has prepared 700,000 hectares of land for sugar cane cultivation until 2028 (Taufani, 2023).

## 2.3 Malaysia

In 1999, renewable energy (RE) was originally presented as Malaysia's '5$^{th}$ fuel' and a substitute source of electricity (IRENA 2023). The government intended for the nation's energy mix to be more diverse. Since then, a number of policies, plans, and programmes have been unveiled and put into action to assist the development of renewable energy technology between 2001 and 2020 (IRENA 2023). The Small Renewable Energy Power (SREP) Program and the Biomass Power Generation and Cogen Full Scale Model Demonstration (BIOGEN) Project were introduced under the Eighth Malaysia Plan (2001–2005) to take advantage of the easily accessible oil palm-based by-products and generate small-scale electricity (IRENA 2023). Figure 2.9 shows the sources of renewable energy generation in Malaysia.

The palm oil industry is a significant component of Malaysia's economy, accounting for between 5% and 7% of GDP from 2012 to 2017. The country has an abundance of resources that are easily exploited for the development of renewable energy, namely biomass. There are about 450 palm oil mills in Malaysia that process 95.5 million tonnes of fresh fruit bunches (FFB) on average each year. This results in the production of a significant amount of waste, including mesocarp fibre (MF), empty fruit bunches (EFB), and palm kernel shells (PKS). Waste palm oil is abundant and has a high calorific value, which makes it an excellent feedstock for burning and producing electricity.

Figure 2.9. Renewable Energy Generation by Source in Malaysia




Source: Hannah et al. (2023).

Table 2.6 presents the status of available feedstock and production in Malaysia. The following are Malaysia's primary sources of biomass to produce bioenergy:

1. Waste from oil palm and timber plants: Malaysia produces a large amount of biomass from these plant sources, which can be used to make bioenergy.
2. Rice husks: In Malaysia, rice husks are a significant agricultural biomass resource with a high potential for energy production.
3. Fibres from coconut trunks: Another biomass source in Malaysia that can be utilised for a range of bioenergy uses is coconut trunk fibres.
4. Municipal and sugarcane waste: Malaysia produces wastes from both sources that can be used to produce biomass energy.
5. Palm oil mill waste: 91% of Malaysia's biomass is composed of agricultural waste, including palm oil mill residues, which makes them a valuable resource for the generation of bioenergy.
6. Forest residues: Another biomass source in Malaysia that can be utilised for a range of bioenergy uses is forest residues.
7. Agricultural waste: In Malaysia, biogas can be produced from agricultural waste, such as crop residues and animal manure.

Table 2.6. Status of Available Feedstock and Production in Malaysia

| Plantation Biomass | Palm Oil Mills (tonnes) | Fresh Fruit Bunches | 94,814,456 |
|---|---|---|---|
| (89.8%) | | Empty Fruit Bunches | 7,300,713 |
| | | Mesocarp Fibres | 7,679,023 |
| | | Palm Kernel Shells | 4,427,835 |
| | | Palm Kernel Cake | 2,465,176 |
| | | Palm Oil Mill Effluent | 63,525,686 |
| | Oil Palm | Fronds | 59,593,762 |
| | | Trunks | 10,548,826 |
| | Cocoa Processing | Bean Shell | 49 |
| | | Hob and Pulp | 364 |
| | Kenaf Planted Area (1,500 hectares) | Shoot | 3,000 |
| | Sago Planted Area (33,928 hectares) | Palm Frond | 53,564 |
| | Palm Sago Mill (Production: 133,911 tonnes) | Sago Bark | 147,302 |
| | | Sago Hampas | 147,302 |
| | | Sago Wastewater | 8,034,660 |

| | | | |
|---|---|---|---|
| **Total Plantation Biomass (tonne)** | | | **164,000,000** |
| **Agricultural Biomass (tonne)** | **Paddy Production** | Rice Straw | 1,307,315 |
| **(2.3%)** | (2,364,453 tonnes) | Rice Husk | 534,356 |
| | **Banana Production** (329,573 tonnes) | Banana Stalk | 790,975 |
| | **Coconut Production** | Coconut Husk | 271,993 |
| | (604,428 tonnes) | Coconut Shell | 72,531 |
| | **Pineapple Production** | Peel Waste | 154,693 |
| | (377,300 tonnes) | Leaf | 565,950 |
| | **Durian Production** (455,458 tonnes) | Husk | 296,048 |
| | **Sweet Corn Production** | Stalk | 113,679 |
| | (63,155 tonnes) | Cob/Husk/Silk | 47,366 |
| | **Sugarcane Production** | Top | 5,006 |
| | (25,032 tonnes) | Bagasse | 7,510 |
| | | Press Mud | 876 |
| | | Molasses | 125 |
| **Total Agricultural Biomass (tonne)** | | | **3,600,000** |
| **Woody Biomass (2.0%)** | **Logging Production** (7 million $m^3$) | Activity Residue | 1,492,341 |
| | **Wood-based Industry Production** (4 million $m^3$) | Wood Residue | 1,943,165 |
| | **Rubber Tree Replanting** (469,669 tonnes) | Biomass (branches, twigs, leaves, roots) | 212,120 |
| **Total Woody Biomass (tonne)** | | | **4,200,000** |
| **Fisheries Industry Waste (0.4%)** | **Fisheries Production** (1,890,288 tonnes) | Fish Waste | 695,133 |
| **Total Fisheries Waste (tonne)** | | | **700,000** |
| **Livestock Industry** | **Poultry** (≈ 295 million) | Manure | 4,000,531 |

| | | | |
|---|---|---|---|
| Waste (5.6%) | | | |
| | | Waste from Slaughter House | 176,103 |
| | Cattle (≈ 721,000) | Manure | 4,418,016 |
| | | Waste from Slaughter House | 15,1561 |
| | Goats (≈ 312,000) | Manure | 219,785 |
| | | Waste from Slaughter House | 237 |
| | Sheep (≈ 125,000) | Manure | 91,034 |
| | | Waste from Slaughter House | 158 |
| | Swine (≈ 1.7 million) | Manure | 1,161,551 |
| | | Waste from Slaughter House | 75,634 |
| Total Livestock Waste (tonne) | | | **10,000,000** |

Source: National Biomass action Plan (2023).

From the 1980s, Malaysia became known as one of the world's top producer of palm oil, and the industry's rapid growth has given rise to by-products like FFB, EFB, MF, and PKS, which are important sources of biofuel (Shuit et al., 2009). Malaysia and Indonesia have the ideal climates for oil palm trees to develop since they have tropical temperatures with lots of rain (Jikol et al., 2022). The environment and climate change have been impacted by the growth of oil palm plantations, especially to produce biofuel, which has resulted in large GHG emissions, deforestation, and the conversion of peatlands (Jikol et al., 2022). However, the country's economic expansion and the fight against poverty have also benefited from the oil palm sector (Norrrahim et al., 2022).

The production of bioenergy in Malaysia is currently at a promising stage with opportunities for significant growth and a range of policy ideas to support this growth. The following are key elements of the current situation:

1) Oil palm industry: Malaysia's oil palm sector is a major producer of biomass, which has tremendous potential for commercialisation in the production of bioenergy.

2) Growth of the bioenergy market: From 2023 to 2028, the Malaysian bioenergy market is expected to expand by 4.79%, reaching a volume of 1.87 billion kWh.

3) Policy insights: According to spatially explicit modelling research, Malaysia's bioelectricity production might change from 4 TWh/year to 18 TWh/year under the Baseline scenario, demonstrating a large potential for the transformation of renewable energy sources (Idris and Hashim, 2022).

4) Framework for sustainable development: A new plan for Malaysia's bioenergy industry is being introduced with an emphasis on methods to boost electricity production from bioenergy, such as utilising residues from palm oil mills.
5) Biomass power plants: To improve waste management and the efficiency of bioenergy conversion, large-scale biomass power plants are being constructed in Malaysia.
6) Biofuel production: The Malaysian Biofuel Industry Act of 2007 allowed licenses for the manufacture of biodiesel with an annual capacity of 6.18 million tonnes.

With 5.9 million hectares of oil palm plantations as of 2021, Malaysia is one of the world's biggest providers of biofuel (Parveez et al., 2021. The production of empty fruit bunches and crude palm oil in Malaysia is shown in Table 2,7. The area of oil palm plantations has increased by more than 100 times in the last 60 years. There are many mills, including 76 large-scale ones that can handle 250,000 tonnes of fresh fruit bunches a year. Although biomass is a significant component of Malaysia's energy mix, it has not yet reached its full potential, primarily because of legislative, financial, and technological obstacles, as well as the unpredictability of the availability of biomass feedstock (Salleh et al., 2020). Biogas, which is mostly produced from sewage, food waste, cattle manure, municipal solid waste, and palm oil mill effluent, has a lot of potential.

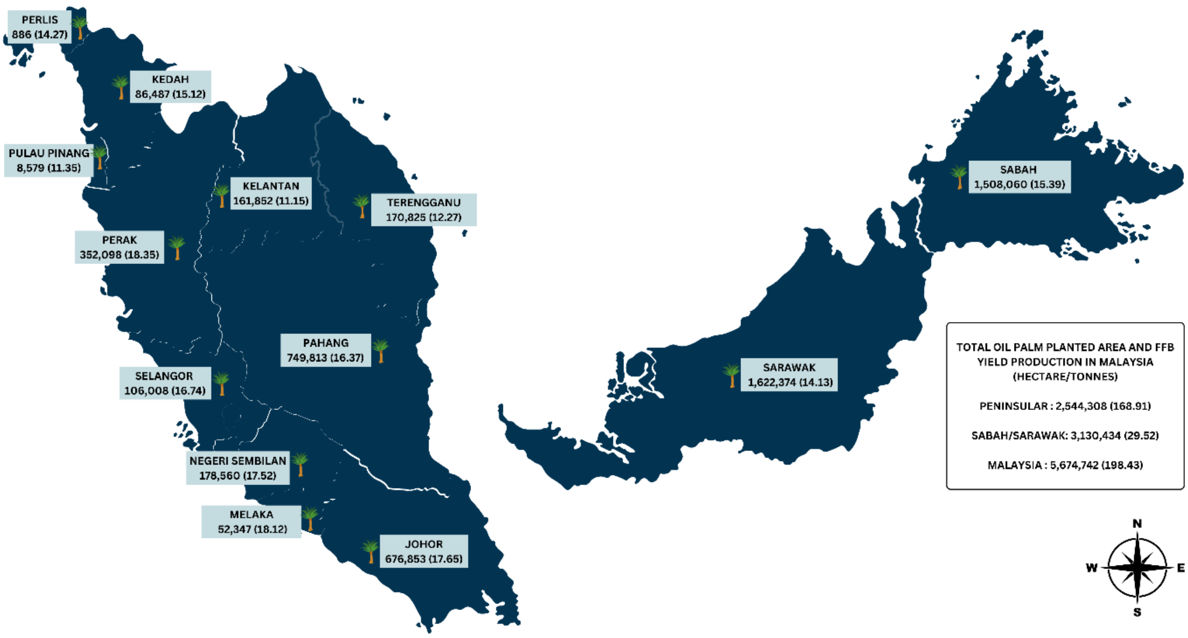
Table 2.7. Production of Oil Palm Empty Fruit Bunches in Malaysia

| State | Empty Fruit Bunches (tonnes) | Crude Palm Oil (tonnes) |
|---|---|---|
| Johor | 11,946,455.45 | 2,969,525 |
| Kedah | 1,307,683.44 | 237,382 |
| Kelantan | 1,804,649.8 | 336,061 |
| N. Sembilan | 3,128,371.2 | 675,767 |
| Pahang | 12,274,438.81 | 3,013,127 |
| Perak | 157,682.02 | 1,866,423 |
| Selangor | 1,774,573.92 | 498,904 |
| Terengganu | 2,096,022.75 | 407,500 |
| Melaka | 948,527.64 | 156,661 |
| P. Pinang | 97,371.65 | 156,661 |
| Perlis | 12,643.22 | 156,661 |

| | | |
|---|---|---|
| **Peninsular Malaysia** | **41,752,094.28** | **10,161,330** |
| Sabah | 23,209,043.4 | 4,286,665 |
| Sarawak | 22,924,144.62 | 4,005,425 |
| **Malaysia Total** | **87,901,753.58** | **18,453,420** |

Source: National Biomass Action Plan (2023).

Figure 2.10. Oil Palm Planted Area and FFB Yield Production in Malaysia




Source: Authors.

Figure 2.10 illustrates the planted area and FFB yield production of oil palm in Malaysia. Malaysia possesses vast tracts of oil palm plantations, totalling 5.9 million hectares in 2021, making oil palm one of the world's biggest biofuel exports (Parveez et al. 2021. Biomass represents the majority of Malaysia's resources, with a potential of about 2.3 GW. Sabah contributes 561 MW and Sarawak 448 MW of the 1.3 GW generated in Peninsular Malaysia. Additionally, biogas and municipal solid waste show promise with a combined capacity of 736 MW and 516 MW, respectively.

In Malaysia, biomass has potential as a source of energy, fuel, and high-value products. However, for biomass value chains, the numerous restrictions and challenges related to the economic and environmental features must be considered. The major concerns regarding the enlargement of biomass plantations are that they require large amounts of land and environmental resources, such as water and soil, which raises the danger of creating severe damage to the ecosystem, such as by deforestation, water pollution, soil depletion, etc.

Malaysia faces several challenges in its efforts to produce bioenergy, such as the assessment of the water footprint in rice production, water scarcity, and the requirement for comprehensive environmental and resource management. Furthermore, water scarcity and the measurement of the water footprint in rice cultivation are amongst the challenges Malaysia must address in implementing bioenergy production. Since rice agriculture requires a lot of water, a study on the water footprint of rice production in Malaysia by Rusli et al. (2023), which uses the Life Cycle Assessment (LCA) approach, emphasises the difficulty of growing more rice with less water. Large amounts of water are also needed for the generation of feedstock in oil palm biomass production, which might be problematic in areas where there is already a water shortage (Norrrahim et al., 2022). Large-scale bioenergy production and conversion initiatives also require a comprehensive assessment of resource and environmental management. These difficulties highlight the significance of managing the environment, water footprint, and water scarcity when implementing bioenergy production in Malaysia.

There are several challenges in converting oil palm biomass to bioenergy in Malaysia besides water scarcity:

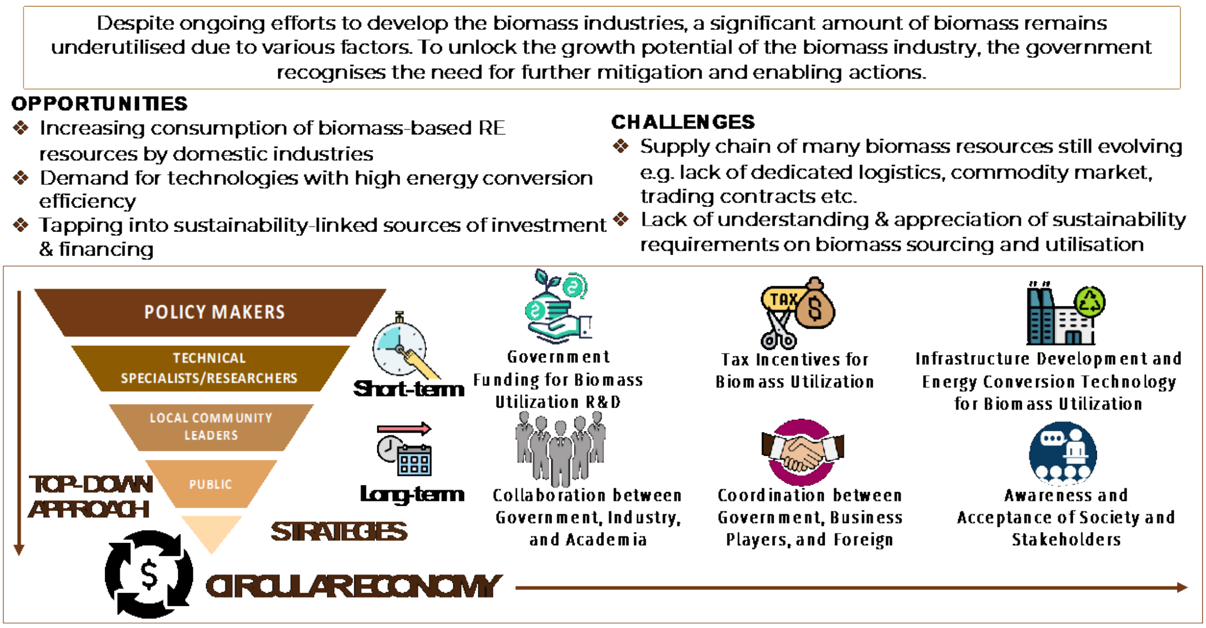
1) Environmental concerns: The growth of oil palm plantations, especially for the production of biofuel, has resulted in a considerable amount of GHG emissions, such as $CO_2$ and nitrous oxides ($N_2O$), as a result of deforestation and the conversion of peatlands (Rashidi et al., 2022). This puts the country's commitment to sustainable development in jeopardy and presents environmental concerns.
2) Land use and food security: The expansion of oil palm plantations has led to concerns about how land usage may affect the oleo-chemical industry and domestic food security (Rashidi et al., 2022). There may be additional negative effects on the ecosystem if rainforests are converted to agricultural plantations since this could change how carbon is stored (Rashidi et al., 2022).
3) Biomass waste management: Due to the oil palm industry's explosive growth, Malaysia now produces a significant amount of biomass waste (Norrrahim et al., 2022). However, in order to solve the problem, efficient waste management techniques are required.
4) Technological challenges: Despite the development of several methods for the conversion of oil palm biomass into marketable products, further innovation and improvement are still required in this field (Norrrahim et al., 2022). Further investigation and advancement are necessary to maximise the utilisation of oil palm biomass in the production of bioenergy.

5) Policy support: Although the Malaysian government has developed a number of projects and programmes to encourage the use of oil palm biomass for energy production and other sustainable uses, a well-considered action plan is required to guarantee the effective conversion of palm oil biomass and to address the difficulties and obstacles for large-scale implementation (Jikol et al., 2022).

6) Social responsibility and sustainability: Regarding workers' rights, land rights, and the effects on local communities, the oil palm industry's explosive growth has sparked worries about the social and environmental effects of its activities (Shuit et al., 2009). When developing and implementing oil palm biomass-based bioenergy projects, it is essential to achieve a balance between social responsibility, environmental sustainability, and economic growth.

Despite ongoing efforts to develop the biomass industries, a significant amount of biomass remains underutilised due to various factors. To unlock the growth potential of the biomass industry, the government recognises the need for further mitigation and enabling actions.

Figure 2.11. Malaysia's Current Situation, Challenges, and Limitations Related to the WEF Nexus



Source: Authors.

## 2.4 Philippines

The Philippines has a total land area of approximately 300,000 square kilometres, of which around 40% is dedicated to agriculture, which is a significant sector in the

Philippines that employs millions of people and contributes to food security, rural livelihoods, and economic development. The country is also endowed with abundant water resources, including rivers, lakes, groundwater, and coastal areas. Approximately 5% of the total land area of the Philippines is inland water. It has one of the richest coastal and marine ecosystems in the world with 36,289 of km coastlines, 220 million hectares of total marine waters, and an estimated value of coastal and marine resources of US$6 trillion (Azanza, et al., 2022).

The Philippines recorded almost 70 million tonnes of produced crops in 2022, which potentially generate agricultural waste, forestry residues, and organic waste potential biomass waste that can be used as feedstock for power generation, not only for biofuels production. The Philippine biomass-based energy industry, including biomass power plants, biogas digesters, and biofuel production facilities, contribute to renewable energy generation and reduce dependence on fossil fuels. As of the time of writing, the country still relies heavily on imported fossil fuels, including oil, coal, and natural gas, to meet its energy needs. Fossil fuel imports as of 2023 accounted for more than 50% of the total energy supply. Domestic production of fossil fuels in the Philippines is limited, with modest reserves of coal, oil, and natural gas. The country's energy sector is gradually shifting towards renewable energy sources, including biomass, solar, wind, and geothermal, to reduce dependence on imported fossil fuels and mitigate climate change impacts.

In pursuit of enhanced energy security and climate change mitigation, the Philippines enacted Republic Act 9367, known as the Philippine Biofuels Act of 2006. The legislation aims to reduce the country's reliance on imported fuels by mandating the blending of biofuels from local and renewable sources with petroleum-based fuels. By virtue of the Act, a bioethanol blending of 5% by volume was implemented in 2009 and was increased to 10% blending in 2012. Effective July 15, 2024, voluntary 20% is now implemented. On the biodiesel front, the Department of Energy (DOE) has maintained the implementation of 2% by volume biodiesel blend, despite a targeted 10% increase by 2020.

### *2.4.1 Current biomass production and its interrelation with other sectors*

A. Food security

The Philippines is characterised by a predominantly agricultural economy, with a significant portion of the population engaged in farming and fishing activities. Despite its agricultural potential, the country experiences food insecurity due to various factors, including land degradation, limited access to resources and technology, natural disasters, and socio-economic disparities. Challenges to food security in the Philippines include land conversion, inadequate infrastructure, low productivity, post-harvest losses, and dependence on imports for certain food items. Efforts to improve food security in the Philippines include promoting sustainable agriculture practices, enhancing access to credit and technology for smallholder farmers, strengthening value chains, investing in research and development, and implementing social protection programs.

### B. Water security

The Philippines faces water security challenges, such as water scarcity, pollution, inadequate infrastructure, inefficient water management practices, and vulnerability to extreme weather events. Rapid urbanisation, industrialisation, and agricultural expansion have put pressure on water resources, leading to the overexploitation of aquifers, depletion of groundwater, and degradation of water quality. Climate change exacerbates water insecurity in the Philippines, with increased frequency and intensity of droughts, floods, and typhoons impacting water availability and quality. Strategies to enhance water security in the Philippines include improving water governance and management, promoting water conservation and efficiency measures, investing in water infrastructure, protecting watersheds and ecosystems, and enhancing climate resilience.

### C. Bioenergy sustainability

The Philippines has significant potential for bioenergy production, particularly from biomass sources such as agricultural residues, forestry residues, and organic waste. Bioenergy development in the Philippines aims to reduce dependence on fossil fuels, mitigate greenhouse gas emissions, promote rural development, and enhance energy security. However, ensuring bioenergy sustainability requires addressing challenges such as land use competition, environmental impacts, social implications, technological constraints, and policy gaps. Sustainable bioenergy initiatives in the Philippines include promoting efficient biomass utilisation technologies, conducting biomass resource assessments, supporting small-scale bioenergy projects, and implementing bioenergy policies and regulations.

### D. Climate change readiness

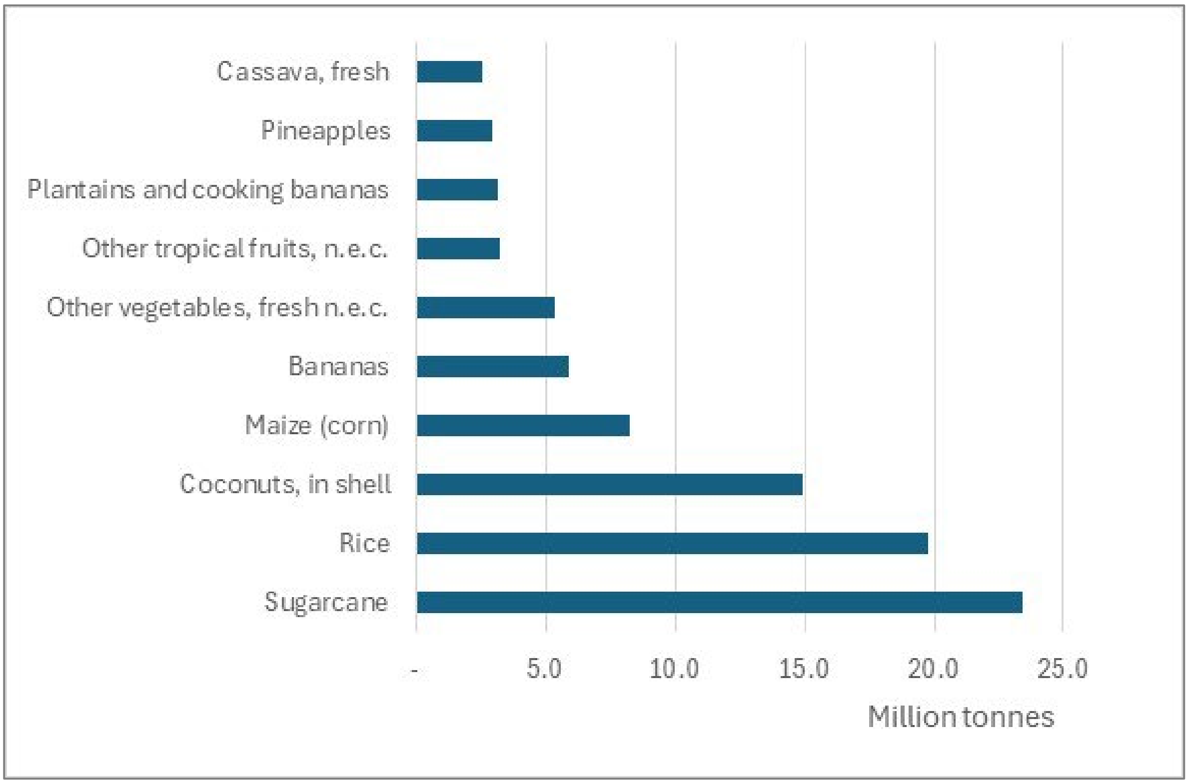
The Philippines is one of the most biologically rich and diverse countries in the world, but in terms of the environment and climate risk, it is also amongst the most vulnerable to climate-related and geological hazards. According to the World Food Programme (WFP, 2023), its geographic location, high exposure to hazards and challenges in adapting to disaster risks, leave an estimated 60% of the land area and 74% of the population exposed to multiple hazards of increasingly high intensity. Based on the Philippines Statistics Authority (PSA, 2020), the country is visited regularly with at least 20 tropical cyclones, and from 2010 to 2019, economic loss due to natural extreme events and disasters amounted to ₱463 billion, with agricultural losses amounting to ₱290 billion or 62.70%.

The Philippines holds the distinction of being amongst the most susceptible nations to disasters, claiming the top spot in the 2022 World Risk Report by Bündnis Entwicklung Hilft and Ruhr University Bochum (Atwii et al., 2022). With such a notably high-risk index ranking, the country has committed to numerous major multilateral environmental agreements. It allocates resources towards policies, initiatives, and capacity-building endeavours aimed at addressing climate change adaptation and mitigation, disaster risk reduction and management, bolstering ecosystem resilience, and fostering the advancement of both blue and green economies, as well as sustainable consumption and production practices (WFP, 2023). Climate change compounds pre-existing socio-economic and environmental concerns in the Philippines, introducing heightened risks to vital aspects such as food and water security, infrastructure integrity, ecological systems, and people's means of making a living. Efforts towards adaptation in the Philippines concentrate on fortifying resilience against climate-related impacts through a variety of measures, encompassing disaster risk reduction, adaptation strategies rooted in ecosystems, the adoption of climate-smart agricultural practices, implementation of water management initiatives, and enhancements to infrastructure. Furthermore, the Philippines actively engages in global climate negotiations and initiatives, advocating for concerted international action on climate change, fostering the expansion of renewable energy resources, and securing access to climate finance aimed at bolstering adaptation and mitigation endeavours.

### *2.4.2. Sugarcane and coconut commodities in the Philippines*

In 2022, sugarcane was the number one commodity produced in the Philippines, reaching more than 23.5 million tonnes and amounting to around US$1.1 million in gross value (Figure 2.12).

Figure 2.12. Top 10 Commodity Production in the Philippines, 2022




Source: FAO (2024a).

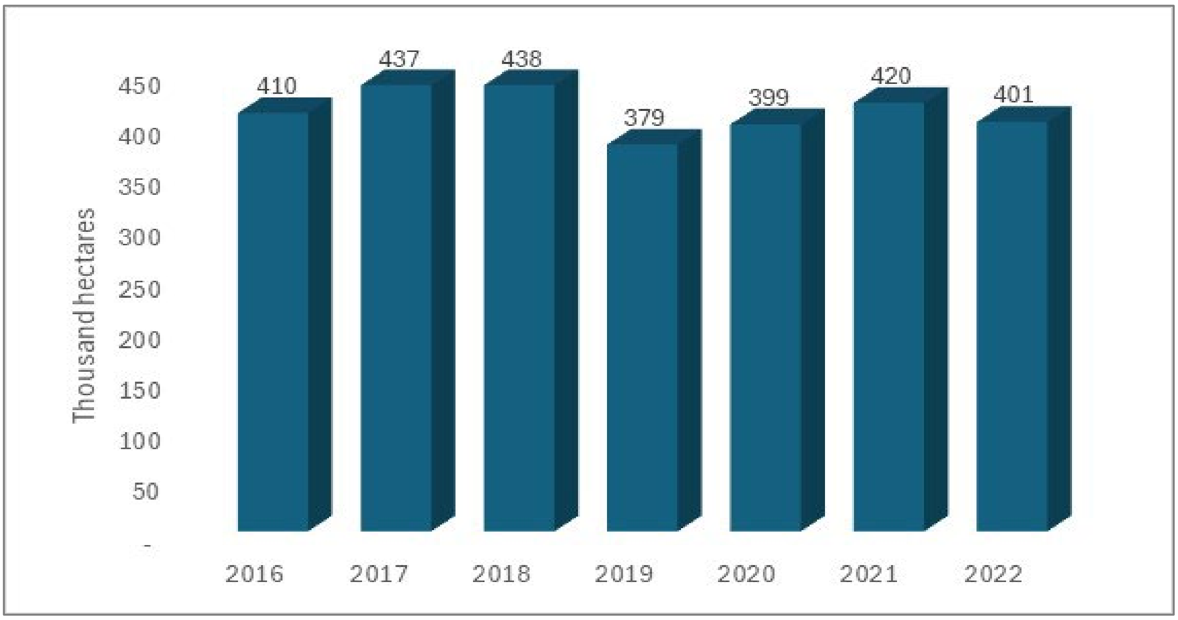
On the other hand, coconuts in shell ranked third amongst the commodities produced in the same year, accounting for more than 14.9 million tonnes and US$2.44 trillion in terms of gross value. The Philippines is also the second largest producer of coconuts in shell (next to Indonesia) as well as the top exporter of coconut oil, desiccated coconut, and cake copra in 2022, according to FAOSTAT (FAO, 2024a).

*A. Sugarcane*

The Philippines has been a significant producer of sugarcane, a major crop for both sugar and ethanol production. Sugarcane is a versatile feedstock for bioenergy production, primarily for ethanol. Ethanol produced from sugarcane can be used as a biofuel, either blended with gasoline or as a standalone fuel.

Figure 2.13 shows the total land area used for sugarcane production in the Philippines. According to the FAO (2024a), in 2022, more than 401,000 hectares of land were planted with sugarcane. Western Visayas remains the top sugarcane-producing region, followed by Northern Mindanao and Central Visayas. The majority of the reported area for sugarcane was for centrifugal sugar, which accounts for roughly 95.6%, whilst the remaining 4.4% was for ethanol, muscovado, chewing, and vinegar.

Figure 2.13. Total Land Area Harvested for Sugarcane Production in the Philippines, 2016–2022




Source: FAO (2024a).

In terms of production, a decline in the sugarcane harvested area by as much as 40,000 hectares was reported in 2023 primarily due to land conversion. The key challenges in the declining sugarcane production include a lack of technology modernisation, which greatly hampers efficiency and productivity and is largely due to climate impacts, such as typhoons and droughts. Land-use productivity depends largely on local sugarcane prices. According to the Sugar Regulatory Administration (SRA, 2011), bioethanol blending for energy use has also encouraged the expansion of sugarcane production.

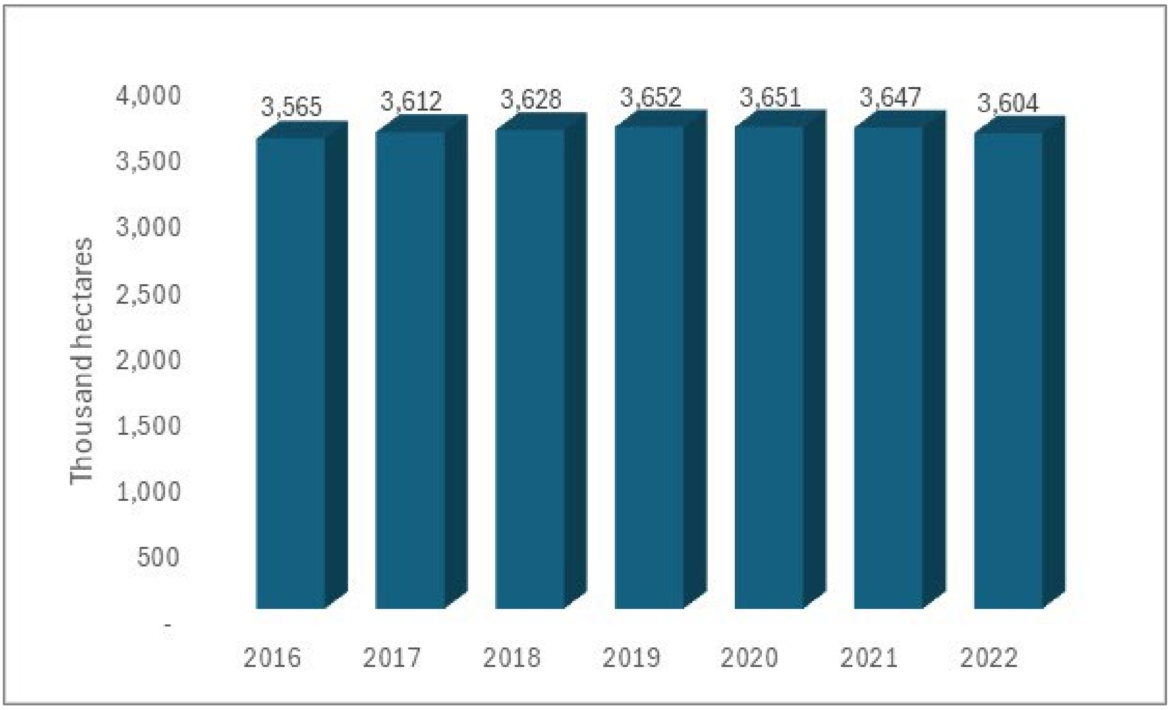
The Sugarcane Regulatory Administration (2020) identified opportunities for the expansion of sugarcane production as demand increases due to increased blend of biofuels production and for power generation, as well as opportunities for exportation with the hike in sugar prices in the world market. The roadmap includes expanding land areas for sugarcane production and improving productivity efficiency, both in terms of tonnes of cane per hectare as well as tonnes of sugar per hectare (SRA, 2011).

### *B. Coconuts*

Similarly, the Philippines is one of the world's leading producers of coconuts. Coconut production is a significant agricultural activity in the country, contributing to both domestic consumption and export markets. The FAO (2024a) estimated that about 3.6 million hectares of land area were harvested for coconuts in 2022 (Figure 2.14). The

Davao region is reported as the largest producer of coconuts, followed by Northern Mindanao and Zamboanga Peninsula.

Figure 2.14. Total Land Area Harvested for Coconut Production in the Philippines, 2016–2022




Source: FAO (2024a)

Coconut production in the Philippines also faces various challenges in terms of production. Pests and diseases, as well as climate change impacts, such as wilder weather and typhoons, have significantly impacted yields and the overall health of the coconut trees. Factors contributing to low productivity, which include outdated farming practices, inadequate farm management, and insufficient access to modern agricultural technology, have been a challenge as well. Similar to the problems faced by sugarcane production, agricultural land in the Philippines is sometimes converted for non-agricultural purposes. This reduces the available land for coconut production and puts pressure on existing coconut plantations.

### *2.4.3. Sugarcane and coconuts as bioenergy sources*

#### *A. Bioethanol*

As of 2022, the current bioethanol blend is maintained at 10%, resulting in a total consumption of 726 million litres. Locally produced bioethanol accounts for less than 50% of this.

For bioethanol-accredited facilities, there were 14 plants in operation as of January 2024 (Table 2.8), with a total capacity of 508 million litres per year (MLPY) (DOE, 2024b). Current estimates suggest that the total available molasses supply from September 2022 to August 2023 was roughly 1 million tonnes, which translates to approximately 250.5 million litres of ethanol based on a 245 litres per tonne of molasses conversion efficiency. Consequently, it was reported from the SRA Prefinal Crop Estimate CY 2022–2023 (SRA, 2023a) that 750,000 tonnes of sugarcane can be used for bioethanol production, yielding around 52.5 million litres of ethanol per year given a 70 litres per tonne conversion efficiency. In total, approximately 303 million litres of ethanol can be produced per year from the available feedstocks, constituting only 65% utilisation of the plant capacity. This falls significantly short of the 763 MLPY required for the 2023 blending scenario, leading to substantial bioethanol imports.

Correspondingly, implementing the planned increase in the bioethanol blending target to 20% will require a significant rise in the bioethanol supply requirement to about 1,897 million litres in 2026. Specifically, this requires an additional 45 distilleries with 30 MLPY capacity and about 7.7 million tonnes of molasses or 27.1 million tonnes of sugarcane as feedstocks. With the current state of the bioethanol industry in the Philippines, bridging the bioethanol supply gap remains a major dilemma, primarily due to the inadequate plant capacity of local bioethanol distilleries and insufficient feedstock availability. Despite efforts to explore alternative feedstocks, sugarcane stalks and molasses remain the primary sources of bioethanol. Further expansion of sugarcane production in the Philippines to complement the local feedstock supply remains a problem due to concerns regarding accessibility to the identified suitable marginal land areas in the country. Thus, to meet the country's bioethanol demand, ethanol has been imported in the country even beyond the allowed provision in the Biofuels Act, which is only 4 years from the effective implementation of 5% blending.

Table 2.8. List of Bioethanol Producers in the Philippines (as of 31 January 2024)

| Island | Region | Province | City/ Municipality | Plant Name | Capacity (million litres per year) |
|---|---|---|---|---|---|
| Luzon | II | Isabela | San Mariano | Green Future Innovations, Inc. | 54 |
| | III | Pampanga | Apalit | Far East Alcohol Corp. | 15 |
| | IV-A | Batangas | Lian | Absolut Distillers, Inc. | 30 |
| | IV-A | Batangas | Calaca | Balayan Distillery, Inc. | 48 |
| | IV-A | Batangas | Nasugbu | Progreen Agricorp, Inc. - Nasugbu | 30 |

| Island | Region | Province | City/ Municipality | Plant Name | Capacity (million litres per year) |
|---|---|---|---|---|---|
| | IV-A | Batangas | Balayan | Progreen Agricorp, Inc. - Balayan | 66 |
| | IV-A | Cavite | Magallanes | Cavite Biofuel Producers, Inc. | 42 |
| Total Luzon Capacity | | | | | **285** |
| Visayas | VI | Negros Occidental | Talisay City | Kooll Company, Inc. | 30 |
| | VI | Negros Occidental | La Carlota City | Universal Robina Corporation - La Carlota Distillery | 45 |
| | VI | Negros Occidental | San Carlos City | San Carlos Bioenergy, Inc. | 40 |
| | VI | Negros Occidental | Manapla | Victorias Milling Company, Inc. | 36 |
| | VI | Negros Occidental | Pulupandan | Asian Alcohol Corporation | 30 |
| | VIII | Leyte | Ormoc City | Leyte Agri Corporation | 12 |
| | VII | Negros Oriental | Bais City | Universal Robina Corporation - Bais Distillery | 30 |
| Total Visayas Capacity | | | | | **223** |
| Total Philippines | | | | | **508** |

Source: DOE (2024b).

### *B. Biodiesel*

The DOE is consistently monitoring the implementation of 2% by volume biodiesel blends. Due to marginally higher pump prices, the recommended increase in the biodiesel blending target has been delayed. With the anticipated implementation of the increased blending mandate, a total of 12 biodiesel-accredited facilities were operating as of 31 January 2024, with a total production capacity of almost 605 million liters of biodiesel per year (Table 2.9). Local production in 2022 translated to approximately 28.4% (221 million tonnes) of the country's total production capacity, which suggests more room to increase blending at 5%. The DOE Department Circular No. 2024-05-0014 mandates a gradual increase of the biodiesel blend to 3% beginning on 1 October 2024, 4% by 1 October 2025, and further to 5% by 1 October 2026 (DOE, 2024a).

The target biodiesel supply even at the increased blending rate only requires about 40% of the total coconut oil available in the country. However, whilst coconut production is abundant in the Philippines, the bulk of coconut oil is directed towards traditional exports, limiting its availability for biodiesel producers. Despite ample coconut production in the Philippines, challenges persist in redirecting coconut oil toward biodiesel production due to existing export markets.

Table 2.9. List of Biodiesel Producers and Distributors in the Philippines (as of 31 January 2024)

| Producer | Registered Capacity (million litres per year) | Location |
|---|---|---|
| 1. Chemrez Technologies, Inc. | 90 | Quezon City |
| 2. Philippines Biochem Products, Inc. | 40 | Muntinlupa City |
| 4. Pure Essence International, Inc. | 72 | Pasig City |
| 5. JNJ Oleochemicals, Inc. | 63 | Lucena City, Quezon |
| 6. Mt. Holly Coco Industrial, Inc. | 60 | Lucena City, Quezon |
| 7. Tantuco Enterprises, Inc. | 90 | Tayabas, Quezon |
| 8. Seaoil Philippines, Inc. | 11 | Pres. M.A. Roxas, Zamboanga Del Norte |
| 9. Archemicals Corp. | 33 | Tagoloan, Misamis Oriental |
| 10. Phoenix Petroleum Philippines, Inc.* | 24 | Villanueva, Misamis Oriental |
| 11. Bioenergy 8 Corporation | 30 | Davao City, Davao Del Sur |
| 12. Freyvonne Milling Services | 16 | Davao City, Davao Del Sur |
| 13. Econergy Corporation | 100 | Polomolok, South Cotabato |
| 14. Bio Renewable Energy Ventures Inc.** | 150 | Jasaan, Misamis Oriental |
| **Total** | **779** | |

* Non-operational.
** Additional capacity with recently issued Certificate of Registration and Notice to Proceed.
Source: DOE (2024b).

*C. Feedstock for power generation*

Moreover, biomass production and bioethanol distillation add value to the investment in their facilities at they provide feedstock for power generation – millers and distillers use their own biomass waste, such as bagasse and biogas from ethanol distillation, to produce electricity not only for their own use but for supplying electricity to the grid. As of 30 November 2023, total installed capacity of the power plant facilities from sugar millers and bioethanol distillers in the Philippine grid recorded a total of 415 megawatt (MW) of installed capacity as shown in Table 2.10 (DOE, 2023b). The renewable energy law encourages sugar mills to venture into power generation for sale to the grid as the RE Act provides additional incentives for the production of electricity (SRA, 2011). Thus, biomass waste also contributes to the realisation of the Philippines' aspirational climate goal of 50% RE share in electricity generation.

Table 2.10. Sugar Mills and Bioethanol Distilleries with Power Plant Facilities Supplying Electricity to the Grid

| Power Plant | Feedstock | Capacity (MW) |
|---|---|---|
| **Luzon Grid** | Bagasse | 12 |
| Green Innovations for Tomorrow Corporation | Bagasse | 12 |
| Green Future Innovation Inc. | Bagasse and biogas | 19.8 |
| Far East Alcohol Corporation | Biogas | 2.4 |
| **Visayas Grid** | | |
| Central Azucarera de Bais | Bagasse | 25 |
| Central Azucarera De San Antonio Inc. | Bagasse | 15 |
| First Farmers Holding Corporation | Bagasse | 21.8 |
| Hawaiian Philippines Company | Bagasse | 28 |
| San Carlos Biopower, Inc. | Bagasse and biogas | 20 |
| South Negros Biopower, Inc. | Bagasse and biogas | 25 |
| North Negros Biopower, Inc. | Bagasse and biogas | 25 |
| Universal Robina Corporation | Bagasse | 46 |
| Victorias Milling Company Inc. | Bagasse | 23 |
| Victorias Milling Company Inc. | Bagasse | 40 |
| BISCOM, Inc. | Bagasse | 48.5 |
| **Mindanao Grid** | | |
| Lamsan Power Corporation | Bagasse | 15 |

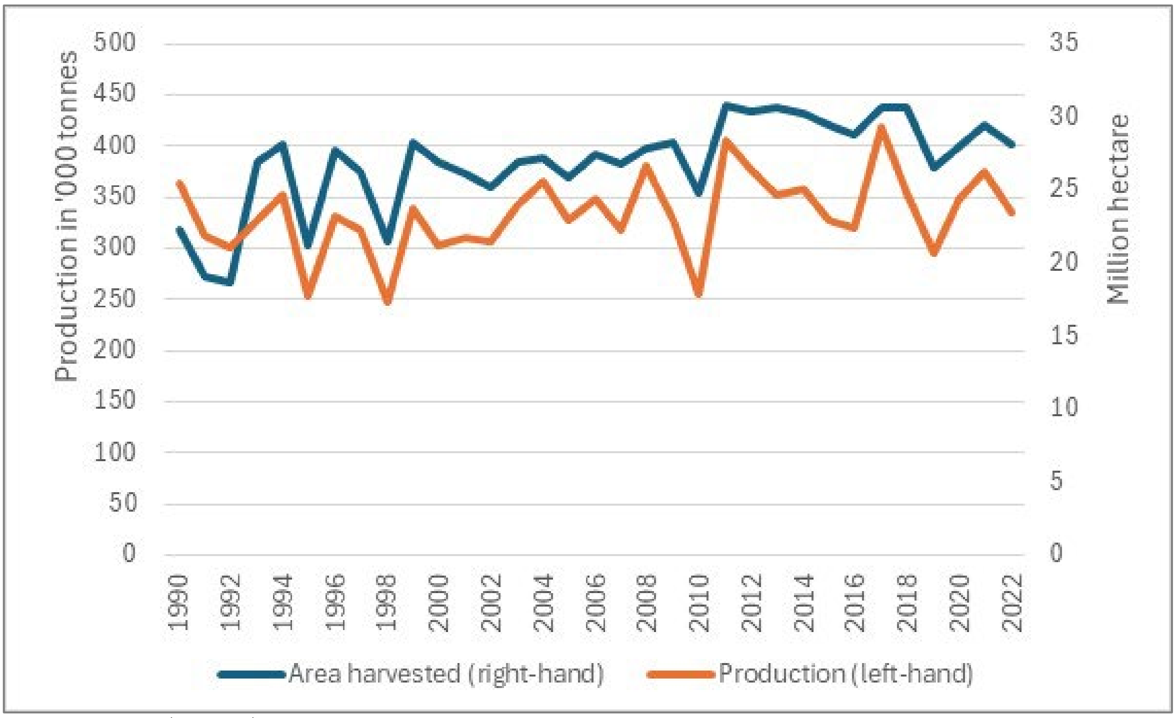
| Power Plant | Feedstock | Capacity (MW) |
|---|---|---|
| Biotech Farms, Inc. | Biogas | 12.29 |
| Crystal Sugar Company, Inc. | Bagasse | 35.9 |
| **Total** | | **414.69** |

Source: DOE (2023b).

### *2.4.4 Biomass production and land-use productivity*

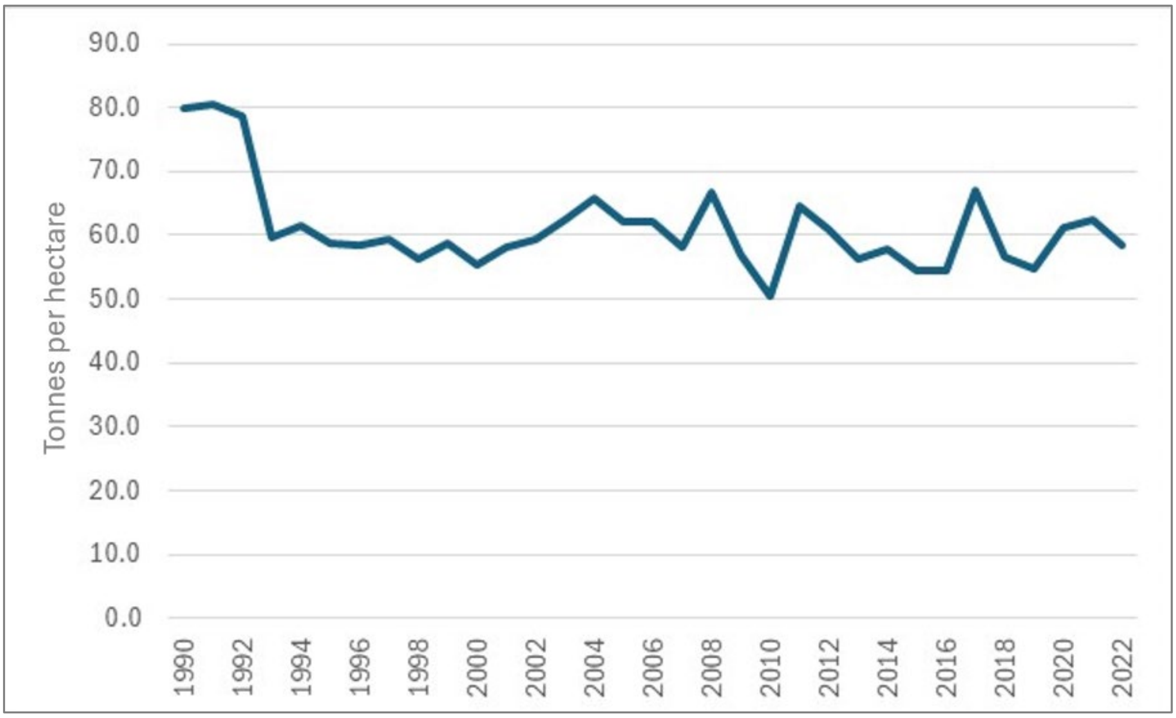
Since 1990, the productivity of sugarcane land has decreased substantially as the production of sugar cane in the Philippines has been decreasing steadily by about 0.3% annually, whilst the area harvested has been steadily increasing by 0.7% (Figure 2.15a), resulting in an average yield of 61 tonnes per hectare (t/ha) of sugarcane, declining from 80 t/ha in 1990 to 58 t/ha in 2022 (Figure 2.15b). This can be attributed to the impacts of climate change that the country experienced between 1990 and 2022. There have been weak-to-strong episodes of the El Niño phenomenon during these periods, with impacts on the stability of the production of sugar cane, which is highly water intensive. As shown in studies such as those by Dias (2008) and Quejada et al. (2021), the main cause of the yield gap in sugar cane production is the water deficit.

Figure 2.15a. Sugarcane Production vs. Area Harvested




Source: FAO (2024a).

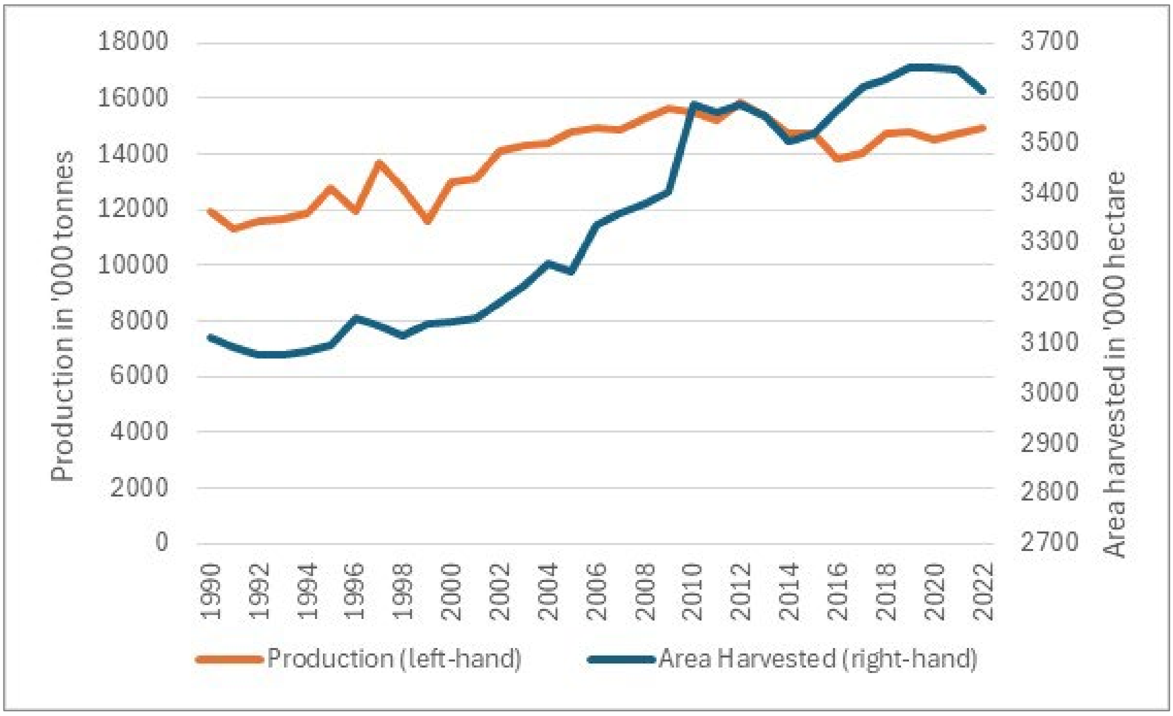
Figure 2.15b. Sugarcane Yield




Source: FAO (2024a).

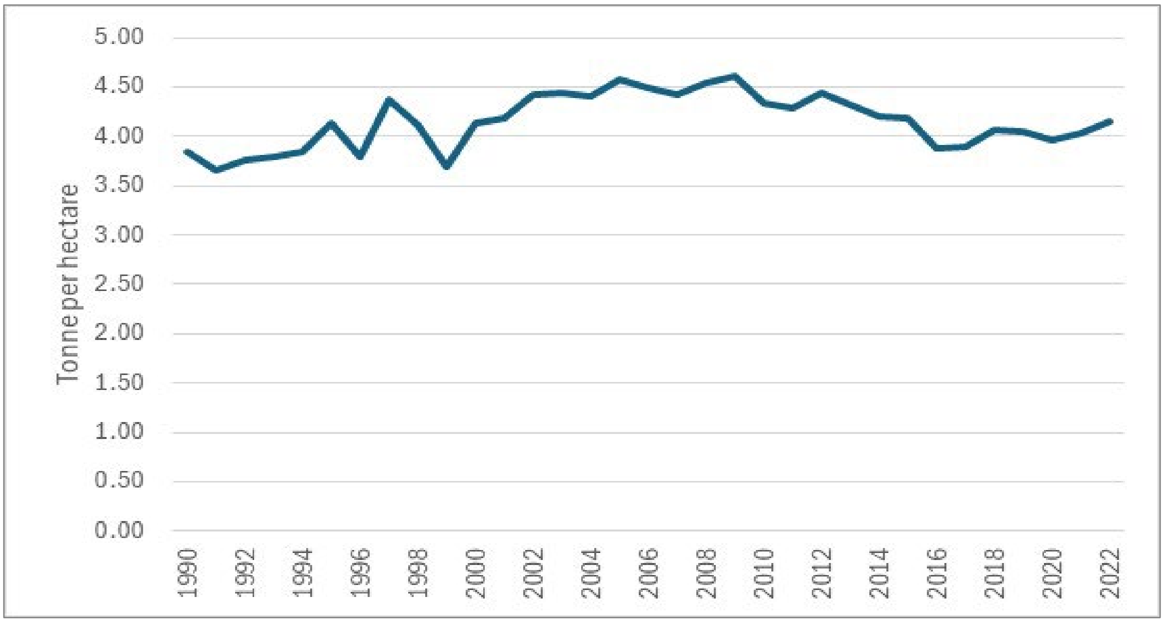
As an archipelagic country with many coastal areas as well as hillsides, the Philippines has many suitable land areas to produce coconuts. In addition, coconut trees are typhoon-resilient and salt-tolerant and can be uprooted only by extremely strong winds (Moreno, 2020). Consequently, the production of coconut shells as a commodity (FAO, 2024) is more stable than sugarcane as both the production and area harvested have been gradually increasing over the past 3 decades by an average growth of 0.7% and 0.5%, respectively (Figure 2.16a). This resulted in an increased yield of 3.8 tonnes/ha in 1990 to 4.2 tonnes/ha in 2022, a meagre increase of 0.2% across the period (Figure 2.16b). According to (Moreno, 2020), coconuts have not been a competitive commodity in recent years. This may have caused the weak growth in coconut production.

Figure 2.16a. Coconut Shell Production vs. Area Harvested




Source: FAO (2024a).

Figure 2.16b. Coconut Shell Yield




Source: FAO (2024a).

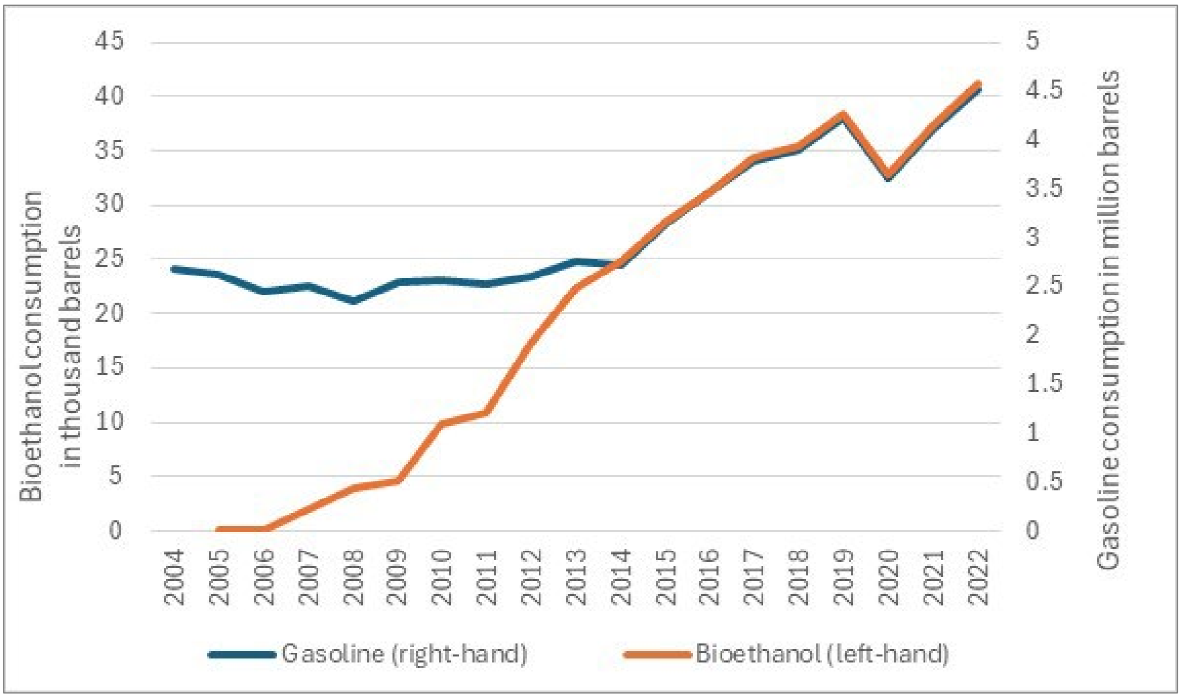
Moreover, the production of both sugarcane and coconuts is also confronted with the challenges of competing uses of land. For example, some sugar plantation areas are converted for solar farm use for energy production as this assures the landowners stable income.

### *2.4.5 Bioenergy consumption and energy footprints*

Bioenergy production contributes to the improvement of energy security by diversifying the energy consumption fuel mix and reducing reliance on imported fossil fuels, ultimately mitigating GHGs. However, the energy balance and efficiency of biomass-based bioenergy systems vary depending on feedstock availability, conversion technology, and logistics. Efficient biomass utilisation technologies, such as anaerobic digestion and gasification, can maximise energy recovery from biomass feedstocks whilst minimising environmental impacts. Integrated energy systems, such as combined heat and power (CHP) plants, can optimise energy production from biomass residues whilst providing heat and electricity for local communities.

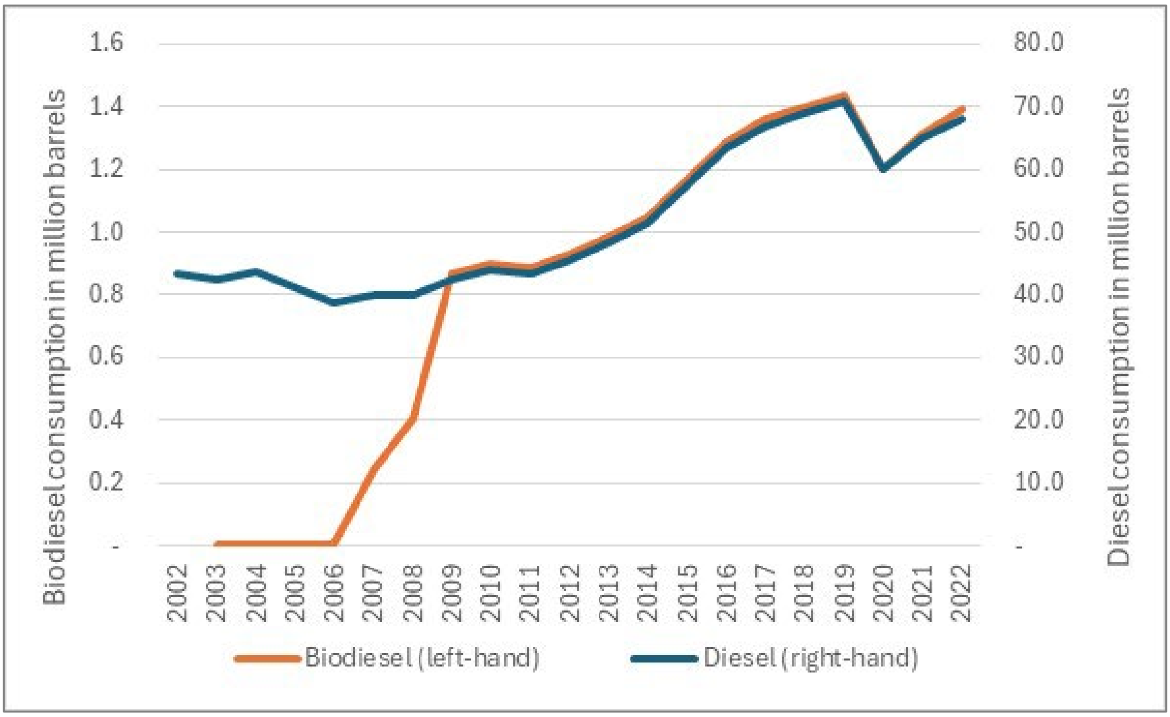
The mandated 5% blending of bioethanol was fully implemented nationwide in 2009 and increased to 10% in 2011. Figure 2.17a shows the trend for bioethanol versus consumption of gasoline in road transport from 2006 to 2022. As shown in Figure 2.17a, full implementation of the mandated blend in all gasoline products started in 2014, as the blue and orange lines converge on the same path. To mitigate the impact of bioethanol price in the blended fuel, regular gasoline, which is being used by the middle-income group, was exempted.

Figure 2.17a. Gasoline and Bioethanol Consumption




Source: DOE (2023a).

Figure 2.17b. Diesel and Biodiesel Consumption

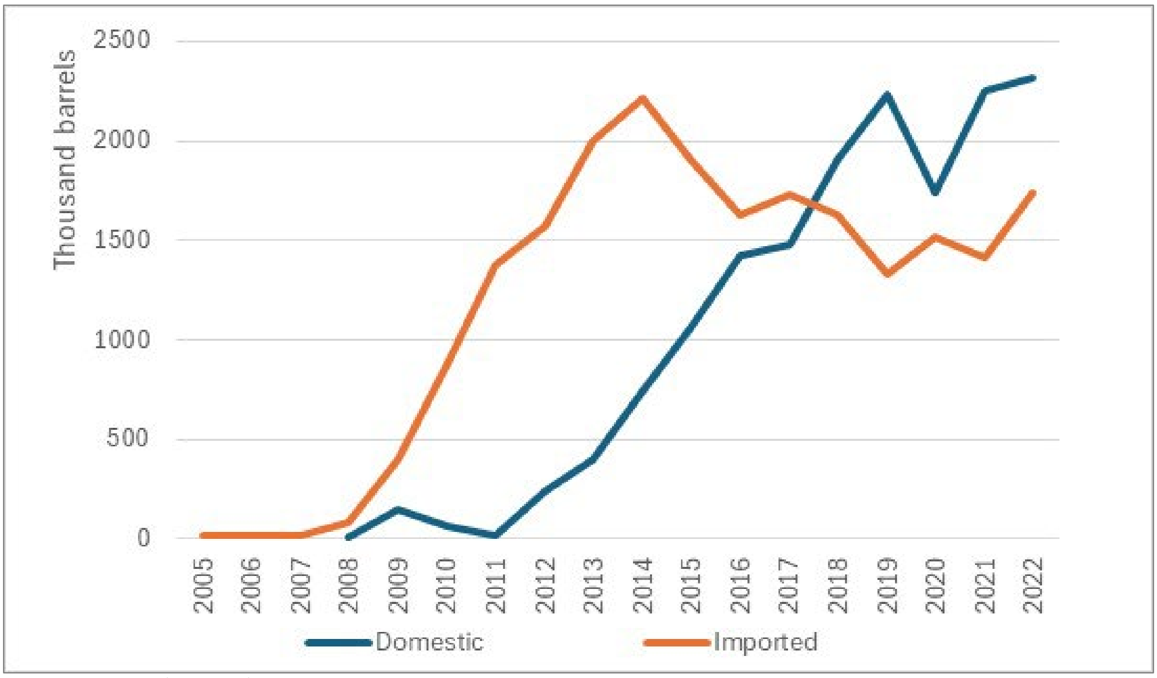



Source: DOE (2023a).

For biodiesel, the effect is the other way around, as seen in Figure 2.17b. Biodiesel (orange line) and diesel (blue line) consumption converged earlier (in 2008) on the same path during the full implementation of the blends. This can be attributed to the lower blending, which is only up to 2% until now. Biodiesel-mandated blending was implemented across the sectors, including for power generation requirements.

The recent oil price hike in the international market has made the domestic price of bioethanol competitive, resulting in a significant increase in its share by 50% in 2018 and around 60% from 2019 to 2022. This has improved energy security in the transport sector (see Figure 2.18).

Figure 2.18. Bioethanol Supply

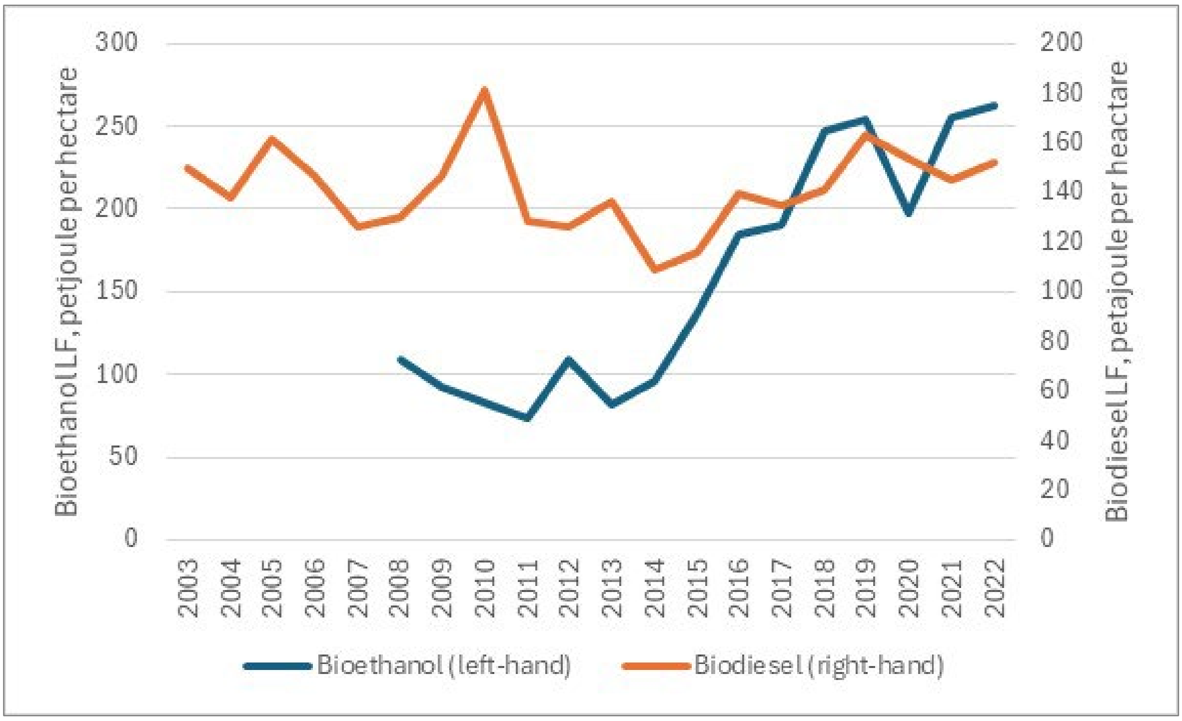



Source: DOE (2023a).

Diesel demand is twice as high as that of gasoline and is highly used at the grassroots levels because its retail price is lower than gasoline in the country. The consumption of diesel and gasoline has been increasing gradually by 2.6% and 2.9%, respectively, over the past 2 decades. This growth could have been higher by 0.6 percentage points for gasoline consumption without the increased blending of bioethanol.

Figure 2.19 shows the bioethanol and biodiesel production per area harvested. Bioethanol has been higher than that of biodiesel because it has a higher land use productivity. Since the Philippines started producing local bioethanol, its energy production per hectare has declined from 109 petajoules per hectare (PJ/ha) in 2008 to 96 PJ/ha in 2022. Likewise, biodiesel's production per hectare has barely increased by an annual average of 0.3%, registering 146 PJ/ha and 152 PJ/ha in the same years, respectively. This suggests the need for more improvement in crop management and addressing the impending gaps in the land nexus.

Figure 2.19. Bioethanol and Biodiesel Production per Area Harvested




Source: DOE (2023a).

### *2.4.6 Bioenergy impacts on food, water, climate, and the local economy*

#### *A. Food impacts*

Bioenergy production has indirect impacts on food security by affecting land use, agricultural practices, and food prices. The expansion of energy crop production may lead to land-use change, deforestation, and the displacement of food crops, potentially compromising food availability and access for local communities. Sustainable biomass production practices, such as agroforestry and crop rotation, enhance food security by diversifying agricultural production and improving soil fertility. Integrated food-energy systems, such as bioenergy co-products for animal feed or organic fertiliser, also promote synergies between biomass production and food production.

Although sugarcane was the most produced crop in 2022, the Philippines still imported 638,000 tonnes of refined sugar, implying a deficit in the supply of food in the country. However, biodiesel production and demand have been increasing to combat the impacts of climate change and improve energy security. Biodiesel producers have increased their capacity to 779 MLPY, as of 31 January 2024 (Table 2.9).

On the other hand, total coconut production, estimated in copra equivalent, roughly accounted for 2.9 million tonnes in 2022, whilst exports of its byproducts, such as copra cake, desiccated coconut, and coconut oil, accounted for 2.2 million tonnes (FAO, 2024a) or 88% in the same year. Consequently, domestic consumption accounted for 12% of this, where biodiesel production registered below 1.0%, and the rest can be attributed to the domestic consumption of food and other by-products. High demand in the international market for coconut byproducts is seen to compete with the domestic consumption of coconuts and not food production. Prices of biodiesel are becoming competitive with the retail prices of diesel in the country, which will likely improve the domestic demand for biodiesel. In fact, coconut producers are already initiating the increase of 2% biodiesel (B2) to 5% biodiesel (B5) (UCAP, 2023). Hence, biodiesel consumption does not affect food security in the Philippines.

### *B. Water impacts*

Biomass production for bioenergy can have significant water implications, including water consumption for irrigation, processing, and biomass cultivation. Irrigation of energy crops, such as sugarcane and maize, may compete with water resources used for food production, leading to potential conflicts and trade-offs. Water-intensive bioenergy processes, such as biomass-to-liquid conversion and bioethanol production, may exacerbate water stress in regions with limited water availability. Sustainable biomass production practices, such as agroforestry and rainwater harvesting, can minimise water impacts and enhance water use efficiency in bioenergy production.

Sugarcane production is highly dependent on water. A policy brief on bioethanol's impact on water showed growing demand for sugarcane production would require more water (Quejada, Morales, G., Kuling, & Niet, 2021). According to AQUASTAT (FAO, 2012) about 65,000 hectares are irrigated crop area in the Philippines. Only about 3% of this is irrigated monthly in the Philippines, unlike other countries with large bioethanol producers, such as Brazil, of which 38% is irrigated monthly (FAO, 2012). This means that the rest of the area harvested is rainfed. Currently, the Philippines is experiencing the El Niño phenomenon, where it was reported that some parts of the sugarcane production areas are affected, i.e. the Negros provinces (OCHA, 2024).

In the past, the Philippines was exporting sugar, but according to the FAO (2024), the country is now importing refined sugar (0.6 million tonnes) and molasses (0.4 million tonnes) as the industry is currently facing challenges of decreasing yields in sugarcane production, from 80 tonnes of cane per hectare in 1990 to 56 tonnes of cane per hectare in 2022. It was also reported that the produced sugar has low sugar recovery (yield per tonne of sugar cane) (Mendoza, 2021) This can be attributed to the impacts of climate change, resulting in a water deficit for production.

On the other hand, coconuts are only planted in areas where ground and sea water are available, i.e. coastal areas and hill sides. According to Moreno (2020), coconut production is constrained by the availability of irrigation systems. Hence, crops are not able to perform well as they are planted in marginal lands, and the intercropping technique is adopted for only 30% of the land.

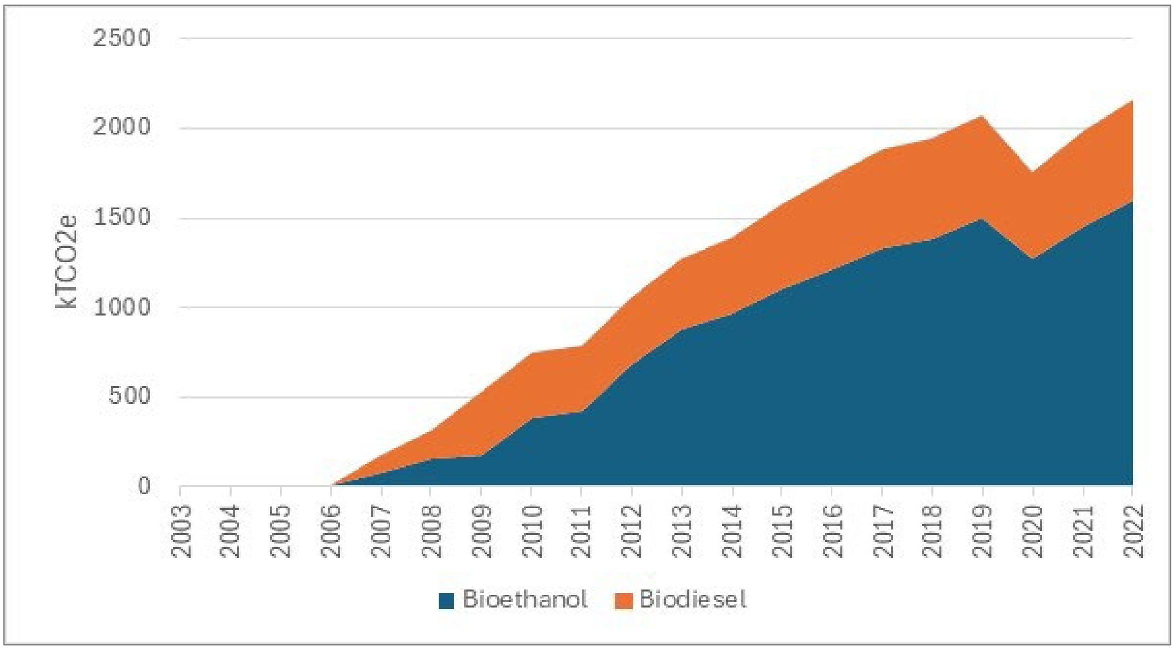
### *C. Climate change impacts*

Biomass-based bioenergy can contribute to climate change mitigation by reducing greenhouse gas emissions and promoting carbon sequestration through sustainable land management practices. However, the net climate impact of bioenergy depends on various factors, including feedstock selection, conversion technology, and lifecycle emissions. Sustainable biomass production and management practices, such as reforestation, agroforestry, and conservation agriculture, can enhance carbon sequestration and ecosystem resilience. Policy incentives and regulations, such as carbon pricing and emission standards, can promote sustainable bioenergy production and ensure climate co-benefits.

*Emissions avoidance in the energy sector*

The use of bioenergy in the energy sector has avoided 2.24 million tonnes of $CO_2$ equivalent since the Philippines implemented the mandatory blend under the Biofuels Act of 2006 (Figure 2.20a).

Figure 2.20a. GHG Emissions Avoidance in the Energy Sector

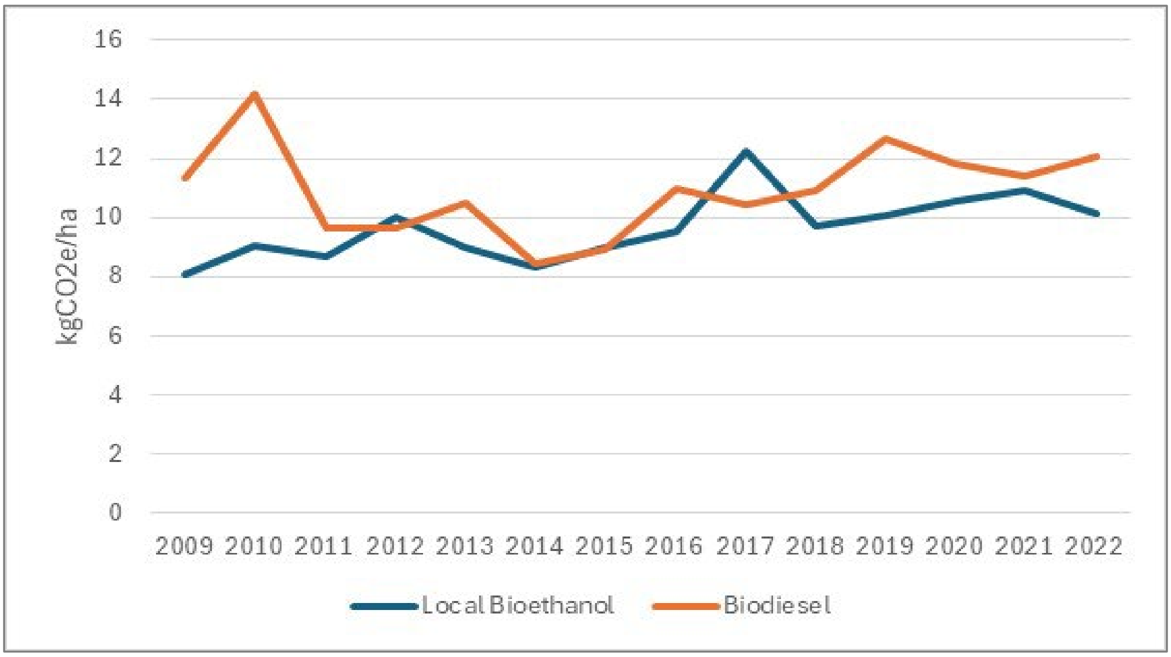



Source: DOE (2023a).

*Carbon emission footprint avoidance*

Over the past decade, the carbon emissions avoidance footprint of bioenergy was an average of 10.0 kg $CO_2e$ per hectare for bioethanol and 10.7 kg $CO_2e$ for biodiesel (Figure 2.20b). This mitigation does not yet include the GHG avoidance from the production of electricity using biomass feedstock from coconut and sugarcane.

Figure 2.20b. Carbon Footprint Avoidance




Source: DOE (2023a).

## *D. Socio-economic impacts*

Biomass production and bioenergy sustainability can have socio-economic implications for rural livelihoods, income generation, and community development. Smallholder farmers and rural communities may benefit from biomass and bioenergy production through increased employment opportunities, income diversification, and access to renewable energy services. However, social equity considerations are crucial for ensuring that biomass production does not exacerbate inequalities or marginalise vulnerable groups, such as indigenous communities or landless farmers. Capacity-building initiatives, stakeholder engagement, and participatory decision-making processes are essential for promoting inclusive and equitable bioenergy development that benefits all stakeholders. The government recognises this as the Sugarcane Industry Roadmap 2020 (SRA, DA, and DTI, 2015), which includes improving the incomes of farmers, millers, and producers, as well as job generation, as an integral part of its framework.

Assessing the impact of biomass production and bioenergy sustainability within the WEF Nexus in the Philippines requires a holistic approach that considers the interconnectedness of water resources, energy production, food security, climate change, and socio-economic dynamics. Effective policies, technologies, and management practices are essential for maximising synergies and minimising trade-offs to achieve sustainable bioenergy development that supports the country's energy, food, and water security goals.

### *2.4.6 Land suitability spatial mapping based on the WEF Nexus*

Land suitability spatial mapping based on the WEF Nexus holds paramount importance for fostering holistic and sustainable resource management. The interconnected nature of water, energy, and food systems necessitates a comprehensive understanding of their interdependencies. Through spatial mapping, decision-makers gain insights into the optimal use of land resources, allowing for the identification of areas where water, energy, and food systems can be integrated efficiently.

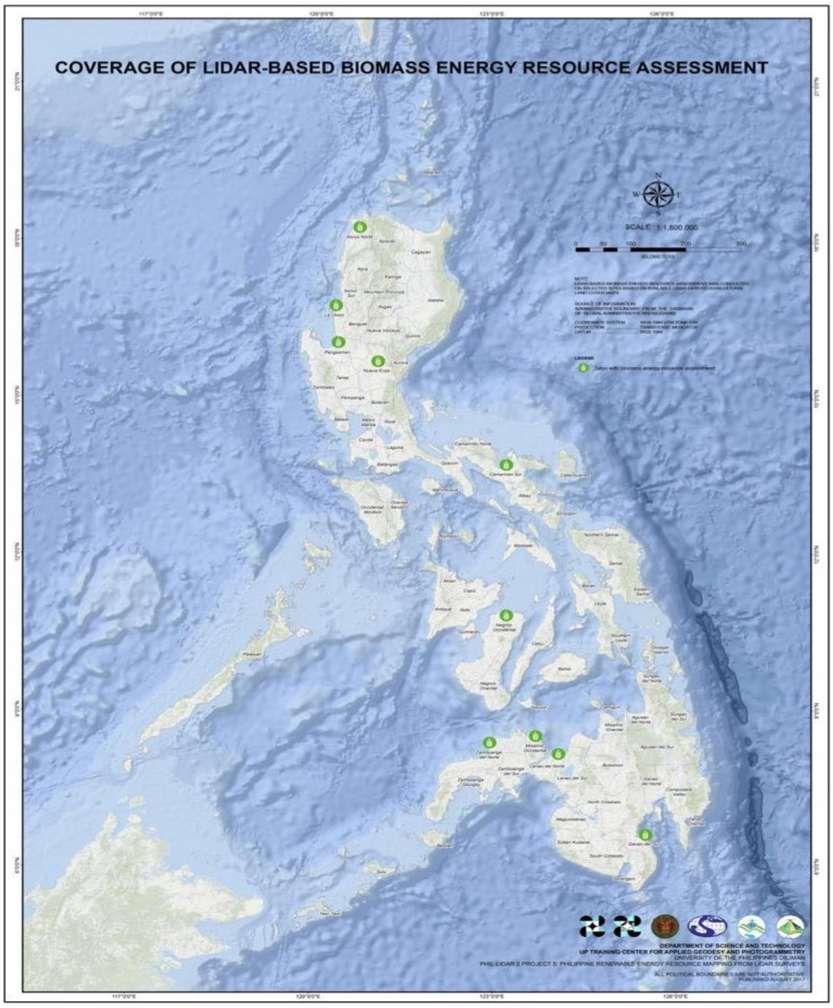
This approach aids in optimising resource use, minimising waste, and mitigating conflicts that may arise due to competing demands for limited land resources. Moreover, as climate change introduces additional complexities, land suitability mapping, when integrated with climate data, becomes crucial for assessing vulnerability and developing climate-resilient land-use plans. By recognising and incorporating ecosystem services into the mapping process, planners ensure that land-use decisions not only meet WEF demands but also sustain essential ecological functions.

Furthermore, strategic infrastructure planning benefits land suitability mapping, facilitating the location of areas suitable for sustainable agriculture, renewable energy projects, and water management infrastructure. Engaging local communities in the mapping process enhances community participation, aligns decisions with local needs and preferences, and promotes social acceptance. Overall, integrating land suitability spatial mapping within the WEF Nexus provides a powerful tool for decision-makers to address the challenges of resource scarcity, climate change, and competing land-use demands, ultimately contributing to sustainable development.

SRA uses digitised maps of all sugarcane fields that are generated and populated with data obtained from actual field surveys to determine the crop estimates and gain updates on the fields planted with sugarcane every cropping season. They are also used as a tool by the Sugar Board to arrive at more reliable and accurate estimates of the cropping season's production (SRA, DA, and DTI, 2015).

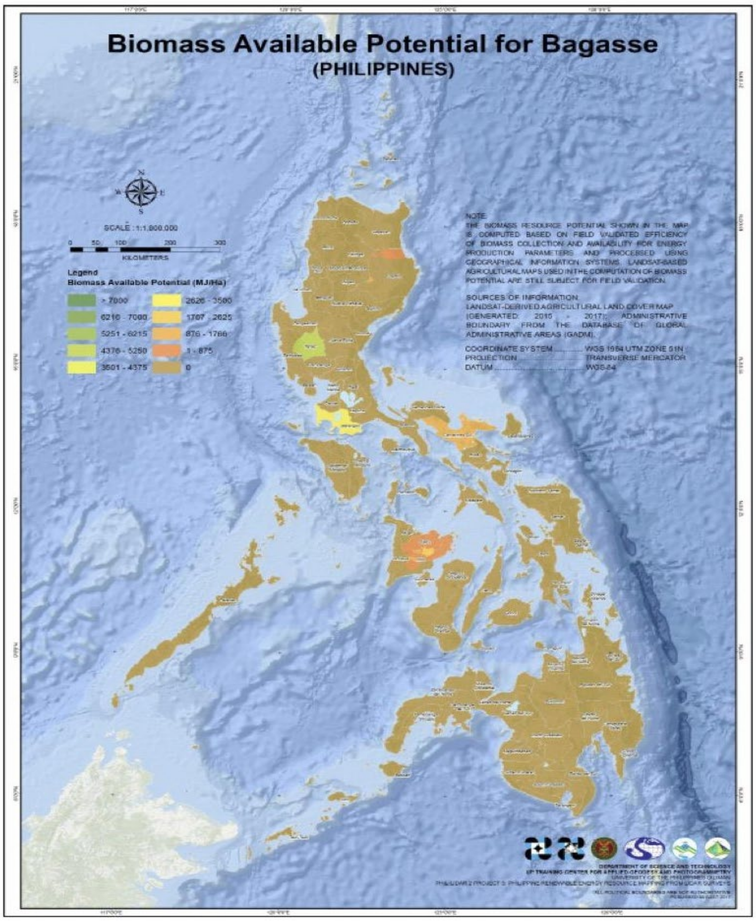
Figures 2.21–2.25 show the biomass resource assessment for potential sourcing and development in the Philippines.

Figure 2.21. Biomass Resource Assessment in the Philippines



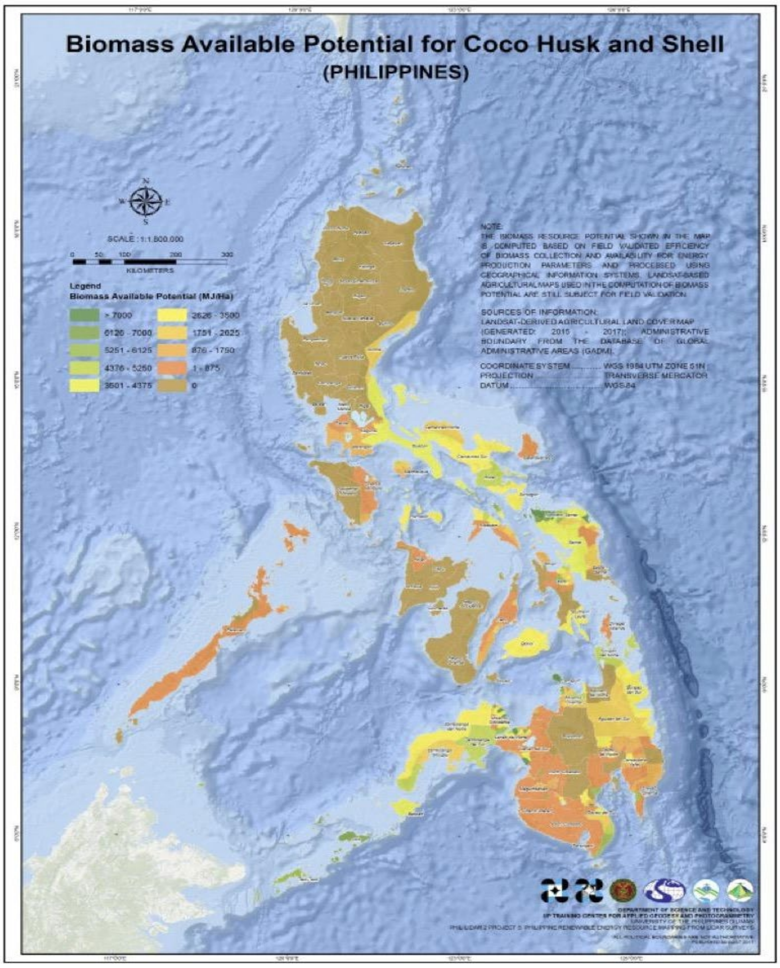

Source: Ang, M. R. C. O., & Blanco, A. C., et al. (2017).

Figure 2.22. Biomass Available Potential for Bagasse in the Philippines




Source: Ang, M. R. C. O., & Blanco, A. C., et al. (2017).

Figure 2.23. Biomass Available for Potential Coco-husks and Shells in the Philippines




Source: Ang, M. R. C. O., & Blanco, A. C., et al. (2017).

Figure 2.24. Suitable Sites for Biomass Energy Development Using Bagasse in the Philippines


Source: Ang, M. R. C. O., & Blanco, A. C., et al. (2017).

Figure 2.25. Suitable Sites for Biomass Energy Development Using Coco-husks and Shells in the Philippines


Source: Ang, M. R. C. O., & Blanco, A. C., et al. (2017).

### *2.4.7 Challenges for sugarcane and coconut biomass utilisation*

Biomass utilisation in the Philippines within the Water-Food-Energy-Climate Change Nexus offers significant potential to address multiple challenges and contribute to sustainable development. Effective policies and strategies that promote biomass energy, sustainable agriculture, water resources management, and climate change mitigation and adaptation are essential for realising this potential and ensuring the resilience and sustainability of the country's energy, food, and water systems.

Overall, despite the existence of policies and initiatives promoting biomass utilisation in the Philippines, several challenges and opportunities remain:

- Limited infrastructure and technology for biomass conversion and utilisation, particularly in rural and remote areas.
- Competition for biomass resources between energy production, agriculture, and other sectors, leading to potential conflicts and trade-offs.
- Socio-economic implications of biomass utilisation, including impacts on land tenure, livelihoods, and rural development.
- Need for integrated planning and coordination amongst relevant government agencies, private sector stakeholders, and local communities to optimise biomass utilisation and maximise socio-economic and environmental benefits.

Tables 2.11 and 2.12 show the current challenges for biomass production and utilisation in the Philippines.

Table 2.11. Challenges for Sugarcane and Molasses Biomass Production and Utilisation in the Philippines

| Production | Challenges | Sources |
|---|---|---|
| **Data for Crop Year 2022–2023**<br>Total sugarcane area = 384,487 ha.<br>average National sugarcane yield = 56.77 TC/ha total Sugarcane milled = 20,458,759 tonnes total Molasses supply = 996,859.27 tonnes<br><br>Total sugarcane area for bioethanol = 15,574.16 ha<br>Total tonnes cane for bioethanol = 754,720 tonnes<br><br>2023 bioethanol demand (at B10) = 763 MLPY<br>2023 local bioethanol production = 303 MLPY<br>Deficit (being imported) = 460 MLPY<br>Note that 2023 max. local capacity = 466 MPY<br><br>**Draft DOE Department Circular** | ➔ Insufficient feedstock availability<br>➔ Inadequate local bioethanol plant capacity<br>➔ High production cost and selling price<br>➔ Low sugarcane production yield<br>➔ Lack of high-yielding varieties (or not being trickled down properly to farmers)<br>➔ Disaggregated land<br>➔ Proper sugarcane farming practices not implemented primarily due to lack of needed farm capital<br>➔ Land conversions | (SRA, 2023b)<br><br>SRA (2023b)<br><br>(DOE-OIMB, 2024) |

| Production | Challenges | Sources |
|---|---|---|
| **Section 3. Voluntary Implementation of the 20% Bioethanol Blend**<br>The downstream oil sector may offer consumers a gasoline fuel containing a 20% bioethanol blend on a voluntary basis. | ➔ Sugarmill closure (case of Central Azucarera Don Pedro, Inc.(CADPI)) | |

Source: Authors' data compilation.

Table 2.12. Challenges for Coconut Biomass Production and Utilisation in the Philippines

| Production | Challenges | Sources |
|---|---|---|
| **Data for Crop Year 2022–2023**<br>2022 coconut plantation = 3.6 million ha<br>2022 coconut production = 14.93 million tonnes<br>Average coconut yield = 44 coconuts per tree (with around 100 trees per hectare; good scenario)<br>Assumptions/based on preliminary data gathering:<br>Copra yield = 0.25 kg copra/kg coconut<br>Coconut oil (CNO) yield = 0.63 kg CNO/kg copra<br>Biodiesel yield = 0.96 kg biodiesel/kg CNO<br>2023 local biodiesel capacity = 708 million L<br>2023 biodiesel demand at B2 = 220 million L<br>Underutilised biodiesel volume = 450 million L | ➔ Low coconut yield and production supply (affected by impacts of climate change, pests, and diseases)<br>➔ Outdated farming practices, inadequate farm management, and insufficient access to modern agricultural technology | (Sausa, 2023)<br>(DOE-OIMB, 2024) |

| Production | Challenges | Sources |
|---|---|---|
| CNO usage based on 2022 biodiesel demand = 257 million L<br><br>The Philippines is a major exporter of coconut oil and other products, such as copra meal and desiccated coconut.<br><br>**Draft DOE Department Circular Section 2. Mandatory Implementation of Higher Biodiesel Blend**<br>All diesel fuel distributed and sold by every oil company in the country shall contain a biodiesel blend at 3% effective 1 July 2024, 4% effective 1 July 2025, and 5% effective 1 July 2026. | | |

Source: Authors' data compilation.

## 2.5 India

With an estimated population of 1.42 billion, India overtook China in 2023, to become the most populous country in the world. It is projected that India's population will increase by another 70 million over the next 6 years to reach 1.5 billion by 2030 and almost 1.7 billion by 2050.

Water, food, and energy are indeed essential for human survival and economic progress and are particularly pertinent for India because of the sheer size of its population and economy. Ensuring availability and sustainability of these resources is not only crucial for meeting present needs but also for safeguarding the well-being of future generations. Supporting the growing population through adequate food and nutrition whilst providing sustainable sources of energy to support its economic development and social progress is critical to India's achievement of the 2030 Sustainable Development Goals and the Paris Agreement targets.

With an estimated food grain production of 329 million tonnes in 2022–2023, India has been successful in achieving self-sufficiency (PIB, 2023) whilst ranking second worldwide in terms of farm output and emerging as the world's largest producer of rice, vegetables, fruit, and cotton. It is equally important to highlight that India may have witnessed unprecedented growth in the production of various food grains since independence, yet its per capital food availability has remained stagnant. To make matter worse, India continues to remain under the 'serious category of hunger', as per the Global Hunger Index 2022, ranking 107 out of the 121 evaluated countries (NABARD, 2022). Wastage of farm produce, which is estimated at 40% largely because of inefficient supply chains, is an issue that impedes the achievement of many of the SDGs, including one that targets sustainable consumption and production, climate change, water and biodiversity, food security, and this loss is reported to occur before the food even reaches consumers.

To meet the demand needs of the growing population, agricultural production will need to increase substantially to ensure food security. If we look at India's crop productivity, it is significantly low compared to other countries. India's rice yield is close to 4 tonnes/ha, whilst countries like Brazil, China, and United States have yields beyond 5 tonnes/ha. Similarly for wheat and other cereals, the average productivity is around 3 tonnes/ha, whilst China has a yield of more than 5 tonnes/ha (FAO, 2023). Low productivity is attributed to many factors, including traditional farming practices, small landholdings, and limited investment in mechanisation.

Water is one of the most important inputs in agricultural production. India's overreliance on water-intensive crops, including rice and sugarcane, is often touted as a leading factor in making India water-stressed. India's annual utilisable water resources have witnessed a decline of 20% per capita over the last 10 years and are likely to decrease by 20%–30% by the middle of this century (TERI, 2022; PIB, 2020). According to the World Resources Institute's (WRI) Aqueduct Water Risk Atlas, India is amongst the leading 25 countries facing extremely high water stress each year (WRI, 2023). There is little doubt that India must increase its agricultural output and, given the paucity of land, this will primarily stem from boosting productivity. However, productivity implies substantial dependence on water. This is evident from the data indicating a projected 6% increase in crop acreage between 2015 and 2050, alongside a substantial 42% growth in water usage for irrigation within the same timeframe. Expansion of agricultural land is expected to be minimal.

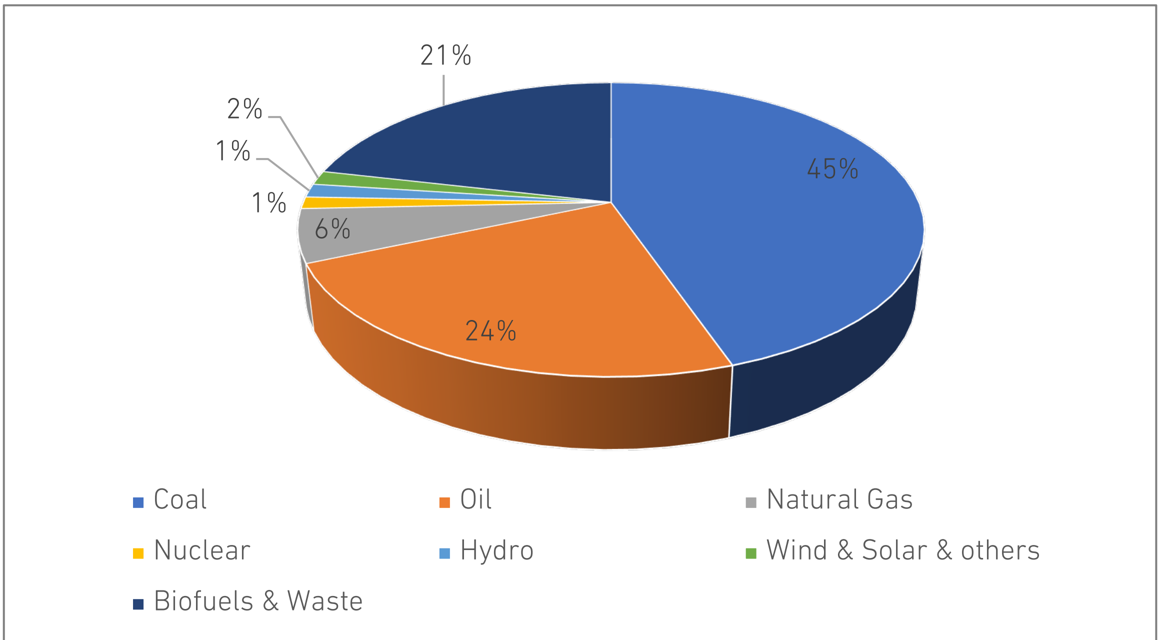
Expanding agricultural areas to meet the growing demand for food can indeed have significant negative impacts on water resources and the environment. Much of the irrigated areas are dependent on groundwater. Agricultural expansion often leads to increased water consumption for irrigation, which can deplete groundwater reserves and strain surface water sources. This can exacerbate water scarcity, particularly in regions already facing water stress. With more land to be converted into arable land, the pressure on waste land and forest land will increase. Whilst the implications of deforestation on GHG emissions need no explanation, the intensive use of fertilisers, pesticides, and herbicides, particularly on waste lands to make them arable, aggravate environmental problems as much of these inputs require the intensive use of fossil fuels, leading to GHG emissions and climate change.

Growing environmental pressure, mostly arising from GHG emissions linked to fossil fuel usage, and the need for energy transition will warrant much of the energy being sourced from renewable sources. However, supporting the sustainable energy transition will imply trade-offs of utilising farm-based grains and/or oilseeds for biofuels production versus human food (or animal feed).

Observations have shown that managing any one aspect in isolation is insufficient; instead, they should be viewed within an integrated system. Consequently, the nexus approach becomes crucial for ensuring the efficient and sustainable utilisation of resources and devising comprehensive strategies. Embracing such an approach enables more cohesive and impactful policymaking and planning, as well as monitoring and evaluation across various sectors interconnected within such a framework.

With an estimated energy supply of 39.4 exajoules (EJ) of primary energy supply, India ranks as the third-largest consumer of energy worldwide (Ministry of Statistics and Programme Implementation, 2023; IEA, 2022), and India's share in global energy consumption is estimated to increase from its current level of 6.1% and to almost 10% by 2050 (IEA, 2022). A significant part of India's energy requirement is met through fossil fuels (largely oil), which is largely met through imports. Of the total primary energy supplied, coal accounts for 44.6%, followed by oil at 23.7%, and biofuels and waste account for 21.6%. The total share of renewable energy in total energy supply is estimated at 25.7%. Around 83% of renewable energy is from biomass. Figure 2.26 presents the detailed shares of various sources of primary energy supply.

Figure 2.26. Shares of Various Primary Sources for Energy Supply




Source: IEA (2021).

Between 2000 and 2020, India's total energy supply has more than doubled, experiencing rapid growth. Despite this expansion, the contribution of bioenergy has remained relatively stable, hovering around 8 EJ, whilst other renewables, such as solar and wind, have remained at comparatively low levels, totalling 0.6 EJ combined. The predominant growth in energy supply over the past decades has been driven by fossil fuels, notably coal, oil, and gas. Coal consumption has surged at an average annual rate of 6%, soaring from 6 EJ in 2000 to 18 EJ in 2020, whilst oil consumption has grown by an average of 5% per year, rising from 4.7 EJ in 2000 to 10 EJ in 2010 (IEA 2021).

Solid biofuels constitute the predominant share (99%) of bioenergy in India. The majority of this biomass is utilised in the residential sector, often largely for cooking and space heating, albeit in an inefficient manner and involving high-emission operations. The quantity of solid biomass employed for residential applications peaked around 2011, surpassing 6 EJ, followed by a consistent decline to 5 EJ by 2019. However, this decline has been partially offset by a rise in bio-power generation from solid biomass, which has doubled since 2010. Table 2.13 provides a breakdown of the bioenergy per capita.

Table 2.13. Contribution of Various Feedstocks for the Production of Biofuels

| Source | Energy Supply per Capita (GJ/capita) |
|---|---|
| Solid biofuels | 5.6 |
| Municipal solid waste | 0.01 |
| Biogas | 0.01 |
| Liquid | 0.03 |
| Others | 0.05 |
| Total bioenergy | 5.7 |

Source: IEA (2021).

The consumption of solid biofuels appears comparatively high when juxtaposed with the domestic forest area, averaging approximately 7 tonnes of dry wood mass per hectare. However, the majority of solid biofuels are not sourced directly from forests. Instead, there is significant reliance on dried cow dung, some straw or stubble, and woody biomass obtained from non-forest land or post-consumer wood waste.

The utilisation of renewable energy from municipal solid waste (MSW) has not witnessed substantial growth yet, although efforts are underway to address this since India has been witnessing substantial growth in the generation of MSW, particularly in urban settings. Liquid biofuels remain at a nascent stage, indicating considerable potential for growth. Similarly, biogas production is also in its infancy, but initiatives are being implemented to foster advancements in both liquid biofuels and biogas technologies.

The energy transition has emerged as the leading pathway in the global campaign for achieving net-zero emissions. India's energy landscape, primarily reliant on imported technology, stands as a crucial catalyst in this transformation. By enabling the commercial viability of biofuel plants in a landscape traditionally dominated by fossil fuels, this shift signifies a pivotal game changer. India's energy mix is undergoing a significant transformation, with renewable energy sources rapidly gaining ground and making substantial inroads. However, given that India has to provide adequate food and nutritional security to the growing population whilst ensuring that the stress on water is not aggravated, there is an urgent need to understand the potential trade-offs in the context of supporting energy transition whilst providing necessary social security.

One of the major challenges the Indian farm sector has witnessed is low farm sizes. An assessment by the Ministry of New and Renewable Energy (Ministry of New and Renewable Energy, 2021) reveals that the average farm holding size is around 2.7 ha. The state of Tripura was found to have lowest land holding of 0.52 ha, whilst the state of Punjab was reported to have the highest average landholding 6.91 ha. This has been attributed as one of the leading reasons for relatively poor investment in farm mechanisation, thereby leading to low yields for most of the crops cultivated.

There is a significant difference in average biomass production across Indian states due to variations in cropping patterns. Punjab and Kerala lead the pack with the highest individual farm-level production, averaging around 93–98 tonnes. This is followed by Karnataka at 54.7 tonnes and Haryana at 32 tonnes. In the remaining states, the average biomass production per farm falls below 10–20 tonnes (Ministry of New and Renewable Energy, 2021).

To understand the extent of biomass residue utilisation at the individual farmer level, a two-level analysis was undertaken to assess the biomass generation and utilisation, as well as the available surplus at the state level and for crops.

Analysis of the compiled data, as presented in Tables 2.14 and 2.15, reveals interesting insights regarding residue utilisation across various categories and states. Cereals, particularly maize, jowar, bajra, and rice, were found to have a better utilisation share of 50%–70%, although there was some variation depending on the state in which the relevant crops are produced. Pulses were found to have a moderate utilisation rate (30%–60%). Interestingly, sesame residue also saw complete utilisation in some states like Uttarakhand and Uttar Pradesh.

However major crops that are produced in the country, including rice, wheat, barley, jowar, bajra, maize, and sugarcane, were found to have a much lower utilisation share.

The primary uses for biomass residue include cattle feed, domestic fuel, and fertiliser composition.

Table 2.14. Regional Distribution of Crop Production, Biomass Generation, and Surplus

| State | Total Crop Area (Mha) | Total Crop Production (MT) | Total Biomass Generation (MT) | Surplus Biomass Potential (MT) | Biomass Utilisation (MT) | Utilisation Percentage |
|---|---|---|---|---|---|---|
| Andhra Pradesh | 7.36 | 28.62 | 40.01 | 17.09 | 22.92 | 43% |
| Arunachal Pradesh | 0.33 | 0.58 | 0.75 | 0.17 | 0.58 | 23% |
| Assam | 3.4 | 8.93 | 12.57 | 2.54 | 10.03 | 20% |
| Bihar | 7.28 | 32.5 | 32.57 | 7.98 | 24.59 | 25% |
| Chhattisgarh | 5.47 | 8.71 | 12.99 | 2.65 | 10.34 | 20% |
| Goa | 0.14 | 0.24 | 0.45 | 0.23 | 0.22 | 51% |
| Gujarat | 9.67 | 32.27 | 50.24 | 21.74 | 28.5 | 43% |
| Haryana | 6.6 | 27.17 | 36.24 | 10.91 | 25.33 | 30% |
| Himachal Pradesh | 0.77 | 1.51 | 2.74 | 0.57 | 2.17 | 21% |
| Jammu and Kashmir | 0.96 | 1.77 | 3.24 | 0.65 | 2.59 | 20% |
| Jharkhand | 1.96 | 3.32 | 5.31 | 1.2 | 4.11 | 23% |
| Karnataka | 10.94 | 51.34 | 34.09 | 14.05 | 20.05 | 41% |
| Kerala | 1.3 | 4.79 | 8.58 | 6.04 | 2.54 | 70% |
| Madhya Pradesh | 23.7 | 43.81 | 70.23 | 19.93 | 50.3 | 28% |
| Maharashtra | 21.07 | 86.48 | 52.54 | 21.49 | 31.05 | 41% |
| Manipur | 0.34 | 1.12 | 1.14 | 0.48 | 0.66 | 42% |
| Meghalaya | 0.25 | 0.91 | 1.37 | 0.56 | 0.81 | 41% |
| Mizoram | 0.05 | 0.13 | 0.13 | 0.02 | 0.11 | 15% |
| Nagaland | 0.44 | 1.37 | 1.37 | 0.44 | 0.94 | 32% |
| Odisha | 4.45 | 7.88 | 11.84 | 2.23 | 9.61 | 19% |
| Punjab | 7.17 | 37.88 | 53 | 22.25 | 30.75 | 42% |
| Rajasthan | 31.93 | 32.11 | 59.5 | 10.21 | 49.29 | 17% |
| Sikkim | 0.08 | 0.12 | 0.23 | 0.04 | 0.19 | 17% |

| State | Total Crop Area (Mha) | Total Crop Production (MT) | Total Biomass Generation (MT) | Surplus Biomass Potential (MT) | Biomass Utilisation (MT) | Utilisation Percentage |
|---|---|---|---|---|---|---|
| Tamil Nadu | 8.96 | 47.92 | 52.14 | 12.22 | 39.92 | 23% |
| Telangana | 9.38 | 18.57 | 33.62 | 13.76 | 19.86 | 41% |
| Tripura | 0.35 | 0.97 | 1.41 | 0.25 | 1.16 | 18% |
| Uttarakhand | 1 | 8.05 | 3.55 | 0.72 | 2.83 | 20% |
| West Bengal | 8.49 | 38.2 | 47.51 | 16.28 | 31.23 | 34% |
| Andaman and Nicobar | 0.04 | 0.08 | 0.2 | 0.13 | 0.07 | 65% |
| Dadra and Nagar Haveli and Daman | 0.02 | 0.1 | 0.07 | 0.02 | 0.06 | 29% |
| Puducherry | 0.02 | 0.27 | 0.12 | 0.04 | 0.08 | 33% |
| Total | 198.11 | 774.37 | 754.5 | 228.53 | 525.98 | 30% |

Source: Ministry of New and Renewable Energy (2021).

Table 2.15. Production, Biomass Generation, and Surpluses of Various Crops in India

| Crop | Total Crop Area (Mha) | Total Crop Production (MT) | Total Biomass Generation (MT) | Biomass Utilisation (MT) | Surplus Biomass Potential (MT) |
|---|---|---|---|---|---|
| Rice | 46.15 | 123.03 | 184.55 | 142.83 | 41.72 |
| Wheat | 34 | 106.85 | 192.34 | 158.97 | 33.37 |
| Barley | 0.62 | 1.7 | 2.22 | 1.99 | 0.22 |
| Jowar | 6.58 | 5.23 | 12.55 | 10.63 | 1.92 |
| Bajra | 7.36 | 8.89 | 23.37 | 19.53 | 3.84 |
| Maize | 9.75 | 30.4 | 69.92 | 54.71 | 15.21 |
| Ragi | 1.2 | 2.03 | 2.64 | 2.37 | 0.27 |
| Small Millet | 1.31 | 0.94 | 1.19 | 1.07 | 0.12 |
| Other Cereals | 0.1 | 0.09 | 0.12 | 0.11 | 0.01 |
| Gram | 10.57 | 8.09 | 8.9 | 7.03 | 1.88 |
| Horse Gram | 0.41 | 0.22 | 0.28 | 0.25 | 0.03 |
| Arhar/Tur | 3.06 | 2.59 | 7.24 | 2.33 | 4.91 |
| Khesari | 0.47 | 0.38 | 0.41 | 0.28 | 0.12 |

| Crop | Total Crop Area (Mha) | Total Crop Production (MT) | Total Biomass Generation (MT) | Biomass Utilisation (MT) | Surplus Biomass Potential (MT) |
|---|---|---|---|---|---|
| Masoor | 1.52 | 1.36 | 2.44 | 0.74 | 1.7 |
| Moong (Green Gram) | 4.56 | 2.03 | 2.53 | 1.74 | 0.8 |
| Urad | 4.24 | 2.48 | 3.23 | 1.93 | 1.3 |
| Other Rabi Pulses | 0.21 | 0.17 | 0.23 | 0.2 | 0.02 |
| Other Kharif Pulses | 0.48 | 0.32 | 0.42 | 0.34 | 0.08 |
| Other Summer Pulses | 0 | 0 | 0 | 0 | 0 |
| Peas and beans | 0.78 | 0.94 | 0.47 | 0.24 | 0.24 |
| Cowpea | 0.2 | 0.13 | 0.14 | 0.12 | 0.03 |
| Moth | 1.2 | 0.5 | 0.9 | 0.81 | 0.09 |
| Castor Seed | 0.9 | 1.56 | 6.39 | 2.12 | 4.27 |
| Groundnut | 5.3 | 7.7 | 17.71 | 16.2 | 1.51 |
| Niger Seed | 0.16 | 0.05 | 0.06 | 0.06 | 0.01 |
| Rapeseed and Mustard | 8.05 | 7.55 | 13.58 | 9.94 | 3.64 |
| Safflower | 0.12 | 0.06 | 0.19 | 0.15 | 0.04 |
| Sunhemp | 0.01 | 0.01 | 0.03 | 0.03 | 0.01 |
| Linseed | 0.22 | 0.13 | 0.19 | 0.16 | 0.04 |
| Sesamum | 1.56 | 0.77 | 1.92 | 1.21 | 0.7 |
| Soyabean | 12.65 | 11.34 | 19.27 | 16.85 | 2.42 |
| Sunflower | 0.37 | 0.23 | 0.46 | 0.04 | 0.42 |
| Other Oilseeds | 1.81 | 3.59 | 7.18 | 0 | 7.18 |
| Turmeric | 0.16 | 0.73 | 0.24 | 0.1 | 0.14 |
| Dry Chillies | 0.61 | 1.74 | 2.6 | 0.52 | 2.08 |
| Garlic | 0.24 | 1.13 | 0.34 | 0 | 0.34 |
| Ginger | 0.09 | 1.18 | 0.06 | 0.04 | 0.02 |
| Coriander | 0.38 | 0.33 | 0.38 | 0.19 | 0.19 |

| Crop | Total Crop Area (Mha) | Total Crop Production (MT) | Total Biomass Generation (MT) | Biomass Utilisation (MT) | Surplus Biomass Potential (MT) |
|---|---|---|---|---|---|
| Black Pepper | 0.13 | 0.3 | 0.15 | 0.13 | 0.02 |
| Arecanut | 0.46 | 2.92 | 3.7 | 0.22 | 3.48 |
| Cardamom | 0.06 | 0.02 | 0.04 | 0.02 | 0.02 |
| Banana | 0.32 | 11 | 33.01 | 25.75 | 7.26 |
| Onion | 0.56 | 8 | 0.4 | 0.31 | 0.09 |
| Potato | 1.69 | 39.86 | 32.29 | 14.92 | 17.37 |
| Sugarcane | 4.71 | 357.77 | 17.89 | 11.51 | 6.38 |
| Sweet Potato | 0.04 | 0.36 | 0.04 | 0.01 | 0.02 |
| Tobacco | 2.54 | 0.88 | 0.88 | 0 | 0.88 |
| Cotton | 12.46 | 4.67 | 57.61 | 11.37 | 46.24 |
| Guar Seed | 4.59 | 2.1 | 4.19 | 3.55 | 0.65 |
| Mesta | 0.05 | 0.07 | 0.15 | 0.07 | 0.07 |
| Jute | 0.73 | 1.83 | 3.66 | 0.73 | 2.93 |
| Coconut | 1.86 | 2.71 | 9.46 | 0.95 | 8.51 |
| Cashew nut | 0.38 | 0.17 | 0.4 | 0 | 0.4 |
| Tapioca | 0.1 | 5.21 | 3.91 | 0.59 | 3.32 |
| Total | 198.11 | 774.38 | 754.5 | 525.98 | 228.52 |

Source: Ministry of New and Renewable Energy (2021).

Whilst a significant surplus of crop residue is generated in India, a moderate portion is unfortunately burned in the fields instead of being properly utilised. Uttar Pradesh contributes the most to this practice, followed by Punjab and Haryana. A study by Jain et al. (2014) found that the percentage of crop residue burned in India varies widely, ranging from 8% to a staggering 80% for rice straw across different states. Furthermore, the study identified rice straw as the biggest contributor to burning, accounting for 43% of the total. This is followed by wheat straw at 21%, sugarcane residue at 19%, and oilseed crop residue at around 5%. Thus, at a national level, out of the total biomass estimated to be generated at 754 million tonnes, 525 million tonnes is estimated to be utilised whilst the remaining 228 million tons are not productively utilised.

In the context of production of 1G or 2G bioenergy in India, the focus has largely been around three major crops – rice, maize, and sugar cane. In fact, the Indian government had allowed the production and procurement of ethanol from C & B heavy molasses, sugarcane juice, maize, and surplus rice. Despite having a surplus of nearly 228 million tonnes of biomass (Tables 2.14 and 2.15), India had to divert 1G feed for producing biofuels.

The increased area and increased production of major crops, including rice and wheat, have been used to divert part of them for biofuel production. Although the acreage of sugarcane has remained almost stagnant, the intensive growth in sugarcane production has created a surplus that has been leveraged to divert part of sugarcane juice to bio ethanol production. However intensive sugarcane farming practices have had serious implications on the consumption of various natural resources, including water. India's biofuel policy mandates the use of 20% blended fuel (ethanol), and if this has to be achieved from only sugarcane, then with current productivity, a significant share of land has to be diverted to sugarcane production.

NITI Aayog has estimated under the business-as-usual scenario the total requirement of 10.16 billion litres of ethanol by 2025 (NITI Aayog and MoPNG, 2021). If 50% of the ethanol has to be produced from sugarcane juice, i.e. around 5 billion litres, then the total quantity of sugarcane that would be required would be around 71 million tonnes. Assuming an average yield of 80 tonnes per Ha, the land requirement will be around 1 million Ha (NFSM, 2014). Major sugarcane-producing states, including Uttar Pradesh, Andhra Pradesh, Karnataka, and Gujarat, are reported to consume around 100 billion cubic metres per 5 million Ha of water (AICRP on Sugarcane, 2023). Thus, 1 million Ha of land would require around 0.4 billion cubic metres of water, or 400 billion litres. Expanding sugarcane cultivation would redirect irrigation water from essential food-grain crops, exacerbating concerns about agricultural sustainability. Additionally, the heightened demand for fertilisers in sugarcane farming amplifies its environmental impact. Therefore, achieving the ambitious ethanol targets through sugarcane may not be environmentally sustainable when considering the broader agricultural system, which possibly would be better understood using the water-energy-food sustainability framework.

If India is looking at producing another 5 billion litres of ethanol from rice and maize, then the requirement of food grains would be to the tune of around 13 million tonnes. Although there has been an increase in utilisation of rice for ethanol production as is presented in Table 2.14, this was largely attributable to surplus production achieved particularly during the Covid-19 period. Given the food security implications of rice diversion to bioethanol production, in the long run, food-grain-based ethanol production will depend largely on maize unless India is able to ramp up its utilisation of surplus residue.

India ranks as a major maize producer globally, but domestic consumption consistently outpaces production. Despite being a major maize producer (with an estimated 34 million tonnes in 2022), India has struggled to meet domestic demand with consumption outpacing production. Over the last few years, India had been importing maize hovering around 0.4 million–0.5 million tonnes. Much of the consumption of maize is in growing the poultry sector in the country lion's share (47%), followed by livestock feed (13%) and starch (14%) (Directorate General of Foreign Trade, 2024). The production is further affected by the relatively poor yield at 3–4 tons/ha against the average reported in some other countries like the United States (US), where the average maize yield in the last decade was around 10–11 tonnes per hectare (t/ha), or 6 t/ha in China, and 5 t/ha in Brazil (Corn Yields, 2023).

The suggestion to use maize for ethanol production in India may also raise significant land-use concerns. Interestingly, the government think tank, NITI Aayog, has advocated the use of maize, but given the ethanol yield of roughly 380 litres/tonne, this would necessitate a massive increase in maize cultivation area (over 4.8 million hectares). This translates to more than half of the existing cultivated area (9.42 million hectares). It becomes imperative to understand the potential adverse environmental affects that the US witnessed due to land-use change inefficiencies whilst driving up maize prices and negatively affecting the poultry and livestock industries (Jang et al. 2020).

## 2.6 Viet Nam

The identification of rice straw and rice husk availability and challenges is based on a review of current utilisation practices outlined in recent publications on these agricultural by-products. The availability and challenges of rice straw and rice husk in Viet Nam primarily entail the current and potential uses of these agricultural by-products, which will be addressed in this section. Additionally, the availability of straw and husk depends on rice production, which is influenced by Vietnamese food security policies, the impacts of climate change and sea level rise, and agricultural restructuring policies.

Rice straw and rice husk are the main by-products of rice production in Viet Nam. Viet Nam grows about 4 million hectares of paddy per year, with an output of approximately 43 million tonnes of paddy in 2023 (USDA, 2024). According to Viet Nam's land use plan up to 2030, the paddy area will be reduced to about 3.5 million hectares, whilst the country aims to export about 4 million tonnes of rice annually (Land Law, 2024). Thus, the available rice straw will vary from 17 million to 52 million tonnes, depending on the collection of both rice straw and stubble, whilst the rice husk output will be about 8.6 million tonnes.

The available straw and husk remain substantial but with limited utilisation. Prior to 2020, rice straw was primarily disposed of through open burning due to the unavailability of rice balers (Hung et al., 2020; Hung et al., 2018; Truc et al., 2012), which was the most cost-effective method at the time. However, with the introduction of straw balers in Viet Nam, particularly in the Vietnamese Mekong Delta, approximately 30% of the straw is now collected and utilised (Vu, 2023; Son et al., 2018). Rice straw finds applications in cultivating straw mushrooms (Volvariella volvacea), mulching various crops (such as watermelon, dragon fruit, etc.), and as cattle feed (Vu, 2023; Van et al., 2014), predominantly serving small-scale farmers. Nevertheless, the economic value of rice straw remains low, leading to a portion of the available straw being left uncollected and open-burned (Son et al., 2018). However, if rice straw were to be efficiently collected and utilised for energy purposes (such as ethanol production, electricity generation, etc.), it could potentially compete with its current non-energy uses. Thus, there is a need to conduct an impact assessment of the alternative uses of rice straw.

Rice husk faces fewer challenges in collection compared to rice straw in Viet Nam. However, due to the predominance of small-scale rice millers, the utilisation of rice husk remains limited. Most rice husks are used for purposes such as drying paddy or burning in brick kilns, with some used as a supplementary soil conditioner or cattle feed, and a small proportion is utilised in industrial processes (Wood Pellet Mill, 2024; Son et al., 2017). There is potential for generating electricity or ethanol from rice husks (Song et al., 2021; Bergqvist et al., 2008). However, the high collection and transportation costs render rice husk impractical for these purposes. Similar concerns exist regarding the impacts of utilising rice husk and rice straw for bioenergy and how they compete with current alternative uses in Viet Nam.

Therefore, this report will examine the availability and challenges associated with rice straw and rice husk. It will explore indicators to assess the WEFLC Nexus for evaluating the alternative uses of these by-products. Additionally, the report will review current policies that may impact the utilisation of rice straw and rice husk in Viet Nam.

### *2.6.1 Rice straw*

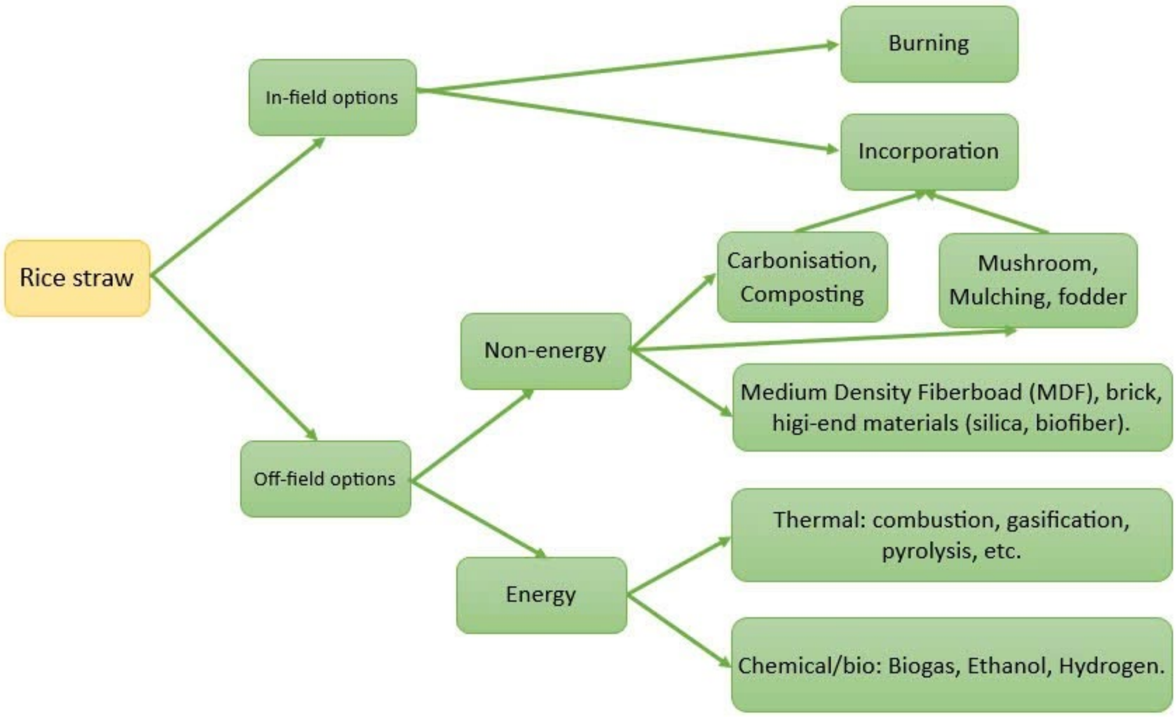
In order to review the utilisation of rice straw and rice husk in Viet Nam, the classification of rice straw and rice husk uses summarised by the IRRI Rice Knowledge Bank were applied (Figures 2.27 and 2.28). Rice straw has either on-field or off-field options. The off-field options are energy or non-energy use. From the classification, they have current or future/potential uses. Rice straw has both on-field and off-field use in Viet Nam. Before Viet Nam introduced straw balers, most rice straw in Viet Nam was open burning, especially in the Vietnamese Mekong Delta in the south of Viet Nam (Truc et al., 2012; Truc et al., 2013). Outdoor straw mushroom production has become popular in Hau Giang, Can Tho, and Dong Thap provinces, with approximately 10%–30% of the straw in the Vietnamese Mekong Delta utilised for this purpose (Nhung and Danh, 2022; Son et al., 2018; Hien, 2017) (Table 2.15). Although indoor mushroom production has been introduced to farmers and local authorities, the return on investment in this method is low. Moreover, the risk of contamination in straw production remains significant. As a result, indoor mushroom production has not been widely adopted across the entire Mekong Delta and Viet Nam.

Rice straw holds potential for industrial utilisation, such as co-firing in coal power plants (Truong et al., 2022), thermal power plants at a local scale (Cuong et al., 2021; Le et al., 2021), and ethanol production (Diep et al., 2015; Kunimitsu and Ueda, 2013). However, these applications are still in the feasibility study stage. The highest constraints are low economic return, technical challenges, and institutional barriers.

The use of composted rice straw as a soil amendment in paddy fields has shown promising results in increasing rice yields and soil carbon levels (Watanabe et al., 2017). However, it's important to note that applying composted rice straw to rice fields can lead to increased methane emissions compared to removing rice straw from the fields (IPCC, 2006; Takakai et al., 2020). To address this, there is a suggestion to combine removing straw from the fields and applying composted straw. However, this practice is currently only feasible for farmers engaged in organic rice farming.

A study by Sarangi et al. (2021) provides a clear overview of the benefits and challenges associated with using composted rice straw as a soil amendment in paddy fields, as well as the potential solution of combining straw removal with composted straw application. Additionally, it highlights the use of *Trichoderma* sp. to accelerate straw decomposition and its potential cost-saving benefits, despite its limited acceptance amongst rice farmers. Overall, it effectively communicates the complexities of rice straw management and the ongoing efforts to optimise its utilisation in agriculture.

Figure 2.27. Potential Rice Straw Utilisation




Source: IRRI Rice Knowledge Bank (2024).

Table 2.16. Challenges to Rice Straw and Rice Husk Use in Viet Nam

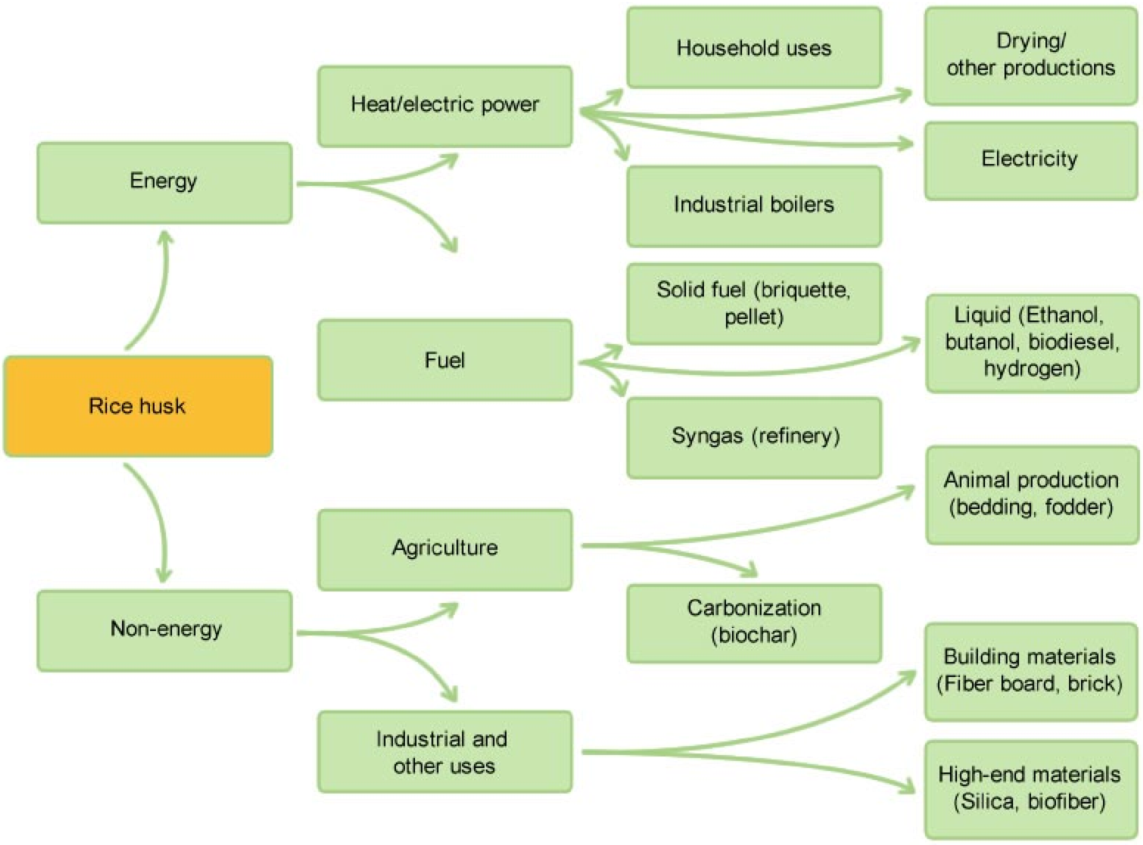
| Rice Straw and Rice Husk Utilisation | Percentage of Use (%) | Challenges |
|---|---|---|
| 1. On farm | | |
| 1.1 Open burning | 70–90 | Air pollution, loss of resources |
| 1.2 Incorporate raw rice straw to the paddy field | | Organic poison, generates greenhouse gas emissions |
| 1.3 Incorporate composted rice straw to the paddy field | | Generates less greenhouse gas emissions, laborious |
| 2. Off-farm | | |
| 2.1 Growing straw mushroom | 10–30 | Low economic efficiency, risky, generates greenhouse gas emissions |
| 2.2 Feeding cattle | <10 | Low feed quality, generates greenhouse gas emissions |
| 2.3 Mulching to upland crops or fruit trees | | Laborious, low economic efficiency |

| Rice Straw and Rice Husk Utilisation | Percentage of Use (%) | Challenges |
|---|---|---|
| 2.4 Biogas | | Low economic efficiency |
| 2.5 Biochar | | Low economic efficiency |
| 2.6 Power generation | | Low economic efficiency |
| 2.7 Straw pellets, briquettes | | Air pollution, low economic efficiency |

Sources: Nhung and Danh (2022); Cuong et al. (2021); Le et al. (2021); Dung (2019); Son et al. (2018); Hien (2017); Truc et al. (2012).

### *2.6.2 Rice husk*

Figure 2.28. Potential Rice Husk Utilisation




Source: IRRI Rice Knowledge Bank (2024).

The value of rice husk has increased significantly due to the rising demand for drying paddy at miller factories rather than traditional household methods. This shift is a crucial policy aimed at reducing harvest loss and improving the quality of milled rice in Viet Nam.

Primarily, rice husk is utilised for energy purposes, including raw burning at households, miller factories, and other industrial facilities. Although it serves as a popular fuel for cooking, its household use for this purpose has decreased. Currently, raw rice husk is predominantly used for drying paddy and brick kiln (about 30%) and producing rice husk briquettes and pellets. Additionally, it serves as an excellent substrate for growing ornamental orchids or seedlings (Wood Pellet Mill, 2024).

Table 2.17. Challenges to Rice Straw and Rice Husk Use in Viet Nam

| Rice Straw and Rice Husk Utilisation | Percentage of Use (%) | Challenges |
|---|---|---|
| 1. Energy | | |
| 1.1 Heat | | |
| 1.1.1. Household uses | 10 | |
| 1.1.2. Drying other products | 40 | Cheap fuel |
| 1.1.3. Industrial boilers | | Low economic efficiency |
| 1.2. Fuel (briquettes, pellets) | 20–30 | Low economic return, air pollution |
| 2. Non-energy | 20 | |
| 2.1. Agriculture | | |
| 2.1.1. Biochar | | Small percentage of use |
| 2.1.2. Mulching | <10 | Small percentage of use |
| 2.1.3. Other agricultural substrates | 10–30 | Small percentage of use |
| 2.2. Industrial and other uses | | Small percentage of use |
| 2.2.1. Building materials | | Small percentage of use |
| 2.2.2. Other industrial uses | | |

Source: Wood Pellet Mill (2024).

### *2.6.3 Land suitability analysis for biomass-related crops*

The availability of rice straw and rice husk relies heavily on rice production and the collection process. Therefore, this section will provide an overview of the current state of rice production in Viet Nam, elucidating its impact on the availability of rice straw and rice husk, as well as their prospects. Furthermore, to estimate the availability of rice straw and rice husk, this section will review rice cultivation areas and relevant government policies pertaining to the rice sub-sector.

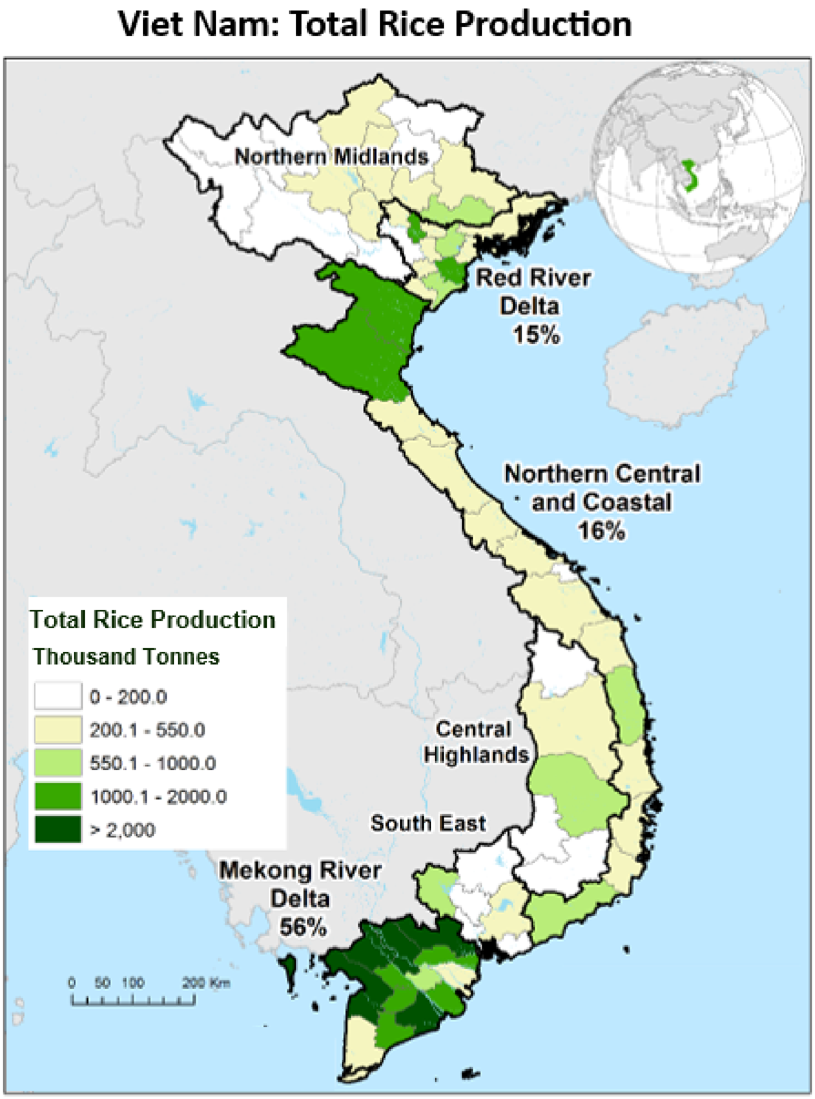
The Vietnamese government has committed to preserving 3.8 million hectares of agricultural land for rice production, of which 3.2 million hectares, equivalent to 10% of the country's total land area, is for growing two or more crops of wet rice each year. In detail, the average cultivation area was 8.285 million ha, and the rough production was 43.339 million tonnes, equivalent to 27.087 million tonnes (62.55% of the rough production). This is the policy that Viet Nam committed to for Vietnamese food security and international relations. The land use law and plan with the law of environmental protection in 2019–2020 have connected to meet this target for rice land up to 2030.

Rice fields in Viet Nam may be repurposed due to natural factors like poor soil or saline intrusion, or for non-agricultural uses, particularly for industrial zones. The conversion of rice land to non-agricultural use or industrial zones is strictly regulated by the law of environmental protection as well as the local management. However, as the economic return of rice is much lower than for other crops, especially when the rice land is threated by climate change (saline intrusion, drought, change in temperature and precipitation), the conversion of the rice land is sometimes not controlled.

The availability of rice straw and husk is determined by the quantity of rice produced. With 3.8 million tonnes of paddy, the rice straw yield is about 3.8 million–4.45 million tonnes, including the rice straw and rice stubble (The ratio of grain to straw is 1 to 1.2). The straw currently is harvested by combined harvesters and balers and yields about 32%–42% of the paddy yield. Due to the low value of rice straw, the stubble left from the field is about 58%–68%. Incorporating fresh stubble can cause organic poison and release methane emissions to the paddy field. Even though there is huge volume of rice straw, it is scattered from the north to the south of Viet Nam (Figure 2.29). In addition, the available straw varies throughout the year based on the crop harvests (spring, winter, or autumn; Figures 31a–31c).

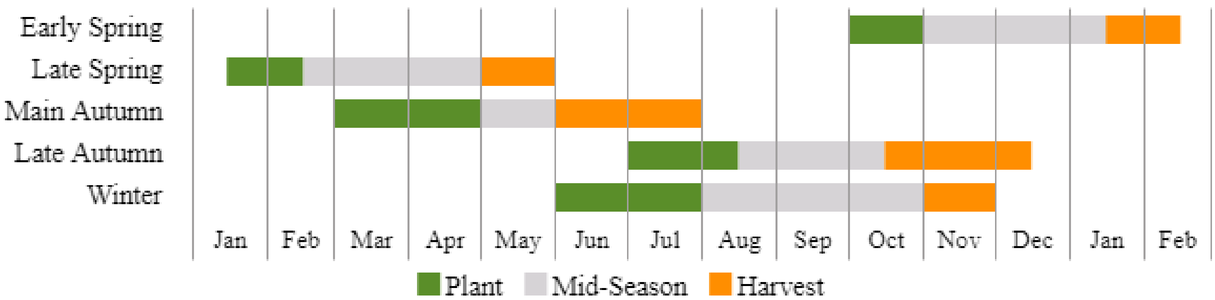
In the case of rice husk, it is collected at the rice millers. Thus, it is less challenging to collect rice husk than rice straw. However, the small scale of rice millers in Viet Nam leads to high costs for the collection of rice husk. The rice husk storage is bulky and easily catches fire. The rice husk is about 20% of the paddy output; thus, the rice husk yield is about 8.7 million tonnes per year in Viet Nam and varies by region and season of production (Wood Pellet Mill, 2024).

Figure 2.29. Rice Production and Distribution in Viet Nam




Source: USDA (2024), cited from Ministry of Agriculture & Rural Development, Viet Nam provincial data 4-year average, 2015–2018.

Figure 2.30. Seasonal Calendar of Rice Production in Viet Nam



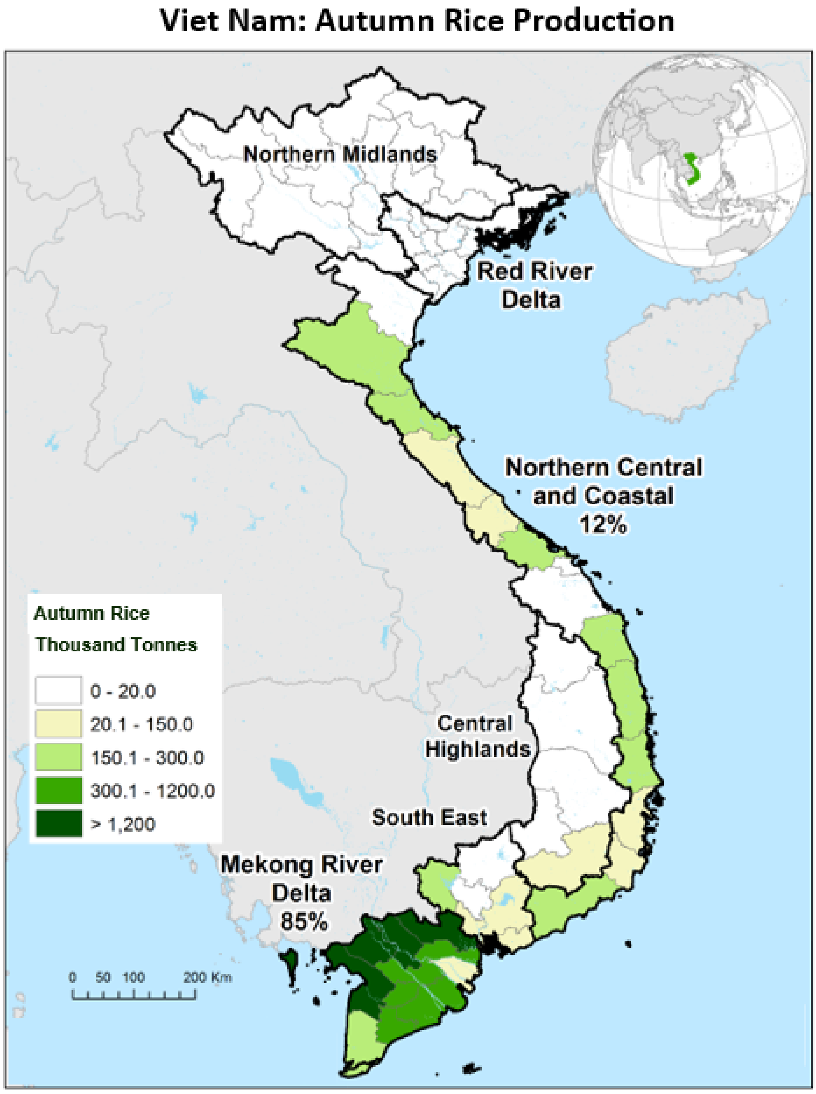

Source: USDA (2024), cited from Ministry of Agriculture & Rural Development, Viet Nam, 2015–2018.

Table 2.18. Rice Production in Viet Nam

| Market Year | Area (1000 Ha) | Milled Production (1000 Tonnes) | Rough Production (1000 Tonnes) | Yield (T/Ha) |
|---|---|---|---|---|
| 2013/2014 | 7,788 | 28,161 | 45,058 | 5.8 |
| 2014/2015 | 7,823 | 28,166 | 45,066 | 5.8 |
| 2015/2016 | 7,704 | 27,584 | 44,134 | 5.7 |
| 2016/2017 | 7,714 | 27,400 | 43,840 | 5.7 |
| 2017/2018 | 7,645 | 27,657 | 44,251 | 5.8 |
| 2018/2019 | 7,540 | 27,344 | 43,750 | 5.8 |
| 2019/2020 | 7,380 | 27,100 | 43,360 | 5.9 |
| 2020/2021 | 7,305 | 27,381 | 43,810 | 6.0 |
| 2021/2022 | 7,100 | 26,670 | 42,672 | 6.0 |
| 2022/2023 | 7,100 | 26,940 | 43,104 | 6.1 |
| 2023/2024 | 7,145 | 27,000 | 43,200 | 6.0 |
| **5-year Average 2018/19 – 2022/23** | **7,285** | **27,087** | **43,339** | **6.0** |
| **Percent Change From 5 year Average (%)** | **-2** | **0** | **59** | **2** |
| **PS&D Online updated on April 11, 2024** | | | | |

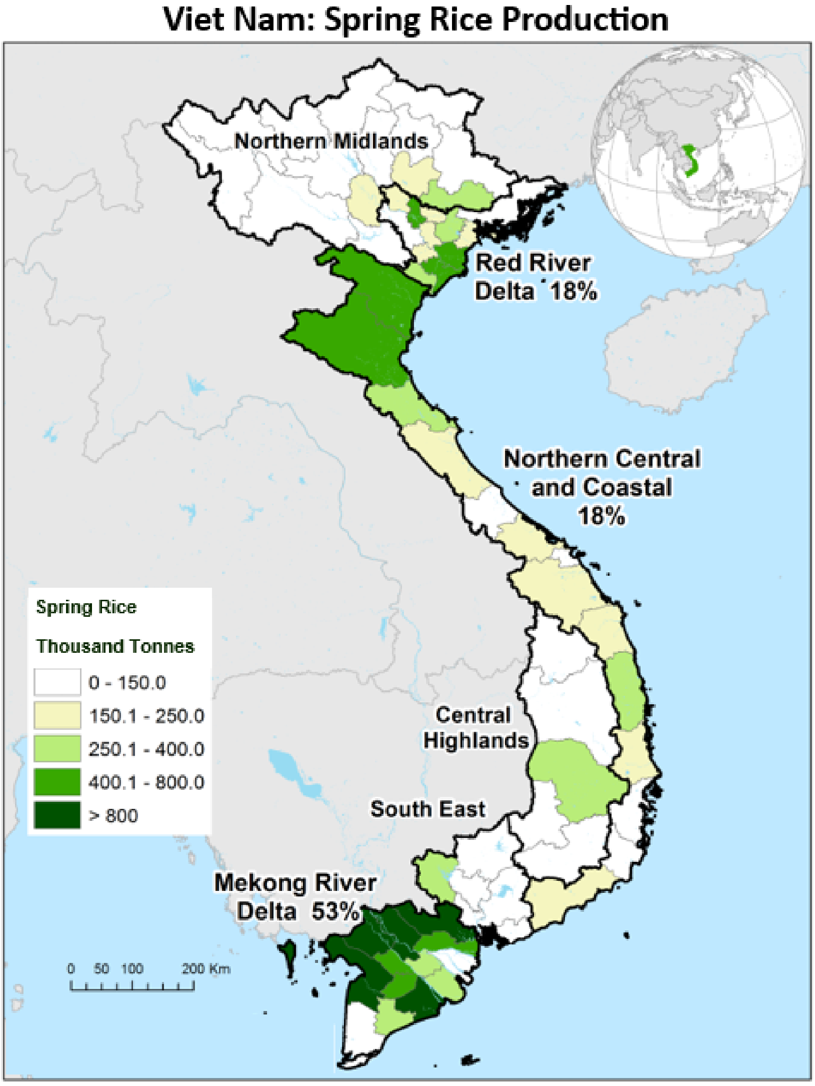
Source: USDA (2024), cited from Ministry of Agriculture & Rural Development, Viet Nam, 2015–2018.

Figure 2.31a. Autumn Rice Production in Viet Nam



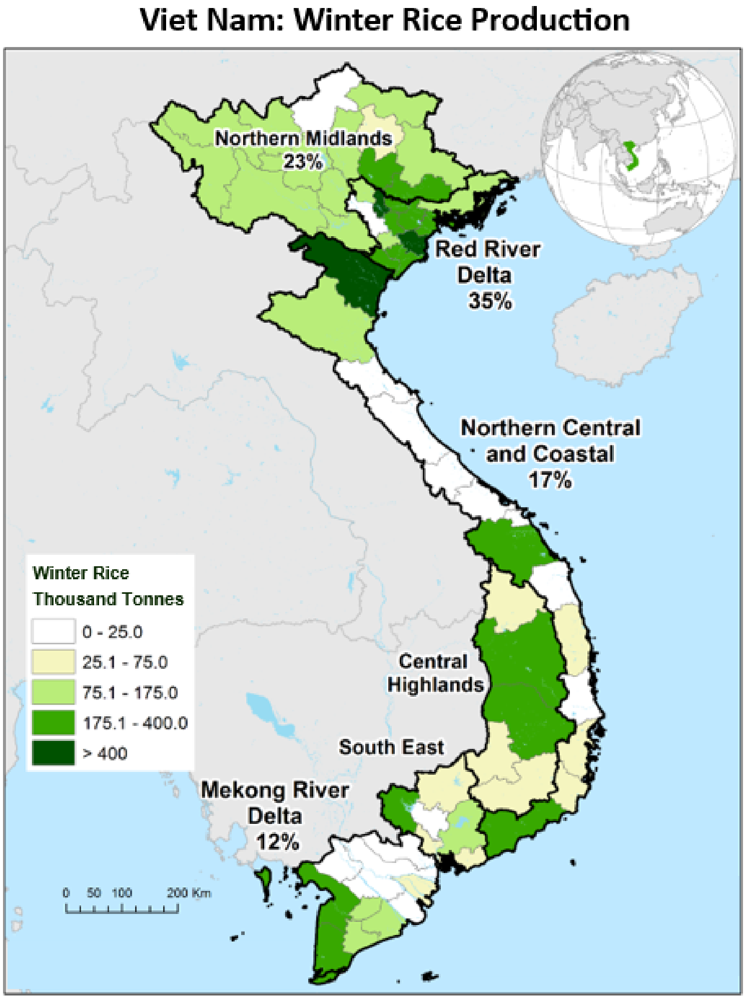

Source: USDA (2024), cited from Ministry of Agriculture & Rural Development, Viet Nam provincial data 4-year average, 2015–2018.

Figure 2.31b. Spring Rice Production in Viet Nam




Source: USDA (2024), cited from Ministry of Agriculture & Rural Development, Viet Nam provincial data 4-year average, 2015–2018.

Figure 2.31c. Winter Rice Production in Viet Nam




Source: USDA (2024), cited from Ministry of Agriculture & Rural Development, Viet Nam provincial data 4-year average, 2015–2018.

# Chapter 3

# Preliminary Evaluation of WEFLC Nexus Indicators in Bioenergy Production in EAS Countries

In this chapter, preliminary evaluation of the indicators related to the WEFLC Nexus in different EAS countries are evaluated. To effectively address the challenges mentioned in Chapter 1, it is imperative to evaluate the Water-Energy-Food-Land-Climate (WEFLC) Nexus indicators in each EAS country. These indicators encompass several critical aspects that are essential for ensuring the sustainability of the available feedstocks for biofuel production. By focusing on the interconnectedness of water, energy, food, land, and climate, the WEFLC Nexus provides a holistic framework for assessing the sustainability of biomass resources. This comprehensive evaluation helps in understanding the multifaceted impacts of biomass production and in developing strategies that promote the efficient and sustainable use of resources.

## 3.1 Thailand

For Thailand, this study focuses on assessing the interlinkages or nexus amongst water, food, energy, land, and climate by examining the sugarcane and cassava crop systems. Akbar et al. (2023) developed the nexus methodology as a problem-solving framework to address complex interdependencies and interactions between water, food, energy, land, and climate systems. This methodology comprises 12 indicators, which fall into three main categories: resource consumption and GHG emissions, economic productivity, and mass productivity. Akbar et al. (2023) normalised all the indicators and estimated the nexus index value by applying the weighted average, which ranges from 0 to 1.

A higher index value signifies sustainable resource use. The nexus approach, assuming a tight interdependence amongst system factors, emphasises that changes in one factor can significantly affect others. It advocates for managing water, food, energy, land, and climate systems sustainably, ensuring present needs are met without jeopardising future generations. This approach employs systems thinking, analytical methods, and decision support to understand and manage the interdependencies and trade-offs between these systems for sustainable development.

### *3.1.1 WEFLC-related nexus equations and indicators*

Twelve indicators were used and normalised to obtain the nexus index score. The indicators are as follows: water consumption ($m^3$/ha), energy consumption (GJ/ha), water mass productivity (t/$m^3$), energy mass productivity (t/GJ), water economic productivity (B/$m^3$), economic productivity of energy (B/GJ), land use (ha), land productivity (t/ha), land economic productivity (t/ha), GHG emissions during farm operations ($CO_2$eq/ha), mass productivity per unit of GHG emissions (kg/$CO_2$eq), and economic productivity per unit of GHG emissions (B/$CO_2$eq). The WELFC Nexus index was applied to the sugarcane and cassava crop systems in the North, Northeastern, and Central regions of Thailand as a case study. The system boundary of the assessment was taken from cradle-to-gate, which starts from cultivation until the farm gate. In the evaluation of the nexus, all indicators were given equal importance.

a) *Water consumption (WP)*

The water consumption indicator ($W_C$) is the water use per hectare of the crop in a season. The water use data for the sugarcane and cassava crops was obtained from Kongboon and Sampattagul (2012).

b) *Energy consumption (EC)*

There are two types of energy usage in farms: direct energy use and indirect energy use. Energy consumed in the form of fuel or electricity during farm operations is considered direct energy consumption. The energy used during the transportation of farm inputs, outputs, and the production of fertilisers and other chemicals is taken as indirect energy consumption. Energy consumption (*E*) is the sum of the direct and indirect energy used in the different farm operations, as shown in Equation 1.

$$E_C = (q_h h + q_m m + q_d d + q_f f + q_p p + q_s s + q_w w) \qquad (1)$$

Where: $q_h$, $q_m$, $q_d$, $q_f$, $q_p$, $q_s$, and $q_w$ are, respectively, the energy equivalents of human labour (J/h), machinery (J/h), diesel oil (J/L), fertiliser (J/kg), pesticides (J/kg), seeds (J/kg), and irrigated water (J/$m^3$) inputs in crop production. Moreover, *h*, *m*, *d*, *f*, *p*, *s*, and *w* are, respectively, human labour (h/ha), machinery (h/ha), diesel fuel (L/ha), electricity (kWh/ha), fertiliser (kg/ha), pesticides (kg/ha), seeds (kg/ha), irrigated water ($m^3$/ha) inputs. The energy equivalents are taken from Zahedi et al. (2015). Energy use was estimated using the fuel, fertiliser, other chemicals, and irrigation water data obtained from Yuttitham et al. (2011) and Silalertruksa and Gheewala (2018) for sugarcane. Additionally, the energy consumption for cassava crop production was estimated based on fuel chemical usage per tonne of production in Thailand, as reported by the Carbon Cloud web database and Arthey et al. (2018).

*c) Water mass productivity ($W_{MP}$)*

Water mass productivity ($W_{MP}$) ($m^3$/ha) indicates the production of a crop in terms of mass per unit of water, as shown in Equation 2. *Y* is the yield of a crop (t/ha) and *W* is the water consumption ($m^3$/ha) of a crop. The average yields (t/ha) for sugarcane and cassava were obtained from Kongboon and Sampattagul (2012).

$$W_{MP} = \frac{Y}{W} \quad (2)$$

*d) Energy mass productivity ($E_{MP}$)*

Energy mass productivity ($E_{MP}$) (J/ha) refers to the production of a crop in terms of mass per unit of energy, as shown in Equation 3. *Y* is the yield of a crop (t/ha) and *E* is the energy consumption (J/ha) of a crop.

$$E_{MP} = \frac{Y}{E} \quad (3)$$

*e) Water economic productivity ($W_{EP}$)*

Water economic productivity ($W_{EP}$) is the ratio of return minus the cost of inputs in terms of monetary values per hectare of a crop to the volume of water consumed per hectare to grow a crop, as shown in Equation 4. *N* is the monetary return per ha from the crop (B/ha), *C* is the cost of inputs used (B/ha), and *W* is the water used ($m^3$/ha) for cultivating a crop. The average net profit from sugarcane cultivation in Thailand is B880 per tonne, as obtained from Sansong (2020). Cassava's selling price is B3,050 per tonne, according to The One Tree Farm (2022), with production costs amounting to B1,877 per tonne, as detailed by the Office of Agricultural Economics (2022).

$$W_{EP=} \frac{N-C}{W} \quad (4)$$

*f) Energy economic productivity (EEP)*

Energy economic productivity ($E_{EP}$) is the ratio of return minus the cost of inputs in terms of the monetary value per hectare of a crop to the energy consumed per hectare to grow a crop, as shown in Equation 5. *N* is the monetary return per ha from a crop (B/ha), *C* is the cost of inputs used (B/ha), and *E* is the energy used (J/ha) of a crop.

$$E_{EP=} \frac{N-C}{E} \quad (5)$$

*g) Land use (LU)*

Land use ($L_U$) is the area under cultivation for that specific crop.

*h) Land productivity (LP)*

Land productivity ($L_P$) is a measure of agricultural outputs (in terms of the mass of a crop) obtained on a given area of land. It is the ratio of farm volume output ($F_M$) in tonnes to the farm planted area ($F_A$) in hectares, as shown in Equation 6. The land used for sugarcane and cassava crops was obtained from Kongboon and Sampattagul (2012).

$$L_P = \frac{F_M}{F_A} \qquad (6)$$

*i) Land economic productivity (LEP)*

Land economic productivity ($L_{EP}$) is the ratio of return minus the cost of inputs in terms of the monetary value of a crop per unit of land. *N* is the monetary return per ha from a crop (B/ha), *C* is the cost of inputs used (B/ha), and $F_A$ is the farm planted area in hectares, as shown in Equation 7.

$$L_E = \frac{N - C}{F_A} \qquad (7)$$

*j) GHG emissions during farm operations*

The GHG emissions in crop production are from the burning of fossil fuels in farm machinery, emissions from the crop fields, and the application of fertilisers in the fields. The GHG emissions were estimated by multiplying the activity data (fossil fuel consumption, electricity use, emissions from the sugarcane and cassava fields, and the application of fertiliser) and emission factors. Total GHG emissions due to the farm operations in terms of $CO_2$eq/ha were estimated by taking the product of activity data, the emission factor, and global warming potential (GWP), as shown in Equation 8.

$$GHG = \{(d \times EF_d) + (e \times EF_e) + (fa \times EF_a)\} \times GWP \qquad (8)$$

Where the diesel use, electricity use, and fertiliser application are expressed by *d*, *e*, and *fa*, respectively. Furthermore, the emission factors of diesel, electricity use, and fertiliser application are represented as $EF_d$, $EF_e$, and $E_{fa}$, respectively. The energy consumption associated with sugarcane cultivation in Thailand, along with the GHG emissions associated with sugarcane cultivation in Thailand, were derived from the literature (Silalertruksa and Gheewala, 2018; Yuttitham et al., 2011). The GHG emissions due to cassava crop production were estimated using the fertiliser application data, fuel, and other agrochemical data obtained from the Carbon Cloud web database, Sampattagul (2012), and Arthey et al. (2018).

*k) Mass productivity per unit of GHG emissions*

Mass productivity per unit of GHG emissions is the ratio of the amount of crop produced in terms of mass for every unit of GHG generated in the farm operations, as shown in Equation 9. *Y* is the yield of the crop (t/ha), and GHG is the crop's emissions during the farm operations ($CO_2$eq/ha).

$$GHG_{M} = \frac{Y}{GHG} \qquad (9)$$

*l) Economic productivity per unit of GHG emissions*

Economic productivity per unit of GHG emissions is a measure of the agricultural outputs (volume valued at constant prices) obtained for every unit of GHG generated in the farm operations, as shown in Equation 9. *N* is the monetary return per ha from a crop (B/ha), *C* is the cost of inputs used (B/ha), and GHG is the crop's emissions during the farm operations ($CO_2$eq/ha).

$$GHG_{E=} \frac{N - C}{GHG} \tag{10}$$

*m) WEFLC Nexus index*

This research uses the nexus index to express the interlinkages amongst water–energy–food–land–climate in sugarcane and cassava production, as shown in Equation 11. It indicates sustainable consumption and production to decision-makers. Different SDGs can be achieved by adopting an integrated policy for the sustainable consumption of resources and sustainable production of food and minimising GHG emissions to mitigate climate change.

$$\text{Nexus index} = \frac{\sum_{i=1}^{n} w_i X_i}{\sum_{i=1}^{n} w_i} \tag{11}$$

Where *w* is the weight of the indicator, *X* is the normalised value of an indicator, and *i* represents the different indicators, such as water consumption, energy consumption, etc. In this study, it was assumed that each indicator is equally important, which is why an equal weight (equal to 1 for all indicators) was assigned to each indicator.

The 12 indicators, as mentioned above, were normalised by applying the minimum-maximum normalisation technique, as shown in Equations 12 and 13. Equation 12 is used when the highest value of an indicator is the most preferred, and Equation 13 is used when the lowest value is the most preferred. As the land, water, and energy productivity values should preferably be the maximum values, these indicators should be normalised by using Equation 12. Moreover, as energy and water consumption should be the lowest in crop production, these indicators should be normalised by using Equation 13.

$$X_i = \frac{x_i - Min\ (x_i)}{Max\ (x_i) - Min\ (x_i)} \tag{12}$$

$$X_i = \frac{Max\ (x_i) - x_i}{Max\ (x_i) - Min\ (x_i)} \tag{13}$$

The minimum (*Min (x)*) and maximum (*Max (x)*) values were taken as the lowest and highest values from the dataset against each indicator. *x* represents the data point value and *i* represents the different indicators, such as water consumption, energy consumption, etc. *X* represents the normalised value of an indicator.

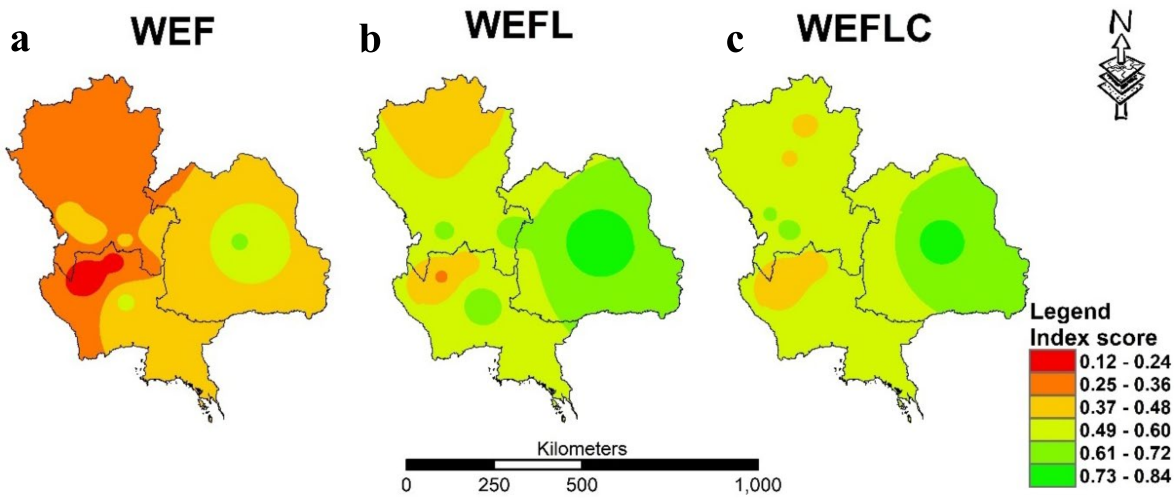
According to the WEF Nexus index used by El-Gafy (2017), as shown in Figure 3.1(a), the Northeastern region of Thailand showed a higher nexus score, whilst the Central region showed the lowest score. A higher WEF Nexus index value represents relatively more sustainable consumption of water and energy resources and more sustainable production of food. Thus, based on the El-Gafy (2017) methodology, the Northeastern region of Thailand is more suitable for sugarcane cultivation compared to the rest of the area. The El-Gafy (2017) approach was also applied to cassava cultivation in the North, Northeast, and Central regions of Thailand. It was found that the Northeastern region is more suitable for cassava cultivation compared to the other regions.

According to the WEFL Nexus index developed by Gazal et al. (2022), the western districts showed better index scores compared to the El-Gafy (2017) WEF Nexus approach, especially in the Central region. The spatial variation in the WEFL Nexus assessment is shown in Figure 3.1(b).

Following the methodology of Akbar et al. (2023), which considers climate along with water, food, energy, and land for the nexus assessment, it was observed that considering the climate factor, the sugarcane and cassava cultivation level of sustainability has increased, and the Northeast region appears as the most suitable region for both sugarcane and cassava crops.

When considering all nexus methods (WEF, WEFL, and WEFLC), the Northeast region consistently appears to be the most sustainable for sugarcane production across all nexus dimensions. The North and Central regions show varying levels of sustainability, with the North generally having less sustainable areas, especially with the WEF Nexus approach. This could imply that the North and Central regions might have better practices or resilience in place when it comes to land use and climate considerations, despite facing more challenges in the WEF Nexus, as shown in Figure 3.1.

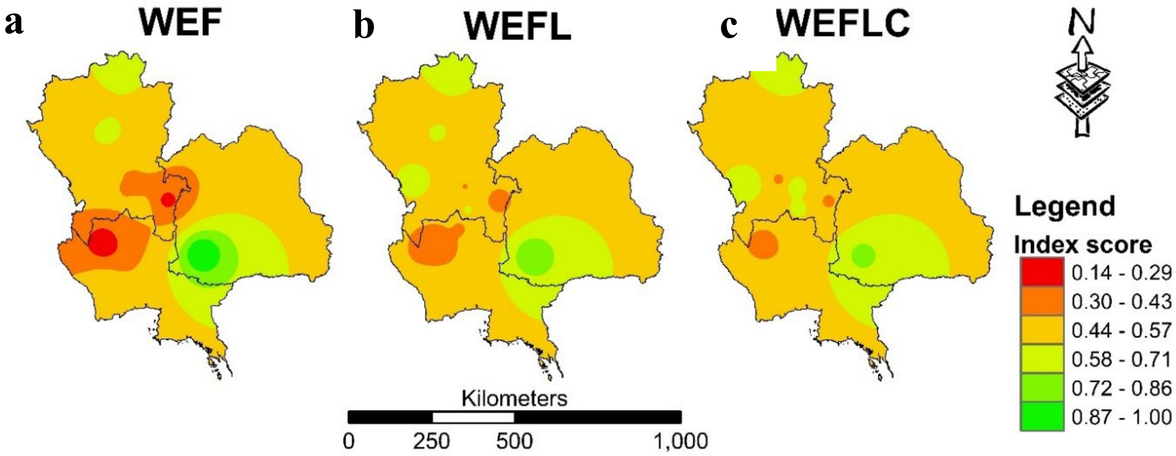
Figure 3.1. Spatial Variation in Nexus Scores for Sugarcane Crops




Source: Authors.

Considering all three nexus methodologies, the Northeast region consistently exhibits the highest levels of sustainability in cassava production. The North, whilst showing less sustainable areas in the WEF Nexus, displays a positive trend towards sustainability when land and climate are factored into the assessment. The Central region generally falls in the middle, with room for improvement in sustainability practices, especially in water, energy, and food aspects. Figure 3.2 serves as valuable information for policy makers and stakeholders, providing a visual and quantitative way to understand the complexities and interdependencies of sustainable cassava production and to target interventions where they are most needed.

Figure 3.2. Spatial Variation in Nexus Scores for Cassava Crops




Source: Authors.

### *3.1.2 Resources consumption or use*

Water, energy, land, chemicals, and seeds are the main inputs for sugarcane and cassava crop production. The water consumption to produce sugarcane and cassava crops varied from 10,309 $m^3$ to 12,689 $m^3$ and from 7,510 $m^3$ to 9,894 $m^3$ per ha, respectively. The average water consumption for the sugarcane and cassava crops was 11,363 $m^3$ and 8,613 $m^3$ per ha, respectively. The average energy consumption for the sugarcane and cassava crops in the North, Northeastern, and Central regions was 48.5 GJ and 40.9 GJ per ha, respectively. The total energy consumption was the sum of energies from human labour, machinery hours, diesel used, fertilisers, herbicides, pesticides, seeds, and water. Furthermore, chemicals and seeds are also used in sugarcane and cassava crop production.

For cassava production, nitrogen fertiliser of 36.3 kg/ha, phosphorus fertiliser of 14.9 kg/ha, potassium fertiliser of 45.1 kg/ha, paraquat of 2.1 kg/ha, glyphosate of 3.9 kg/ha, diesel of 35.6 kg/ha, and other chemicals of 2.1 kg/ha were used from

Usubharatana and Phungrassami (2015). Fertiliser used for sugarcane and cassava in the Northern region of Thailand was obtained from Kongboon and Sampattagul (2012).

### *3.1.3 Resources productivity*

There are three main types of resource productivity: water, energy, and land. Water productivity includes water mass productivity and water economic productivity, whilst energy productivity encompasses energy mass productivity and energy economic productivity. The mean weights of the indicators for (a) sugarcane and (b) cassava crops are shown in Figure 3.3.

*Water mass productivity (WMP)*

Water mass productivity (kg/$m^3$) is the measure of crop production in terms of mass (kg) per unit volume of water consumed ($m^3$). The water mass productivity for sugarcane production varied from 4.6 kg/$m^3$ to 8.0 kg/$m^3$, and for cassava, it varied from 2.1 kg/$m^3$ to 2.9 kg/$m^3$. The average water mass productivity for sugarcane and cassava was 6.0 kg/$m^3$ and 2.4 kg/$m^3$, respectively.

*Water economic productivity (WEP)*

Water economic productivity (B/$m^3$) is the measure of economic output (B) per unit volume of water consumed ($m^3$). The water economic productivity for sugarcane and cassava production varied from B4.0/$m^3$ to B7.1/$m^3$ for sugarcane and from B2.5/$m^3$ to B3.3 /$m^3$ for cassava, and the average water economic productivity was B5.3/$m^3$ and B2.8/$m^3$ for sugarcane and cassava, respectively.

*Energy mass productivity (EMP)*

Energy mass productivity (kg/MJ) is the measure of crop production in terms of mass (kg) per unit of energy consumed (MJ). The average energy mass productivity for sugarcane and cassava was 1.6 kg/MJ and 0.7 kg/MJ, respectively.

*Energy economic productivity (EEP)*

Energy economic productivity (B/MJ) is the measure of economic output (B) per unit of energy consumed (MJ). The average energy economic productivity for sugarcane and cassava was B1.4/MJ and B0.8/MJ, respectively.

*Land mass productivity (LMP)*

Land mass productivity (kg/ha) is the measure of crop production in terms of mass (kg) per unit land use (ha). It was found that the average land mass productivity was 67.9 tonnes/ha and 20.8 tonnes/ha for sugarcane and cassava, respectively.

*Land economic productivity (LEP)*

Land economic productivity (B/ha) is the measure of crop production in terms of monetary value (B) per unit land use (ha). It was found that the land economic productivity average value was B67,278/ha and B24,291/ha for sugarcane and cassava, respectively.

### *3.1.4 Climate change*

The GHG emissions during farm operations were used as a proxy for climate change. GHG emissions were estimated by adding the emissions from different farm operations viz. emissions from land preparation, crop harvesting, fertiliser applications, and seeds, etc. The average GHG emissions from the sugarcane and cassava crops were estimated at 2,272 kg $CO_2$eq/ha and 2,128 kg $CO_2$eq/ha for sugarcane and cassava, respectively.

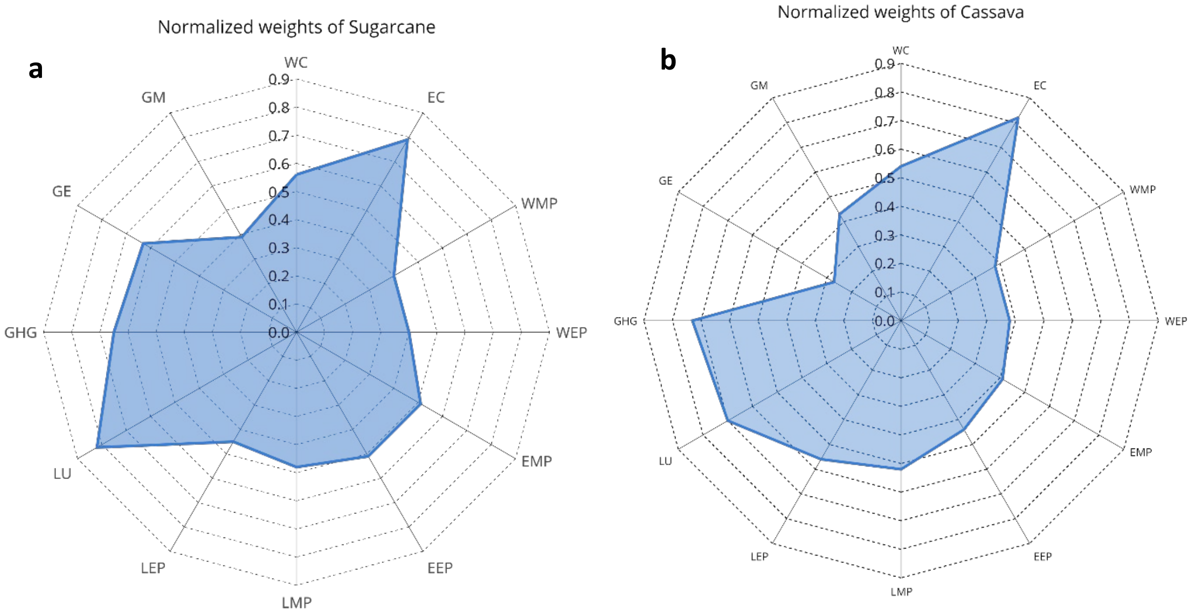
*GHG emissions over mass productivity*

GHG emissions over mass productivity (kg/kg $CO_2$eq) is a measure of crop production in terms of mass (kg) per unit of GHG emission (kg $CO_2$eq). The average GHG emissions over mass productivity for the sugarcane and cassava crops were estimated at 29.3 kg/kg $CO_2$eq and 9.7 kg/kg $CO_2$eq, respectively.

*GHG emissions over economic productivity*

GHG emissions over economic productivity (B/kg $CO_2$eq) is a measure of crop production in terms of monetary numbers (B) per unit of GHG emission (kg $CO_2$eq). The average GHG emissions over economic productivity during the sugarcane and cassava crops were estimated at B49,753/kg$CO_2$eq and B24,289/kg$CO_2$eq, respectively.

Figure 3.3. Mean Normalised Values of Each Indicator for Sugarcane and Cassava

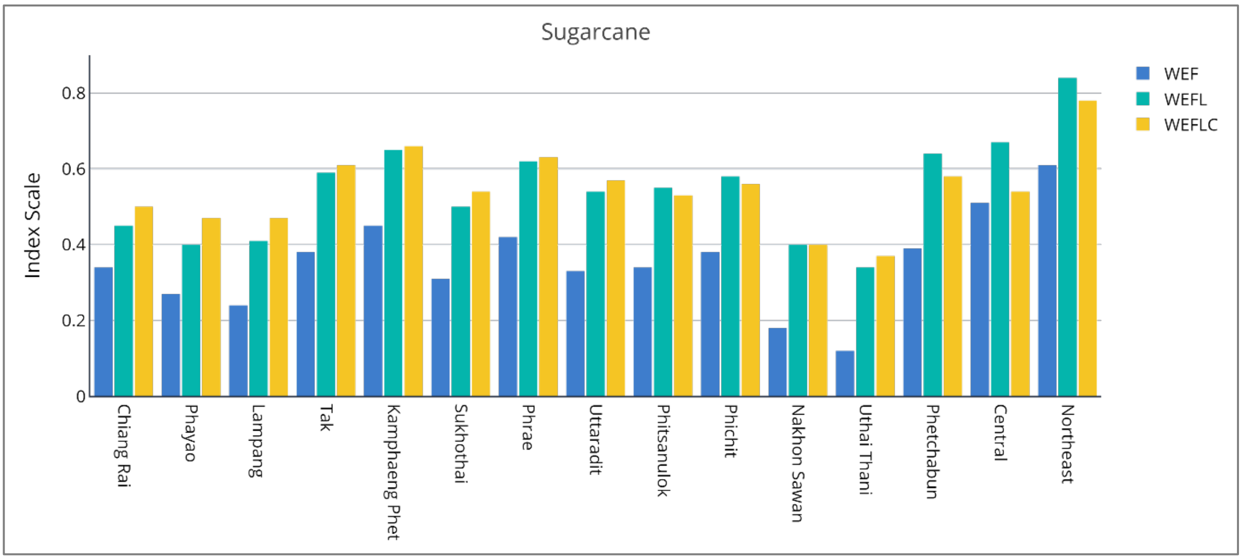



Note: The figure shows water use ($W_C$), energy use ($E_C$), land use for wheat crop ($L_U$), GHG emissions per ha (GHG), water mass productivity ($W_{MP}$), energy mass productivity ($E_{MP}$), land mass productivity ($L_{MP}$), mass of output per unit of GHG emissions ($G_M$), water economic productivity ($W_{EP}$), energy economic productivity ($E_{EP}$), land economic productivity ($L_{EP}$), and economic output per unit of GHG emissions ($G_E$).
Source: Authors.

### *3.1.5 WEFLC Nexus index*

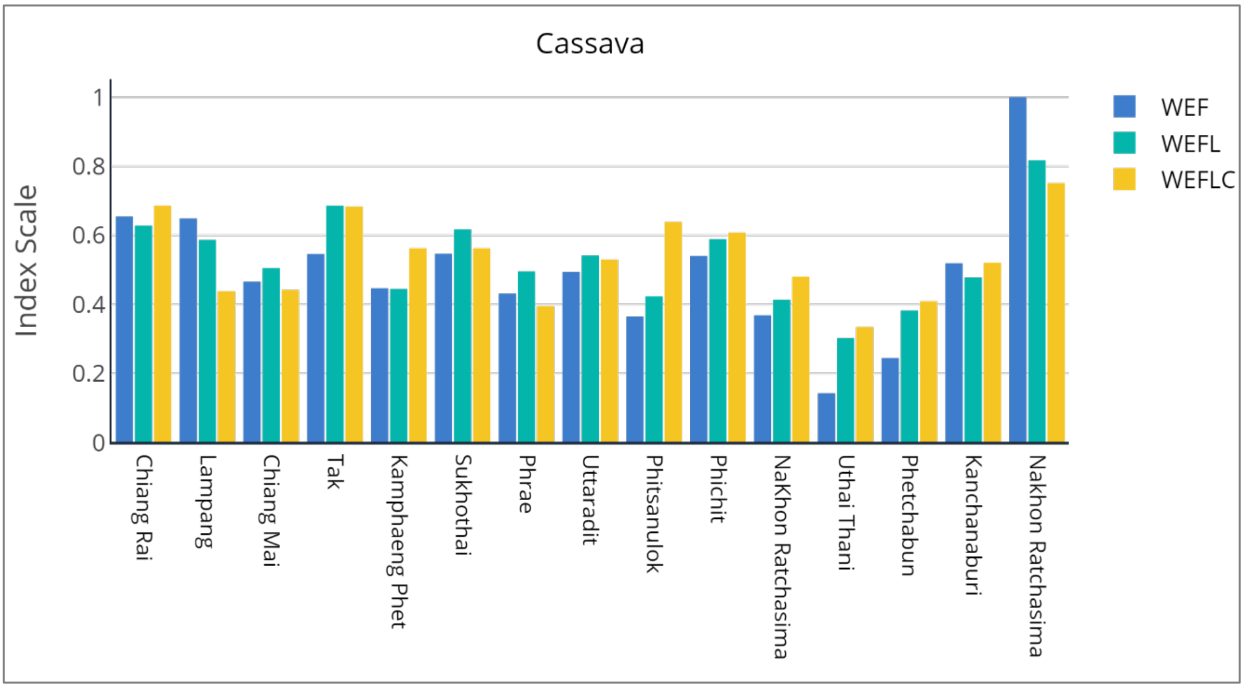
The WEFLC Nexus index was formulated to solve the problems related to resource efficiency in an integrated way, not in an isolated manner to get the maximum yield. This nexus index gives quantitative insight into the use of water, energy, land, and other inputs for food production. The average value of the WEF Nexus index was estimated at 0.35, whilst the WEFL index showed a 0.55 value. Moreover, the WEFLC Nexus index scored 0.55 for sugarcane. Similarly, the value of the WEF Nexus index was estimated at 0.49, whilst the WEFL index showed a 0.53 value. Moreover, the WEFLC Nexus index scored 0.54 for cassava. The index value ranges from 0 to 1, where 0 represents the worst case, and 1 represents the best case. The nexus score of individual stations with respect to the three different nexus approaches is shown in Figure 3.4 and Figure 3.5 for sugarcane and cassava crops, respectively, in the North, Northeast, and Central regions of Thailand. Details of the nexus scores for each method for cassava and sugarcane crops in different provinces of Thailand are given in Table 3.1.

Figure 3.4. Nexus Scores for Sugarcane Crops in the North, Northeast, and Central Regions of Thailand




Source: Authors.

Figure 3.5. Nexus Scores for Cassava Crops in the North, Northeast, and Central Regions of Thailand




Source: Authors.

Table 3.1. Nexus Scores for Cassava and Sugarcane Crops in Various Provinces of Thailand

| Region | Province | Sugarcane | | | Cassava | | |
|---|---|---|---|---|---|---|---|
| | | WEF | WEFL | WEFLC | WEF | WEFL | WEFLC |
| Northern Region | Chiang Rai | 0.34 | 0.45 | 0.50 | 0.66 | 0.63 | 0.69 |
| | Phayao | 0.27 | 0.40 | 0.47 | - | - | - |
| | Lampang | 0.24 | 0.41 | 0.47 | 0.65 | 0.59 | 0.44 |
| | Chiang Mai | - | - | - | 0.47 | 0.51 | 0.44 |
| | Tak | 0.38 | 0.59 | 0.61 | 0.55 | 0.69 | 0.68 |
| | Kamphaeng Phet | 0.45 | 0.65 | 0.66 | 0.45 | 0.45 | 0.56 |
| | Sukhothai | 0.31 | 0.50 | 0.54 | 0.55 | 0.62 | 0.56 |
| | Phrae | 0.42 | 0.62 | 0.63 | 0.43 | 0.50 | 0.40 |
| | Uttaradit | 0.33 | 0.54 | 0.57 | 0.49 | 0.54 | 0.53 |
| | Phitsanulok | 0.34 | 0.55 | 0.53 | 0.37 | 0.42 | 0.64 |
| | Phichit | 0.38 | 0.58 | 0.56 | 0.54 | 0.59 | 0.61 |
| Central Region | Nakhon Sawan | 0.18 | 0.40 | 0.40 | 0.37 | 0.41 | 0.48 |
| | Uthai Thani | 0.12 | 0.34 | 0.37 | 0.14 | 0.30 | 0.33 |
| | Phetchabun | 0.39 | 0.64 | 0.58 | 0.24 | 0.38 | 0.41 |
| | Kanchanaburi | - | - | - | 0.52 | 0.48 | 0.52 |
| Northeastern Region | Nakhon Ratchasima | - | - | - | 1.00 | 0.82 | 0.75 |
| Areas of the Central Region | | 0.51 | 0.67 | 0.54 | - | - | - |
| Areas of the Northeast Region | | 0.61 | 0.84 | 0.78 | - | - | - |

Source: Authors' data compilation.

The North, Northeastern, and Central regions of Thailand were considered for the sugarcane and cassava nexus in this work. In the case of sugarcane production, the Northeastern region stands out as the most sustainable area for sugarcane production in Thailand, showing robust performance across all nexus approaches, including the WEF, WEFL, and WEFLC. In contrast, the Northern and Central regions exhibit mixed sustainability results, with the North particularly lagging in the WEF Nexus. However, both these regions may exhibit stronger practices or adaptability regarding land and climate factors, which could counterbalance their lower WEF Nexus scores. This suggests a need for targeted improvements in water, energy, and food-related sustainability in these areas.

In the case of cassava, it was observed that across the WEF, WEFL, and WEFLC Nexus assessments, the Northeastern region stands out for its relatively sustainable cassava production practices. The North showed higher nexus scores, especially when land and climate factors were considered. The Central region's sustainability is intermediate, with hotspot areas (relatively unsustainable cultivation), particularly in managing resources such as water and energy.

## 3.2 Indonesia

The Food and Agriculture Organization (FAO) and Climate Action Tracker (CAT) programmes can be used to develop indicators that reflect the balance between the three pillars of water, food, and energy (WEF) as an effort to increase bioenergy in Indonesia. The balance of the WEF Nexus is very important to achieve sustainable development in Indonesia. Water, food, and energy are vital interrelated resources and must be managed sustainably. Unbalanced management can cause problems such as water shortages, food crises, and energy crises.

### *3.2.1 WEF Nexus ranking of difierent crops in Indonesia*

Based on wefnexusindex.org, the WEF Nexus Index is a composite indicator that aggregates 21 globally available indicators. The WEF Nexus Index value for Indonesian energy is 65, placing the nation in the 33rd position amongst the countries assessed. Indonesia has a value of 76 for the water pillar, 61.1 for the energy pillar, and 57.7 for the food pillar. Biomass use also has an index value based on the three pillars, as follows.

*A. Palm oil biomass*

According to the WEF Nexus Index 2023, Indonesia scored 62.2 for biodiesel from palm biomass, ranking 24th out of 132 countries. Indonesia has an index value for palm oil as a biofuel of 58.1 (30th world ranking), a score of 68.7 (17th world ranking) for the energy pillar, and a score of 59.4 for food (23rd world ranking).

*B. Sugarcane biomass*

Based on WEF Nexus Index data for 2023, Indonesia has a value of 52.2 for bioethanol from sugarcane biomass. This value places Indonesia in 43rd place out of the 128 countries measured. The WEF Nexus Index pillar values for bioethanol from sugarcane biomass in Indonesia are 52.8 for water (ranked 40th), 49.8 for energy (ranked 52nd), and 54.2 for food (ranked 33rd).

*C. Rice biomass*

Based on 2023 WEF Nexus Index data, Indonesia has a score of 48.2 and ranks 61st for biofuels out of the 128 countries measured. The WEF Nexus Index pillar values for biofuel from rice biomass in Indonesia are 52.1 for water (ranked 43rd), 48.3 for energy (ranked 62nd), and 44.7 for food (ranked 76$_{th}$).

Bioethanol from rice/rice husk biomass in Indonesia has a lower value and ranking than sugar cane and palm oil biomass. This shows that bioethanol from rice biomass/rice husks has a smaller impact on Indonesia's water, energy, and food security. Each type of biomass has an index value based on the three pillars, which includes access and availability criteria.

Table 3.2. WEF Nexus Indicators Based on FAO and Climate Action Tracker Indicators

| Pillar | Coverage | Palm Oil Biomass | Sugarcane Biomass | Rice Biomass | Source |
|---|---|---|---|---|---|
| | Access | | | | |
| | Percentage of people using at least basic drinking water services (%) for agricultural needs and human consumption | 92 | 89 | 77.8 | Ministry of Public Works and Public Housing (PUPR) (Strategic Plan of the Ministry of Public Works and Public Housing 2020-2024) |
| | Percentage of people using at least basic sanitation services (%) | 74 | 74.5 | 75.4 | |
| Water | Degree of integrated water resources management implementation (1–100) | 67 | 56 | 60 | |
| | Availability | | | | |
| | Annual freshwater withdrawals, total (% of internal resources) | 48 | 40 | 43.3 | Ministry of Energy and Mineral Resources; BPS (2021b); Environmental Statistics 2022; World Resources Institute (WRI); World Economic Forum (2023); |
| | Renewable internal freshwater resources per capita ($m^3$) | 4,840 | 4,136 | 4,404 | |
| | Environmental flow requirements ($10^6 m^3$/annum) | 144 | 104 | 128 | |

| | | | | | |
|---|---|---|---|---|---|
| | Average precipitation by depth (mm/annum) | 2,334 | 2,345 | 2,350 | The Nexus Index |
| Energy | Access | | | | |
| | Access to electricity (% of population) | 99.8 | 99.4 | 99.3 | Ministry of Energy and Mineral Resources (2023); BPS Republic of Indonesia (2023); World Economic Forum (2023); The Nexus Index, PLN (2023); World bank (2023); Climate Action Tracker (CAT); Global Forest Watch |
| | Renewable energy consumption (% of total final energy consumption) | 12.2 | 11.2 | 11.2 | |
| | Renewable electricity output (% of total electricity output) | 23 | 23.4 | 23.4 | |
| | $CO_2$ emissions (tonnes per capita) | 4.8 | 1.6 | 1.74 | |
| | Availability | | | | |
| | Electric power consumption (kWh/capita) | 1,100 | 1,117 | 1,146 | PLN (2023); Ministry of Energy and Mineral Resources (2023) |
| | Energy imports, net (% of energy use) | 8.2 | 15.4 | 8.5 | |
| Food | Access | | | | |
| | Prevalence of undernourishment (%) | 2.7 | 7.2 | 7.2 | World Food Program - Hunger Map 2023<br>Central Statistics Agency (BPS) - People's |
| | Percentage of children under 5 years of age affected by wasting (%) | 7 | 7.4 | 7.4 | |
| | Percentage of children under 5 years of age who are stunted (%) | 23.3 | 27.2 | 24.4 | |

| | | | | | |
|---|---|---|---|---|---|
| | Prevalence of obesity in the adult population (18 years and older) | 20.8 | 21.8 | 21.8 | Welfare Statistics 2023<br>Ministry of Agriculture - Rice Production Data 2023<br>International Food Policy Research Institute - Global Food Policy Report 2023 |
| | **Availability** | | | | |
| | Average protein supply (grammes/capita/day) | 57.2 | 62.4 | 64.4 | World Food Program - Hunger Map 2023<br>Central Statistics Agency (BPS) - People's Welfare Statistics 2023.<br>Ministry of Agriculture - Rice Production Data 2023<br>International Food Policy Research Institute - Global Food Policy Report 2023 |
| | Cereal yield (tonnes/hectare) | 2.81 | 3.64 | 7.28 | |
| | Average dietary energy supply adequacy (%) | 25 | 18 | 7 | |
| | Average value of food production (Rp/capita) | 0.812 | 0.016 | 0.344 | |

### *3.2.2. WEFLC Nexus index: Case studies of Sumatera Island, Indonesia*

The nexus index score was calculated using 12 indicators. The value was then normalised to obtain the nexus index score. The indicators are as follows: water use ($m^3$/ha), energy use (GJ/ha), land use (ha), GHG emissions during farm operations ($CO_2$ eq/ha), water mass productivity (t/$m^3$), energy mass productivity (t/GJ), land mass productivity (t/ha), mass output per unit of GHG emissions (kg/kg $CO_2$ eq), water economic productivity (US$/$m^3$), energy economic productivity (US$/GJ), land economic productivity (US$/ha), and economic output per unit of GHG emission (US$/kg $CO_2$ eq). The WEFLC Nexus index was applied to the paddy, palm oil, and sugarcane crop systems in Sumatera Island, Indonesia.

A. *WEFLC Nexus index for the palm oil crop system*
   a) Water use for palm oil crop production varied from 14,879 $m^3$/ha to 17,845 $m^3$/ha. The average water use for palm oil crops was 16,180 $m^3$/ha. Water use was lowest in Lampung province, and the highest water use was found in West Sumatera.
   b) Energy use during the entire palm oil crop season in Sumatera Island varied from 58.91 GJ/ha to 62.98 GJ/ha. The average energy use for palm oil crops was 60.92 GJ/ha. Energy use in Riau province was found to be lowest, and the highest energy use was found in Riau Islands province. The total energy use is the sum of energies from electricity, human labour, machinery hours, diesel used, fertilisers, herbicides, pesticides, seeds, and water.
   c) Land use is a crucial factor in palm oil crop production. The lowest and highest areas under cultivation for the palm oil crop were recorded for Riau Islands province and Riau province, respectively, with 7.3 kilohectares and 2,858.2 kilohectares of land dedicated to palm oil cultivation.
   d) The GHG emissions during farm operations were used as a proxy for climate change. The GHG emissions were estimated by adding the emissions from different farm operations, groundwater pumping, soil separation, crop harvesting, fertiliser applications, fertiliser production, and the transportation of chemical and seeds, etc. The GHG emissions varied from 10,934.2 kg $CO_2$ eq/ha to 12,439.8 kg $CO_2$ eq/ha. The average GHG emissions from the palm oil crop were estimated at 11,745.10 kg $CO_2$ eq/ha.

Mainly, three types of resource productivities are used in this study: mass productivity, economic productivity, and land productivity. However, mass productivity is further divided into water mass productivity, energy mass productivity, land mass productivity, and per unit of GHG emissions for mass productivity. Similarly, economic productivity is further split into water economic productivity, energy economic productivity, land economic productivity, and per unit of GHG emissions for economic productivity. Further details are discussed below.

a) Water mass productivity (kg/m$^3$) is the measure of crop production in terms of mass (kg) per unit volume of water consumed (m$^3$). The water mass productivity for palm production varied from 0.13 kg/m$^3$ to 0.28 kg/m$^3$, and the average water mass productivity was 0.18 kg/m$^3$. Water mass productivity was the highest in the North Sumatera province but was lowest in the Aceh province. The spatial variation in the water mass productivity can be due to the different climatic zones, soil fertility, topography, availability of surface water, and groundwater.
b) Energy mass productivity (kg/MJ) is the measure of crop production in terms of mass (kg) per unit of energy consumed (MJ). The energy mass productivity for palm oil production varied from 0.03 kg/MJ to 0.06 kg/MJ, and the average energy mass productivity was 0.05 kg/MJ. Energy mass productivity was lowest in the Aceh and Riau Islands provinces, whilst it was highest in the North Sumatera province.
c) Land mass productivity (kg/ha) is the measure of crop production in terms of mass (kg) per unit of land use (ha). Land mass productivity was estimated with the help of the survey conducted across Sumatera Island. Land mass productivity varied from 2.03 t/ha to 4.22 t/ha, and the average value was 2.88 t/ha. Land mass productivity was the lowest in Aceh province and was the highest in North Sumatera province.
d) Mass output per unit of GHG emissions (kg/kg $CO_2$ eq) is a measure of crop production in terms of mass (kg) per unit of GHG emissions (kg $CO_2$ eq). It varied from 0.16 kg/kg $CO_2$ eq to 0.34 kg/kg $CO_2$ eq. The average mass output per unit of GHG emissions for the palm oil crops was estimated at 0.25 kg/kg $CO_2$ eq.
e) Water economic productivity (US$/m$^3$) is the measure of economic output (US$) per unit volume of water consumed (m$^3$). The water economic productivity for palm oil production varied from US$0.16/m$^3$ to US$0.22/m$^3$, and the average water economic productivity was US$0.20/m$^3$.
f) Energy economic productivity (US$/MJ) is the measure of economic output (US$) per unit of energy consumed (MJ). The energy economic productivity for palm oil production varied from US$0.05/MJ to US$0.06/MJ, and the average value was US$0.05/MJ. It was lowest in Bengkulu province and highest the West Sumatera province. Lower energy economic productivity was mainly due to the lower soil fertility and higher dependency on groundwater for irrigation. On the other hand, the higher energy economic productivity was mainly because of the higher yield of the crop.
g) Land economic productivity (US$/ha) is the measure of crop production in terms of the monetary value (US$) per unit of land use (ha). Land economic productivity varied from US$2,918/ha to US$3,412/ha, and the average value was US$3,155/ha.

h) The economic output per unit of GHG emissions (US$/kg $CO_2$ eq) is a measure of crop production in terms of the monetary value (US$) per unit of GHG emissions (kg $CO_2$ eq). It varied from US$0.24/kg $CO_2$ US$0.30/kg $CO_2$ eq. The average economic output per unit of GHG emissions was estimated at US$0.27/kg $CO_2$ eq for the palm oil crops. The economic output per unit of GHG emissions in Bengkulu was the lowest, whilst it was highest in Central Sumatera.

Table 3.3. WEFLC Nexus Index for the Palm Oil Crop System

| Province | Normalised Indicators | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Resources Use | | | | Resources Use | | | | Economic Productivity | | | | |
| | $W_C$ | $E_C$ | $L_U$ | GHG | $W_{MP}$ | $E_{MP}$ | $L_{MP}$ | $GHG_{MO}$ | $W_{EP}$ | $E_{EP}$ | $L_{EP}$ | $GHG_{EO}$ | Nexus Index |
| Aceh | 0.84 | 0.83 | 0.84 | 0.83 | 0.00 | 0.00 | 0.00 | 0.85 | 0.82 | 0.82 | 0.85 | 0.48 | 0.60 |
| North Sumatera | 0.58 | 0.54 | 0.56 | 0.55 | 1.00 | 1.00 | 1.00 | 0.41 | 0.69 | 0.21 | 0.41 | 0.21 | 0.60 |
| West Sumatera | 0.82 | 0.84 | 0.85 | 0.85 | 0.30 | 0.52 | 0.49 | 1.00 | 0.46 | 1.00 | 1.00 | 1.00 | 0.76 |
| Riau | 0.00 | 0.00 | 0.00 | 0.00 | 0.48 | 0.57 | 0.50 | 0.44 | 0.60 | 0.56 | 0.44 | 0.40 | 0.33 |
| Riau Islands | 1.00 | 1.00 | 1.00 | 1.00 | 0.09 | 0.02 | 0.05 | 0.88 | 1.00 | 0.56 | 0.88 | 0.85 | 0.69 |
| Jambi | 0.61 | 0.60 | 0.62 | 0.60 | 0.07 | 0.07 | 0.10 | 0.44 | 0.52 | 0.20 | 0.44 | 0.20 | 0.37 |
| Bengkulu | 0.85 | 0.87 | 0.87 | 0.87 | 0.14 | 0.32 | 0.29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.35 |
| South Sumatera | 0.60 | 0.60 | 0.61 | 0.63 | 0.50 | 0.60 | 0.58 | 0.20 | 0.36 | 0.09 | 0.20 | 0.44 | 0.45 |
| Bangka Belitung Islands | 0.91 | 0.92 | 0.92 | 0.93 | 0.57 | 0.76 | 0.76 | 0.33 | 0.24 | 0.17 | 0.33 | 0.68 | 0.63 |
| Lampung | 0.94 | 0.93 | 0.93 | 0.94 | 0.16 | 0.13 | 0.12 | 0.26 | 0.68 | 0.24 | 0.26 | 0.50 | 0.51 |

Source: Authors' data compilation.

*B. WEFLC Nexus index for the Sugarcane System*

In the case of sugarcane, sugarcane planting activities are only found in three provinces: North Sumatera, South Sumatera, and Lampung (see Table 3.4).

a) Water use for sugarcane crop production varied from 19,094 $m^3$/ha to 21,981 $m^3$/ha. The average water use for sugarcane crops was 20,450 $m^3$/ha. Water use was lowest in Lampung province and highest in South Sumatera.
b) Energy use during the entire season of the sugarcane crop in Sumatera Island varied from 95.1 GJ/ha to 97.3 GJ/ha. The average energy use for the sugarcane crops was 96.10 GJ/ha. Energy use in North Sumatera was found to be the lowest and was highest in South Sumatera.
c) The lowest and highest areas under cultivation for the sugarcane crops were recorded at North Sumatera and Lampung, respectively, with 6.1 kilohectares and 136.2 kilohectares of land dedicated to sugarcane cultivation.
d) GHG emissions varied from 2,651.9 kg $CO_2$ eq/ha to 2,792.3 kg $CO_2$ eq/ha. The average GHG emissions from the sugarcane crops were estimated at 2,722.9 kg $CO_2$ eq/ha.
e) Water mass productivity for sugarcane production varied from 0.16 kg/$m^3$ to 0.30 kg/$m^3$, and the average water mass productivity was 0.21 kg/$m^3$. Water mass productivity was highest in Lampung province and lowest in North Sumatera province.
f) Energy mass productivity (kg/MJ) is the measure of crop production in terms of mass (kg) per unit of energy consumed (MJ). The energy mass productivity for sugarcane production varied from 0.04 kg/MJ to 0.06 kg/MJ, and the average energy mass productivity was 0.05 kg/MJ. Energy mass productivity was lowest in South Sumatera province and highest in Lampung province.
g) Land mass productivity varied from 3.44 t/ha to 5.73 t/ha, and the average value was 4.18 t/ha. Land mass productivity was lowest in North Sumatera province and was highest in Lampung province.
h) Mass output per unit of GHG emissions (kg/kg $CO_2$ eq) is a measure of crop production in terms of mass (kg) per unit of GHG emissions (kg $CO_2$ eq). It varied from 1.26 kg/kg $CO_2$ eq to 2.05 kg/kg $CO_2$ eq. The average mass output per unit of GHG emissions for the palm oil crops was estimated at 1.53 kg/kg $CO_2$ eq.
i) Water economic productivity (US$/$m^3$) is the measure of economic output (US$) per unit volume of water consumed ($m^3$). The water economic productivity for sugarcane production varied from US$0.07/$m^3$ to US$0.08/$m^3$, and the average water economic productivity was US$0.08/$m^3$.
j) Energy economic productivity (US$/MJ) is the measure of economic output (US$) per unit of energy consumed (MJ). The energy economic productivity for sugarcane production varied from US$0.016/MJ to US$0.017/MJ, and the average value was US$0.02/MJ. It was lowest in South Sumatera province and highest in Lampung province.

k) Land economic productivity (US$/ha) is the measure of crop production in terms of monetary value (US$) per unit of land use (ha). Land economic productivity varied from US$1,537/ha to US$1,620/ha, and the average value was US$1,590/ha.
l) The economic output per unit of GHG emissions (US$/kg $CO_2$ eq) is a measure of crop production in terms of monetary value (US$) per unit of GHG emissions (kg $CO_2$ eq). It varied from US$0.56/kg $CO_2$ eq to US$0.61/kg $CO_2$ eq. The average economic output per unit of GHG emissions was estimated at US$0.58 /kg $CO_2$ eq for the sugarcane crops. The economic output per unit of GHG emissions was lowest in North Sumatera and highest in Lampung.

Table 3.4. WEFLC Nexus Index for the Sugarcane System

| Province | Normalised Indicators | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Resources Use | | | | Resources Use | | | | Economic Productivity | | | | |
| | $W_C$ | $E_C$ | $L_U$ | GHG | $W_{MP}$ | $E_{MP}$ | $L_{MP}$ | $GHG_{MO}$ | $W_{EP}$ | $E_{EP}$ | $L_{EP}$ | $GHG_{EO}$ | Nexus Index |
| Aceh | 0.84 | 0.83 | 0.84 | 0.83 | 0.00 | 0.00 | 0.00 | 0.85 | 0.82 | 0.82 | 0.85 | 0.48 | 0.60 |
| North Sumatera | 0.58 | 0.54 | 0.56 | 0.55 | 1.00 | 1.00 | 1.00 | 0.41 | 0.69 | 0.21 | 0.41 | 0.21 | 0.60 |
| West Sumatera | 0.82 | 0.84 | 0.85 | 0.85 | 0.30 | 0.52 | 0.49 | 1.00 | 0.46 | 1.00 | 1.00 | 1.00 | 0.76 |
| Riau | 0.00 | 0.00 | 0.00 | 0.00 | 0.48 | 0.57 | 0.50 | 0.44 | 0.60 | 0.56 | 0.44 | 0.40 | 0.33 |
| Riau Islands | 1.00 | 1.00 | 1.00 | 1.00 | 0.09 | 0.02 | 0.05 | 0.88 | 1.00 | 0.56 | 0.88 | 0.85 | 0.69 |
| Jambi | 0.61 | 0.60 | 0.62 | 0.60 | 0.07 | 0.07 | 0.10 | 0.44 | 0.52 | 0.20 | 0.44 | 0.20 | 0.37 |
| Bengkulu | 0.85 | 0.87 | 0.87 | 0.87 | 0.14 | 0.32 | 0.29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.35 |
| South Sumatera | 0.60 | 0.60 | 0.61 | 0.63 | 0.50 | 0.60 | 0.58 | 0.20 | 0.36 | 0.09 | 0.20 | 0.44 | 0.45 |
| Bangka Belitung Islands | 0.91 | 0.92 | 0.92 | 0.93 | 0.57 | 0.76 | 0.76 | 0.33 | 0.24 | 0.17 | 0.33 | 0.68 | 0.63 |
| Lampung | 0.94 | 0.93 | 0.93 | 0.94 | 0.16 | 0.13 | 0.12 | 0.26 | 0.68 | 0.24 | 0.26 | 0.50 | 0.51 |

Source: Authors' data compilation.

C. *WEFLC Nexus index for the paddy crop system*

a) The water use for paddy crop production varied from 8,356 $m^3$/ha to 13,904 $m^3$/ha, with an average of 10,763 $m^3$/ha. Water use was lowest in West Sumatera province and highest in Lampung.

b) Energy use during the entire season for paddy crops in Sumatera Island varied from 98.3 GJ/ha to 104.2 GJ/ha. The average energy use was 101.0 GJ/ha. Energy use was lowest in North Sumatera and highest in Bengkulu.

c) The lowest and highest areas of land dedicated to paddy cultivation were recorded, respectively at 0.2 kilohectares in Riau Islands province and 530.2 kilohectares in Lampung.

d) GHG emissions varied from 3,918 kg $CO_2$ eq/ha to 4,479 kg $CO_2$ eq/ha. The average GHG emissions from paddy crops were estimated at 4,171 kg $CO_2$ eq/ha.

e) Water mass productivity for paddy production varied from 0.32 kg/$m^3$ to 0.59 kg/$m^3$, and the average water mass productivity was 0.44 kg/$m^3$. Water mass productivity was highest in West Sumatera and lowest in Riau Islands province.

f) Energy mass productivity (kg/MJ) is a measure of crop production in terms of mass (kg) per unit of energy consumed (MJ). The energy mass productivity for paddy varied from 0.03 kg/MJ to 0.06 kg/MJ, and the average energy mass productivity was 0.05 kg/MJ. Energy mass productivity was lowest in Riau Islands province and highest in South Sumatera province.

g) Land mass productivity varied from 2.81 t/ha to 5.62 t/ha, and the average value was 4.70 t/ha. Land mass productivity was lowest in Riau Islands province and highest in South Sumatera.

h) Mass output per unit of GHG emissions (kg/kg $CO_2$ eq) is a measure of crop production in terms of mass (kg) per unit of GHG emissions (kg $CO_2$ eq). It varied from 0.66 kg/kg $CO_2$ eq to 1.40 kg/kg $CO_2$ eq. The average mass output per unit of GHG emissions for paddy crops was estimated at 1.13 kg/kg $CO_2$ eq.

i) Water economic productivity (US$/$m^3$) is a measure of economic output (US$) per unit volume of water consumed ($m^3$). The water economic productivity for paddy production varied from US$0.08/$m^3$ to US$0.15/$m^3$, and the average water economic productivity was US$0.12/$m^3$.

j) Energy economic productivity (US$/MJ) is a measure of economic output (US$) per unit of energy consumed (MJ). The energy economic productivity for paddy production varied from US$0.010/MJ to US$0.013/MJ, and the average value was US$0.012/MJ. It was lowest in Bengkulu province and highest in South Sumatera province.

k) Land economic productivity (US$/ha) is the measure of crop production in terms of the monetary value (US$) per unit of land use (ha). Land economic productivity varied from US$1,034/ha to US$1,312/ha, and the average value was US$1,209/ha.

l) Economic output per unit of GHG emissions (US$/kg $CO_2$ eq) is a measure of crop production in terms of the monetary value (US$) per unit of GHG emissions (kg $CO_2$ eq). It varied from US$0.26/kg $CO_2$ eq to US$0.33/kg $CO_2$ eq. The average economic output per unit of GHG emissions was estimated at US$0.29/kg $CO_2$ eq for the paddy crops. The economic output per unit of GHG emissions was lowest in Bengkulu and highest in South Sumatera.

Table 3.5. WEFLC Nexus Index for the Paddy Crop System

| Province | Normalised Indicators | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Resources Use | | | | Resources Use | | | | Economic Productivity | | | | |
| | $W_C$ | $E_C$ | $L_U$ | GHG | $W_{MP}$ | $E_{MP}$ | $L_{MP}$ | $GHG_{MO}$ | $W_{EP}$ | $E_{EP}$ | $L_{EP}$ | $GHG_{EO}$ | Nexus Index |
| Aceh | 0.57 | 0.51 | 0.52 | 0.49 | 0.46 | 0.93 | 0.97 | 0.77 | 0.32 | 0.80 | 0.86 | 0.34 | 0.63 |
| North Sumatera | 0.41 | 0.25 | 0.23 | 0.29 | 0.58 | 0.86 | 0.83 | 0.88 | 0.46 | 0.76 | 0.64 | 0.73 | 0.58 |
| West Sumatera | 0.66 | 0.42 | 0.43 | 0.44 | 1.00 | 0.70 | 0.76 | 0.70 | 1.00 | 0.67 | 0.75 | 0.52 | 0.67 |
| Riau | 0.93 | 0.90 | 0.90 | 0.91 | 0.20 | 0.43 | 0.41 | 0.40 | 0.62 | 0.97 | 0.92 | 0.77 | 0.70 |
| Riau Islands | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.77 | 0.51 | 0.45 | 0.17 | 0.49 |
| Jambi | 0.92 | 0.89 | 0.88 | 0.89 | 0.59 | 0.62 | 0.60 | 0.54 | 0.69 | 0.66 | 0.57 | 0.30 | 0.68 |
| Bengkulu | 0.91 | 0.89 | 0.89 | 0.90 | 0.35 | 0.69 | 0.76 | 0.80 | 0.08 | 0.00 | 0.00 | 0.00 | 0.52 |
| South Sumatera | 0.21 | 0.06 | 0.05 | 0.10 | 0.62 | 1.00 | 1.00 | 1.00 | 0.49 | 1.00 | 1.00 | 1.00 | 0.63 |
| Bangka Belitung Islands | 0.98 | 0.97 | 0.97 | 0.97 | 0.36 | 0.52 | 0.55 | 0.47 | 0.58 | 0.73 | 0.76 | 0.41 | 0.69 |
| Lampung | 0.00 | 0.00 | 0.00 | 0.00 | 0.19 | 0.84 | 0.85 | 0.76 | 0.00 | 0.41 | 0.36 | 0.07 | 0.29 |

Source: Authors' data compilation.

*D. WEFLC Nexus index*

The nexus index was formulated to solve the problems related to resource efficiency in an integrated way, not in an isolated manner to get the maximum yield. The nexus index gives quantitative insights into the use of water, energy, land, and other inputs for food production. Based on the calculation of the nexus index value and normalisation, in the case of palm oil plants, the highest nexus index value was obtained for West Sumatra at 0.76. The lowest nexus index was obtained for Riau at 0.33. For sugarcane, the highest nexus index was for North Sumatra at 0.65, and the lowest was for South Sumatra at 0.27. For rice, the highest index value was for Riau with a value of 0.70. The lowest index value was 0.29 for Lampung. The results of the index calculation, which is a formulation to produce an efficient system, prove that even though the crop productivity produced may be high, the resulting index value may not necessarily be high. This is because the calculation of the index value involves 12 indicators, as mentioned earlier. The areas with index values close to one are areas that can be said to have run their agricultural systems efficiently. Therefore, the calculation of water, energy, food, land, and climate can be used as a reference to evaluate existing agricultural systems and improve the efficiency of agricultural systems that are still lacking.

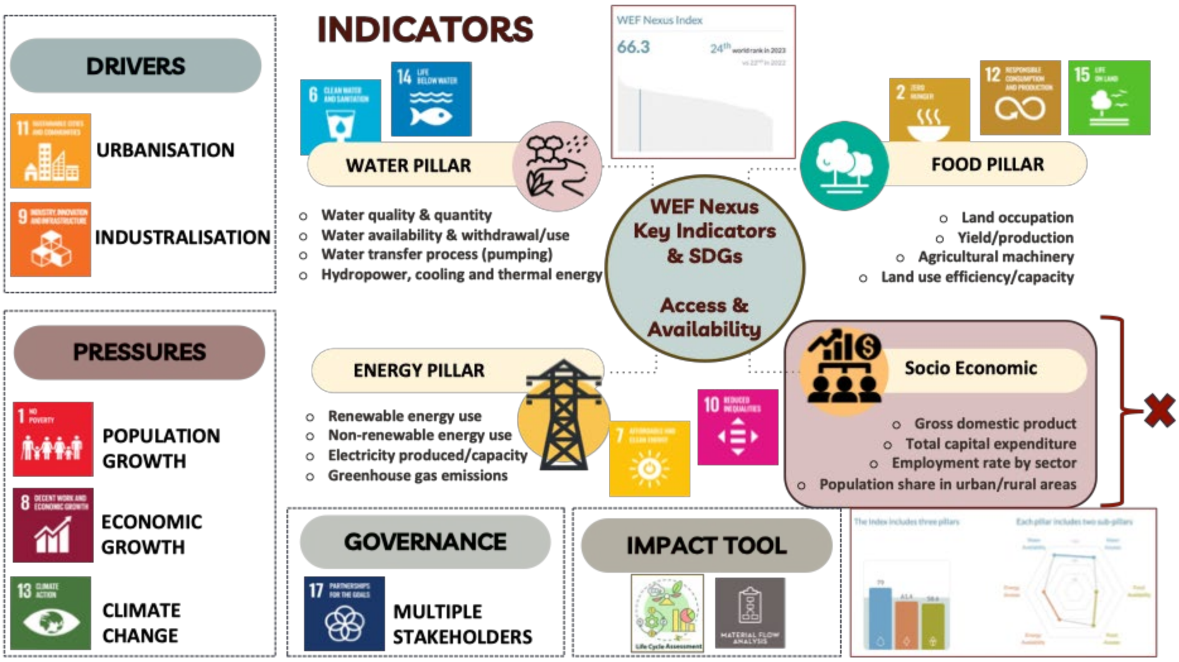
## 3.3 Malaysia

According to an FAO (2024) report, the oil palm industry in Malaysia plays a significant role in the WEF Nexus. The report highlights the interconnections between water, food, and energy in the production and processing of oil palm. Oil palm cultivation requires large amounts of water, land, and energy inputs, making it closely linked to the WEF Nexus.

- Water: The cultivation of oil palm requires significant amounts of water for irrigation. Malaysia's oil palm plantations rely on water sources such as rivers, lakes, and groundwater for irrigation purposes. However, the report emphasises the need for sustainable water management practices to ensure the availability of water resources for both oil palm cultivation and other sectors.
- Food: Oil palm is a major contributor to Malaysia's food production. The oil extracted from palm fruits is used in various food products, including cooking oil, margarine, and processed foods. The report highlights the importance of sustainable agricultural practices to ensure food security whilst minimising the environmental impact of oil palm cultivation.
- Energy: The oil palm industry also plays a crucial role in Malaysia's energy sector. Palm oil is used as a feedstock for biofuel production, particularly biodiesel. Oil palm biomass also has potential for energy generation through

the production of biogas and bioelectricity. The production of biodiesel or bioenergy from oil palm contributes to the country's renewable energy targets and reduces greenhouse gas emissions and environmental degradation. However, the oil palm industry also faces challenges and criticisms related to the WEF Nexus. The expansion of oil palm plantations has led to deforestation, biodiversity loss, and habitat destruction, impacting the availability of water resources and affecting food production. Additionally, the intensive use of fertilisers and pesticides in oil palm cultivation can lead to water pollution and degradation of soil quality.

Figure 3.6. Proposed Indicators for the WEFLC Nexus Using Variables on the Sustainable Development Goals and the Impact of Climate Change

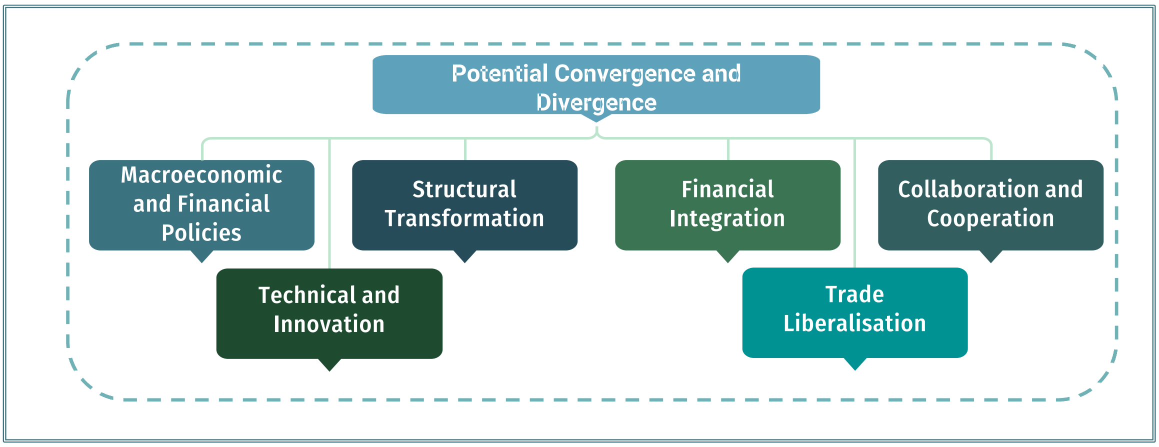



Source: Authors.

*Converging and diverging factors at the regional (EAS/ASEAN) level*

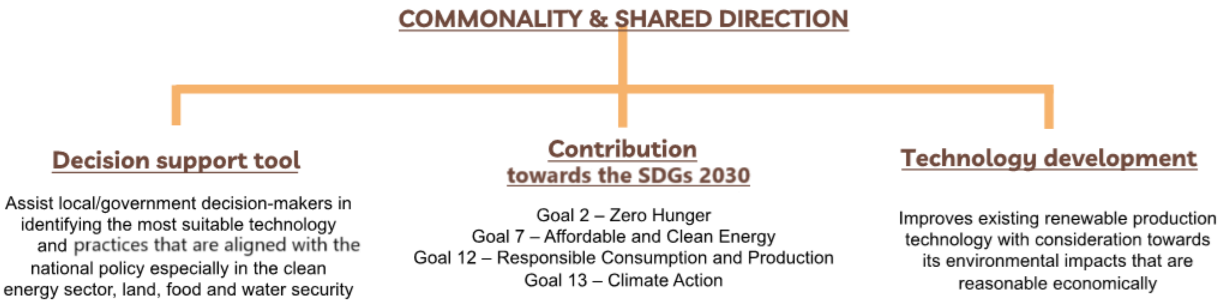
The issue of convergence of the nexus at the regional level is important as it has implications for efforts towards decarbonisation and a sustainable WEFL Nexus from the climate change perspective (Figure 3.7). Several converging factors, such as investment, openness to foreign trade, and inflows of foreign direct investment, can influence convergence on energy and food and need appropriate policy intervention at the regional (EAS/ASEAN) level. Technology and energy market convergence can provide solutions to the impacts on the nexus by promoting more equitable energy access across countries. As the energy consumption rate changes based on economic growth in most of the countries, policies related to improving energy efficiency and reducing energy intensity have been adopted in these countries. In addition, the commonality and shared direction of policies in Malaysia are summarised in Figure 3.8.

Figure 3.7. Converging and Diverging Factors at the Regional (EAS/ASEAN) Level




Source: Authors.

Figure 3.8. Commonality and Shared Direction of Policies in Malaysia




Source: Authors.

The policies explain that the indicators of the nexus are tied as environmental impacts on the planet causing climate change; thus, they are equally important considerations for those aiming to set targets to reduce their environmental footprint.

## 3.4 Philippines

The Philippines is confronted with significant hurdles concerning food security, water security, bioenergy sustainability, and climate change preparedness, all of which are interconnected and exert an influence on the nation's overall resilience and sustainability. As per the World Bank's *Atlas of Sustainable Development Goals 2023* (Pirlea, 2023), the Philippines exhibits a notably low water stress level, standing at 26%

in 2020.  Regarding food security, the Philippines occupies 67th position out of 113 countries in the Global Food Security Index 2022 (GFSI, 2022). The index evaluates various criteria encompassing affordability (ranked 60th), availability (ranked 70th), quality and safety (ranked 61st), as well as sustainability and adaptation (ranked 97th). Notably, approximately 75.2 million individuals in the Philippines lack the means to afford a nutritious diet (Pirlea, 2023).

To estimate the impact of bioenergy production on water, energy, food, land, and climate for the Philippine case, this study adopts the methodology of Akbar et al. (2023), using water use ($m^3$/ha), energy use (GJ/ha), land use (ha), GHG emissions during farm operations (kg $CO_2$eq/ha), water mass productivity (t/$m^3$), energy productivity (t/GJ), land productivity (t/ha), mass output per unit of GHG emissions (kg/$CO_2$eq), and resource economic productivity indictors. In the evaluation of the nexus, all indicators are given equal importance. Table 3.6 shows the environmental footprint indicators for the WEFLC sustainability analysis

Table 3.6. Summary of Environmental Footprints and Indicators for the WEFLC Sustainability Analysis

| Indicators | Units |
|---|---|
| *I. Resources use* | - |
| Water consumption | $m^3$/ha |
| Energy consumption | MJ/ha |
| Land use | ha |
| GHG emissions during farm operations | kg $CO_2$eq/ha |
| *II. Mass productivity* | |
| Water mass productivity | Tonnes of cane (tc) /$m^3$ |
| Energy mass productivity | tc/MJ |
| Land productivity | tc/ha |
| Mass productivity per unit of GHG emissions | Million litres (Mli)/t$CO_2$eq |
| *III. Resources economic productivity* | |
| Water economic productivity | ₱/$m^3$ |
| Energy economic productivity | ₱/MJ |
| Land economic productivity | ₱/ha |
| Economic productivity per unit of GHG emissions | ₱/kg $CO_2$eq |

Source: Authors’ data compilation.

*Sugarcane and bioethanol*

Table 3.7 and Table 3.8 show a summary of the indicators and normalised indices for sugarcane and bioethanol production, as well as for coconut and biodiesel production, in the Philippines. The normalised values are plotted in a radar plot to exhibit the weakest data points that need improvement.

Under the resource indicators, the normalised value is highest for land use, estimated at 0.51. However, in terms of the productivity index, this reduces to 0.48, making it the third highest amongst the indicators under the productivity indices. In terms of economic productivity, this score improves to 0.53 but is still ranked third. There seems to be an imbalance in land use for sugarcane since the data shows that more molasses are being used on a larger scale in quite a few periods than sugarcane juice. This may seemingly result in higher efficiency of land use in this case. However, according to FAO data, the Philippines is likewise importing a considerable amount of molasses.

Under mass productivity, energy productivity has the highest value, at 0.52, which is an improvement from its value of 0.50 under the resources indicators. This value further improves to 0.81 under the economic productivity indicator, which is amongst the highest values. The reason for this is that its utilisation for energy has been maximised in the Philippines since sugarcane is used as a feedstock for biofuels and power generation.

Consequently, both energy and GHG emissions result in the highest value at 0.81 for both under economic productivity, which is relatively plausible since GHG emissions are determined by the level of energy utilisation. These values indicate an improvement from the first two stages.

Table 3.7. Sugarcane and Bioethanol Production WEFLC Indicators, 2022

| Indicators | Units | Max | Min | CY 2022 | Normalised |
|---|---|---|---|---|---|
| *I. Resources use* | | | | | |
| Water consumption | $m^3$/ha | 341.53 | 277.78 | 297.40 | 0.308 |
| Energy consumption | MJ/ha | 23,062.08 | 18,156.31 | 20,585.38 | 0.495 |
| Land use | ha | 28,551.25 | 10,806.25 | 19,906.25 | 0.513 |
| GHG emissions during farm operations | kg $CO_2$eq/ ha | 1,079.31 | 849.72 | 963.40 | 0.495 |
| *II. Mass productivity* | | | | | |

| Indicators | Units | Max | Min | CY 2022 | Normalised |
|---|---|---|---|---|---|
| Water mass productivity | tc/m$^3$ | 0.1967 | 0.1959 | 0.1965 | 0.255 |
| Energy mass productivity | tc/MJ | 1,503.19 | 927.42 | 1,202.92 | 0.522 |
| Land productivity | tc/ha | 65.18 | 51.08 | 58.44 | 0.478 |
| Mass productivity per unit of GHG emissions | Mli/t$CO_2$eq | 4,419.02 | 3,479.00 | 3,944.45 | 0.505 |
| *III. Resources economic productivity* | | | | | |
| Water economic productivity | ₱/m$^3$ | 124.08 | 104.56 | 125.15 | 0.528 |
| Energy economic productivity | ₱/MJ | 1.90 | 1.44 | 1.81 | 0.806 |
| Land economic productivity | ₱/ha | 2.01 | 1.70 | 2.03 | 0.531 |
| Economic productivity per unit of GHG emissions | ₱/kg $CO_2$eq | 31.21 | 23.79 | 29.77 | 0.806 |

Sources: Water and energy indicators are based on Demafelis et al. (2020a); GHG emissions during farm operations are based on Demafelis et al. (2020b).

As seen in Figure 3.9, water consumption, water production, and land use productivity are the weakest indicators. These areas have to be considered for improvement in the nexus.

Figure 3.9. Sugarcane and Bioethanol Normalised Indicators


Source: Authors.

*Coconut and bioethanol*

Table 3.8 shows the estimated WEFLC indicator indices for coconut and bioethanol production. In terms of resource utilisation, water consumption has the highest value at 0.80. This falls to 0.69 in terms of mass productivity but is still the highest value amongst the mass productivity indicators. The value further reduces to 0.63 in terms of economic productivity.

In terms of economic productivity, the results show that both energy and GHG emissions economic productivity have the highest value, at 0.72 for both. This means that energy is used efficiently for coconut and biofuel production, resulting in a high value for GHG emissions productivity.

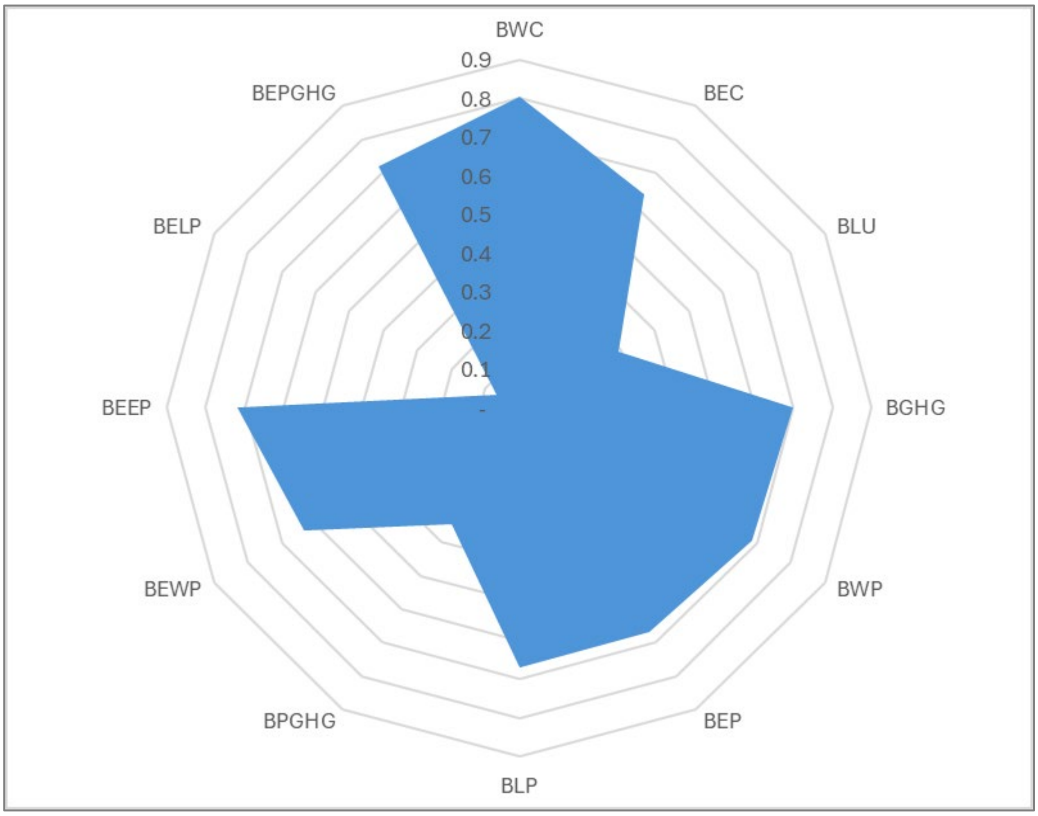
Table 3.8. Coconut and Bioethanol Production WEFLC Indicators, 2022

| Indicators | Units | Max | Min | 2022 | Normalised |
|---|---|---|---|---|---|
| *I. Resources use* | | | | | |
| Water consumption | $m^3$/ha | 45.15 | 35.44 | 43.25 | 0.804 |
| Energy consumption | MJ/ha | 1,826.09 | 1,660.62 | 1,871.06 | 0.636 |
| Land use | ha | 305,876 | 237,705 | 257,642 | 0.292 |
| GHG emissions during farm operations | kg $CO_2$eq/ha | 428.23 | 374.60 | 449.58 | 0.699 |
| *II. Mass productivity* | | | | | |
| Water mass productivity | t/$m^3$ | 1,097.42 | 894.19 | 957.91 | 0.686 |
| Energy mass productivity | t/MJ | 2.44 | 2.27 | 2.21 | 0.666 |
| Land productivity | t/ha | 4.04 | 3.97 | 4.14 | 0.669 |
| Mass productivity per unit of GHG emissions | Mli/t$CO_2$eq | 990.43 | 769.69 | 913.78 | 0.347 |
| *III. Resources economic productivity* | | | | | |
| Water economic productivity | ₱/$m^3$ | 896.46 | 525.06 | 661.15 | 0.634 |
| Energy economic productivity | ₱/MJ | 4,919.08 | 3,210.61 | 3,688.83 | 0.720 |
| Land economic productivity | ₱/ha | 688.06 | 535.31 | 678.16 | 0.065 |
| Economic productivity per unit of GHG emissions | ₱/kg $CO_2$eq | 84.81 | 55.35 | 63.60 | 0.720 |

Sources: Data on energy and GHG footprints are based on Demafelis et al. (2020b); data on water consumption are based on Demafelis et al. (2022).

As seen in Figure 3.10, coconut land use, land use economic productivity, and GHG emission economic productivity need improvement as their normalised indicators have the lowest values. This can be attributed to the fact that coconut production in the country has not been improving over the years, with a 0.2% meagre growth rate and an average of 4.15 tonnes/ha. Since water consumption and water productivity have high index values, there must be other factors that affect land-use efficiency, such as a lack of intercropping techniques or production technology, lack of availability of irrigation in the country (Moreno, 2020), and other factors such as typhoons and pestilence.

Figure 3.10. Normalised Indicators for Coconut and Biodiesel Production




Source: Authors.

Table 3.9 shows the nexus index in three stages, namely the WEF index, WEFL index, and WEFLC index. For sugarcane, the nexus index increases from the first index to the third index, where the highest value is at 0.52 under the WEFLC index. On the other hand, the nexus index decreases with the inclusion of land and cost for coconuts, where the WEF nexus results in the highest index value at 0.64.

Table 3.9. Sugarcane and Coconut Nexus Index Scores in the Philippines

| Crop | WEF | WEFL | WEFLC |
|---|---|---|---|
| Sugarcane | 0.4298 | 0.4463 | 0.5201 |
| Coconuts | 0.6399 | 0.6001 | 0.5783 |

Source: Authors' data compilation.

The Philippine report on Bioethanol Impact on Climate, Land, Energy, and Water highlights several key findings and challenges related to sustainable development in these interconnected sectors (Quejada et al., 2021). The effective management of these resources is crucial for sustainable development in the Philippines. The Philippine archipelago faces unique challenges due to its geographic, demographic, and economic characteristics, which impact resource availability and management.

Table 3.10. Candidate Footprints and Indicators

| Indicators | Units | Max | Min | CY 2022 | Normalised |
|---|---|---|---|---|---|
| *I. Resources use* | | | | | |
| Water consumption | $m^3$/ha | 341.53 | 277.78 | 297.40 | 0.308 |
| Energy consumption | MJ/ha | 23,062.08 | 18,156.31 | 20,585.38 | 0.495 |
| Land use | ha | 28,551.25 | 10,806.25 | 19,906.25 | 0.513 |
| GHG emissions during farm operations | kg $CO_2$eq/ ha | 1,079.31 | 849.72 | 963.40 | 0.495 |
| ***II. Mass productivity*** | | | | | |
| Water mass productivity | tc/$m^3$ | 0.1967 | 0.1959 | 0.1965 | 0.255 |
| Energy mass productivity | tc/MJ | 1,503.19 | 927.42 | 1,202.92 | 0.522 |
| Land productivity | tc/ha | 65.18 | 51.08 | 58.44 | 0.478 |
| Mass productivity per unit of GHG emissions | Mli/t$CO_2$eq | 4,419.02 | 3,479.00 | 3,944.45 | 0.505 |
| ***III. Resources economic productivity*** | | | | | |
| Water economic productivity | ₱/$m^3$ | 124.08 | 104.56 | 125.15 | 0.528 |
| Energy economic productivity | ₱/MJ | 1.90 | 1.44 | 1.81 | 0.806 |
| Land economic productivity | ₱/ha | 2.01 | 1.70 | 2.03 | 0.531 |
| Economic productivity per | ₱/kg $CO_2$eq | 31.21 | 23.79 | 29.77 | 0.806 |

| Indicators | Units | Max | Min | CY 2022 | Normalised |
| --- | --- | --- | --- | --- | --- |
| unit of GHG emissions | | | | | |

Sources: Water and energy indicators are based on Demafelis et al. (2020a); GHG emissions during farm operations are based on Demafelis et al. (2020b).

## 3.5 India

Agriculture is a multifaceted sector that encompasses numerous elements, including land, water, and energy utilisation, the production and application of fertilisers, as well as the extraction of groundwater, land preparation, etc. Mainly due to fossil fuel-based processes, agricultural activities are also linked to climate change. This is why water, food, energy, land, and climate are interconnected, comprising a coherent system (the 'Nexus'). Managing one of them cannot be considered in isolation but should be seen as part of an integrated system. To provide solutions to the interlinkages, El-Gafy (2017) provided a comprehensive water-food-energy (WEF) nexus approach. Further, Gazal et al. (2022) improved the WEF Nexus methodology by adding a land indicator, which was further modified by Akbar et al. (2023) by integrating climate as an indicator into the water-food-energy-land nexus index (the WEFLC Nexus), thereby addressing a critical gap in the existing methodologies. By aiming to provide decision-makers with a comprehensive tool to analyse nexus dynamics in crop production systems, the study contributes directly to the achievement of the SDGs.

In our study, we computed the 12 indicators of the WEFLC Nexus as proposed by Akbar et al. (2023) for two major crops produced in India: sugarcane and maize. Both crops are rich sources of food (sugar and starch) and also a source of energy (bioethanol). However, due to a lack of temporal and spatial data across the country for both crops, the index was calculated only at the state level (top two producing states for each individual crop). This gives a primary understanding of how the WEFLC Nexus can be better implemented for all the major crops across individual states to understand the interdependencies and their impacts on sustainable resource consumption and production.

The 12 indicators in the Table 3.11 are sub-divided according to resource use, mass productivity, and economic productivity. The resource use indicators explain the natural resources involved in the sugarcane and maize production systems, specifically focusing on water, energy, land use, and GHG emissions. The table presents the water, energy, land and GHG emissions intensity for sugarcane and maize based on the available secondary data.

Table 3.11. Water, Energy, Land Use and GHG Emissions Intensity for Sugarcane and Maize in Selected States in India

| Indicators | Sugarcane | | Maize | |
|---|---|---|---|---|
| | Uttar Pradesh | Maharashtra | Karnataka | Madhya Pradesh |
| Water use ($m^3$/ha) | 16,639.00 | 18,750 | 3,112 | NA |
| Energy use (MJ/ha) | 38,565 | 50,652.28 | 16,701.61 | 13,521.59 |
| Land use (2019–2020) (lakh ha) | 22.08 | 8.22 | 14.2 | 14.00 |
| GHG emissions during farm operations (kg $CO_2$ eq/ha) | 5,233.73 | 4,519.9364 | 5,030.61 | NA |

Source: Authors' data compilation.

The table highlights that sugarcane production in both states involves significant resource use; interestingly, Maharashtra shows higher water and energy use but lower GHG emissions per hectare compared to Uttar Pradesh. Whilst maize production in both Karnataka and Madhya Pradesh demonstrates substantial use of natural resources, Karnataka shows higher energy per hectare compared to Madhya Pradesh.

a. *Resource mass productivity and mass output per unit of GHG emissions*

Resource use productivity measures how effectively inputs are used to generate outputs. In the context of the two crops analysed, the indicators of productivity considered here include production per unit of water, energy, and land, as well as the mass output per unit of GHG emissions, as presented in Table 3.12.

Table 3.12. Sugarcane and Maize Productivity with Regard to Water, Energy, Land Use, and GHG Emissions Intensity in Selected States in India

| Indicators | Sugarcane | | Maize | |
|---|---|---|---|---|
| | Uttar Pradesh | Maharashtra | Karnataka | Madhya Pradesh |
| **Water mass productivity (kg/$m^3$)** | 4.8861 | 4.4949 | 0.9608 | |
| **Energy mass productivity (kg/MJ)** | 2.11 | 1.66 | 0.18 | 0.21 |
| **Land mass productivity (2019–2020) (t/ha)** | 78.131 | 117.825 | 11.133 | 8.507 |
| **Mass output per unit of GHG emissions (t/$CO_2$ eq)** | 15.53 | 18.65 | 0.59 | |

Source: Authors' data compilation.

Sugarcane land mass productivity in Maharashtra (84,280 kg/ha) is higher than in Uttar Pradesh (81,300 kg/ha). Therefore, Maharashtra achieves a higher mass output per unit of GHG emissions, indicating better environmental efficiency in sugarcane production compared to Uttar Pradesh. Maize production in Madhya Pradesh shows slightly higher energy mass productivity at 0.21 kg/MJ compared to Karnataka's 0.18 Kg/MJ, suggesting that Madhya Pradesh is more efficient in converting energy into maize mass. Karnataka exhibits higher land mass productivity at 11.133 t/ha compared to Madhya Pradesh's 8.507 t/ha, which indicates that Karnataka achieves higher yields per hectare of land used for maize cultivation.

*b. Resource economic productivity and mass output per unit of GHG emissions*

Finally, the economic productivity and mass output per unit of GHG emissions for sugarcane and maize are presented in Table 3.13.

Table 3.13. Resource Economic Productivity and Mass Output per Unit of GHG Emissions Indicators

| Indicators | Sugarcane | | Maize | |
|---|---|---|---|---|
| | Uttar Pradesh | Maharashtra | Karnataka | Madhya Pradesh |
| Water economic productivity (2020–2021) (Rs/m$^3$) | 4.351 | 2.764 | 0.674 | |
| Energy economic productivity (2020–2021) (Rs/MJ) | 1.877 | 1.023 | 0.126 | 0.073 |
| Land economic productivity (2020–2021) (Rs/ha) | 223,610.62 | 231,883.21 | 52,800.00 | 51,165.71 |
| Economic output per unit of GHG emissions (2020–2021) (Rs/kg $CO_2$ eq) | 42.725 | 51.302 | 10.496 | |

Source: Authors' data compilation.

Uttar Pradesh has a higher water economic productivity (Rs4.351/m$^3$) compared to Maharashtra (Rs2.764/m$^3$). This indicates that Uttar Pradesh generates more economic value per unit of water used in sugarcane production, suggesting better water use efficiency. Uttar Pradesh also excels in energy economic productivity at Rs1.877/MJ, significantly higher than Maharashtra's Rs1.023/MJ. This suggests that Uttar Pradesh is more efficient in converting energy inputs into economic output for sugarcane production. Maharashtra leads in land economic productivity at Rs231,883.21/ha, slightly surpassing Uttar Pradesh's Rs223,610.62/ha. This implies that Maharashtra is more effective in generating economic returns from each hectare of land used for sugarcane cultivation. Maharashtra demonstrates superior economic output per unit of GHG emissions performance, at Rs51.302/kg $CO_2$ eq compared to Uttar Pradesh's Rs42.725/kg $CO_2$ eq. This indicates that Maharashtra's sugarcane production is more sustainable, providing higher economic returns relative to its carbon footprint.

In terms of maize, the data on maize crop production for 2020–2021 indicates that Karnataka demonstrates superior efficiency in resource utilisation compared to Madhya Pradesh. Energy economic productivity in Karnataka is Rs0.126/MJ, significantly higher than Madhya Pradesh's Rs0.073/MJ, suggesting Karnataka generates about 73% more economic output per unit of energy consumed. Additionally, Karnataka's land economic productivity is Rs52,800/ha, slightly surpassing Madhya Pradesh's Rs51,165.71/ha. This indicator underscores Karnataka's relative advantage in resource productivity and environmental impact for maize farming, although the absence of water economic productivity and GHG-related data for Madhya Pradesh limits a comprehensive comparison.

## 3.6 Viet Nam

The indicators of the WEFLC nexus will be reviewed and proposed based on the FAO WEF Nexus framework and other relevant literature (Kalvani and Celico, 2024; Molajou et al., 2021, Hatfield et al., 2017; FAO, 2014). These indicators serve to assess the sustainability of alternative utilisation methods for rice straw and rice husk, particularly their conversion into bioenergy. Across the five dimensions of water, energy, food, land, and climate, the indicators encompass the following:

1. Resource use (water, energy, and land).
2. Mass productivity (yield per unit of hectare over unit of resource use).
3. Resource economic productivity (monetary value of mass outputs (US$/ha) over unit resource uses (water, energy, and land) or per tonne of rice straw or rice husk (US$/tonne of rice straw or rice husk)).
4. Environmental impact, including GHG emissions per tonne of rice straw or rice husk, as well as other environmental factors, such as water and soil quality, waste or by-products from energy, feed, or food production (Kalvani and Celico, 2024; Hatfield et al., 2017).

These indicators are applicable to all alternative utilisation methods of rice straw and rice husk. These utilisations will be categorised into resources for food, feed, energy, or others to understand the competition for resource use, who benefits, and for what purposes rice straw and rice husk are utilised.

The interaction between food and resource use (water, energy, and land) is rooted in food security principles, encompassing food availability, access, utilisation, and stability (FAO, 2014). The extraction of rice straw and rice husk from fields, along with the compost derived from these materials, can potentially impact soil quality and degradation rates (Hatfield et al., 2017). In reviewing the nexus linkages, direct connections amongst nexus elements will be scrutinised within the context of the alternative utilisation of rice straw and rice husk. This examination will include the relationships between water and energy, water and food, water and land, water and climate change, energy and food, energy and land, energy and climate change, food and land, and land and climate change.

The list of indicators in Table 3.14 is based on Akbar et al. (2023). It has been reviewed and supplemented with new indicators relevant to the current and potential utilisation of rice straw and rice husk. The newly added indicators focus on the environmental impacts of rice straw and rice husk, encompassing both GHG emissions and soil impacts. These indicators are applied in various in-field uses of rice straw, including its use as compost or biochar, as well as the return of rice straw and rice husk to soil (Kalvani and Celico, 2024; Hatfield et al., 2017).

Table 3.14. Indicators Chosen in the Context of the Analysis of the Uses of Rice Straw and Husk

| Dimensions | Water | Energy | Food | Land | Climate Change |
|---|---|---|---|---|---|
| 1. Resource uses<br>1.1. How much resources in 1 ha to produce paddy? | $m^3$/ha | MJ/ha | Tonnes paddy/ha | Ha | $CO_2$eq/ha |
| 1.2. How much resources needed to produce 1 tonne of biomass? | $m^3$/tonne biomass | MJ/tonne biomass | Tonnes product/ tonne biomass | Tonnes biomass/ha | $CO_2$eq/tonne biomass |

| Dimensions | Water | Energy | Food | Land | Climate Change |
|---|---|---|---|---|---|
| 2. Mass productivity How many tonnes of biomass to produce 1 unit (tonne/L) of product | $m^3$/tonne biomass/ unit of product | MJ/tonne biomass/unit of product | Tonnes product/ tonne biomass | Tonnes product/ha | $CO_2$eq/unit of product |
| 3. Resource economic productivity 3.1. How much does it cost to utilise 1 tonne of biomass? | US$/tonne biomass | US$/tonne biomass | US$/tonne biomass | US$/tonne biomass | US$/tonne biomass |
| 3.2. How much profit/cost to produce 1 unit of product? | US$/unit of product | US$/unit of product | US$/unit of product | US$/unit of product | US$/unit of product |
| 4.1 Soil quality (organic content) per tonne of biomass | | | | Organic content/ton biomass | |
| Soil quality (organic content) per unit of product | | | | Organic content/ unit of product | |
| 4.2. Soil degradation rate | | | | Degradation rate/tonne biomass | |
| | | | | Degradation rate/unit of product | |

Source: Adapted from Akbar et al. (2023).

An initial set of indicators concerning resource uses was categorised into two groups: the resources required to produce 1 tonne of paddy, and the resources needed to produce rice straw and rice husk, determined by the ratio of paddy production to the rice straw and rice husk yield.

In the second group of indicators, mass productivity is based on the quantity of rice straw or rice husk required to produce 1 tonne or 1 litre of biomass product. For instance, it assesses how many tonnes or kilogrammes of mushrooms can be produced from 1 tonne of rice straw or how many tonnes of pellets can be produced from 1 tonne of rice husk. Similar indicators are applied to resource economic productivity, with the unit of analysis being currency. In the last group of indicators, the focus shifts to the impacts of using rice straw or rice husk to improve soil quality. Numerous indicators exist to evaluate soil quality or degradation, which will be specified later.

The impacts of utilising rice straw and rice husk on climate change primarily concern GHG emissions, and this aspect is addressed within the climate change group.

### Possible effects of rice straw and husk utilisation on the WEFLC Nexus

The indicators applied to the current and potential use of rice straw and rice husk for bioenergy are presented in Table 3.15 based on the current and potential uses of rice straw in Viet Nam.

Table 3.15. Possible Effects of Rice Straw Utilisation in Viet Nam on the WEFLC Nexus

| Rice Straw Utilisation | Water | Energy | Food | Land | Climate Change |
|---|---|---|---|---|---|
| 1. In-field | | | | | |
| 1.1 Open burning | -5 | -5 | -5 | -5 | -3 |
| 1.2 Incorporate raw rice straw into the paddy field | 3 | 1 | 5 | 3 | -5 |
| 1.3 Incorporate composted rice straw into the paddy field | -1 | 3 | 5 | 5 | -3 |
| 2. Off-field | | | | | |
| 2.1 Growing mushrooms | -5 | 5 | 5 | 5 | -3 |
| 2.2 Feeding straw to cattle | -3 | 5 | 5 | 3 | -5 |
| 2.3 Mulch for upland crops or fruit trees | 5 | 3 | 5 | 5 | 5 |
| 2.4 Biochar | 3 | 5 | 5 | 5 | 3 |
| 2.5 Biogas | 3 | 5 | 3 | 5 | 5 |
| 2.6 Power generation | 1 | 5 | 1 | -5 | 3 |
| 2.7 Straw pellet | 1 | 5 | 1 | -5 | 3 |

Note: The scores provided are based on the author's best estimations and insights drawn from references. A score of 1 indicates slight or no impact, 3 suggests moderate impact, and 5 indicates strong impact. Additionally, '+' denotes a positive impact, '-' denotes a negative impact, and '+/-' indicates both positive and negative impacts.
Source: Author's data compilation.

In-field uses of rice straw include open burning, incorporating rice straw into the paddy field, or applying composted rice straw to the paddy field. Although applying composted rice straw to the paddy field generates higher GHG emissions than burning rice straw or removing it from the paddy field, it provides nutrients to the paddy field and also reduces organic poisoning, similar to incorporating fresh or raw rice straw into the paddy field.

For off-field uses of rice straw, options include using straw to grow straw mushrooms, feeding cattle, mulching upland crops or fruit trees, and producing biochar, which are non-energy alternatives. In Viet Nam, biochar remains relatively unpopular despite being introduced to farmers many years ago. Using rice straw to grow straw mushrooms generates fewer GHG emissions than feeding cattle. Therefore, straw should be pre-treated before feeding to cattle to reduce both GHG emissions and increase nutrient content and digestibility for the cattle. The residues of straw after growing straw mushrooms can be composted for use in plants; however, they are often open-burned to expedite rice straw disposal.

Biogas, power generation, and straw pellets represent bioenergy utilisation of rice straw. Whilst these methods are not widely popular, they are categorised as off-field uses and, thus, do not directly impact the land. However, they contribute to green energy sources, resulting in positive effects in reducing GHG emissions.

Table 3.16. Possible Effects of Rice Husk Utilisation in Viet Nam on the WEFLC Nexus

| Rice Husk Utilisation | Water | Energy | Food | Land | Climate Change |
|---|---|---|---|---|---|
| 1. Energy | | | | | |
| 1.1 Heat | | | | | |
| 1.2.1. Household uses | 1 | 5 | 3 | -3 | 3 |
| 1.2.2. Drying other products | 1 | 5 | 3 | -3 | 3 |
| 1.2.3. Industrial boilers | 1 | 5 | 3 | -3 | 5 |
| 1.3. Fuel (briquettes, pellets) | 1 | 5 | 3 | -3 | 3 |
| 2. Non-energy | | | | | |
| 2.1. Agriculture | | | | | |
| 2.1.1. Biochar | 3 | 1 | 5 | 5 | 3 |
| 2.1.2. Mulching | 5 | 1 | 5 | 5 | 5 |
| 2.1.3. Other agricultural substrates | 5 | 1 | 5 | 5 | 5 |
| 2.2. Industrial and other uses | 1 | 1 | 1 | -3 | 1 |
| 2.2.1. Building materials | 1 | 1 | 1 | -3 | 1 |
| 2.2.2. Other industrial uses | 1 | 1 | 1 | -3 | 1 |

Note: The scores provided are based on the author's best estimations and insights drawn from references. A score of 1 indicates slight or no impact, 3 suggests moderate impact, and 5 indicates strong impact. Additionally, '+' denotes a positive impact, '-' denotes a negative impact, and '+/-' indicates both positive and negative impacts.

Source: Authors' data compilation.

Utilising rice husk for energy and industrial purposes, amongst other uses, can have negative impacts on soil quality. Conversely, employing rice husk for agricultural purposes, such as biochar or mulching, can yield positive benefits for the soil, enhancing nutrient levels and creating conditions conducive to food production. Rice husk also serves as a green energy source when utilised for energy production, though its direct impact on soil quality improvement is limited.

Using rice husk to reduce fossil fuel dependency in industrial boilers aids in decreasing GHG emissions. Additionally, employing rice husk for mulching or as an agricultural substrate helps conserve water in agriculture and enhances soil quality. These practices are particularly beneficial for upland crops and fruit trees and contribute to reduced GHG emissions.

# Chapter 4

# Policy-centric Analysis on the Existing Major Policies on Biomass Production

This chapter emphasises the importance of adopting a cross-sectoral approach to policymaking and implementation. This involves integrating considerations of water use, energy efficiency, food security, land management, and climate impact into the planning and development of biomass utilisation strategies. By doing so, EAS countries can better navigate the complexities of biomass production and mitigate potential negative impacts on the environment and economy. This integrated approach is crucial for achieving long-term sustainability and for fostering the growth of biofuels in a manner that aligns with broader environmental and economic goals.

## 4.1 Thailand

In Thailand, the level of water stress, as per SDG indicator 6.4.2, increased by more than 30% from 2015 to 2019. In 2015, it was 9.38%, and in 2019, it jumped to 12.64%. To tackle the water resources issues, in January 2019, Thailand implemented the Act on Water Resources B.E. 2561 (2018), serving as the primary legislation for the country's water resource management. This enactment was anticipated to foster sustainable solutions to water management issues (Yotmongkol, 2022). Thailand's water management guidelines are anchored on three principal objectives: firstly, to conserve water through economical and efficient utilisation; secondly, to enhance GDP whilst reducing water use in the agricultural sector; and thirdly, to diminish overall water demand and boost the rate of water recycling.

Thailand has a 20-Year Energy Efficiency Development Plan (2011–2030). This 20-year Energy Efficiency Development Plan (EEDP) (Ministry of Energy, 2011) aims to cut energy intensity by 25% by 2030 from 2005 levels, equalling a final energy consumption reduction of 20%, or approximately 30 million tonnes of oil equivalent, by adopting multiple options to promote all forms of renewable energy, such as biomass, biogas, energy from waste, etc. Key compulsory actions involve implementing the amended Energy Conservation Promotion Act of 1992, as amended up to No. 2 2007, establishing Minimum Energy Performance Standards, and introducing energy efficiency labels (Ministry of Energy, 2011). Thailand is shifting its energy policy to lessen its reliance on natural gas, aiming to bolster energy security. As the cost of variable renewable energy decreases, conventional power generation methods in Thailand are gradually being replaced by alternative energy sources (IEA, 2021).

Thailand aims to have renewable energy account for more than 50% of its power generation mix by 2037.

Thailand's Draft Climate Change Act 2022 outlines strategies for climate action, focusing on mitigation, adaptation, and emissions cuts. Key aspects include citizens' rights, governmental duties, the establishment of a National Climate Change Policy Committee, and a GHG inventory. Aligning with the Paris Agreement, Thailand has committed to a 20% reduction in GHG emissions by 2030 from projected levels, with the potential to increase to 25% with sufficient support and resources (Conventus Law, 2022).

Thailand has launched a 20-year National Strategy to guide the nation towards security, prosperity, and sustainability. This strategy, anchored in the Sufficiency Economy Philosophy, aims to create a happy society with a high income, stable and fair economy, and competitive edge. It focuses on six key areas: national security, competitiveness enhancement, human capital development, social equality and opportunity, eco-friendly growth, and government administration reform (Office of Agricultural Economics, 2017). The Thai government has pledged to enhance public sector efficiency to steer food systems towards enhanced sustainability and equilibrium across all facets, including bolstering food security and guaranteeing fair access to safe and nutritious food for everyone (Phulkerd et al., 2022).

The WEFLC Nexus offers a holistic framework to identify suitable crop zones and sustainable agriculture, especially sugarcane and cassava production systems, for Thailand. Sugarcane and cassava play a crucial role in the WEFLC Nexus, offering opportunities to achieve sustainability goals. These resilient crops contribute to carbon sequestration and serve as staple foods. Moreover, the biomass obtained through these crops can be utilised to enhance energy security whilst reducing GHG emissions. Sustainable cultivation practices ensure water security, whilst integrated land-use strategies optimise productivity. Leveraging these interconnections can address climate, food, and energy security challenges simultaneously.

## 4.2 Indonesia

The WEF Nexus policy and biomass production are important for achieving sustainable development in Indonesia. These policies can help ensure that water, energy, and food are sustainably available to everyone. The government has made and will make different regulations targeted at allowing various sectors to enter bioenergy production in Indonesia to encourage domestic bioenergy growth.

Table 4.1. Policy-centric Analysis of Indonesia Using the WEFLC Nexus

| 1945 State Constitution (UUD' 45) | Sectoral Regulations on Water | Sectoral Regulations on Food | Sectoral Regulations on Energy | Sectoral Regulations on Land Change | Sectoral Regulations on Climate Change |
|---|---|---|---|---|---|
| Law (UU) | UU17/2019 on water resources: Establishes sustainable water resource management, including supporting biomass production | UU 18/2012 on food: Establishes food security as one of the national development goals | – UU 30/2007 on energy<br>– UU 3/2023 concerning new and renewable energy: Establishes the legal framework for the development of new and renewable energy, including biomass | – UU 32/2009 concerning environmental protection and management: Regulates the precautionary principle in environmental management, including land change<br>– UU 16/2016 officially ratifies the Paris Agreement, an international agreement that aims to limit global temperature rise, reduce GHG emissions, and increase resilience to climate change | – UU 32/2009 concerning environmental protection and management: Regulates efforts to control pollution and environmental damage due to climate change<br>– UU 11/2020 concerning job creation: Accelerating green investment, reducing deforestation, and increasing energy efficiency |
| Government Regulation (PP) | – PP 20/2006 on irrigation<br>– PP 42/2008 on water resource management<br>– PP 38/2011 concerning procedures for granting water | – PP 17/2015 on food safety and nutrition<br>– PP 61/15: Policy for the acceleration of food consumption diversification: Encourages | – PP 5/2006 concerning National Energy Policy: Establishes biodiesel as a national energy source and encourages its development | – PP 62/2013 concerning management agency for reducing greenhouse gas emissions from deforestation, forest, and peatland degradation<br>– PP 47/2012 concerning control of environmental | – PP 22/2021 strengthens efforts to control air pollution, including GHG emissions, which contribute to climate change<br>– PP No. 44 of 2021 concerning |

| 1945 State Constitution (UUD' 45) | Sectoral Regulations on Water | Sectoral Regulations on Food | Sectoral Regulations on Energy | Sectoral Regulations on Land Change | Sectoral Regulations on Climate Change |
|---|---|---|---|---|---|
| | utilisation business permits: Regulates permits for water use for business activities, including the biofuel industry<br>– PP 37/2012 on watershed management<br>– PP 121/2015 on exploitation of water resources<br>– PP 22/2021 on water resource management<br>PP 40/2023 concerning acceleration of national sugar self-sufficiency and provision of bioethanol as biofuel | diversification of food consumption to reduce dependence on rice, including using palm oil biomass for non-rice food products<br>– PP 86/2019 on food safety<br>– PP 150/2000 concerning control of soil damage for biomass production | – PP 79/2014: Accelerating the implementation of renewable energy: Providing incentives and convenience for developing renewable energy, including biomass<br>– PP 25/2021: Implementing the energy and mineral resources sector | pollution and/or damage: Establishes environmental quality standards for various activities, including land change<br>– PP 22/2021 concerning the implementation of environmental protection and management<br>– PP 44/2021 concerning deforestation reduction: Reducing deforestation by encouraging sustainable business practices. Deforestation is one of the main causes of climate change.<br>– PP 121/2022 concerning implementation of control over the conversion of peat land: Establishes procedures for the conversion of peat land | renewable energy development: Development of renewable energy by creating a conducive investment climate, reducing GHG emissions, and combating climate change<br>– PERPU 2/2022 concerning job creation: Accelerating green investment, reducing deforestation, and increasing energy efficiency |

| 1945 State Constitution (UUD' 45) | Sectoral Regulations on Water | Sectoral Regulations on Food | Sectoral Regulations on Energy | Sectoral Regulations on Land Change | Sectoral Regulations on Climate Change |
|---|---|---|---|---|---|
| Presidential Regulation/ Decree/ Instruction (PERPRES/ KEPPRES/ INPRES) | – PERPRES 10/2017 on National Water Resources Council<br>– PERPRES 73/2012: National strategy for domestic waste processing<br>– KEPPRES 14/2015 concerning Food Security Agency<br>– PERPRES 14/2024: Development of water system infrastructure to support the energy transition | – PERPRES 22/2009 on policy to accelerate food consumption diversification based on local resources<br>– PERPRES 83/2017 on strategic policy for food and nutrition<br>– PERPRES 64/2020 concerning national strategic area spatial planning: Determining areas for developing renewable energy, including biomass, and areas for food production<br>– PERPRES 66/2021 on National Food Agency | – KEPRRES 17/2011 concerning the National Coordination Team for Renewable Energy Management<br>– INPRES 7/2016 concerning the acceleration of renewable energy development<br>– PERPRES 22/2017 on general plan for national energy<br>– INPRES 18/2018 concerning accelerating control of greenhouse gas emissions: Encouraging renewable energy, including biomass, to reduce greenhouse gas emissions | – INPRES 6/2013 concerning postponement of granting new permits and improving governance of primary natural forests and peatlands to reduce the rate of deforestation and GHG emissions<br>– PERPRES 88/2017 concerning procedures for determining and imposing administrative sanctions on business actors who commit violations in the field of pollution control and/or environmental damage: Establishes sanctions for business actors who carry out forest and land conversion without permission<br>– PERPRES 62/2023 concerning the acceleration of implementation of | – PERPRES 98/2021 concerning implementation of carbon economic value to achieve nationally determined contribution targets and control of greenhouse gas emissions in national development: Implementation of efforts to achieve NDC targets is carried out through implementing climate change mitigation and climate change adaptation<br>– Presidential Decree 14/2024 increasing climate resilience and reducing GHG emissions: Encouraging the |

| 1945 State Constitution (UUD' 45) | Sectoral Regulations on Water | Sectoral Regulations on Food | Sectoral Regulations on Energy | Sectoral Regulations on Land Change | Sectoral Regulations on Climate Change |
|---|---|---|---|---|---|
| | | – PERPRES 14/2024: Development of sustainable food infrastructure and increased adaptation to climate change that supports the energy transition | – PERPRES 64/2020 concerning national strategic area spatial planning: Determining areas for developing renewable energy, including biomass, and areas for food production<br>– PERPRES 64/2020 concerning national strategic area spatial planning: Determining areas for developing renewable energy, including biomass, and areas for food production<br>– PERPRES 112/2022 concerning the acceleration of | agrarian reform to reduce inequality in land tenure<br>– PERPRES 14/2024 concerning reducing land conversion: Regulates urban area spatial planning, which is expected to minimise land conversion | development of infrastructure that is resilient to the impacts of climate change |

| 1945 State Constitution (UUD' 45) | Sectoral Regulations on Water | Sectoral Regulations on Food | Sectoral Regulations on Energy | Sectoral Regulations on Land Change | Sectoral Regulations on Climate Change |
|---|---|---|---|---|---|
| | | | renewable energy development for the supply of electric power: Sets a national energy mix target of 23% from renewable energy by 2025, focusing on developing large-scale renewable energy, including biomass<br>– PERPRES 14/2024: Establish the Energy Transition Coordinating Body and prepare the General National Energy Plan to achieve the energy transition target | | |

| 1945 State Constitution (UUD' 45) | Sectoral Regulations on Water | Sectoral Regulations on Food | Sectoral Regulations on Energy | Sectoral Regulations on Land Change | Sectoral Regulations on Climate Change |
|---|---|---|---|---|---|
| Ministerial regulation/ Decree (PERMEN/ KEPMEN) | – Regulation/Decree from Ministry of Public Works and Human Settlements<br>– PUPR ministerial decree 14/2023 concerning technical guidelines for domestic wastewater management: Establishes technical guidelines for domestic wastewater management to support the sustainability of water resources, including supporting biomass production | – Regulation/Decree from Ministry of Agriculture (at least 12 regulations)<br>– Minister of Agriculture regulation number 13/2018 concerning guidelines for diversifying food consumption: Provides guidelines for diversifying food consumption, including using palm oil biomass for non-rice food products<br>– Minister of Agriculture regulation 38/2022 concerning guidelines for good food crop | – Regulation/Decree from the Ministry of Energy and Mineral Resources<br>– KEPMEN ESDM 22/2011 concerning retail selling prices for general types of fuel oil, diesel, and biodiesel: Determine the retail selling price of biodiesel, which the government subsidises<br>– ESDM ministerial decree 13/2021 concerning benchmark prices for purchasing biomass power electricity: Determines the purchase price of electricity from biomass power plants (PLTBm) | – Regulation of the Minister of Environment and Forestry of the Republic of Indonesia 70/2017 about procedures for implementing reducing emissions from deforestation and forest degradation, role of conservation, sustainable management of forest and enhancement of forest carbon stocks<br>– Minister of Agriculture regulation 41/2019 concerning control of the use of chemical fertilizers and pesticides: Establishes rules for the sustainable use of fertilisers and pesticides to maintain soil fertility and food security<br>– Minister of Public Works and Public Housing | – |

| 1945 State Constitution (UUD' 45) | Sectoral Regulations on Water | Sectoral Regulations on Food | Sectoral Regulations on Energy | Sectoral Regulations on Land Change | Sectoral Regulations on Climate Change |
|---|---|---|---|---|---|
| | | cultivation: Encouraging good and sustainable crop cultivation, including biomass as organic fertiliser | – ESDM ministerial decree 16/2023 concerning benchmark prices for purchases of biomass and biogas powered electricity: Determines the purchase price of electricity from PLTBm and biogas power plants<br>– ESDM ministerial decree 12/2023 concerning using biomass fuel as a fuel mixture in steam power plants | Regulation 14/2017 concerning guidelines for implementing urban drainage systems: Establishes technical requirements for drainage systems that consider water and energy security aspects<br>– Regulation of the Minister of Agrarian Affairs and Spatial Planning/Head of the National Land Agency 14/2022 concerning procedures for determining and determining sustainable food agricultural land: Regulates the determining and establishing of sustainable food agricultural land to support national food security | |

| 1945 State Constitution (UUD' 45) | Sectoral Regulations on Water | Sectoral Regulations on Food | Sectoral Regulations on Energy | Sectoral Regulations on Land Change | Sectoral Regulations on Climate Change |
|---|---|---|---|---|---|
| Provincial/ District regulation (PERDA) | – Regional regulations in each province and district/city related to renewable energy, food security, and water resources management | | | – | – |

Other policies that may be in sync are as follows:

- UU 25/2004 on Development Planning
- UU26/2007 on Spatial Planning
- Law 6/2014 on Villages
- Law 32/2009 on Environment
- Law 37/2014 on Soil and Water Conservation
- Law 11/2020 on Job Creation
- PP 5/2021 on Implementation of Risk-Based Business Licensing
- PP 62/2021 Concerning National Strategic Area Spatial Planning

Sources:
Indonesia (2016); KLHK (2016); Menteri Agraria Dan Tata Ruang/Badan Pertanahan Nasional (2022); Nugroho et al. (2022); Pemerintah Republik Indonesia (2021); Pemerintah RI (2017); Peraturan Presiden (2021); Presiden Republik Indonesia (2012, 2017, 2021, 2023b, 2024); Provinsi et al. (2015) Republik Indonesia (2008).

The government's transition programme to biofuels will require a massive increase in palm oil production. This will likely mean opening up more land to establish new palm oil plantations, leading to deforestation and other environmental risks. Indonesia's biofuel push, which includes using biomass for biofuel, must go beyond palm oil to reduce risks to the country's water, energy, and food security. Some impacts of using biomass for biofuel in Indonesia are shown in Table 4.2.

Table 4.2. Impacts of the WEF Nexus Balance on Bioenergy Production in Indonesia

| Impact | Palm Oil | Sugarcane | Rice |
|---|---|---|---|
| Water resistance | Developing biofuel from palm oil can increase pressure on water resources because intensive irrigation is required for palm oil farming. | Developing biofuel from sugar cane can reduce pressure on water resources because it does not require intensive irrigation like palm oil farming. Still, it can disrupt local water ecosystems and cause problems related to water quality if not managed properly. | Rice production requires much water, especially in the plant growth phase. If rice is diverted for bioethanol production, it could increase water use in the energy sector. This could affect water availability, especially in areas with high water pressure. (Source: Food and Agriculture Organization) |
| Food security | The use of palm oil for biofuel can compete with food production due to competition for land. Diversifying biofuel feedstocks is important to reduce pressure on food production. | Using sugar cane for bioethanol can compete with food production due to land competition. However, sugar cane can be grown on land unsuitable for food production, reducing pressure on food production. | Shifting the use of rice from food consumption to bioethanol production could have an impact on food security in Indonesia. Rice availability and rice prices may be affected by this shift, especially in areas that depend on rice as a staple food source. |

| Impact | Palm Oil | Sugarcane | Rice |
|---|---|---|---|
| Energy Security | The use of biofuels can help reduce dependence on imported fossil fuels.<br>Land conversion for oil palm cultivation can compete with food production, increasing prices.<br>Unsustainable use of biofuels can cause environmental damage. | The government has provided policy support for biofuel development from sugar cane to reduce deforestation and dependence on imports of fossil fuels. | Using rice biomass for bioethanol production can diversify Indonesia's energy sources, directly supporting energy security. However, it is important to consider the social and environmental impacts of using rice as an alternative fuel. |
| Land changes | The development of oil palm plantations causes significant land changes, including deforestation and degradation of natural habitats. This can reduce biodiversity and ecosystem services and accelerate the loss of environmental balance. | Developing a bioethanol industry from sugar cane can reduce pressure on land and climate change because sugar cane can be planted on land unsuitable for food production. However, sugar cane cultivation must be carried out sustainably and not cause deforestation or land degradation.<br><br>Using sugarcane biomass for bioethanol can reduce greenhouse gas emissions because bioethanol from sugarcane has a smaller carbon | Conversion of agricultural land for rice production into land for producing rice biomass for bioethanol can cause significant land changes. This could include deforestation or conversion of forest land or peatlands important for biodiversity and ecosystem balance. These changes can increase vulnerability to natural disasters and reduce natural resources important to local communities. (Source: Center for International Forestry Research) |
| Climate change | Land changes due to the development of oil palm | | The production and use of bioethanol from rice biomass |

| Impact | Palm Oil | Sugarcane | Rice |
|---|---|---|---|
| | plantations can cause greenhouse gas emissions and increase carbon dioxide levels in the atmosphere. In addition, the production and transportation process of palm oil biofuel can also produce additional carbon emissions. | footprint than fossil fuels. | can affect climate change. Using bioethanol as fuel can reduce overall greenhouse gas emissions if produced sustainably. However, land conversion for rice biomass production can also lead to the release of carbon from disturbed soil and vegetation, causing additional carbon emissions. (Source: United Nations Environment Program) |
| Overshadowing policy | – National Action Plan for Sustainable Palm Oil (RAN KSB) 2019-2024: Determines targets and strategies for sustainable palm oil development, including supporting biodiesel production.<br>– Indonesia Sustainable Palm Oil (ISPO): Sustainability certification for palm oil plantations that promotes environmentally and socially | – National Bioethanol Action Plan 2010-2025: Determines targets and strategies for bioethanol development, including supporting national energy security.<br>– Indonesia Sustainable Cane Sugar (ISCS): Sustainability certification for sugar cane plantations that promotes environmentally and socially | – National Bioethanol Action Plan 2010-2025: Determines targets and strategies for bioethanol development, including supporting national energy security.<br>– Indonesia Sustainable Rice Platform (ISRP): Sustainability certification for rice cultivation that promotes environmentally and socially friendly cultivation practices. |

| Impact | Palm Oil | Sugarcane | Rice |
|---|---|---|---|
| | friendly cultivation practices. | friendly cultivation practices. | |

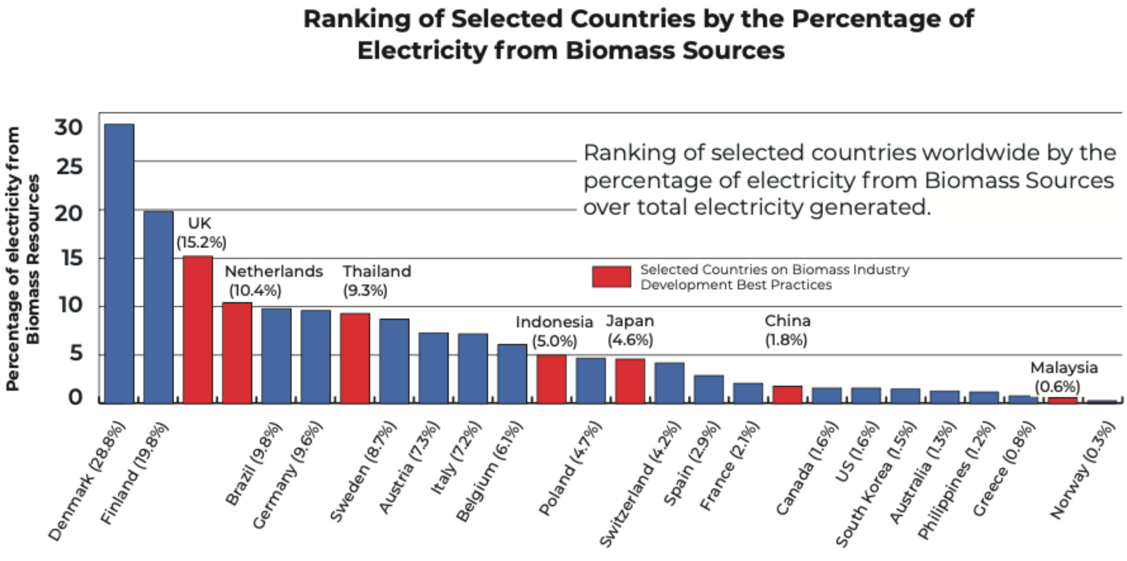
Sources: Kharina et al. (2016); Haryanto and Filda Citra Yusgiantoro (2021)

## 4.3 Malaysia

In Malaysia, the share of direct renewable energy use is rather small, at approximately 1%. This is primarily due to the use of biodiesel, which makes up 1.5% of the transportation sector's overall final energy consumption. 20% of the final consumption is made up of electricity (IRENA, 2023). Of this capacity, more than 7 MW was used in off-grid systems in 2021. Solid biofuels had a significant installed capacity from 2013 to 2016, but after that, it started to decrease, reaching 774 MW by the end of 2021. In contrast, biogas systems are growing quickly, with an estimated 120 MW of installed capacity by 2021 (IRENA 2023). Major energy policies have been implemented by Malaysia. The 1990 introduction of the Electricity Supply Act was followed by its 2015 amendment. The Energy Commission Act was introduced in 2001 then revised in 2010. In 2010, the Malaysia New Energy Policy and the National Renewable Energy Policy and Action Plan were introduced. In 2011, the Sustainable Energy Development Authority (SEDA) Malaysia and Renewable Energy Acts were introduced. The National Energy Efficiency Action Plan was introduced in 2015.

In terms of bioenergy, Malaysia has carried out a project for the transportation sector to blend biodiesel under the National Biofuel Policy, which was put into effect in 2006. The practice of blending biofuels for use in vehicles began in 2010, and within five years, the percentage of biodiesel blended was 7%. With a blending mandate of B10 (10% biodiesel) for the road transport sector and B7 for industrial use, Malaysian biodiesel now serves both the domestic and export markets (Wahab, 2021). The Covid-19 pandemic compounded supply chain problems and caused the 2020 B20 blending objective to be postponed. In order to encourage energy-intensive companies to use more biomass in their energy consumption, a more comprehensive National Biomass Industry Action Plan was created (GoM, 2013).

Figure 4.1. Ranking of Electricity from Biomass Sources of Selected Countries




Source: IEA

**Summary of Key Statistics for the Selected Countries**

| | Malaysia | Thailand | Japan | China | Indonesia | United Kingdom | The Netherlands |
|---|---|---|---|---|---|---|---|
| **Population (2021)** | 33.57 million | 71.6 million | 125.7 million | 1.412 billion | 273.7 million | 67.33 million | 17.53 million |
| **GDP per capita (2021)** | USD 11,109 | USD 7,066 | USD 39,312 | USD 12,556 | USD 4,333 | USD 46,510 | USD 57,767 |
| **GDP (2021)** | USD 373 million | USD 505.9 million | USD 4.941 trillion | USD 17.73 trillion | USD 1.187 million | USD 3.133 trillion | USD 1.013 trillion |
| **Percentage of agricultural land (2020)** | 26% | 45% | 12% | 56% | 33% | 71% | 54% |
| **Percentage of electricity from biomass (2021)** | 0.6% | 9.3% | 4.6% | 1.8% | 14.7% | 15.2% | 10.4% |
| **RE Target mix** | 31% by 2025 | 30% by 2037 | 36-38% by 2030 | 25% by 2030 | 23% by 2023 | 50% by 2030 | 16% by 2023 |

Source:
World Bank, IEA, NRECC, Thailand AEDP, Japan METI, UK Committee Climate Change, Ministry of Economic Affairs and Climate Policy (The Netherlands), National Energy Administration (NEA) China

Source: International Energy Agency (IEA).

The Green Technology Master Plan was introduced in 2017, and it is valid until 2030. With the exception of major hydropower, Malaysia intends to raise the amount of renewable energy in the overall generation mix to 20% by 2020 (2,080 MW), 23% by 2025, and 30% by 2030 (4,000 MW). 7.3 GW is anticipated to come from solar PV under the New Capacity Target scenario of the Malaysia Renewable Energy Roadmap (SEDA Malaysia, 2021), which was launched at the end of 2021 and lays out strategies and an action plan to meet the target of 40% renewable energy installed capacity, or 18 GW, by 2035 (SEDA Malaysia, 2021).

For the upcoming years, every utility provider in Malaysia has created a plan of action. TNB in Peninsular Malaysia has declared its intention to achieve net zero by 2050 by implementing a sustainable pathway to lower its emissions intensity by 35% and half its coal generation capacity by 2035. TNB has set a target of 20% renewable energy capacity by 2025 (IRENA, 2023). The government also seeks to achieve the following other objectives: least-cost dispatch (to encourage market liberalisation to lower transmission and distribution costs); optimal generation expansion plan (to improve service reliability at minimal cost); and fuel portfolio diversification (to balance affordable electricity and energy security). The Incentive Based Regulation (IBR) mechanism is a tariff price-setting mechanism for affordable and secure energy supply in a deregulated market.

In Peninsular Malaysia, solid waste, small hydropower, biomass, biogas, geothermal, and solar energy are all sources of renewable energy. Large hydropower facilities with a capacity of more than 100 MW are not regarded as renewable energy sources. In addition to boosting solar generation capacity, TNB's goal of 20% renewable energy capacity by 2025 also aims to open up new economic prospects for large corporations, small and medium-sized businesses, microbusinesses, and consumers.

Peninsular Malaysia's most recent generation development plan, which covers the years 2021–2039, raises the baseline target of 20% (excluding large hydropower plants) to 31% by the year 2025 (IRENA, 2023). By 2035, the percentage of renewable energy in the capacity mix is expected to rise to 40%. This means that by 2025, Peninsular Malaysia will need to add 1,178 MW of new capacity, the majority of which will come from solar PV. Between 2026 and 2035, another 2,414 MW of capacity will need to be added. By 2025, there would be 8,531 MW of installed renewable energy capacity, and by 2035, there would be 10,944 MW.

According to the plan, natural gas's proportion is predicted to slightly rise from 45% to 47%, whilst coal's share is predicted to decrease from 37% in 2021 to 22% in 2039. With a capacity of 8,531 MW, Peninsular Malaysia would contribute 26% of the 31% share of renewable energy, whilst East Malaysia would contribute 5%. Despite the energy sector's perception that this is an ambitious goal, much more may be done given the nation's considerable resource potential, which would also present investment opportunities.

Since Sabah's grid is heavily dependent on natural gas due to an outdated fleet, its goals differ from other grids. Planning and development for renewable energy also face obstacles. The grid's electricity supply is heavily subsidised by the government. To maintain a stable supply of power to satisfy rising demand, Sabah's grid is working to find solutions to these problems. Through network extension and connecting projects, the Sabah grid seeks to enhance the availability of power. In addition, it aims to raise the proportion of renewable energy sources, particularly solar photovoltaic plants, which will aid in lowering the intensity of greenhouse gas emissions.

By implementing the Sabah grid in Peninsular Malaysia, the IBR is intended to be introduced. Furthermore, the energy ministry declared in 2019 that by 2025, it aimed to achieve an 8% reduction in energy consumption through energy efficiency initiatives and a 20% share of renewable energy in the Sabah grid. Initiatives include the design of micro-grid frameworks specific to the Sabah grid and project monitoring for rural electrification (IRENA, 2023).

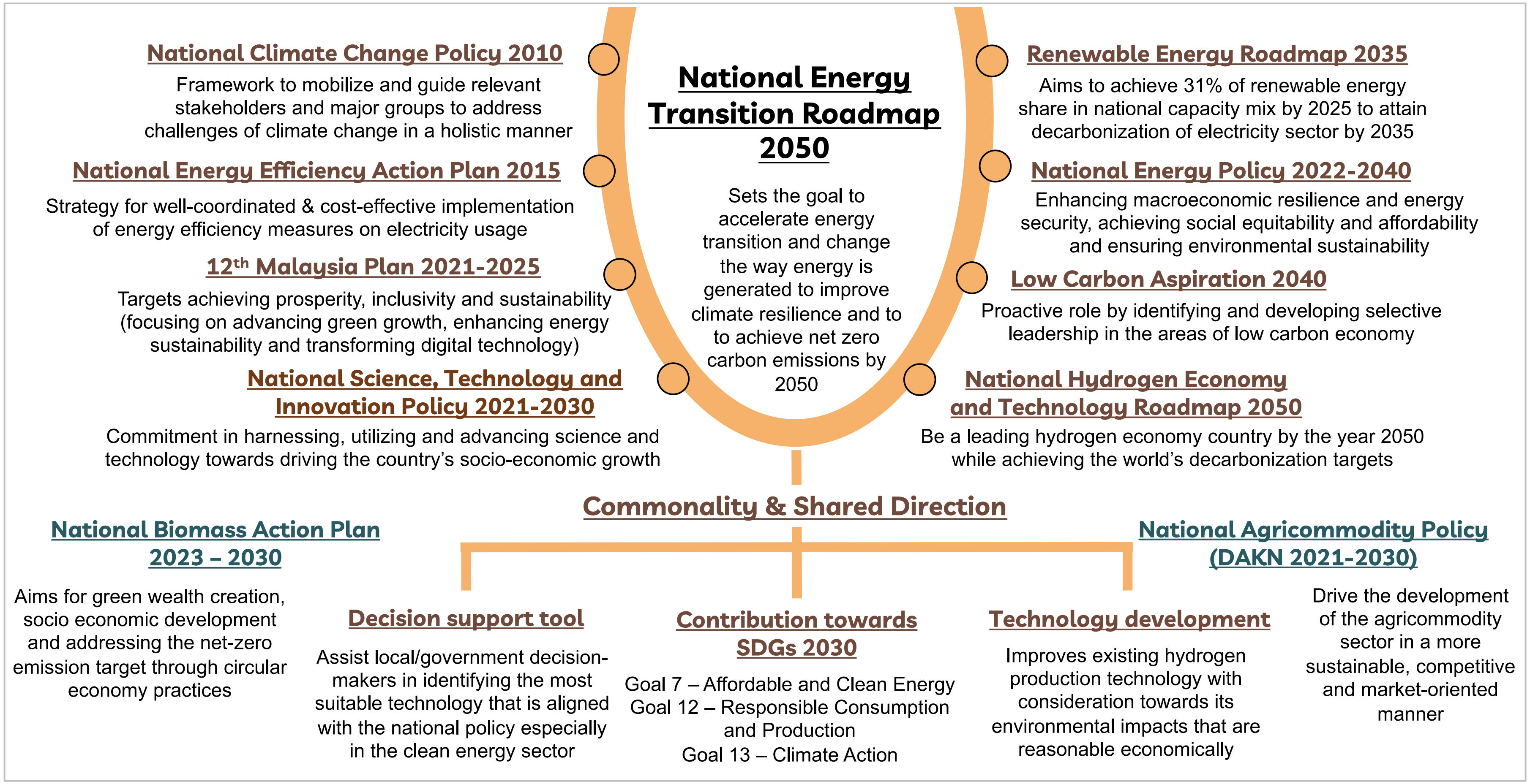
Efforts are being made to address these challenges and improve the sustainability of the oil palm industry within the WEF Nexus. This includes implementing best management practices, promoting water-efficient irrigation techniques, and adopting sustainable land-use practices. The government and industry stakeholders are also working towards reducing the environmental impact of oil palm cultivation and ensuring the industry's long-term viability within the WEF Nexus.

Overall, the report underscores the importance of managing the oil palm industry within the context of the WEF Nexus. It emphasises the need for sustainable water management, responsible agricultural practices, and environmentally friendly energy production to ensure the long-term viability of the oil palm sector in Malaysia. In Malaysia, the policy measures for oil palm linkages with the WEF Nexus include the following:

1. National Policy on the Environment: This policy aims to ensure sustainable development and conservation of the environment, including the water resources and biodiversity affected by oil palm cultivation. It emphasises the need for integrated planning and management of land use, water resources, and energy to minimise negative impacts.
2. National Policy on Agriculture: This policy recognises the importance of the agriculture sector, including oil palm cultivation, in ensuring food security and economic development. It promotes sustainable agricultural practices, including the efficient use of water and energy resources, to enhance productivity and minimise environmental degradation.
3. National Water Resources Policy: This policy focuses on the sustainable management and conservation of water resources. It emphasises the need for integrated water resources management, including the consideration of water availability and quality in land-use planning, such as oil palm cultivation. The policy encourages the adoption of water-efficient irrigation techniques and the reduction of water pollution from agricultural activities.

4. National Energy Policy: This policy aims to ensure the availability, affordability, and sustainability of energy resources in Malaysia. It promotes the use of renewable energy sources, including biomass from oil palm residues, to reduce dependence on fossil fuels. The policy encourages the development of sustainable bioenergy production from oil palm whilst considering the potential impacts on water and food resources.
5. National Biodiversity Policy: This policy focuses on the conservation and sustainable use of biodiversity in Malaysia. It recognises the importance of protecting natural habitats, including forests, affected by oil palm cultivation. The policy promotes the adoption of sustainable land management practices, such as agroforestry and biodiversity-friendly farming, to minimise biodiversity loss and enhance ecosystem services.

Figure 4.2. Existing and Initiatives and Policies in Malaysia




Source: Authors.

Table 4.3. Existing and Current Initiatives and Policies in Malaysia

| Title | Year | Aim | Agency |
|---|---|---|---|
| Water | | | |
| Water Sector Transformation 2040 | 2023 | Aspires to transform the national water sector into a dynamic and vibrant economic sector that can contribute more significantly to GDP and provide good quality affordable water to the Rakyat as well as create new job opportunities and facilitate resilient development of Science, Technology, Innovation and Economics (STIE) in the sector. | Ministry of Economy, Ministry of Energy Transition and Water Transformation, Academy of Sciences Malaysia |
| National Integrated Water Resources Management Plan | 2016 | In as far as water and sewerage services are concerned, the Ministry of Energy, Green Technology and Water (KeTTHA), with support from the National Water Services Commission (SPAN), has set targets for improvements by 2020. The three targeted areas are a reduction in non-revenue water (NRW) to 25%, reduction in per capita demand of water to 180 litres per day, and establishing a tariff setting mechanism for Peninsular Malaysia and WP Labuan that is fair and transparent. The aim is to harmonise the tariff structure by 2020. | Academy of Sciences Malaysia |
| Energy | | | |
| National Energy Transition Roadmap (NETR) 2050 | 2023 | The NETR sets ambitious targets for Malaysia, aiming to achieve net-zero emissions by 2050. The plan | Ministry of Economy |

| Title | Year | Aim | Agency |
|---|---|---|---|
| | | is comprehensive and outlines a gradual increase in renewable energy shares, targeting 31% by 2025, 40% by 2035, and an impressive 70% by 2050. To reduce high reliance on natural gas (extracted or imported), renewable energy should be scaled up to 70% of installed capacity of the power mix. | |
| National Energy Policy 2022–2040 (NEP) | 2022 | The NEP has clearly laid out the roadmap for Malaysia to achieve the Aspiration targets by the year 2040 and improve its socio-economic position and is in line with its other policies to achieve net-zero GHG emissions by 2050. To reach these targets by 2040, the NEP sets four strategic goals: optimising energy resources to help with sustainable economic growth; stimulating growth, market opportunities, and cost advantages for the economy and people; increasing the energy sector's input to environmental sustainability; and ensuring energy security and delivering financial sustainability. The NEP also incorporates 31 action plans under these four goals. | Economic Planning Unit, Prime Minister's Department |
| Malaysia Renewable Energy Roadmap (MyRER) 2035 | 2021 | Decarbonise the electricity supply sector, increasing RE installed capacity from 23% (8.5 GW) in 2020 to 31% (12.9 GW) by 2025 and 40% (18 GW) by 2035. Increasing RE capacity targets aim to cut electricity sector carbon | Sustainable Energy Development Authority (SEDA) Malaysia |

| Title | Year | Aim | Agency |
|---|---|---|---|
| | | emissions by 45% in 2030 and 60% in 2035. | |
| National Energy Efficiency Action Plan | 2015 | Strategy for well-coordinated and cost-effective implementation of energy-efficiency measures on electricity usage. | Ministry of Energy, Green Technology and Water |
| **Food** | | | |
| National Agricommodity Policy 2021–2030 (DAKN) | 2021 | Drives the development of the agricommodity sector in a more sustainable, competitive, and market-oriented manner. Focuses on promoting agricommodity-based industries and increasing the adoption of the circular economy. | Ministry of Plantation Industries and Commodities |
| National food Security Policy Action Plan 2021–2025 | 2021 | A specific action plan to strengthen national food securities has been developed taking into account issues and challenges along the food supply chain, ranging from agricultural inputs to food waste. The National Food Security Policy (DSMN Action Plan) 2021–2025, covering 5 core strategies, 15 strategies, and 96 initiatives, will ensure the sustainability of the country's food supply at all times, especially in the face of unexpected situations. | Ministry of Agriculture and Food Security/Industries |
| National Agrofood Policy 2021–2030 (NAP 2.0) | 2021 | This policy supports the aspirations and future direction of the national agrofood sector to be more sustainable, resilient, and highly technology driven. It aspires to drive economic growth and improve the wellbeing of the people | Ministry of Agriculture and Food Security/Industries |

| Title | Year | Aim | Agency |
|---|---|---|---|
| | | whilst prioritising national food security and nutrition. Five policy thrusts have been formulated with emphasis on modernisation and smart agriculture; strengthening market and product access; human capital development; food system sustainability; as well as creating conducive business ecosystems and governance. | |
| National Agrofood Policy 2011–2020 (NAP 1.0) | 2011 | This policy aimed to address the challenges faced by the agricultural sector, especially in meeting the demand for agro-food products in the domestic and global markets. The objectives were increased production, competitiveness, and sustainable production. | Ministry of Agriculture and Food Security/Industries |
| National Agricultural Policy III (NAP III) 1998–2010 | 1998 | NAP III was formulated to address the challenges faced by the sector such as, the economic structure changes due to lack of arable land, shortage of labour due to competition with other sectors, the efficiency and the utilisation of resources to improve competitiveness. | Ministry of Agriculture Malaysia |
| National Agricultural Policy II (NAP II) 1992–1997 | 1992 | This policy aimed to address the challenges faced by the agricultural sector, especially in meeting the demand for agro-food products in the domestic and global markets. The objectives were increased production, competitiveness, and sustainable production. | Ministry of Agriculture Malaysia |

| Title | Year | Aim | Agency |
|---|---|---|---|
| National Agricultural Policy I (NAP I) 1984–1991 | 1984 | NAP I was implemented with a focus on export-oriented development and designed to ensure a balanced and sustained rate of growth in the agricultural sector vis-à-vis other sectors in the economy. The policy objectives of the NAP were aimed specifically at maximising income from agriculture through effective and efficient utilisation of the country's resources and revitalisation of the sector's contribution to the national economy. | Ministry of Agriculture Malaysia |
| Land | | | |
| National Biomass Action Plan 2023–2030 | 2023 | Generate significant sustainable development benefits in terms of green wealth creation, socio-economic development, and addressing the net-zero emissions target through circular economy practices. By 2025, it is expected that various institutional enablers will be further strengthened, and by the year 2030, it is envisioned that the Plan will contribute to an incremental RM17 billion in economic value and generate around 33,000 jobs based on the desired results areas of the Plan. | Ministry of Plantation and Commodities |
| Malaysia Forestry Policy | 2021 | Ensure that at least 50% of land area will remain permanently under forest cover. | National Land Council |
| Malaysian Biomass Industry Action Plan 2020 | 2020 | The Biomass Industry Action Plan 2020 aims to provide a common direction and | Malaysian Industry-Government Group |

| Title | Year | Aim | Agency |
|---|---|---|---|
| | | concerted strategy and action plan to drive the growth of SMEs. | for High Technology (MIGHT) |
| National Biomass Strategy 2020 | 2013 | Assess how Malaysia can develop new industries and high-value opportunities by utilising agricultural biomass for high-value products, starting with oil palm biomass. | Agensi Inovasi Malaysia (AIM) |
| Climate | | | |
| National Climate Change Policy | 2010 | Framework to mobilise and guide relevant stakeholders and major groups to address the challenges of climate change in a holistic manner. | Ministry of Natural Resources and Environment |

Source: Authors' data compilation.

### *4.3.1 Existing and current initiatives and policies in Malaysia and their interconnections with the five sectors*

A. National Energy Policy (NEP) 2022–2040 and Water Sector Transformation 2040 (WST2040) Policy

The NEP sets a target to increase the total installed capacity of renewable energy to 18,431 MW by 2040. This aligns with the WST2040's focus on applying smart and sustainable water infrastructure, including the integration of renewable energy sources. Both policies address the need to strengthen climate change adaptation measures for the water and energy sectors. The WST2040 provides strategic inputs and national strategies to enhance adaptive capacity and build resilience in the water sector. This complements the NEP's objective of ensuring environmental sustainability.

Ensuring environmental sustainability is a key objective in both the WST2040 and NEP 2022–2040. The WST2040 focuses on climate change adaptation and implementing the WEF Nexus. The NEP 2022–2040 aims to drive environmental sustainability to future-proof the economy and improve living standards.

The WST2040 emphasises the importance of establishing an Integrated Water Sector Data Centre to facilitate data-driven decision-making, research, and development in the water sector. This supports the NEP's focus on capturing economic benefits and remaining globally competitive by keeping pace with energy transition trends.

Enhancing data integration and evidence-based decision-making is a priority in both policies. The WST2040 emphasises strengthening data integration and establishing water footprint and virtual water inventory to support sustainable water resources management. The NEP 2022–2040 also highlights the importance of data-driven decision-making in the energy sector.

The WST2040 explores alternative financing mechanisms to ensure the long-term sustainability of the water sector, which can also benefit the energy sector's transition. This aligns with the NEP's aim to catalyse strong economic growth and fiscal health. Both policies recognise the need to adopt smart technologies and digitalisation to improve efficiency and sustainability. The WST2040 proposes increasing digitalisation and connectivity through water digitalisation and IR 4.0 solutions. The NEP 2022–2040 similarly aims to leverage technology and innovation to drive the energy transition. Both policies emphasise the importance of stakeholder engagement and public awareness. The WST2040 aims to empower people and strengthen engagement with the public. The NEP 2022–2040 also highlights the need for fair and equitable distribution of costs and benefits from the energy transition.

### B. Malaysia Renewable Energy Roadmap (MyRER) 2035 and Water Sector Transformation 2040 (WST2040) Policy

Both initiatives aim to transform their respective sectors towards sustainable development and economic growth over a long-term period. The WST2040 spans 20 years, whilst MyRER 2035 focuses on renewable energy development until 2035. The water and energy sectors are inherently linked, as water is required for energy production (e.g. hydropower, thermal power plants) and energy is needed for water treatment and distribution. MyRER 2035 and the WST2040 both recognise this water-energy nexus and aim to address the interdependencies between the two sectors.

The MyRER 2035 roadmap outlines strategies to increase the share of renewable energy in Malaysia's power generation mix, which will have implications for the water sector. Increased RE integration, especially from variable sources like solar and wind, will require the water sector to adapt in terms of water management and infrastructure to maintain grid stability.

Both initiatives outline phased approaches with specific strategies, initiatives, and programmes to guide the transformation of the water sector and renewable energy sector. The WST2040 is structured in four phases, whilst MyRER 2035 includes scenarios and pathways to achieve renewable energy targets. The WST2040 emphasises Integrated Water Resources Management (IWRM) to ensure water security and sustainable development. Similarly, MyRER 2035 focuses on reducing GHG emissions and transitioning towards a low-carbon energy system.

Both MyRER 2035 and the WST2040 acknowledge the need to address climate change impacts on the energy and water sectors, respectively. The roadmaps aim to enhance the resilience of these sectors through strategies like improving water infrastructure, promoting water conservation, and diversifying energy sources.

The overarching goals of MyRER 2035 and the WST2040 are aligned with Malaysia's sustainable development agenda. Both roadmaps seek to balance environmental, economic, and social considerations in the transformation of the energy and water sectors. The WST2040 emphasises the need to establish an integrated water sector data centre to facilitate data-driven decision-making. This centralised data platform could also benefit the energy sector by providing integrated water-energy data to support planning and operations.

Collaboration between the public and private sectors is a key aspect of both policies. The WST2040 establishes a dedicated taskforce comprising members from both sectors to guide and monitor progress, whilst MyRER 2035 highlights the importance of aligning with current energy trends and reviewing targets for renewable energy development.

### C. National Biomass Action Plan (NBAP) 2023–2030 and National Climate Change Policy (NCCP)

Both the NBAP and NCCP aim to support Malaysia's transition to a low-carbon and sustainable economy. The NBAP emphasises the circular economy concept and reducing greenhouse gas emissions, whilst the NCCP focuses on strengthening actions towards a low-carbon nation. The NBAP includes plans for co-firing biomass pellets with coal in power stations to contribute to Malaysia's sustainable energy goals. Similarly, the NCCP aims to enhance the use of renewable energy sources.

The NBAP is expected to help Malaysia meet its net-zero emissions target, whilst the NCCP focuses on increasing resilience against climate change and disaster.

Both policies emphasise the importance of green financing and investments. The NCCP mentions initiatives, such as the Sustainable and Responsible Investment Taxonomy and the Climate Change and Principle-based Taxonomy, which are relevant to the biomass industry. The NBAP calls upon all stakeholders to collaborate in supporting and implementing the plan, whilst the NCCP aims to instil a sense of ownership and shared responsibility in addressing environmental challenges.

### D. National Energy Policy (NEP) 2022–2040 and National Climate Change Policy

The NEP aims to achieve a low-carbon nation by 2040, which aligns with the National Climate Change Policy's goal of achieving net-zero GHG emissions by 2050. This shared aspiration underscores the importance of reducing carbon emissions and transitioning to cleaner energy sources.

The NEP targets a significant reduction in GHG emissions, which is a key component of the National Climate Change Policy. The NEP aims to reduce the percentage of coal in installed capacity and increase the use of renewable energy sources, both of which contribute to lowering GHG emissions. The NEP and National Climate Change Policy both emphasise the need for an energy transition driven by technological advancements and strong climate change policies. This transition aims to enhance environmental sustainability and reduce reliance on non-renewable energy sources. Both policies recognise the economic benefits of transitioning to cleaner energy sources. The NEP aims to leverage the energy sector as a catalyst for investments and economic growth, whilst the National Climate Change Policy seeks to achieve strong economic benefits from energy transition.

### E. Water Sector Transformation 2040 (WST2040) Policy and National Energy Transition Roadmap (NETR) 2050 Policy

Both policies emphasise the importance of sustainability and resilience in the face of challenges like climate change. The WST2040 addresses climate change adaptation strategies, whilst the NETR aims to reduce GHG emissions from the energy sector by 32% by 2050. Both policies recognise the need for integrated planning and governance across different sectors and stakeholders. The WST2040 promotes empowering water governance at the federal, state, and local levels towards Integrated Water Resources Management (IWRM), whilst the NETR calls for establishing a National Energy Council for holistic planning and policy development.

Both policies highlight the role of technology and innovation in transforming their respective sectors. The WST2040 emphasises the application of smart technology and sustainable water infrastructure, whilst the NETR identifies technology and infrastructure as a key enabler for an effective energy transition.

Both policies underscore the importance of data access, integration, and research and development to support evidence-based decision-making. The WST2040 aims to enable data access and integration to promote data-based decision-making, whilst the NETR calls for determining national energy technology priorities and enhancing future-proof skills across the energy sector workforce.

Both policies recognise the need for sustainable financing mechanisms to support long-term development. The WST2040 examines alternative financing mechanisms for the water sector, whilst the NETR emphasises driving smart public and private investments for large energy infrastructure development.

### F. Water Sector Transformation 2040 (WST2040) Policy and National Agricommodity Policy 2021–2030 (DAKN)

Both policies emphasise the importance of sustainable practices. The WST2040 aims to transform the water sector to ensure water security for all, whilst DAKN 2030 focuses on leading the way in sustainable production and consumption and scaling up the circular economy.

Both policies recognise the importance of technological advancements. The WST2040 proposes adopting smart technological solutions, increasing digitalisation, and implementing IR 4.0 in various water sub-sectors. Similarly, DAKN 2030 aims to accelerate productivity through research and development (R&D), commercialisation and innovation (C&I), and technology application.

Both policies emphasize the need to strengthen data integration and governance. The WST2040 aims to enhance the capacity of data-driven decision-making and strengthen governance at all levels. DAKN 2030 also focuses on increasing efficiency for maximum impact through impactful delivery.

Both policies aim to promote inclusiveness. The WST2040 focuses on empowering people and strengthening the participation of local communities in water and sanitation management. DAKN 2030 aims to increase inclusiveness and ensure fairer wealth distribution.

Both policies recognise the importance of addressing climate change. WST2040 focuses on climate change impacts and adaptation in the water sector, while DAKN 2030 prioritises sustainability from an environmental perspective.

### G. Water Sector Transformation 2040 (WST2040) Policy and National Biomass Action Plan (NBAP) 2023–2030

Both policies emphasise the importance of stakeholder engagement and collaboration. The WST2040 aims to create a mindset shift for collective well-being through sufficient engagement platforms, whilst the NBAP highlights the need for coordination between government and industry, as well as collaboration between industry and academia.

Both policies aim to strengthen governance and management in their respective sectors. The WST2040 focuses on empowering water governance at the federal, state and local government levels towards IWRM, whilst the NBAP is built on a dynamic ecosystem that integrates planning, regulation, and reassessment of the biomass sector.

Both policies recognise the importance of technology and innovation. The WST2040 promotes the application of smart technology and sustainable water infrastructure to support long-term development and resilience in the water sector, whilst the NBAP aims to streamline the nation's biomass supply chain through the establishment of a biomass hub.

Both policies emphasise the need for data-driven decision-making. The WST2040 aims to enable data access and integration to promote data-based decision-making and encourage research and development in the water sector, whilst the NBAP is expected to contribute significantly to Malaysia's sustainable energy goal of achieving a 70% power generation energy mix by 2050.

Both policies aim to transform their respective sectors into dynamic economic contributors. The WST2040 focuses on enhancing public and private sector cooperation towards making water a dynamic economic sector, whilst the NBAP is expected to create job opportunities, boost household income, particularly for small-scale farmers, and contribute significantly to the nation's sustainable energy agenda.

### H. Water Sector Transformation 2040 (WST2040) Policy and National Climate Change Policy

The WST2040 policy acknowledges the impact of climate change on the water sector and the need for adaptation measures, which is a key aspect of the National Climate Change Policy.

The WST2040 policy's focus on the WEF Nexus is closely related to the National Climate Change Policy's emphasis on addressing the interlinkages between energy, water, and food security in the context of climate change. Both policies promote the development of sustainable infrastructure, including in the water sector to support climate-resilient development and mitigate the impacts of climate change.

The WST2040 policy's emphasis on enhancing the capacity for data-driven decision-making is also relevant to the National Climate Change Policy, which requires accurate data and information to inform climate change mitigation and adaptation strategies. Both policies recognise the importance of international cooperation and collaboration in addressing global challenges like climate change and water security.

### I. National Food Security Policy Action Plan 2021–2025 and National Biomass Action Plan 2023–2030

Both plans emphasise the importance of a circular economy approach. The National Biomass Action Plan focuses on reducing GHG emissions through circular economy practices, whilst the National Food Security Policy Action Plan likely addresses sustainability and resource efficiency within the food sector.

Both plans view their respective sectors as economic catalysts. The National Biomass Action Plan aims to boost the economy through the biomass industry, creating job opportunities and enhancing household income. Similarly, the National Food Security Policy Action Plan seeks to strengthen the economy by ensuring food security and sustainability.

Both plans prioritise environmental sustainability. The National Biomass Action Plan aims to address environmental concerns and reduce GHG emissions, whilst the National Food Security Policy Action Plan includes measures to promote sustainable agricultural practices and reduce environmental impacts.

Both plans focus on generating employment opportunities. The National Biomass Action Plan expects to create thousands of jobs in the biomass industry, whilst the National Food Security Policy Action Plan includes strategies to support employment in the food and agriculture sectors.

Both plans emphasise resource efficiency. The National Biomass Action Plan aims to utilise biomass resources effectively, whilst the National Food Security Policy Action Plan focuses on optimising food production and distribution to ensure efficient resource use.

### J. Malaysia Forestry Policy and National Climate Change Policy

The Malaysia Forestry Policy focuses on managing forest resources for social, economic, and environmental benefits, including maximising the use of forest land, promoting sustainable forest development, and ensuring the efficient utilisation of forest resources, whilst the National Climate Change Policy aims to mainstream climate change considerations into national policies, enhance environmental conservation, and strengthen economic competitiveness whilst addressing the impacts of climate change.

Both policies emphasise the importance of sustainable practices, such as sound forest management, the conservation of biological diversity, and reducing GHG emissions to mitigate climate change effects. The Malaysia Forestry Policy's focus on sustainable forest management aligns with the National Climate Change Policy's goal of strengthening resilience against climate change impacts and reducing environmental degradation.

### K. Malaysia's climate policy and net-zero targets

Aiming for a 45% decrease in GHG emissions intensity (tonnes of $CO_2$ emissions per unit of GDP) by 2030 compared to 2005, Malaysia's Intended Nationally Determined Contribution (INDC) was submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015. It is divided into a 35% unconditional aim and a

10% conditional target if developed countries provide climate finance, technology transfer, and capacity building to the nation (GoM, 2015).

The unconditional target was raised to 45% in July 2021 by the cabinet, a 10-percentage point increase over the previous NDC (GoM, 2021). Malaysia's prime minister pledged in September 2021 to cease construction of new coal-fired power plants after 2040 and set a target for the nation to become carbon neutral as early as 2050 (IRENA, 2023).

In addition to announcing that it will boost its investments in renewable energy, Malaysia's state-owned PETRONAS oil and gas firm set a goal in 2016 to become a net-zero emitter of greenhouse emissions by 2050. PETRONAS announced on 5 November 2020 that it will keep up its efforts to reduce Scope 1 and Scope 2 emissions from its assets. It will do this by implementing innovative operations and technologies, as well as by continuously improving operational excellence (PETRONAS, 2020).

CIMB, the second-largest asset-based lender in Malaysia, has pledged to eliminate coal from its portfolio by 2040 and to stop financing new coal mines and generators as early as 2021 (Reuters, 2020). TNB declared in August 2021 that it aimed to achieve net-zero emissions by the year 2050 through the implementation of a sustainable pathway that would lower its emissions by 35% and its coal generation capacity by 50% by 2035 (TNB, 2021). Furthermore, in an effort to create greener portfolios and investments, national investment arms like Khazanah Nasional and Permodalan Nasional Berhad (PNB) have committed to net-zero aims by 2050 (Khazanah, 2022; PNB, 2022).

In order to help businesses offset their pollution footprints and meet climate targets, Bursa Malaysia launched the Bursa Carbon Exchange on 9 December 2022. This voluntary carbon exchange allows enterprises to trade voluntary carbon credits from climate-friendly projects and solutions. The first auction was scheduled to begin in March 2023; initiatives that help prevent, minimise, or eliminate greenhouse gas emissions and are based on technology and the environment are allowed to be traded (Bursa Malaysia, 2022; IRENA, 2023).

These policies highlight the importance of considering the interconnections between water, food, and energy in the context of oil palm cultivation in Malaysia. They aim to promote sustainable practices that minimise negative impacts on water resources, food production, and energy sustainability whilst ensuring economic development and food security. The generation of bioenergy is significantly influenced by the WEF Nexus. The goal of the WEF Nexus framework is to optimise the use and management of water, energy, and food systems whilst acknowledging their connection. Several nations have adopted the WEF Nexus approach to ensure food and energy security whilst upholding the connection between environmental preservation and socio-economic advancement (Llanaj et al., 2023).

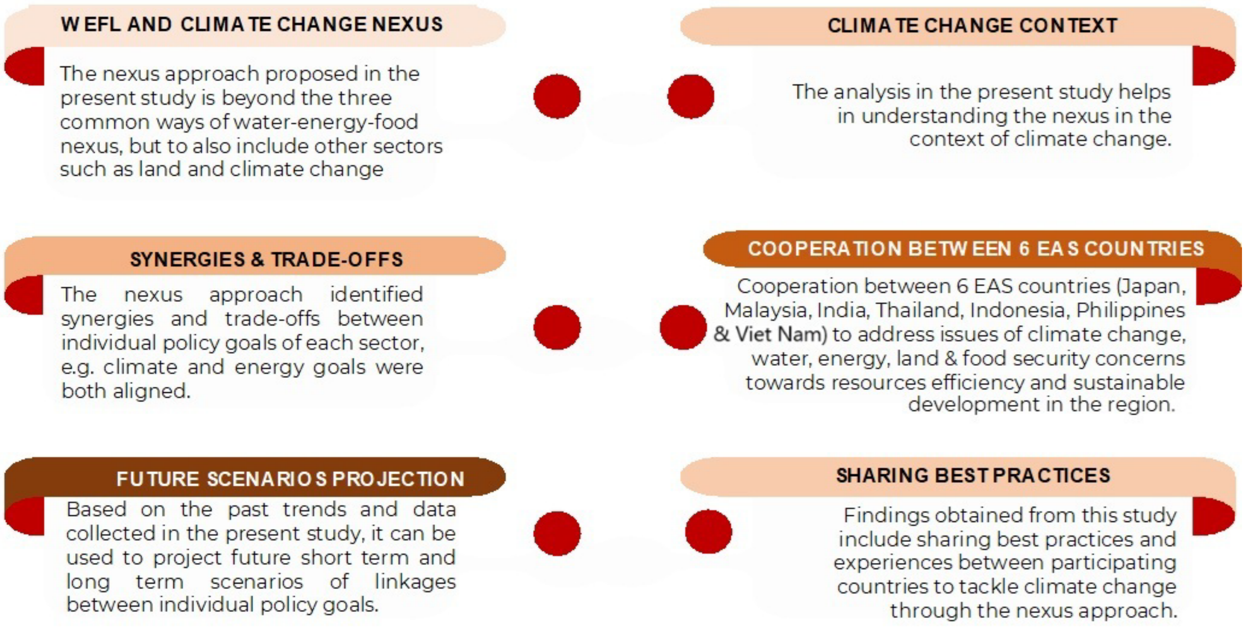
To reduce environmental pollution, the WEF Nexus approach is being used in energy processes such as biorefineries, renewable energies (solar and wind), sustainable agriculture, hydropower, and ethanol in gasoline. To integrate the environmental and socio-political aspects of WEF, employ collaborative frameworks, and seek the engagement of decision-makers, the WEF Nexus approach is crucial. Utilising biomass feedstocks is vital for energy security, and they are a promising alternative to fossil fuels offered by bioenergy. The WEF Nexus emphasises the necessity of managing water, energy, and food resource trade-offs and synergies carefully in the context of bioenergy to ensure efficient and sustainable bioenergy production.

1. Water: Growing feedstock crops and carrying out the actual production procedures both demand large volumes of water in the production of bioenergy. Effective management of water resources is crucial to maintaining the sustainability of water supplies and avoiding competition with food production.
2. Energy: The process of producing bioenergy itself involves energy inputs and the viability and sustainability of bioenergy production are directly impacted by the availability of energy supplies. Furthermore, bioenergy can supplement the energy supply overall, possibly lowering dependency on fossil fuels and slowing global warming.
3. Food: The development of bioenergy feedstocks on agricultural land may have an impact on the security of food supplies. A fundamental component of the WEF Nexus is the balancing of land usage for food and bioenergy production; sustainable bioenergy operations should minimise adverse effects on food production.

Malaysia may overcome the obstacles to the development of a low-carbon economy by implementing the suggested activities. In addition, understanding of the WEF Nexus and the biomass availability and utilisation potential in Malaysia must be strengthened. This will not only help to achieve sustainability objectives and reduce GHG emissions but will also help Malaysia become a global leader in the energy transition. Low-carbon energy's effective integration will provide new business opportunities, improve energy security, and open the door to a cleaner, more sustainable future.

Climate change mitigation efforts through technologies, education, regional/international cooperation, and green investments are powerful strategies for examining the complexities and trade-offs between indicators. These solutions can help countries evaluate options for understanding and addressing climate change issues and serve as a useful lens for analysing policy and efficient resource management in a specific geography towards sustainability. The policies explain that the indicators of the nexus are tied as environmental impacts on the planet causing climate change. Thus, they are equally important considerations for those aiming to set targets to reduce their environmental footprint.

Figure 4.3. Efficient Resource Management in a Specific Geography Towards Sustainability




Source: Authors.

### *4.3.2 Gaps, limitations, and recommendations*

Malaysia has a huge opportunity to reduce greenhouse gas emissions and diversify its energy mix by moving towards a low-carbon economy. To ensure the proper implementation of this big project, various gaps and constraints must be addressed. Addressing the issues of infrastructure development and affordability is crucial for Malaysia's smooth transition to a low-carbon economy. It can be expensive to set up the necessary infrastructure for biomass-based energy generation, especially in the beginning. It is essential to make low-carbon and related technologies accessible to consumers and businesses, especially in the early stages of adoption (Ahmed et al., 2016). These elements have the potential to considerably slow market expansion and exacerbate the overall transition process. Malaysia should give the development of affordable technologies top priority in order to get past these obstacles. This can be accomplished through boosting research and development spending and encouraging collaboration amongst industry, academia, and research institutions.

The Malaysian government must simultaneously address the issues related to cost and accessibility. To lessen the cost burden connected with the adoption of low-carbon energy, financial aid and incentives should be offered. These can come in the form of grants, subsidies, and tax incentives to help build infrastructure, as well as financial assistance for households and businesses switching to low-carbon energy. Malaysia can encourage more use of low-carbon energy and guarantee that it is affordable for all stakeholders by lessening the financial burden. The country should also place a priority on its technology preparedness by fostering technological innovation and scalability. Malaysia may solve issues with technological readiness by funding R&D and fostering collaboration amongst business, academia, and research institutions. This will lay a strong framework for the creation and adoption of a low-carbon energy economy, allowing the nation to fully capitalise on the advantages of biomass-based renewable energy technology.

CIMB, the second-largest asset-based lender in Malaysia, has pledged to eliminate coal from its portfolio by 2040 and to stop financing new coal mines and generators as early as 2021 (Reuters, 2020). The implementation of supportive measures, such as offering retraining opportunities to workers in industries affected by the transition and guaranteeing a fair and equitable transition for all stakeholders, is also necessary to address potential economic and social effects. (Mah et al., 2019).

Malaysia must build a strong regulatory framework to enable the effective implementation of a low-carbon economy. This framework should include rules and guidelines for renewable energy production, as well as for safety requirements and market incentives. The creation and application of such a system require cooperation between numerous government agencies, business players, and foreign partners. Investors will have more security thanks to clear and consistent laws, which will also foster the development of the low-carbon industry and ensure the successful implementation of a green economy with low-carbon emissions.

Coordination between numerous government agencies, business players, and foreign partners is necessary for this process. Due to the difficulty of coordinating several stakeholders and balancing their interests, Malaysian regulatory framework development may encounter challenges. A clean economy with zero carbon emissions must be developed through international cooperation. For Malaysia, forming strategic alliances and entering international markets to transfer knowledge might be difficult. Negotiating trade agreements, developing a supporting international framework, and engaging in diplomatic activities are all necessary for establishing and maintaining these alliances (Pudukudy et al., 2014). To profit from the global transition to a low-carbon economy, Malaysia must overcome these obstacles and make the most of international cooperation.

It is essential to raise public awareness and acceptance of renewable energy as a practical alternative energy source in order to make the transition to a low-carbon economy successful. The market demand for low carbon is mostly driven by public perception and awareness, which also contributes to the acceleration of the transition process. Launching education campaigns and public engagement projects is crucial to removing misconceptions, fostering trust, and fostering public support for renewable energy technology (Pudukudy et al., 2014).

## 4.4 Philippines

Addressing policy gaps in the Philippines in relation to food security, water security, bioenergy sustainability, and climate change readiness requires a comprehensive understanding of existing laws and policies, as well as an assessment of their effectiveness and implementation.

### *4.4.1 List of policies in the Philippines related to WEFLC sectors*

*A. Food security*

Food security refers to the availability, access, utilisation, and stability of food supplies. In the Philippines, several laws and policies aim to address food security issues:

1. National Agriculture and Fisheries Modernization and Industrialization Plan 2021–2030 (NAFMIP): The NAFMIP 2021–2030, as a whole-of-nation plan, serves as a directional plan to steer sector-wide growth over the next decade. It will guide the trajectory of more detailed and operations-oriented agri-fishery development plans, such as the commodity system roadmaps, Provincial Commodity Investment Plans, and Comprehensive Land Use Plans. The policy aims to transform the agriculture and fisheries sector into a modern and responsive component of the Philippine economy and society. The NAFMIP's goal is transformation towards a food-and-nutrition-secure, resilient Philippines with empowered and prosperous farmers and fisherfolk by 2030.
2. Philippine Development Plan (PDP) 2023–2028: The PDP 2023–2028 outlines strategies and programmes to ensure food security for all Filipinos. It includes initiatives to promote agricultural productivity, enhance food distribution systems, and improve nutrition and food safety.
3. Rice Tariffication Law (RA 11203): This law aims to liberalise rice importation to improve access to affordable rice for consumers. However, it also poses challenges to local rice producers, particularly small-scale farmers, who may struggle to compete with cheaper imported rice.
4. National Organic Agriculture Program (NOAP) (RA 10068): The NOAP promotes the adoption of organic farming practices to improve soil health, reduce reliance on chemical inputs, and enhance food safety. It provides support for organic certification, training, and market development for organic products.
5. National Land Use Act (NLUA) (House Bill (HB) 8162): The NLUA is a proposed law that aims to establish a rational and comprehensive land use and physical

planning mechanism for the Philippines. The NLUA aims to protect the country's land and water resources and to foster food security. The law is also intended to protect prime agricultural lands whilst allocating scarce land resources to meet the needs of a growing population.

6. High Value Crops Development Act (HVCDA) (RA 9700): The HVCDA promotes the production, processing, marketing, and distribution of high-value crops. The act aims to help address poverty, food security, and sustainable growth through these efforts.

*B. Water security*

Water security involves ensuring reliable access to clean water for drinking, sanitation, agriculture, and industry. In the Philippines, key laws and policies related to water security include the following:

1. Philippine Water Code: The Water Code governs the management, appropriation, utilisation, and conservation of water resources in the Philippines. It establishes the framework for integrated water resources management and delineates water rights and responsibilities.
2. Philippine Clean Water Act (RA 9275): This law aims to protect and preserve water quality by regulating the discharge of pollutants into water bodies, promoting wastewater treatment, and establishing water quality standards.
3. National Water Resources Board (NWRB): The NWRB is responsible for regulating water use, issuing water permits, and coordinating water resources management efforts nationwide.
4. Integrated Water Resources Management (IWRM) Framework: The IWRM framework promotes a holistic approach to water resources management, incorporating social, economic, and environmental considerations.
5. Irrigation Act of the Philippines (RA 2152): The act provides a system for the appropriation of public waters and the determination of existing rights.

*C. Bioenergy sustainability*

Bioenergy sustainability involves the production and use of renewable energy sources derived from biomass, such as agricultural residues, forestry waste, and biofuels. In the Philippines, relevant laws and policies include the following:

1. Renewable Energy Act: This law promotes the development and utilisation of renewable energy sources, including biofuels, biomass, solar, wind, and hydropower. It establishes incentives and mechanisms to encourage investment in renewable energy projects.

2. Biofuels Act: The Biofuels Act mandates the blending of biofuels, such as ethanol and biodiesel, with conventional fuels to reduce dependence on imported fossil fuels and mitigate GHG emissions.
3. Republic Act No. 10659: The act supports the competitiveness of the Sugarcane industry and other purposes. The Sugar Industry Development Act of 2015 promotes the competitiveness of the sugarcane industry and maximises the utilisation of sugarcane resources. It improves the incomes of farmers and farm workers through improved productivity, product diversification, job generation, and increased efficiency of sugar mills. The utilisation of sugarcane includes the production of bioenergy, such as bioethanol and power generation.
4. National Biofuels Program: The National Biofuels Program aims to promote the production, distribution, and use of biofuels in the transportation sector. It sets targets for biofuel blending and provides incentives for biofuel producers and users.
5. Philippines' National Energy Efficiency and Conservation Plan and Roadmap 2023–2050. The whole-of-nation plan aims to have 50% renewable energy by 2050. In a more ambitious 'clean energy' scenario, the goal is to reach 50% by 2040.
6. Formulation and Implementation of the Renewable Energy Program for the Agri-Fishery Sector (REPAFS) (MC2021-02-001): The REPAFS is a joint memorandum circular signed by the Department of Agriculture and the Department of Energy. The programme aims to increase the use of renewable energy systems and technologies in the agriculture and fisheries sector to improve productivity, sustainability, and environmental protection. The programme will run from 2022 to 2030 and will have total funding of ₱7.98 billion.
7. Joint Administrative Order (JAO) 2008-1. The JAO 2008-1 governs the production, distribution, and sale of biofuel feedstocks, biofuels, and biofuel blends. It also provides guidance and information for all concerned.

*D. Climate change readiness*

Climate change readiness involves building resilience and adaptive capacity to cope with the impacts of climate change, such as extreme weather events, sea-level rise, and shifting precipitation patterns. In the Philippines, key laws and policies related to climate change include the following:

1. Climate Change Act: The Climate Change Act establishes the framework for climate change adaptation and mitigation efforts in the Philippines. It mandates the formulation of the National Climate Change Action Plan and the creation of a Climate Change Commission to coordinate climate change initiatives.

2. National Disaster Risk Reduction and Management Act (NDRRMA): The NDRRMA aims to strengthen disaster risk reduction and management efforts to reduce vulnerability and enhance resilience to natural hazards and climate-related disasters.
3. Philippine Disaster Risk Reduction and Management Framework: The framework provides guidance for integrating climate change adaptation into disaster risk reduction and management strategies at the national, regional, and local levels.
4. National Climate Change Adaptation Plan: The adaptation plan outlines priority actions and strategies for adapting to climate change impacts, including for water resource management, agriculture, coastal zone management, and infrastructure development.

*E. Policies on bioethanol industry and the biomass utilisation in the Philippines*

*1. Policy on bioethanol importation*

RA 9367 recognises that the Philippines may not have sufficient locally produced bioethanol for the needed blending, so importation of bioethanol may be allowed, subject to the guidelines set forth by the DOE and the Department of Finance, under DOE Circular No. 2006-08-0011 and Revenue Regulation No. 8-2006, respectively (DOE, 2006).

In the event of a shortage, DOE Circular No. 2011-12-0013 (Guidelines on the Utilization of Locally- Produced Bioethanol in the Production of E-gasoline) mandates giving priority to the utilisation of locally produced bioethanol, consistent with RA No. 9367. The circular was drafted as a compromise to help encourage further investments in the local ethanol industry and at the same time keep prices fair. The circular obliges oil firms to source part of the ethanol used to meet mandatory blending levels from local producers before imports will be allowed. Non-compliant oil companies are fined ₱500 for every litre of locally produced bioethanol not purchased as prescribed.

*2. Policy on feedstock sources for biofuels*

Consistent with the aim of improving the country's energy security, the importation of feedstock for biofuel production is prohibited under the Biofuels Act. Specifically, Section 2 of the Biofuels Act declares that only 'indigenous renewable and sustainably sourced clean energy sources' are allowed to be developed and utilised for biofuel production.

*3. Policy on food vs. fuel*

It is stated under JAO 2008-1, or the 'Guidelines governing the biofuel feedstocks production, and biofuels and biofuel blends production, distribution and sale under

Republic Act No. 9367', that rice, corn, and other cereals cannot be used as biofuel feedstocks in the Philippines. This policy is in place to safeguard the food resources of the country and address concerns on the 'food vs. fuel' issue. Aside from concerns on land availability and competition, growing of biofuel feedstock is expected to compete with food crops for resources like water and fertilisers, which could prompt higher food prices.

Whilst one of the objectives of the JAO 2008 is to promote the development of the biofuels industry in the Philippines, encourage private sector participation, and institute mechanisms that will fast track investments in the biofuels industry as a priority development for land conversion, it also provides safety nets for food security in the country. In general, it ensures that land devoted to food crops shall not be utilised for biofuels feedstock production. As provided by Chapter II of the JAO 2008, a biofuels feedstock producer shall secure, amongst others, a Department of Agriculture (DA) Certificate. Furthermore, Section 4.1 outlines the criteria for DA Certification, as specified in the following policy directives related to food security, land use, irrigation, and water usage for areas of 25 hectares or more, whether they are contiguous or fragmented.

A. Cereals that can be used both for food and biofuels production, such as, but not limited to, corn and wheat, shall not be used for biofuels production;
B. The area that will be used is not the only remaining food production area of the community;
C. Land cannot be used for biofuel production in the following three cases.
    a. All areas covered by government-funded irrigation facilities, either national agency or Local Government Units, designed to support rice and other crops production, and all irrigated lands where water is not available for rice and other crops but that are within areas programmed for irrigation facility rehabilitation by the DA and National Irrigation Administration (NIA);
    b. All irrigable lands already covered by irrigation projects with firm commitment as certified by the NIA at the time of the application for land use conversion; and
    c. All privately irrigated alluvial plain lands utilised for rice and corn production.

The 'food vs. fuel' issue is based on a local perspective. Since there is an insufficient local feedstock supply for bioethanol production as well as restrictions on feedstock importation, there is an impending threat that bioethanol production could entail using resources that are intended for food production. The government has recognized the interconnections, synergies, and trade-offs among Water, Energy, Food, and Land-Climate (WEFLC) issues, as shown in the Sugarcane Roadmap 2020 initiative. This initiative includes partnerships with Government Financial Institutions (GFIs), industry players, and other private sector participants, alongside relevant government agencies such as the Sugar Regulatory Administration (SRA), Department of Agriculture (DA), Department of Trade and Industry's Board of Investments, Department of Agrarian Reform (DAR), and other national agencies (SRA, 2015).

### *4.4.2 Policy-centric analysis related to the WEFLC Nexus*

Biomass utilisation in the Philippines plays a critical role in the WEFLC Nexus, as it intersects with multiple sectors and addresses key challenges related to sustainable development and environmental management. A policy-centric analysis of biomass utilisation in the Philippines within this framework involves examining existing policies and strategies related to biomass energy, agriculture, water resources management, and climate change adaptation and mitigation. Table 4.4 summarises the relevant policies and laws in the Philippines in relation to the WEFLC Nexus and the biomass for bioenergy sustainability direction.

Table 4.4. Policy-centric Analysis of the Philippines Using the WEFLC Nexus

| Policy | Water | Energy | Food | Land | Climate Change |
|---|---|---|---|---|---|
| 1987 Philippine Constitution | ✓ | ✓ | ✓ | ✓ | ✓ |
| Philippine Environmental Impact Statement System (PD 1586) | ✓ | ✓ | ✓ | ✓ | ✓ |
| Philippine Development Plan 2023–2028 | ✓ | ✓ | ✓ | ✓ | ✓ |
| Forestry Reform Code of 1975 (PD 705) | | | | ✓ | |
| Rice Tariffication Law (RA 11203) | | | ✓ | ✓ | |
| NAFMIP 2021–2030 | ✓ | ✓ | ✓ | ✓ | ✓ |
| National Organic Agriculture Program (NOAP) (RA 10068) | ✓ | | ✓ | ✓ | ✓ |
| Water Code of the Philippines of 1976 (PD 1067) | ✓ | | | | ✓ |
| National Land Use Act (NLUA) (House Bill (HB) 8162) | ✓ | ✓ | ✓ | ✓ | |
| Comprehensive Agrarian Reform Law of 1988 (RA 6657) | | | ✓ | ✓ | |
| High Value Crops Development Act (HVCDA) (RA 9700) | ✓ | | ✓ | ✓ | |
| National Integrated Protected Areas System Act of 1991 (RA 7586) | ✓ | ✓ | | ✓ | |

| Policy | Water | Energy | Food | Land | Climate Change |
|---|---|---|---|---|---|
| Philippine Clean Water Act of 2004 (RA 9275 Act) | ■ | | | | ■ |
| Irrigation Act of the Philippines (RA 2152) | ■ | | ■ | ■ | |
| Integrated Water Resources Management (IWRM) Framework | ■ | | ■ | | ■ |
| Ecological Solid Waste Management Act of 2000 (RA 9003) | | | | ■ | |
| Electric Power Industry Reform Act of 2001 (RA 9136) | | ■ | | | |
| Biofuels Act of 2006 (RA 9367) | | ■ | ■ | | ■ |
| JAO 2008-1 (Guidelines of RA 9367) | | ■ | ■ | | ■ |
| REPAFS (MC2021-02-001) | ■ | ■ | ■ | ■ | ■ |
| Renewable Energy Act of 2008 (RA 9513) | | ■ | | | ■ |
| Climate Change Act of 2009 (RA 9729) | | | | | ■ |
| Philippine Disaster Risk Reduction and Management Act of 2010 (RA 10121) | | | | | ■ |
| Philippines' National Energy Efficiency and Conservation Plan and Roadmap 2023-2050 | | ■ | | | ■ |

Source: Authors' data compilation.

Food security policies like the National Agriculture and Fisheries Modernization and Industrialization Plan (NAFMIP), the Philippine Development Plan (PDP), and the Rice Tariffication Law aim to improve food security but face implementation challenges, insufficient investment in agricultural R&D, and inadequate support for smallholder farmers.

Water security governed by the Philippine Water Code, likewise, faces issues such as water scarcity, pollution, and inadequate infrastructure. Bioenergy sustainability policies, such as the Philippine Biofuels Act, aims to reduce reliance on imported fuels through biofuels but faces challenges like limited local feedstock and infrastructure.

On climate change readiness, this report underscores the importance of climate change adaptation and mitigation strategies. Policies like the National Integrated Protected Areas System Act of 1991 (RA 7586) and the Ecological Solid Waste Management Act of 2000 (RA 9003) contribute to this effort.

### *4.4.3 Policy gaps*

*A. Policy gaps in food security*

Despite the existence of these laws and policies, there are several gaps and challenges in achieving food security in the Philippines:

- Limited implementation and enforcement of existing policies, leading to persistent food insecurity, especially in rural and marginalised communities.
- Insufficient investment in agricultural research and development, resulting in low productivity and vulnerability to climate change and other environmental stresses.
- Lack of comprehensive measures to address post-harvest losses and food waste along the supply chain.
- Inadequate support for smallholder farmers, including access to credit, markets, and extension services.
- Weak coordination and collaboration amongst government agencies, NGOs, and other stakeholders involved in food security initiatives.

*B. Policy gaps in water security*

Despite these laws and policies, water security remains a significant challenge in the Philippines due to various factors:

- Inadequate enforcement of water quality standards, resulting in the pollution and contamination of water sources.
- Limited investment in water infrastructure and sanitation facilities, particularly in rural and underserved areas.
- Fragmented governance and weak coordination amongst the government agencies responsible for water management and regulation.
- Increasing water demand due to population growth, urbanisation, and industrialisation, exacerbating pressure on finite water resources.
- Climate change impacts, including changes in rainfall patterns, sea-level rise, and extreme weather events, further exacerbate water scarcity and variability.

*C. Policy gaps in bioenergy sustainability*

Despite these initiatives, several challenges and gaps exist in promoting bioenergy sustainability in the Philippines:

- Limited availability of feedstocks for biofuel production, leading to competition with food crops and potential land-use conflicts.
- Lack of comprehensive sustainability criteria and certification schemes for biofuels, raising concerns about environmental and social impacts.
- Insufficient infrastructure and distribution networks for biofuel production and distribution, particularly in rural areas.
- Uncertainty regarding the long-term viability and scalability of bioenergy technologies, including biofuel production and biomass utilisation.
- Need for stronger policy support and incentives to stimulate investment in bioenergy projects and enhance their competitiveness compared to conventional energy sources.

*D. Policy gaps in climate change readiness*

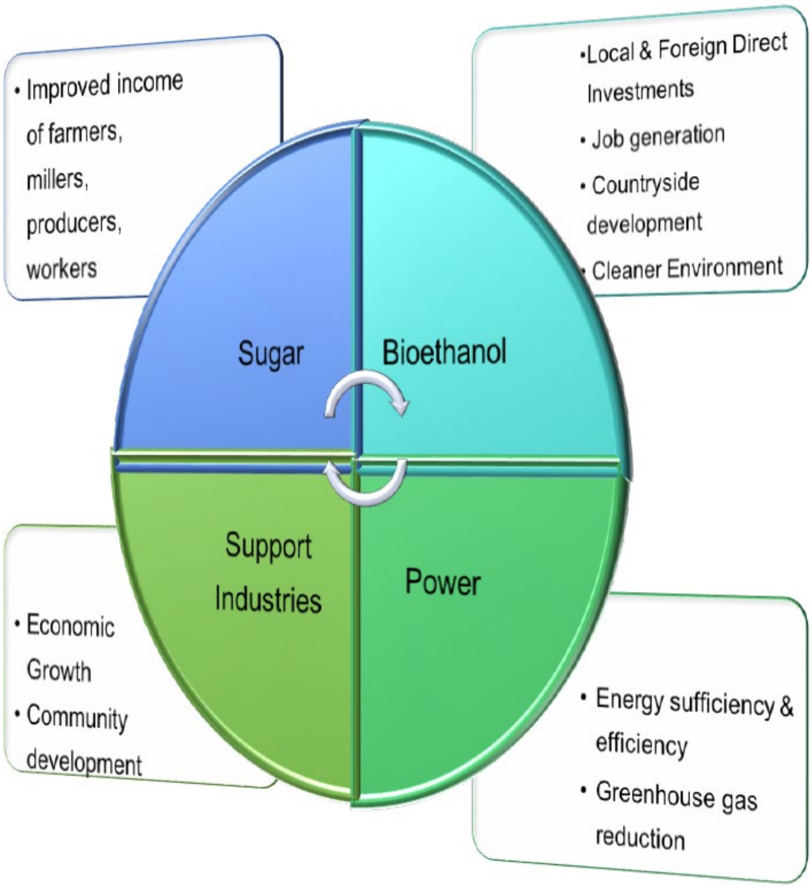
Despite these initiatives, there are several gaps and challenges in building climate change resilience in the Philippines:

- Limited implementation and enforcement of climate change policies and strategies at the local level, leading to gaps in preparedness and response efforts.
- Insufficient funding and resources for climate change adaptation and mitigation activities, particularly in vulnerable and marginalised communities.
- Low integration of climate change considerations into sectoral planning and decision-making processes, hindering mainstreaming efforts.
- Lack of awareness and capacity amongst stakeholders, including local governments, communities, and private sector actors, to address climate change risks and opportunities effectively.
- Need for enhanced coordination and collaboration amongst government agencies, civil society organisations, and the private sector to scale up climate change initiatives and maximise impact.

### *4.4.4 Sugarcane Industry Roadmap*

The Sugarcane Industry Roadmap 2020, published in 2015, aimed at identifying plans and programmes towards the development of a sustainable and multi-product sugarcane industry that contributes significantly to the national economy (SRA, DA, and DTI, 2015).

Figure 4.4. Conceptual Framework for Sustainable and Diversified Bioethanol Production in the Sugarcane Industry




Source: SRA (2015).

Concerns about small family-operated farms, largely due to the implementation of the agrarian reform programme, were addressed by the SRA, the DA, and the DAR by implementing the block farming programme, which consolidated small farms into an aggregate area of 30–50 hectares (SRA, 2015). These block farms are operated by agribusiness ventures that provide efficient tractor operations, volume purchases and sales, technical assistance for better farming practices, crop loans, and other services to improve farmers' incomes, which encourages businesses to develop service companies for farming services (SRA, 2011).

Land suitability spatial mapping based on the WEF Nexus holds paramount importance for fostering holistic and sustainable resource management. The interconnected nature of water, energy, and food systems necessitates a comprehensive understanding of their interdependencies. Through spatial mapping, decision-makers gain insights into the optimal use of land resources, allowing for the identification of areas where water, energy, and food systems can be integrated efficiently. This approach aids in optimising resource use, minimising waste, and mitigating conflicts that may arise due to competing demands for limited land resources. Moreover, as climate change introduces additional complexities, land suitability mapping, when integrated with climate data, becomes crucial for assessing vulnerability and developing climate-resilient land-use plans. By recognising and incorporating ecosystem services into the mapping process, planners ensure that land-use decisions not only meet WEF demands but also sustain essential ecological functions. Furthermore, strategic infrastructure planning benefits from land suitability mapping, facilitating the location of areas suitable for sustainable agriculture, renewable energy projects, and water management infrastructure. Engaging local communities in the mapping process enhances community participation, aligns decisions with local needs and preferences, and promotes social acceptance. Overall, integrating land suitability spatial mapping within the WEF Nexus provides a powerful tool for decision-makers to address the challenges of resource scarcity, climate change, and competing land-use demands, ultimately contributing to sustainable development.

The SRA uses digitised maps of all sugarcane fields. These are generated and populated with data obtained from actual field surveys to determine the crop estimates, and the fields planted with sugarcane are updated every cropping season as a tool for the Sugar Board to arrive at more reliable and accurate estimates of the cropping season's production (SRA, DA, and DTI, 2015).

### *4.4.5 Programmes and major policies addressing WEFLC challenges*

The following are the programmes and policies addressing WEFLC challenges:

1. **National Agriculture and Fisheries Modernization and Industrialization Plan (NAFMIP)**: Aims for sector-wide growth by 2030 with a focus on modernising agriculture and fisheries.
2. **Philippine Development Plan (PDP) 2023–2028**: Promotes agricultural productivity, food distribution systems, and nutrition improvement.
3. **National Organic Agriculture Program (NOAP)**: Encourages organic farming to improve soil health and food safety.
4. **Sugarcane Industry Roadmap**: Focuses on sustainable and multi-product sugarcane industry development.
5. **Integrated Resource Management programmes**: Implementation of Integrated Water Resources Management frameworks to balance water use across agriculture, industry, and domestic needs. Expansion of renewable energy projects, particularly in biomass, to reduce reliance on fossil fuels and manage agricultural waste sustainably.
6. **Capacity building and technology transfer**: Promotion of capacity-building initiatives for stakeholders in the agriculture, energy, and water management

sectors. Encourages technology transfer and innovation in bioenergy production, efficient irrigation systems, and climate-smart agricultural practices.

7. **Cross-sectoral policy coordination**: Establishment of cross-sectoral committees or taskforces to ensure policy coherence and effective implementation of WEFLC-related initiatives. Enhances data sharing and collaborative planning amongst government agencies, the private sector, and civil society organisations.

*A. Addressing cross-sectoral challenges*

Table 4.5 shows the nexus index in three stages, namely, the water-energy-food (WEF) index, water-energy-food-land (WEFL) index, and water-energy-food-land-cost (WEFLC) index. For sugarcane, the nexus index increases from the first index to the third index, where the highest value is at 0.52 under the WEFLC. On the other hand, for coconut, the WEF Nexus results in the highest index value at 0.64. However, the nexus index value decreases with the inclusion of land and climate parameters. This is primarily due to the low score of land use and land use productivity for coconut production.

Table 4.5. Sugarcane and Coconut Nexus

| | WEF | WEFL | WEFLC |
|---|---|---|---|
| Sugarcane | 0.4298 | 0.4463 | 0.5201 |
| Coconut | 0.6399 | 0.6001 | 0.5783 |

Source: Author's data compilation.

Given the analysis in Table 4.5, there is a need for integrated planning and coordination, with better coordination amongst government agencies, private sector stakeholders, and local communities to optimise resource utilisation and address trade-offs between sectors. Additionally, there is a greater need to conduct land suitability spatial mapping to utilise WEFCL Nexus-based mapping to inform land-use decisions, optimise resource use, and integrate climate data for resilience planning.

Managing cross-sectoral challenges demands collaborative governance models and integrated policy frameworks. Developing governance models that foster collaboration between different sectors and levels of government is highly recommended. This includes creating platforms for dialogue and joint decision-making. Examples include inter-agency committees on water management and energy planning, which involve stakeholders from the agriculture, environment, and industry sectors.

On the other hand, there is a need to formulate integrated policy frameworks that align objectives across sectors. For instance, they should ensure that agricultural policies support energy production goals without compromising water availability or food security. They should also implement spatial planning tools to identify and manage land-use conflicts and ensure the optimal allocation of resources for agriculture, energy, and conservation purposes.

*B. Conflicting policies in cross-sectoral management*

This report provides an extensive list of policies impacting the WEFLC Nexus, highlighting the need for coherence and coordination across different sectors and levels of government. Conflicting policies, such as land-use regulations and energy production targets, need resolution to achieve integrated and sustainable outcomes. Establishing mechanisms for resolving policy conflicts, such as arbitration panels or mediation processes, can address disputes arising from overlapping mandates or competing resource needs. An example is coordination between the Department of Energy and the Department of Agriculture to harmonise biofuel production targets with food security objectives.

*C. Food vs. fuel conflict*

The competition between bioenergy production and food resources poses significant challenges, particularly in the context of bioethanol production. This competition is heightened by the limited availability of local feedstock, which can strain food production systems. Furthermore, restrictions on feedstock importation exacerbate these challenges, as they limit the ability to supplement local supplies, potentially leading to higher food prices and reduced food security. These dynamics necessitate careful consideration of resource allocation and policy development to balance the goals of energy production and food security.

*D. Water allocation for agriculture and industry*

Competing demands for water resources between agricultural irrigation and industrial use, particularly in water-scarce regions, require integrated management approaches. Policies such as the Philippine Clean Water Act (RA 9275) and the Irrigation Act of the Philippines (RA 2152) need coordination to ensure sustainable water use across sectors.

*E. Land use and energy production*

Policies aimed at bioenergy production and agricultural land use can sometimes be at odds, necessitating a balanced approach to land allocation. Conflicts often arise between land-use policies for agriculture and the need for land for renewable energy projects, such as biomass plantations. The Comprehensive Agrarian Reform Law of 1988 (RA 6657) and the National Land Use Act (House Bill 8162) need harmonisation to address land allocation for energy crops without undermining food production.

*F. Climate and environmental regulations*

Environmental regulations sometimes conflict with development objectives, such as the expansion of biofuel production impacting forest conservation efforts. The National Integrated Protected Areas System Act (RA 7586) and the Biofuels Act of 2006 (RA 9367) need careful balancing to protect biodiversity whilst promoting renewable energy.

## 4.5 India

In the context of the WEF nexus in India, there are primarily six overarching policies which directly or indirectly impact the nexus. They include (i) the National Water Policy, 2012; (ii) National Biofuel Policy, 2018; (iii) Waste to Energy Programme, 2022; (iv) Biomass Programme, 2022; (v) Sustainable Agrarian Mission, 2021; and (vi) Energy Policy, 2017. The energy policy is still in the draft phase and is yet to be implemented. Therefore, it has not been discussed at length since there are anticipated to be further changes in the policy before implementation. However, the overarching aim of the energy policy is to support the government's energy security agenda with more focus on developing alternate energy sources. Although most of the policies are yet to discuss land as their core subject, they do acknowledge that land is a limited resource, like fossil fuels, and cannot be further exploited for energy production. Therefore, all the policies emphasise generating energy from the current biomass that needs to be utilised and organised in the country.

The subsequent sections present in detail the relevance of these policies, particularly on the WEF Nexus as captured through their impacts on water consumption, the energy requirements for crops and their utilisation for fuels, and the consequences such policies have on food security, land utilisation, and the climate.

*1. National Water Policy, 2012*

The National Water Policy (NWP) aims to understand the current situation and suggest a plan to establish laws, institutions, and actions with a unified national approach regarding water management. It acknowledges that 'irrigation consumes 80-90 per cent of India's water, most of which is used by rice, wheat and sugarcane. Without a radical change in this pattern of water demand, the basic water needs of millions of people cannot be met' (Ministry of Water Resources, 2012). This means diversifying cropping patterns to include less water-intensive crops, in line with regional agroecology. The policy recommends diversifying public procurement practices, including nutri-cereals, pulses, and oilseeds. In this regard, initiatives under the National Water Mission, such as the Sahi Fasal campaign to nudge farmers in water-stressed areas to grow crops that are not water intensive, are significant.

From the perspective of the WEF Nexus, the procured crops will play a crucial role in nourishing children through midday meals and the public distribution system to provide food grains to millions of citizens. These measures encourage farmers to diversify their crop choices, leading to substantial water conservation. Additionally, establishing this link can contribute to addressing health challenges, such as malnutrition and diabetes, owing to the superior nutritional composition of these crops.

The NWP 2012 came into force to highlight the pre-emptive need for safe drinking water and sanitation whilst achieving food security for all, especially poor people dependent on sustenance agriculture. The policy also emphasised that given the future climate change scenario, it is important to develop adaptation strategies for managing water resources. The policy did not directly delve into the energy transition, but overtly mentioned ecosystem-based adaptation for food security. This translates to growing crops that are better suited to the landscape, suggesting minimising irrigation in water-stressed regions, which require high energy consumption due to pumping. Overall, the NWP 2012 mentioned the WEF Nexus but only had a limited focus on the energy perspective.

*2. National Biofuel Policy, 2018*

This policy aims to increase the use of biofuels in the energy and transportation sectors of the country during the coming decade. It aims to utilise, develop, and promote domestic feedstock and its utilisation for the production of biofuels, thereby increasingly substituting fossil fuels whilst contributing to national energy security and climate change mitigation, in addition to creating new employment opportunities in a sustainable way.

For the future, India's major focus is on second generation (2G) biofuels. This pathway helps in the sustainable utilisation of the waste lignocellulosic crop biomass with low or no economic use, leading to the direct management of $CO_2$ emissions and GHG emissions caused by crop burning and aerobic waste digestion.

Given the water scarcity in India, the National Biofuel Policy does not intend to place pressure on water resources but instead leverage the current water usage to produce energy without tampering with water security. India's biofuel policy is clearly aimed at 2G feedstocks and land regeneration to ensure water, energy, and food security in the transition towards net zero. The government is developing a roadmap to ensure a steady supply of feedstock by understanding the spatial and temporal constraints regarding 2G feedstocks whilst simultaneously financing research and development regarding 3G feedstock. However, the main hurdle lies in the ambitious targets set by the government, such as achieving a 20% ethanol blending rate by 2025. This goal inadvertently promotes using 1G feedstock since current constraints make it impractical to rely solely on 2G sources to meet the target.

*3. Waste to Energy Programme*

The aim of the programme is to support the setting up of energy projects for the generation of biogas/bio-compressed natural gas/power/producers or syngas from urban, industrial, and agricultural wastes/residues. The urban and industrial waste that is regularly dumped at the landfill sites often leads to water contamination in nearby surface water and also in the groundwater. The use of this urban and industrial waste will therefore reduce the chances of water contamination near the landfill sites, and in the near future, those landfill sites can also be converted for agriculture (given their nutrient-rich soil from waste dumping).

*4. Biomass Programme*

The Biomass Programme aims to support the setting up of biomass briquette/pellet manufacturing plants and to support biomass-based (non-bagasse) cogeneration projects in industries in the country. Given the surplus biomass available as presented in the previous sections, the policy supports its utilisation for energy production without having any negative implications on the biomass availability of the country. Thus, the initiative does not seem to have any impact on the country's water security whilst contributing towards energy transition and energy security. However, it is hypothesised that the incentives implemented for the complete removal of crop residue might lead to some deterioration in soil health, which might impact the food production ability of the soil in the long run. Therefore, it is suggested to keep a certain percentage of crop residue in the field for microbial population and nutrient cycling.

The Waste to Energy Programme and Biomass Programme are both under the broader umbrella of the National Bioenergy Programme. The aim is to support the setting up of facilities in the energy transition of the nation through the use of waste and agricultural surplus. Moreover, these programmes not only align with the WEF Nexus but also synergise with India's cleanliness campaign, *Swachh Bharat Abhiyan*. It is crucial to note that cleanliness significantly affects both the direct and indirect aspects of the country's food and water security.

*5. Sustainable Agrarian Mission (SAMARTH)*

The policy promotes the increase of biomass co-firing in thermal power plants, as well as research and development activities for boiler design whilst facilitating overcoming the constraints in the supply chain of biomass pellets and agro-residue. The SAMARTH initiative complements the Biomass Programme, as the latter provides central financial assistance to support the setting up of biomass briquette/pellet manufacturing plants and biomass-based (non-bagasse) cogeneration projects in the country.

*6. Energy Policy, 2017*

The draft policy aims to chart how to meet the government's commitments in the energy domain. It is a multifaceted endeavour to balance economic growth, environmental sustainability, and energy security. It showcases the government's commitment towards diversifying the energy mix and facilitating the future transition towards net-zero emission. However, the current draft also highlights the challenges regarding infrastructural limitations, financial constraints, and intermittency issues associated with renewable energy sources. As the policy remains in the draft phase, a more focused strategy is necessary across various sectors, prioritizing sustainability, affordability, and accessibility to guarantee a robust energy future.

Based on the above discussion, the extent of coverage of these policies to address water, energy, food, land, and climate change-related issues are presented in Table 4.6.

Table 4.6. Policy-centric Analysis of India Using the WEFLC Nexus

| Policy | Water | Energy | Food | Land | Climate Change |
|---|---|---|---|---|---|
| National Water Policy | Encourages water management. | Not discussed. | Diversification of crops. | Not discussed. | Highlights the issue of water conservation and sustainable utilisation of water. |
| National Biofuel Policy | Encourages water management. | Energy security and alternate sources of energy. | Focus on 2G and 3G feedstock, but needs more clarity as it currently | Focus should not be on diverting land resources | Discusses that the ongoing climate change situation |

| Policy | Water | Energy | Food | Land | Climate Change |
|---|---|---|---|---|---|
| | | | relies on 1G feedstock. | but on 2G and 3G feedstock, which do not require additional land. | needs an energy transition. |
| **Waste to Energy Programme** | Not discussed. | Energy security and alternative sources of energy. | Use of urban, industrial and agricultural waste. | Not discussed. | Pushing towards a net-zero transition. |
| **Biomass Programme** | Not discussed. | Energy transition and security. | Use of surplus biomass and agriculture remains. | Not discussed. | Pushing towards a net-zero transition. |
| **Sustainable Agrarian Mission** | Development of boiler design. | Energy transition and security. | Use of biomass procured through biomass programme. | Not discussed. | Pushing towards a net-zero transition. |
| **Energy Policy (draft)** | Mentions hydropower and water conservation through the redesigning of boilers. | Supporting energy targets in general. | Not discussed | Discusses land resources required for the energy transition. | Highlights concerns about climate change and current energy emissions. Aims to stay within the NDC targets whilst transitioning towards more renewable sources. |

Source: Authors' data compilation

## 4.6 Viet Nam

By 2024, Viet Nam has enacted new laws concerning land, water, and energy, alongside national strategies for energy, land, water, and climate change development extending to 2030 or 2050. These policies aim to achieve food security, enhance resource efficiency, and promote sustainable resource utilisation.

Policies concerning water resources in Viet Nam encompass several key initiatives, such as the government decree for implementing the law on water resources (W1); the plan to implement water resources planning from 2021 to 2030, with a vision toward 2050 (W2); incentives aimed at promoting economical and efficient water usage (W3); and guidelines for repairing or maintaining dyke systems (W4). The irrigation and dyke systems play a crucial role in agricultural production and serve as preventive measures against climate change and saline intrusion and ensure water availability for both agricultural and domestic purposes.

The most recent energy-related policies in Viet Nam include the National Energy Development Strategy up to 2030 (E1), the National Energy Master Plan for 2021–2030 with a Vision to 2050 (W2), Viet Nam's Eighth Power Development Plan covering 2021–2030 and envisioning goals for 2050 (E3), and decisions to support the development of biomass power projects in Viet Nam (E4). Viet Nam is committed to achieving net-zero emissions by 2050, prompting several policies to facilitate the transition from fossil fuels to green energy sources, including biomass. Notably, rice straw and rice husk are significant biomass sources.

The main goals of the food policies in Viet Nam are centred around food security. The government plans to retain 3.5 million hectares of rice land until 2030 (F1), aiming to restructure Viet Nam's rice industry by 2025–2030 (F2). This involves transitioning inefficient rice land to other crops and aquaculture to enhance the value of rice, increase farmers' income, and adapt to climate change. Another initiative is a new project for the sustainable development of 1 million hectares of high-quality rice, focusing on low emissions and green growth in the Mekong Delta by 2030 (E3). Additionally, there are guidelines and protocols for rice straw collection, treatment in the field, and the processing of collected straw in the Mekong Delta (F4). Due to changes in rice export policies for ensuring food security in major rice-producing countries, Viet Nam significantly increased its rice exports in 2023, prompting updates to rice export policies (F5).

The new land law was issued and implemented in Viet Nam in 2024 (L1 and L2). Agriculture, particularly rice cultivation, remains pivotal for food security in the country. The government safeguards rice land conversion by providing support to rice farmers, maintaining irrigation systems, and implementing strategies to address climate change whilst enhancing the value of rice in plans extending up to 2030 and envisioning goals for 2050 (L3 and L4).

As the rice sector in Viet Nam and the Mekong Delta grapples with the impacts of climate change, the national strategy on climate change extending to 2050 has been approved (C1). Additionally, plans are in place to mitigate greenhouse gas emissions (C2) and provide support for agriculture and the rice sector to proactively adapt to climate change (C3).

Table 4.7. Policy-centric Analysis of Viet Nam Using the WEFLC Nexus

| Policies | Water | Energy | Food | Land | Climate Change |
|---|---|---|---|---|---|
| W1 | X | ● | ● | ● | ● |
| W2 | X | ● | ● | ● | ● |
| W3 | X | ● | ● | ● | ● |
| W4 | X | | ● | ● | ● |
| E1 | ● | X | ● | ● | ● |
| E2 | ● | X | ● | ● | ● |
| E3 | ● | X | ● | ● | ● |
| E4 | | X | ● | ● | ● |
| F1 | ● | ● | X | ● | ● |
| F2 | ● | ● | X | ● | ● |
| F3 | ● | ● | X | ● | ● |
| F4 | | ● | X | ● | ● |
| F5 | | | X | ● | ● |
| L1 | ● | ● | ● | X | ● |
| L2 | ● | ● | ● | X | ● |
| L3 | ● | | ● | X | ● |
| L4 | ● | ● | ● | X | ● |
| C1 | ● | ● | ● | ● | X |
| C2 | ● | ● | ● | ● | X |
| C3 | ● | ● | ● | ● | X |

Note: X indicates the policy of the sector, and ● indicates strong interaction of the related sectors.
Source: Author's data compilation.

There are interconnections amongst Vietnamese policies across five key sectors: water, energy, food, land, and climate change. All national policies and regulations are geared towards enhancing resource utilisation efficiency amidst resource degradation and/or scarcity. A primary focus is on Viet Nam's commitment to achieving net-zero emissions by 2050, which necessitates significant changes in the energy sector and related resources. Maintaining the production of 3.8 million hectares of paddy is a crucial objective, driving stringent policies in land-use management and the rice sector. Climate change has had a significant impact on Vietnamese agriculture, underscoring the need for adaptive and mitigating strategies to address climate variability. Moreover, rice straw and rice husk, by-products of the rice sector, are renewable energy sources, making them a priority for rapid development in the future. Table 4.7 presents the interrelations amongst the Vietnamese central policies. The most important policies across five dimensions are indicated (X). These policies were examined to determine whether they have a strong relation with the other dimensions (●). The assessment of strong interrelations is based on the summary of these policy.

The '1 Million Hectares of High-Quality Rice, Low Emissions, Green Growth' project, slated to revolutionise Viet Nam's rice production industry by 2030, stands as the most significant policy capable of transforming the rice sector over the next five years. Moreover, it has the potential to drive changes in the utilisation of rice straw and rice husk. By promoting production techniques that reduce emissions and increase efficiency, this initiative seeks to replicate its success across the Mekong Delta, which accounts for nearly 30% of the country's rice area. The project's targets for GHG emissions in the rice industry include implementing a regime for transferring organic products and utilising straw manure on rice fields in the near future. Additionally, efforts will be made to collect straw from fields for alternative uses up to 2030. Currently, only about 40% of straw is collected, whilst the remaining stubble is often left to decompose or is burned due to limited usage options and intensive farming practices involving two to three rice crop systems.

The protocols and guidelines for utilising the collected straw primarily focus on its current uses, such as growing straw mushrooms, producing compost from rice straw and cow manure, and treating straw as animal feed. In the protocol and guidelines for using straw (Policy F4, Decision No. 248/QĐ-TT-CLT on procedures and guidelines for collecting, utilising, and processing straw in the Mekong Delta), no specific target has been set for the stubble collection and bioenergy priority. However, the requirement of the '1 Million Hectare Rice Project' is to collect 100% of straw from fields to reduce field burning. The collected straw holds potential as a bioenergy source for industries seeking to meet their energy needs. Nevertheless, there is currently no research tool available to assess the multicriteria analysis (i.e. WEFLC) for rice straw and rice husk utilisation in the future. About 50%–60% of the total available stubble holds potential as a biomass energy source, necessitating investments in straw cutters or modifications to combine harvesters in the future to collect this amount of straw and stubble.

## Summary of important Vietnamese policies on water, energy, food, land, and climate change

### 1. Water

*Policy W1. Decree No. 02/2023/ND-CP dated 01 February 2023 of the government.*

This decree provides detailed regulations for the implementation of several articles of the Law on Water Resources. The decree implements provisions of the Law on Water Resources relative to granting water resource-related licences. To receive a licence, organisations and individuals must complete the data requirements, and have projects and reports that match approved relevant planning schemes. Specifically, exploiting underground water for production, and business and service activities with a scale not exceeding 10 $m^3$/day and night do not fall into the case specified in Clause 2, Article 44 of the Law on Water Resources.

Surface water exploitation for business, service, and non-agricultural production purposes does not exceed 100 $m^3$/day and night. Cases where water resource exploitation and use works must be registered include reservoirs, irrigation dams with a total capacity from 0.01 million $m^3$ to 0.2 million $m^3$ or water exploitation and use works. On the other hand, agricultural production and aquaculture purposes (excluding other purposes with a scale that requires licensing) can be registered with an exploitation flow greater than 0.1 $m^3$/second to 0.5 $m^3$ /second.

*Policy W2. Decision 161/QD-TTg dated 4 February 2024 approving the plan for implementing water resources planning for the period 2021–2030, with a vision to 2050.*

The implementation plan involves several key steps: preparing, reviewing, and adjusting integrated plans for inter-provincial river basins; preparing and reviewing specialised technical plans for water exploitation and use; reviewing, amending, supplementing, and building institutions and policies; developing and operating a water resources data information system and national water resources monitoring; regulating, distributing, and developing water resources; improving water use efficiency; protecting water resources and preventing degradation, depletion, pollution, and harm caused by water; implementing a dam and reservoir safety programme; advancing science, technology, and international cooperation; and conducting propaganda to raise awareness and train human resources.

*Policy W3. Decree 54/2015/ND-CP dated 8 June 2015 stipulates incentives for economical and efficient water use. Accordingly, organisations, households and individuals will receive preferential loans, tax exemptions and reductions for economical and effective water use.*

This decree applies to state agencies, organisations, households, and individuals involved in water conservation activities in Viet Nam. The principles governing the incentives are the following: (1) Organisations, households, and individuals that conduct several water conservation activities eligible for incentives shall enjoy the incentives prescribed for such activities as prescribed in the Decree. (2) In case a water conservation activity is eligible for different forms or levels of incentives, organisations, households, and individuals may choose the most beneficial ones. (3) Incentives shall not be given to investment in obsolete water conservation equipment and technologies. Chapter II specifies capital borrowing and tax exemption and reduction incentives for water conservation activities.

*Policy W4. The Irrigation law issued by the consolidated document No. 43/VBHN- dated 27 December 2023 of the representative of the National Assembly, establishes a comprehensive framework for the management, development, and utilisation of irrigation systems.*

Key elements include:

1. Management and development: It outlines the responsibilities of various levels of government in managing and developing irrigation infrastructure, ensuring effective water distribution for agricultural and other uses.
2. Investment and funding: The law addresses funding mechanisms for irrigation projects, including state investments, public-private partnerships, and other financial sources.
3. Water use and efficiency: It promotes efficient water use and conservation practices, aiming to optimise water resource management and minimise waste.
4. Regulations and compliance: The law sets forth regulations for the construction, maintenance, and operation of irrigation systems, including standards for quality and safety.
5. Community involvement: It encourages the participation of local communities in the management and decision-making processes related to irrigation, ensuring that their needs and inputs are considered.

Overall, the law aims to enhance the sustainability and effectiveness of irrigation systems, support agricultural productivity, and ensure equitable access to water resources.

## 2. Energy

*Policy E1. Resolution No. 55NQ/TW dated 11 February 2020 on the orientation of the National Energy Development Strategy of Vietnam to 2030.*

This resolution reviews Viet Nam's National Energy Development Strategy to 2030 and extends its goals to 2045, aiming to promote renewable energy development by easing regulatory frameworks and enhancing the energy sector's economic structure, with targets to reduce GHG emissions from energy activities by 15% by 2030 and 20% by 2045 compared to the BAU scenario, increase energy efficiency to 7% by 2030 and 14% by 2045, and achieve a renewable energy mix of 15%–20% by 2030 and 25%–30% by 2045.

*Policy E2. Decision 893/QD-TTg dated 26 July 2023 to approve the National Energy Master Plan in the 2021–2030 period with a vision to 2050.*

The plan targets ensuring national energy security for socio-economic development and national industrialisation and modernisation, and protection of the environment. In particular, the plan aims to successfully transform energy, significantly contributing to materialising the net-zero emissions goal by 2050, formulating an overall industrial energy ecosystem based on renewable energy and new energy.

*Policy E3. Viet Nam's Eight Power Development Plan (PDP8) for the period 2021–2030, with a vision to 2050.*

The release of the policy was severely delayed due to disagreements amongst authorities regarding the country's future power mix, particularly the pace of the phase down of coal-fired power generators and the expansion of renewable energy. The PDP8 encompasses the planning of Viet Nam's future power sources and the planning of the national transmission grid infrastructure. The planning assumes that the country's GDP will grow at a rate of 6.5%–7.5% annually from 2021 to 2050. The PDP8 outlines the development of wind power capacity along the coast to about 21,880 MW by 2030; rooftop solar power (self-generation, self-consumption) to increase by an additional 2,600 MW. Biomass and waste-to-energy capacity is set at 2,270 MW, and hydropower at 29,346 MW.

*Policy E4. Decision 08/2020/QD-TTg dated 5 March 2020 on amending and supplementing several articles of the Prime Minister's Decision No. 24/2014/QD-TTg dated 24 March 2014 on support mechanisms for the development of biomass power projects in Viet Nam.*

This decision provides an incentive mechanism for the development of power generation projects with the use of grid-tied biomass energy in Viet Nam. It applies to organisations and individuals participating in power activities that are related to the development of biomass power projects.

### 3. Food

*Policy F1. Resolution No. 34/NQ-CP dated 25 March 2021 of the government on ensuring national food security until 2030.*

The goal is to ensure enough food for domestic consumption in all situations and partly for export; increase people's income to ensure access to quality food and food safety; and gradually improve the stature, physical strength, and mental capacity of the Vietnamese people. This resolution requires by 2030 to stabilise 3.5 million hectares of rice land, with guaranteed annual rice output of at least 35 million tonnes, and exports of about 4 million tonnes of rice.

*Policy F2. Decision No. 555/QD-BNN-TT dated 26 January 2021 on approving the 'Project for Restructuring Viet Nam's Rice Industry to 2025 and 2030'.*

This is an important project with the goal of improving the efficiency and sustainable development of the rice industry. Accordingly, in addition to fully meeting domestic consumer demand, it is also necessary to form and improve the efficiency of the rice value chain. Rice restructuring in the new phase must bring about increased income for farmers and benefits for consumers whilst promoting rice exports towards high quality and high value.

## 4. Food-rice subsector

*Policy F3. Decision No. 1490/QD-TTg dated 27 November 2023 of the prime minister on approving the project on 'Sustainable development of 1 million hectares specialising in high-quality rice cultivation and low emissions associated with green growth in the Mekong Delta to year 2030'.*

The goal of the '1 million hectares of high-quality rice' project is to build areas specialising in high-quality and low-emissions rice cultivation, reduce the amount of rice seeds sown to 80–100 kg/ha, reduce the amount of chemical fertilisers and agro-chemicals by 20%, reduce irrigation water by 20% compared to traditional/current farming practices. The targets are for 100% of the area to apply at least one sustainable farming practice, such as '1 must, 5 reductions', alternate wet and dry, sustainable rice production standards (Sustainable Rice Platform), Certification of good agricultural practice standards and granting of planting area codes.

To achieve the environmental protection and green growth targets, the post-harvest loss rate should be less than 10%; 70% of straw should be collected from the fields and processed for reuse; and greenhouse gas emissions should be reduced by over 10% compared to traditional rice farming.

*Policy F4. Decision No. 248/QD/TT-CLT dated 10 July 2023 signed by the Department of Crop Production on the guidelines and protocols for rice straw collection, treatment of rice straw in the field, and utilisation and processing of collected straw in the Mekong Delta, Viet Nam.*

Viet Nam's Department of Crop Production (DCP), Ministry of Agriculture and Rural Development, and the International Rice Research Institute (IRRI) successfully developed a technical guideline on rice straw management for circular and low-emission agriculture. Through DCP Decision No. 248, the guideline will be implemented in the whole Mekong River Delta region, covering the protocols for rice straw collection, treatment of rice straw in the field, and utilisation and processing of collected straw.

*Policy F5. Decision No. 583/QD-TTg dated May 26, 2023 approving Viet Nam's rice export market development strategy until 2030.*

The specific goal is to increase added value, improve the value of exported rice, and reduce the export volume by 2030 to about 4 million tonnes with a turnover equivalent to about US$2.62 billion and reduce exporting the low and medium quality rice.

### 5. Land

*Policy L1. Land Law 2024 dated 18 January 2024.*

The amended Land Law prohibits 'changing land use purposes without proper authority, without the right subjects, and without conformity with the annual land use plan at the district level approved by a competent state agency', adding regulations to handle the violations of not allowing the change of land use purpose when performing official duties.

The law also adds regulations that allow agricultural land users to change the structure of crops and livestock and use an area of land to build works that directly serve agricultural production. In addition, agricultural land users are allowed to combine trade, services, animal husbandry, and growing medicinal plants but must not change the land type determined according to the provisions of the Land Law.

The Law extends the allocation term for agricultural land of all categories within prescribed quotas to households and individuals from 20 years to 50 years. Households and individuals are allowed to accumulate larger land areas (not exceeding 10 times the agricultural land allocation quota) and are encouraged to accumulate land to facilitate scientific and technological application, mechanisation, and commodity production development.

The government has a solution to keep 3.5 million hectares of rice land to ensure national food security. National Assembly Chairman Vuong Dinh Hue has asked the government to strictly control the conversion of rice land, especially for rice farmers, from land specialised in wet rice cultivation to non-agricultural land, especially land in industrial zones; strictly handle cases of land encroachment, change of land use purpose, and illegal house construction; and promptly detect and apply measures to prevent and thoroughly handle cases of illegal construction of housing and infrastructure to form new residential areas on agricultural land.

*Policy L2. Degree No. 10/2023/ND-CP dated 3 April 2023 on guidelines for Law on Land.*

In accordance with the current regulations, the requirement to permit the change in the land-use purpose of land for rice cultivation, land with protection forest, and land with special-use forest to implement investment projects includes the approval of the

National Assembly, prime minister, or the provincial People's Council (depending on the size of the land area) and the procedures specified in Article 68 Degree No. 43/2014/ND-CP (amended, supplemented by Degree No. 148/2020/ND-CP). However, the criteria for the competent authority to consider and decide whether to allow the change of land-use purpose are not clearly laid out but scattered in many different legal documents (law on investment, law on land, law on environmental protection, etc.).

*Policy L3. Decree No. 62/2019/ND-CP dated 11 July 2019 amending Decree No. 35/2015/ND-CP on the management and use of rice cultivation land.*

This decree regulates the management and effective use of paddy land and policies supporting rice cultivation for the protection and development of paddy land across the country.

*Policy L4. Decree No. 94/2019/ND-CP dated 13 December 2019 of the government detailing a number of articles of the Law on Crop Production on Plant Varieties and Cultivation.*

Clause 1, Article 13 stipulates:

a) A crop restructuring plan approved by the competent authority.

b) The conditions for growing rice should not be lost, deform the ground, cause pollution or degradation of rice land and do not damage traffic works or irrigation works serving rice growing.

c) In the case of converting rice cultivation to rice cultivation combined with aquaculture, a maximum of 20% of the rice cultivation land area can be used to lower the aquaculture surface to a depth of no more than 120 centimetres compared to the field surface.

### 6. Climate change

*Policy C1. Decision No. 896/QD-TTg dated July 26, 2022 approving the National Strategy on Climate Change for the period up to 2050.*

This policy aims to proactively adapt and effectively reduce the level of vulnerability, loss and damage caused by climate change; reduce GHG emissions according to the net-zero emission target by 2050, making a positive and responsible contribution to the international community in protecting the Earth's climate system; and take advantage of opportunities for responding to climate change to transform the growth model and improve the economy's resilience and competitiveness.

*Policy C2. Decree 06/2022/ND-CP dated 1 January 2022 on the mitigation of greenhouse gas emissions and protection of the ozone layer.*

This decree applies to organisations and individuals related to GHG emissions and the mitigation of GHG emissions and absorption; the development of a domestic carbon market; and the production, import, export, consumption and settlement of ozone-depleting substances (ODS) and greenhouse gases controlled under the Montreal Protocol on substances that deplete the ozone layer.

*Policy C3. Directive No. 10/CT-TTg in 2022 of the prime minister on a number of tasks to promote sustainable agricultural and rural development in the Mekong Delta and proactively adapt to climate change.*

The goal in the coming period is to develop the Mekong Delta quickly and sustainably; proactively adapt to climate change; create breakthroughs to improve people's material and spiritual lives; maintain national security, political stability, and social order; focus on developing agriculture and rural areas in the direction of 'ecological agriculture, modern rural areas, civilised farmers'; determine 'agriculture is the driving force, farmers are the centre, rural areas are the foundation', 'transforming agricultural production to agricultural economic development', based on developing a copper infrastructure system modern and smart, developing large-scale, high-quality commodity agriculture combined with trade, logistics services, eco-tourism, processing industry, and improving value and competitiveness; and closely linking agriculture with industry and services between rural areas and urban areas.

# Chapter 5
# Summary of Key Findings and Policy Implications

Within the EAS countries, Indonesia, Malaysia, Thailand, Viet Nam, India, and the Philippines exhibit substantial potential for bioenergy production. These countries are endowed with abundant natural resources, including biomass and land, which can be effectively harnessed for the generation of bioenergy. Thus, this study provides insightful and detailed information on the relationship between water, food, energy, land, and climate.

## 5.1 Key Points on Feedstock Availability and Challenges

### Thailand

Thailand's agricultural sector generates substantial biomass from sugarcane, cassava, and rice. Annually, sugarcane produces 74.2 million tonnes of biomass, cassava contributes 28.7 million tonnes, and rice adds another 32.9 million tonnes. Despite this potential, challenges include the dispersed nature of biomass, small landholdings hindering mechanisation, economic pressures like declining cassava prices and rising input costs, and the 'food versus fuel' debate. Optimising biomass utilisation could significantly enhance Thailand's energy security and sustainability.

### Indonesia

Indonesia's biofuel potential is immense due to its extensive agricultural lands. Key feedstocks include oil palm (48.23 million tonnes in 2023), sugarcane (45.58 million tonnes in 2022), and rice (31.10 million tonnes in 2023). Challenges include the need for large land areas, competition with food crops, environmental concerns, declining rice production due to extreme weather, and the dispersed nature of biomass, complicating collection and processing. Addressing these issues is essential for optimising biomass utilisation for sustainable energy production.

### Malaysia

Malaysia's bioenergy sector benefits from abundant biomass feedstock from oil palm, agricultural residues, woody biomass, fisheries, and livestock waste. Annually, the country processes 94.8 million tonnes of fresh fruit bunches, generating substantial amounts of empty fruit bunches, mesocarp fibres, and palm kernel shells. Agricultural biomass includes 3.6 million tonnes from sources like rice straw, rice husks, banana stalks, coconut husks, and sugarcane bagasse. Challenges include environmental concerns, land-use impacts, waste management, technological hurdles, policy support, and social responsibility issues. Sustainable practices and comprehensive management strategies are needed to balance these factors in bioenergy production.

### Philippines

The Philippines has significant potential for bioenergy production from sugarcane, coconut, and agricultural residues. In 2022, sugarcane was the number one commodity produced in the Philippines, reaching more than 23.5 million tonnes and translating to US$1.05 million in gross value. On the other hand, coconuts in shell were in the top three amongst the commodities produced in the same year, accounting for more than 14.9 million tonnes and US$2.44 trillion in terms of gross value (FAO, 2024). The Philippines was also the second largest producer of coconuts in shell (next to Indonesia) as well as the top exporter of coconut oil, desiccated coconut, and cake copra in 2022 (FAO, 2024). However, the challenges the country is facing include insufficient feedstock availability, low production yields, inadequate infrastructure, and climate change impacts. The country's bioethanol industries face issues like inadequate local plant capacity and competition for biomass resources, whilst water security is threatened by overexploitation and pollution. Efforts to enhance bioenergy sustainability include promoting efficient biomass utilisation technologies and integrated planning to address environmental, social, and economic impacts.

### India

India, the world's most populous country, faces significant challenges in balancing its water, food, and energy needs. With a population expected to reach 1.7 billion by 2050, sustainable resource management is critical. India has achieved self-sufficiency in food grain production but still struggles with low per capita food availability and significant wastage. Water resources are under severe stress, exacerbated by the reliance on water-intensive crops like rice and sugarcane. The energy sector is heavily dependent on fossil fuels but is transitioning towards renewables, with biofuels playing a crucial role. Despite having a surplus of nearly 228 million tonnes of biomass, India has had to divert 1G feed for producing biofuels. Also, biofuel production raises concerns about land and water use. Integrated approaches within the WEF Nexus are essential for sustainable development.

### Viet Nam

Viet Nam produces significant amounts of rice straw and rice husk, with 17 million–52 million tonnes of rice straw and about 8.6 million tonnes of rice husk annually. Rice straw is utilised for mushroom cultivation, mulching crops, and cattle feed but faces challenges like low economic value and collection inefficiencies, leading to open burning practices. Rice husk is primarily used for drying paddy, as fuel in brick kilns, and as an agricultural substrate. However, utilisation is limited due to high collection and transportation costs. Addressing these challenges could improve the economic viability and environmental sustainability of rice by-product utilisation in Viet Nam.

EAS countries like Thailand, Indonesia, Malaysia, Philippines, India, and Viet Nam have significant potential for biomass utilisation in energy production. However, each faces unique challenges related to feedstock availability, economic factors, environmental impacts, and infrastructural limitations. Addressing these challenges through sustainable practices and integrated management strategies is crucial for enhancing energy security and sustainability in the region.

## 5.2 Key Points on the Preliminary Evaluation of the WEFLC Indicators

*Thailand* (sugarcane and cassava)

In Thailand, sugarcane and cassava exhibit distinct resource use and productivity characteristics. Sugarcane consumes 11,363 $m^3$/ha of water per crop season, significantly more than cassava's 8,613 $m^3$/ha. Despite this higher consumption, sugarcane demonstrates better water efficiency, producing 6 tonnes of biomass per cubic meter of water compared to cassava's 2.4 tonnes. In terms of energy, sugarcane requires 48.5 GJ/ha, surpassing cassava's 40.9 GJ/ha. This higher energy use is mirrored in GHG emissions, with sugarcane farming generating 2,272 kg $CO_2$eq/ha, slightly above cassava's 2,128 kg $CO_2$eq/ha. Economically, sugarcane is more productive, yielding B49,753 per kg of $CO_2$eq, nearly double cassava's B24,289 per kg of $CO_2$eq. Additionally, sugarcane has a much higher land productivity, yielding 67.9 tonnes per hectare compared to cassava's 20.8 tonnes per hectare, highlighting its high biomass productivity.

The nexus assessment indicates that Thailand's Northeast region is the most suitable for sustainable sugarcane and cassava cultivation. In comparing nexus scores for sugarcane, Nakhon Ratchasima in the Northeast emerged as the leader with a WEFLC Nexus index score of 0.78, followed by Kamphaeng Phet and Phrae with scores of 0.66 and 0.63, respectively. Uthai Thani recorded the lowest score at 0.37, with the overall average for all regions being 0.55. This comprehensive evaluation reveals that the Northeast consistently excels in cassava production sustainability, highlighting robust agricultural practices that could serve as a model for other regions.

Despite facing some challenges with the WEF Nexus, the Northern region shows promising improvements when land and climate factors are included. Meanwhile, the Central region exhibits moderate performance, indicating areas for potential enhancement, particularly in integrating water, energy, and food sustainability. These findings underscore the need for targeted strategies to improve resource management across the different regions in Thailand.

*Indonesia* (palm oil, sugarcane, and rice)

Palm oil, sugarcane, and rice biomass each have distinct profiles in terms of resource use and productivity. Palm oil requires 16,180 $m^3$/ha of water, 60.92 GJ/ha of energy, and emits 11,745.10 kg $CO_2$eq/ha, with an economic productivity of US$0.27/kg $CO_2$eq and a land productivity of 2.88 t/ha. Sugarcane, on the other hand, uses the most water and energy at 20,450 $m^3$/ha and 96.1 GJ/ha, respectively, emits 2,722.90 kg $CO_2$eq/ha, and has an economic return of US$0.58/kg $CO_2$eq along with a land productivity of 4.18 t/ha. Rice biomass stands out with the highest land productivity at 4.7 t/ha, moderate water use at 10,763 $m^3$/ha, high energy use at 101 GJ/ha, and emits 4,171 kg $CO_2$eq/ha, with an economic return of US$0.29/kg $CO_2$eq. Whilst sugarcane and rice biomass are more productive per unit of land, palm oil has the highest GHG emissions and the lowest economic returns relative to its emissions.

Over the past decade, Indonesia's energy demand has grown by an average of 7% annually, making biomass a key consideration for reducing dependence on conventional energy sources. According to the FAO Nexus assessment, palm oil biomass holds the highest potential for bioenergy, particularly biodiesel, due to its superior WEF Nexus and energy pillar values when compared to rice and sugarcane. However, sugarcane is more favourable in terms of water pillar values, indicating it could be a more environmentally sustainable bioenergy option in terms of water usage.

On the other hand, rice biomass has the lowest values across all pillars, suggesting that its use for bioenergy could compromise national food security. The availability, production, and consumption of these biomasses – palm oil, sugarcane, and rice – have been influenced by climate change and land-use changes in Indonesia, necessitating a balanced approach to ensure sustainable bioenergy development.

*Malaysia* (palm oil)

The cultivation of oil palm in Malaysia has significant implications for the water, food, and energy sectors. Oil palm plantations heavily rely on water sources like rivers, lakes, and groundwater, highlighting the need for sustainable water management practices to ensure resource availability for both agriculture and other uses. As a major contributor to Malaysia's food production, palm oil is used in various food products, such as cooking oil, margarine, and processed foods, necessitating sustainable agricultural practices to maintain food security and minimise environmental impacts. In the energy sector, palm oil serves as a key feedstock for biofuel production, particularly biodiesel, and oil palm biomass is used for biogas and bioelectricity, supporting renewable energy targets and reducing GHG emissions. However, the industry faces challenges such as deforestation, biodiversity loss, habitat destruction, water resource impacts, and soil degradation due to fertiliser and pesticide use, underscoring the need for balanced approaches to manage the nexus.

The issue of convergence of the nexus at the regional level is importance as it has implications for efforts towards decarbonisation and a sustainable WEFL Nexus from the climate change perspective. Several converging factors, such as investment, openness to foreign trade, and inflows of foreign direct investment, can influence convergence on energy and food that need appropriate policy intervention at the regional (EAS/ASEAN) level.

*Philippines* (coconut and sugarcane)

In the Philippines, coconut and sugarcane farming show significant differences in resource use and productivity. Coconut farming uses substantially less water at 43.25 $m^3$/ha compared to sugarcane's 297.4 $m^3$/ha and requires far less energy, at 1,871.06 MJ/ha versus sugarcane's 20,585.38 MJ/ha. Coconut farming also emits less GHGs, at 449.58 kg $CO_2$eq/ha, compared to sugarcane's 963.4 kg $CO_2$eq/ha. In terms of economic returns, coconut is more productive per unit of GHG emissions, generating ₱63.6/kg $CO_2$eq, whilst sugarcane generates ₱29.77/kg $CO_2$eq. However, sugarcane has a significantly higher land productivity, yielding 58.44 tonnes of cane/ha compared to coconut's 4.14 tonnes of cane/ha.

Resource utilisation for coconut and bioethanol production shows significant variability across different WEFLC indicators. Water consumption has the highest value at 0.80, but this drops to 0.69 for mass productivity, which remains the highest amongst mass productivity indicators, and further reduces to 0.63 for economic productivity. Both energy and GHG emissions economic productivity scores are high at 0.72, indicating efficient energy use and high GHG emissions productivity in coconut and biofuel production.

However, coconut land-use economic productivity and GHG emissions economic productivity need improvement, as these indicators have the lowest values. This can be attributed to the minimal growth rate of coconut production, averaging 0.2% with yields of 4.15 tonnes per hectare. Despite high water consumption and productivity indices, factors such as inadequate intercropping techniques, production technology, irrigation availability, and impacts from typhoons and pests affect land-use efficiency.

Analysing the nexus index in three stages – WEF, WEFL, and WEFLC – shows that for sugarcane, the index increases from the WEF to WEFLC, peaking at 0.52 under the WEFLC. Conversely, for coconut, the nexus index decreases when land and climate are included, with the highest value at 0.64 under the WEF index. This indicates that integrating land and climate factors impacts the overall nexus score differently for different crops.

*India* (sugarcane and maize)

Sugarcane and maize cultivation across different regions in India show varied resource use and productivity. In Uttar Pradesh, sugarcane uses 16,639.00 $m^3$/ha of water, requires 38,565.00 MJ/ha of energy, emits 5,233.73 kg $CO_2$eq/ha, and achieves an economic return of RS42.725/kg $CO_2$eq with a land productivity of 78.131 t/ha. In Maharashtra, sugarcane's water use is higher at 18,750.00 $m^3$/ha, energy consumption is 50,652.28 MJ/ha, GHG emissions are 4,519.94 kg $CO_2$eq/ha, and it provides a better economic return of RS51.302/kg $CO_2$eq, with a higher land productivity of 117.825 t/ha. In contrast, maize cultivation in Karnataka uses significantly less water at 3,112.00 $m^3$/ha, requires 16,701.61 MJ/ha of energy, emits 5,030.61 kg $CO_2$eq/ha, has an economic return of Rs10.496/kg $CO_2$eq, and yields 11.133 t/ha. This illustrates that whilst maize is less resource-intensive, sugarcane, particularly in Maharashtra, provides higher land productivity and better economic returns per unit of GHG emissions.

In India, Maharashtra's sugarcane productivity stands at 84,280 kg/ha, surpassing Uttar Pradesh's 81,300 kg/ha, indicating greater environmental efficiency concerning GHG emissions. In maize production, Madhya Pradesh demonstrates slightly better energy mass productivity at 0.21 kg/MJ compared to Karnataka's 0.18 kg/MJ, meaning it converts energy into maize mass more efficiently. However, Karnataka achieves higher land mass productivity, yielding 11.133 tonnes per hectare, compared to Madhya Pradesh's 8.507 tonnes per hectare.

These findings highlight significant resource use in sugarcane production, with Maharashtra utilising more water and energy but emitting lower GHGs per hectare compared to Uttar Pradesh. In maize production, both Karnataka and Madhya Pradesh show substantial use of natural resources, with Karnataka using more energy per hectare than Madhya Pradesh but achieving higher yields.

*Viet Nam* (rice straw and rice husk)

Rice straw can be utilised in-field through open burning, raw incorporation into paddy fields, or composting, with composting offering soil benefits despite higher GHG emissions. Off-field uses include growing mushrooms, feeding cattle, and producing biochar and biogas, which enhance soil quality and reduce GHG emissions. Rice husk is mainly used for energy and industrial purposes, providing positive impacts on soil quality when used for agricultural applications like biochar and mulching and reducing GHG emissions when used as a green energy source. Overall, the sustainable management of rice straw and rice husk through these indicators can significantly improve environmental and economic outcomes in Viet Nam.

The utilisation of rice husk in Viet Nam has diverse effects on water, energy, food, land, and climate change. For energy purposes, rice husk used in household heating, for drying other products, and industrial boilers generally has a slight positive impact on water and food resources, with high positive impacts on energy and moderate positive impacts on climate change. However, these applications have a moderate negative impact on land use. The use of rice husk as fuel in the form of briquettes or pellets follows a similar pattern of impacts. In non-energy applications, particularly agriculture, rice husk utilisation shows significant benefits. Using rice husk for biochar has a moderate positive impact on water and climate change, a slight positive impact on energy, and strong positive impacts on food and land. Mulching and other agricultural substrates exhibit strong positive impacts across all dimensions – water, energy, food, land, and climate change. Industrial and other uses of rice husk, including building materials and other industrial applications, have slight positive impacts on water, energy, food, and climate change but show moderate negative impacts on land use.

These varied impacts highlight the importance of choosing the appropriate application for rice husk to maximise benefits and minimise adverse effects, contributing to sustainable resource management in Viet Nam.

## 5.3 Policy implications

In developing effective policies for sustainable biomass utilisation in EAS countries, it is crucial to integrate regional insights and address overarching challenges. Table 5.1 highlights the policies within the WEFLC Nexus in EAS countries, providing a clear linkage between the policies and their impact on each aspect of the WEFLC Nexus. Based on this list, the following are comprehensive policy recommendations that synthesise the key observations from various EAS countries.

### Spatial nexus assessments

Thailand emphasises the importance of spatial nexus assessments for decision-making. High sustainability scores in the Northeast region for sugarcane production underscore the value of localised metrics. Policymakers should incorporate climate indicators like GHG emissions to optimise land suitability and crop zoning and promote sustainable practices aligned with SDG 12.

### Energy efficiency and environmental regulations

Indonesia needs to enhance energy efficiency to reduce GHG emissions and improve energy security. This requires streamlining overlapping regulations, particularly those related to deforestation and carbon emissions. Simultaneous efforts to curb deforestation and carbon emissions should involve better strategies and evaluations to avoid competition for land and environmental degradation. Using nexus balance impact assessment methods can help identify both positive and negative impacts, whilst regional authorities should craft supportive policies for sustainable bioenergy production.

### Transition to a clean economy

Malaysia faces significant potential and challenges in its transition to a clean economy. Addressing issues such as public awareness, legal frameworks, cost, barriers to energy transition, and technological readiness is essential. Overcoming these obstacles necessitates collaboration amongst the government, the business community, international partners, and the public. Policies should promote equitable energy access, improve energy efficiency, and reduce energy intensity. Government-led public awareness campaigns should highlight the benefits of low-carbon energy, involving various stakeholders in educational initiatives to foster commitment to the transition.

### Land use and water management

The Philippines should focus on efficient land-use management and suitability to ensure sustainable development. The scarcity of arable land requires strategic planning to identify suitable areas for bioenergy cultivation without compromising food security or causing deforestation. Managing water resources is also crucial, as bioenergy production demands substantial water inputs. Integrating land suitability assessments with water availability and quality considerations can minimise the risks of water scarcity and pollution. Including climate change mitigation and adaptation strategies in land-use management will bolster the resilience of bioenergy systems.

### Integrated policy frameworks

India struggles with managing its WEF resources due to siloed policies. Developing an analytical framework with appropriate tools and models is vital for informed policy decisions. A WEFLC Nexus approach that fosters synergies and manages trade-offs can help India achieve its sustainable development goals. This integrated approach ensures policy coherence and maximises the positive impacts of bioenergy initiatives.

### Utilisation of other agricultural residues

Viet Nam has significant potential for utilising rice straw and rice husk for energy production, as recent national plans suggest. Policies should focus on efficiently harnessing these resources to overcome challenges related to storage and handling. Increased investment in industrial applications is necessary to realise this potential. By implementing these strategies, Viet Nam can promote the sustainable use of agricultural residues.

### Regional strategies and policy recommendations

For Phase I, it was found that EAS countries face common challenges related to feedstock availability, with many biofuel production plans relying on crops or a limited subset of wastes and residues. Future feedstock potential mainly comes from agricultural and forestry woody wastes, residues, or crops grown on marginal land.

Policies should aim to establish *cross-sectoral committees or taskforces* to ensure coherent policies and effective implementation of WEFLC-related initiatives. Forming these committees is crucial for addressing the complexities and interdependencies within the WEFLC framework. Resolving conflicting policies, such as those related to land use and energy production targets, is essential for achieving integrated and sustainable outcomes.

*Enhancing data sharing and fostering collaborative planning* amongst various stakeholders, including government agencies, the private sector, and societal organisations, is vital. Improved data transparency can facilitate the development and implementation of strategies that balance demands on WEFLC systems. These collaborative efforts are critical for ensuring that WEFLC initiatives are well-coordinated and aligned with broader sustainability goals, paving the way for a more sustainable and resilient future.

By integrating these comprehensive policy recommendations, EAS countries can enhance sustainable biomass utilisation, address specific regional needs, and promote overall environmental and economic sustainability.

Table 5.1. Summary of EAS Policies Related to the WEFLC Nexus

| Country | Water | Energy | Food | Land | Climate |
|---|---|---|---|---|---|
| Thailand | - Act on Water Resources B.E. 2561 (2018): Primary legislation for water resource management.<br>- Water Management Guidelines: Conserve water, enhance GDP whilst reducing water use, and boost water recycling. | - 20-Year Energy Efficiency Development Plan (2011–2030): Aims to reduce energy intensity by 25% by 2030.<br>- Shift in energy policy: Reduce reliance on natural gas and increase renewable energy. | - National Strategy (2017–2036): Focuses on food security, fair access to nutritious food, and sustainable food systems. | - Integrated Land-Use Strategies: Optimise land productivity through sustainable practices, especially for sugarcane and cassava. | - Draft Climate Change Act (2022): Focuses on mitigation, adaptation, and emissions cuts. |
| Indonesia | - UU 17/2019 on Water Resources: Establishes sustainable water resource management.<br>- PP 20/2006 on Irrigation: Regulates irrigation systems.<br>- PP 42/2008 on Water Resource Management: | - UU 30/2007 on Energy: Establishes energy management principles.<br>- UU 3/2023 on New and Renewable Energy: Develops renewable energy.<br>- PP 5/2006 on National Energy Policy: National energy policy framework. | - UU 18/2012 on Food: Establishes food security as a national goal.<br>- PP 17/2015 on Food Safety and Nutrition: Ensures food safety and nutrition.<br>- PP 61/15 on Food Consumption Diversification: Promotes food diversity. | - UU 32/2009 on Environmental Protection and Management: Regulates environmental management and land change.<br>- PP 62/2013 on Reducing GHG Emissions from Deforestation and Peatland | - UU 16/2016 ratifying the Paris Agreement: Limits global temperature rise and reduces GHG emissions.<br>- PP 22/2021 on Environmental Protection and Management: Manages environmental protection. |

| Country | Water | Energy | Food | Land | Climate |
|---|---|---|---|---|---|
| | Manages water resources effectively.<br><br>- PP 38/2011 on Water Utilization Business Permits: Issues permits for water use. - PP 37/2012 on Watershed Management: Manages watershed areas.<br><br>- PP 121/2015 on Water Resource Exploitation: Controls water exploitation.<br><br>- PP 22/2021 on Water Resource Management: Integrates water resource management.<br><br>- PERPRES 10/2017 on National Water Resources Council: | - PP 79/2014 on Accelerating Renewable Energy: Promotes renewable energy.<br><br>- PP 25/2021 on Implementing the Energy and Mineral Resources Sector: Implements energy sector strategies.<br><br>- PERPRES 22/2017 on General Plan for National Energy: Long-term energy plan.<br><br>- PERPRES 112/2022 on Accelerating Renewable Energy Development for Electric Power: Targets renewable energy in national mix. | - PP 86/2019 on Food Safety: Enhances food safety measures.<br><br>- PERPRES 22/2009 on Policy to Accelerate Food Consumption Diversification: Accelerates food diversity.<br><br>- PERPRES 64/2020 on National Strategic Area Spatial Planning: Plans for renewable energy and food production areas.<br><br>- Minister of Agriculture Regulation 13/2018 on Diversifying Food Consumption: Promotes food diversity.<br><br>- Minister of Agriculture Regulation 38/2022 on Good Food Crop Cultivation | Degradation: Reduces GHG emissions.<br><br>- PP 47/2012 on Control of Environmental Pollution and Damage: Controls pollution and environmental damage.<br><br>- PP 44/2021 on Deforestation Reduction: Reduces deforestation.<br><br>- PP 121/2022 on Control over Peat Land Conversion: Manages peatland conversion.<br><br>- PERPRES 62/2023 on Agrarian Reform: | - PP 44/2021 on Renewable Energy Development: Focuses on renewable energy and climate change.<br><br>- PERPRES 98/2021 on Implementation of Carbon Economic Value: Achieves NDC targets through mitigation and adaptation.<br><br>- Minister of Environment and Forestry Regulation 70/2017 on Reducing Emissions from Deforestation and Forest Degradation: Reduces emissions from deforestation. |

| Country | Water | Energy | Food | Land | Climate |
|---|---|---|---|---|---|
| | National coordination of water resources.<br><br>- PERPRES 73/2012 on Domestic Waste Processing: Manages domestic waste.<br><br>- PUPR Ministerial Decree 14/2023 on Domestic Wastewater Management: Guidelines for domestic wastewater management. | - KEPMEN ESDM 22/2011 on Retail Selling Prices for Fuel Oil, Diesel, and Biodiesel: Regulates fuel prices.<br><br>- ESDM Ministerial Decree 13/2021 on Biomass Power Electricity Prices: Sets electricity prices for biomass power.<br><br>- ESDM Ministerial Decree 12/2023 on Using Biomass Fuel in Steam Power Plants (PLTU): Guidelines for biomass fuel use in power plants. | Guidelines: Establishes cultivation guidelines. | Implements agrarian reform.<br><br>- PERPRES 14/2024 on Reducing Land Conversion: Minimizes land conversion.<br><br>- Minister of Agrarian Affairs Regulation 14/2022 on Sustainable Food Agricultural Land: Establishes sustainable agricultural land. | |
| Malaysia | - Water Sector Transformation 2040 (WST2040) Policy: | - National Energy Transition Roadmap (NETR) 2050: Targets | - National Agricommodity Policy 2021–2030 (DAKN): Focuses on sustainable | - National Biomass Action Plan 2023–2030: Promotes sustainable | - National Climate Change Policy (2010): Addresses |

| Country | Water | Energy | Food | Land | Climate |
|---|---|---|---|---|---|
| | Transforms the water sector by 2040.<br><br>- National Integrated Water Resources Management Plan (2016): Focuses on sustainable water and sewerage services. | net-zero emissions by 2050.<br><br>- National Energy Policy 2022-2040: Sets strategic energy goals.<br><br>- Malaysia Renewable Energy Roadmap (MyRER) 2035: Increases renewable energy capacity.<br><br>- National Energy Efficiency Action Plan (2015): Implements energy efficiency measures. | agricommodity development.<br><br>- National Food Security Policy Action Plan 2021–2025: Develops strategies for food supply sustainability.<br><br>- National Agrofood Policy 2021–2030 (NAP 2.0): Aims for a sustainable and resilient agrofood sector.<br><br>- National Agrofood Policy 2011–2020 (NAP 1.0): Addresses agricultural challenges. | biomass utilisation.<br><br>- Malaysia Forestry Policy (2021): Ensures forest cover remains at least 50%.<br><br>- Malaysian Biomass Industry Action Plan (2020): Provides strategy for biomass industry growth.<br><br>- National Biomass Strategy (2013): Utilises agricultural biomass. | climate change challenges.<br><br>- National Energy Policy 2022–2040: Aims for a low-carbon nation by 2040.<br><br>- Malaysia Forestry Policy: Promotes sustainable forest management. |
| Philippines | - Philippine Water Code of 1976 (PD 1067): Governs water resource management. | - Electric Power Industry Reform Act of 2001 (RA 9136): Promotes competitive electricity market. | - National Agriculture and Fisheries Modernization and Industrialization Plan 2021–2030 (NAFMIP): | - National Land Use Act/NLUA (House Bill 8162): Proposes comprehensive land-use policy. | - Climate Change Act of 2009 (RA 9729): Establishes climate change adaptation and |

| Country | Water | Energy | Food | Land | Climate |
|---|---|---|---|---|---|
| | - Philippine Clean Water Act of 2004 (RA 9275): Protects water quality.<br><br>- Integrated Water Resources Management (IWRM) Framework: Promotes holistic water management. | - Biofuels Act of 2006 (RA 9367): Mandates biofuel blending.<br><br>- Renewable Energy Act of 2008 (RA 9513): Encourages renewable energy development. | Modernises agriculture and fisheries.<br><br>- Philippine Development Plan (PDP) 2023–2028: Ensures food security and improves productivity.<br><br>- Rice Tariffication Law (RA 11203): Liberalises rice importation. | - Comprehensive Agrarian Reform Law of 1988 (RA 6657): Promotes equitable land distribution.<br><br>- Forestry Reform Code of 1975 (PD 705): Regulates forest land use. | mitigation framework.<br><br>- National Disaster Risk Reduction and Management Act of 2010 (RA 10121): Strengthens disaster risk reduction.<br><br>- National Integrated Protected Areas System Act of 1991 (RA 7586): Protects biodiversity and natural habitats. |
| India | - - National Water Policy, 2012: Encourages efficient water management, diversification of crops, and water conservation.<br><br>- National Biofuel Policy, 2018: Promotes water- | - National Biofuel Policy, 2018: Focuses on energy security and developing alternate energy sources.<br><br>- Waste to Energy Programme, 2022: Supports energy security by | - National Water Policy, 2012: Promotes crop diversification to include less water-intensive varieties.<br><br>- National Biofuel Policy, 2018: Encourages use of non-food biomass for biofuel to reduce | - National Biofuel Policy, 2018: Recommends using non-arable and waste land for biofuel crops.<br><br>- Energy Policy, 2017 (draft): Discusses land resources | - National Water Policy, 2012: Emphasises adaptation strategies for managing water resources in the context of climate change. |

| Country | Water | Energy | Food | Land | Climate |
|---|---|---|---|---|---|
| | efficient biofuel production methods.<br><br>- Waste to Energy Programme, 2022: Not discussed explicitly, but reduces water contamination by utilising waste.<br><br>- Biomass Programme, 2022: Not discussed explicitly.<br><br>- Sustainable Agrarian Mission, 2021: Supports the development of water-efficient boiler designs.<br><br>- Energy Policy, 2017 (draft): Mentions hydropower and water conservation. | promoting biogas, bio-compressed natural gas, and power generation from waste.<br><br>- Biomass Programme, 2022: Aims at energy transition by promoting biomass briquette/pellet manufacturing.<br><br>- Sustainable Agrarian Mission, 2021: Promotes energy security through biomass co-firing in thermal power plants.<br><br>- Energy Policy, 2017 (draft): Supports energy targets and diversifies energy sources. | competition with food crops.<br><br>- Waste to Energy Programme, 2022: Utilises agricultural waste, reducing waste disposal issues.<br><br>- Biomass Programme, 2022: Uses surplus biomass and agricultural residues.<br><br>- Sustainable Agrarian Mission, 2021: Uses biomass from the Biomass Programme for energy generation. | required for energy projects. | - National Biofuel Policy, 2018: Aims at reducing GHG emissions through biofuel utilisation.<br><br>- Waste to Energy Programme, 2022: Supports transition to net-zero emissions.<br><br>- Biomass Programme, 2022: Aims at reducing GHG emissions through biomass utilisation.<br><br>- Sustainable Agrarian Mission, 2021: Focuses on reducing GHG emissions through biomass utilisation.<br><br>- Energy Policy, 2017 (draft): Highlights the need |

| Country | Water | Energy | Food | Land | Climate |
|---|---|---|---|---|---|
| | | | | | to stay within NDC targets and reduce current energy emissions. |
| Viet Nam | - Decree No. 02/2023/ND-CP on implementation of the Law on Water Resources: Implements the law on water resources.<br><br>- Decision 161/QD-TTg approving the Water Resources Planning for 2021-2030, with a Vision to 2050: Plans water resources for the future.<br><br>- Decree 54/2015/ND-CP on incentives for economical and efficient water use: Encourages efficient water use. | - Resolution No. 55NQ/TW on the National Energy Development Strategy to 2030: Develops the national energy strategy.<br><br>- Decision 893/QD-TTg approving the National Energy Master Plan for 2021-2030: Approves the energy master plan.<br><br>- Viet Nam's Eighth Power Development Plan (PDP8) for 2021–2030: Develops the power sector. | - Resolution No. 34/NQ-CP on ensuring national food security until 2030: Ensures food security.<br><br>- Decision No. 555/QD-BNN-TT on restructuring Viet Nam's rice industry to 2025 and 2030: Restructures the rice industry.<br><br>- Decision No. 1490/QD-TTg on the sustainable development of one million hectares of high-quality rice: Develops high-quality rice cultivation. | - Land Law 2024: Comprehensive law governing land use.<br><br>- Degree No. 10/2023/ND-CP on guidelines for the Law on Land: Provides guidelines for land law implementation.<br><br>- Decree No. 62/2019/ND-CP on management and use of rice cultivation land: Manages rice cultivation land.<br><br>- Decree No. 94/2019/ND-CP | - Decision No. 896/QD-TTg approving the National Strategy on Climate Change up to 2050: Approves the long-term climate strategy.<br><br>- Decree 06/2022/ND-CP on mitigation of greenhouse gas emissions and ozone layer protection: Mitigates GHG emissions.<br><br>- Directive No. 10/CT-TTg on sustainable agricultural and rural development in the Mekong Delta: |

| Country | Water | Energy | Food | Land | Climate |
| --- | --- | --- | --- | --- | --- |
| | - Circular No. 25/2023/TT-BNNPTNT on guidelines for dyke maintenance and repair: Provides guidelines for maintaining and repairing dykes. | - Decision 08/2020/QD-TTg on support mechanisms for biomass power projects: Provides support mechanisms for biomass power. | - Decision No. 248/QD/TT-CLT on guidelines for rice straw collection and utilisation: Provides guidelines for collecting and utilising rice straw.<br>- Decision No. 583/QD-TTg on Viet Nam's rice export market development strategy until 2030: Develops the rice export market. | on crop production and plant varieties: Regulates crop production and plant varieties. | Promotes sustainable development in the Mekong Delta. |

Source: Author's compilation.

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