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REVIEW

Valorization of Agricultural Wastes to Offset Greenhouse Gases (GHGs) Emissions: An Insight in Southeast Asia

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ABSTRACT

This paper aims to review and synthesize the existing literature on agricultural waste valorization in the Southeast Asian (SEA) region, with a focus on its potential to offset greenhouse gas (GHG) emissions. The SEA region generates abundant agricultural wastes from major commodity crops, such as: rice, palm oil, sugarcane, coconut, and corn, which present opportunities for valorization. The review found that countries like Indonesia, Malaysia, and Thailand have conducted several studies on agricultural waste valorization, exploring pathways such as bioenergy, value-added products, and soil amendments. However, only a few studies exist for some countries with high residue valorization potential, such as Vietnam and the Philippines. The reviewed literature showed a relationship between agricultural waste valorization and emissions that could contribute to air pollution, but no direct association was established with the associated GHG emissions. The abundance of agricultural residues across SEA presents opportunities for valorization to offset GHG emissions. However, effective valorization is hindered by challenges like open burning practices, logistical issues, and a lack of sustainable waste management strategies. This review highlights the need for further research to establish the direct relationship between agricultural waste valorization and GHG emissions reduction in the SEA region.

Keywords: Agricultural waste; Biomass; Valorization; Greenhouse gas; Southeast Asia

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1. Introduction

Southeast Asia (SEA) is recognized as one of the most dynamic and diverse regions worldwide [1,2]. It is a geographic sub-region located in the Southeastern part of Asia, comprising eleven nations spanning from the areas southeast of the Indian subcontinent, southern China, and the Northwestern region of Australia [3] (**Figure 1**).

Geographically, the region is separated into "mainland" and "island" zones. The mainland zone includes Myanmar, Thailand, Laos, Cambodia, Vietnam, and Peninsular Malaysia; while the island zone encompasses Brunei, East Malaysia, Timor-Leste, Indonesia, the Philippines, and Singapore [4].

The agricultural sector plays a crucial role in the economies of Southeast Asian nations [6], making a significant contribution to the countries' gross domestic product (GDP) and employment rates [7]. The demand for agricultural products is currently at an all-time high due to population growth [8], with substantial quantities of crops produced for both domestic consumption and export [9]. Many countries in the region are among the world's top producers of agricultural commodities such as rice, sugarcane, palm oil, and coconut [10].

Table 1 presents the production levels of various commodities across different Southeast Asian nations.

Rice is a major crop grown in most countries in SEA, with Indonesia having the highest output [1,12,13]. Vietnam is the second highest rice producer, followed by Thailand, the Philippines, and Myanmar. Indonesia stands out as the largest producer of several commodities, including corn, oilseed copra, oilseed palm kernel, and palm oil while Malaysia is a notable producer of oilseed palm kernel and palm oil [1,14–18], reflecting the importance of the palm oil industry in these two countries. The Philippines and Thailand are also significant producers of corn [19]. Agricultural output has been enhanced to ensure food availability for the region's population of 600 million or more and to facilitate trade, resulting in the annual generation of massive amounts of agricultural waste [3]. Agricultural wastes are typically classified into crop residues (e.g. bagasse, discarded fruits and vegetables, prunings), livestock wastes (e.g. manure and animal carcasses), and food processing wastes (e.g. rice husks and wheat straw) [20].

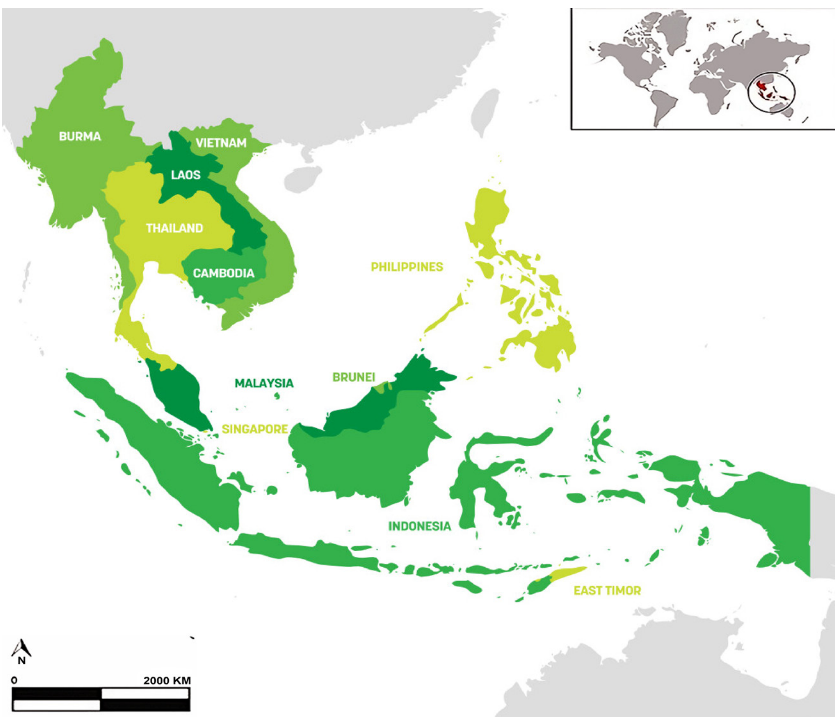

Figure 1. Map of Southeast Asia adapted.

Source: Zain et al. [5].

Table 1. Agricultural production in selected SEA countries (as of May 2024).

Country	Commodity	Production (million metric tons, Mmt)
Cambodia	Rice	7.38
Indonesia	Corn	13.2
	Rice	34.0
	Oilseed	1.20
	Soybean	0.36
	Peanut	0.84
	Oilseed, Copra	1.68
	Oilseed, Palm Kernel	12.2
	Oil, Palm	47.5
Laos	Rice	1.97
Malaysia	Rice	1.75
	Oilseed, Copra	0.03
	Oilseed, Palm Kernel	4.70
	Oil, Palm	19.0
Myanmar	Rice	12.1
	Oilseed	2.46
	Soybean	0.13
	Peanut	1.75
Philippines	Corn	8.50
	Rice	12.7
	Oilseed, Copra	2.50
Thailand	Corn	5.40
	Rice	20.1
	Soybean	0.05
	Peanut	0.04
	Oilseed, Copra	0.09
	Oilseed, Palm Kernel	0.86
	Oil, Palm	3.36
Vietnam	Corn	4.30
	Rice	27.0
	Soybean	0.05
	Peanut	0.37
	Oilseed, Copra	0.29

Source: Chataut et al. [11].

The high agricultural productivity in SEA generates significant quantities of underutilized residues [21]. A portion of the residue is incorporated back into the soil, while a certain amount is used for energy purposes; the remainder is either dumped in landfills or openly burned in fields [22]. Open burning of crop residues leads to the release of substantial amounts of air pollutants, such as particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOCs), black carbon (BC), and organic carbon (OC), as well as potent greenhouse gases (GHGs) like methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O), and small levels of nitrogen oxides (NOx) and sulfur oxides (SOx) [23].

GHG emissions are considered one of the primary root causes and most significant challenges in addressing climate change [6]. Agricultural burning, particularly when conducted on a large scale for commercial agriculture, is a leading source of CO_2 and GHG emissions [24,25]. Farmers often find the collection and transportation of residues from fields costly, making burning the most economical method for disposing of excessive residues [4,22,23,26]. SEA has been reported as one of the largest biomass-burning source regions globally [27,28] and has the highest per capita GHG emissions in the agriculture, forestry, and other land use (AFOLU) sectors in Asia [29].

Agricultural waste is often a valuable resource that can be repurposed or given to new uses [4]. However, despite their multiple applications and significant potential [26], when mismanaged, they not only contribute to GHG emissions in post-harvest activities [30] but also represent a missed opportunity for valorization into valuable products. Nowadays, where the principles of sustainability and resource efficiency are paramount, the concept of a circular economy has emerged as a key approach for promoting sustainable resource utilization and minimizing waste generation [31].

Figure 2 shows the concept of agricultural waste valorization in a circular economy approach (adapted from Amran et al. [20]).

Valorization, or the process of increasing the value, of agricultural wastes can transform these residues into high-value-added products, including biofuels, biochemicals, and biomaterials [32], offsetting GHG emissions while generating economic benefits. Currently, SEA has an abundance of agricultural waste generation due to high agricultural produc-

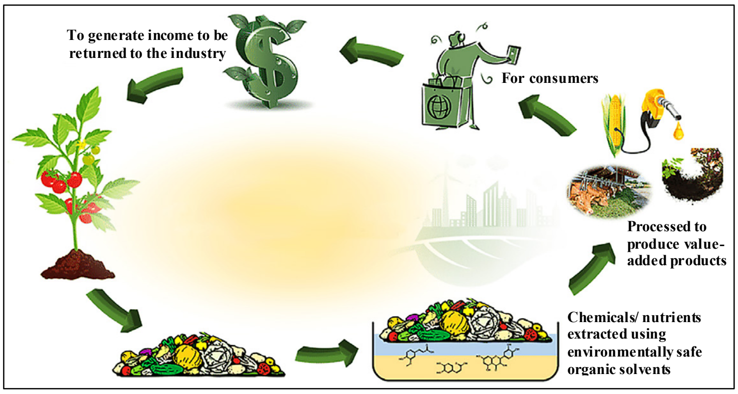

Figure 2. Valorization of agricultural wastes in a circular economy concept.

tivity, and several pathways for valorization exist in each country in the region.

This paper aims to review and synthesize the literature on agricultural waste valorization in the SEA region in the context of offsetting GHG emissions. Presently, other existing review articles in SEA are specific to individual countries, and there are no studies encompassing the valorization of agricultural wastes across the entire SEA region; hence, this review was undertaken. Sixty five (65) papers were obtained from Google Scholar, including those indexed in Scopus and Clarivate databases, by searching for the following keywords: agricultural waste, valorization, agricultural residues, biomass, Southeast Asia from the year 2015–2024.

The review consists of three main subsections: (a) status, (b) challenges, and (c) future directions.

2. Status

The Southeast Asian region is endowed with abundant agricultural residues arising from the cultivation of major commodities like rice, oil palm, sugarcane, coconut, corn, cassava, and others.

Table 2 summarizes the key agricultural commodities and the associated residues generated from the relevant literature sources across the regional countries.

Table 2. Agricultural waste generation in Southeast Asia.

Country	Commodity	Waste	Reference
Brunei	Rice, corn, coconut	Coconut shell and fiber, corn fiber, rice husk	[10, 19]
Cambodia	Rice, corn, coconut cassava, sugarcane, groundnut	Rice straw, rice husk, corn cob, cassava stalk, sugarcane bagasse, groundnut shells/husks, coconut shells	[4, 10, 19]
Indonesia	Rice, coconut, oil palm, sugarcane, cocoa, banana, pineapple, natural rubber, acacia, cassava/tapioca	Empty fruit bunches, palm kernel shells, mesocarp fiber, fronds, trunks, rice straw, rice husk, sugarcane bagasse, cocoa pod waste, coconut shells/husks, banana stems/leaves/peels, pineapple residues, pulp residues	[1, 5, 11, 13, 15, 16, 20, 33, 34]
Laos	Rice, corn	Rice residues, corn cobs	[19]
Malaysia	Rice, coconut, oil palm, pineapple, banana, durian	Empty fruit bunches, palm kernel shells, fronds, trunks, rice straw, coconut residues, pineapple residues, banana residues, durian biomass	[10, 22, 37, 38, 40, 42, 46, 51, 53–56]
Myanmar	Rice, corn, cassava	Rice straw, paddy, rice husk, bagasse, corn cobs, cassava stalks	[19]
Philippines	Rice, corn, coconut, sugarcane	Rice straw, rice husk, rice bran, corn cobs/stover, coconut husks/fronds, sugarcane bagasse	[1, 13, 49, 50]
Singapore	-	Empty fruit bunches (imported)	[18]
Thailand	Rice, sugarcane, cassava, palm oil, tobacco, teak, rubber	Rice straw, rice husk, sugarcane bagasse/tops/leaves, palm kernel shells, empty fruit bunches, old trunks, rubber residues, teak residues, cassava roots/starch, tobacco stalks	[1, 5, 19, 26, 32, 42, 43, 47, 57]
Vietnam	Rice, corn, coconut, coffee	Rice straw, rice husk, bagasse, cane trash, maize trash, cassava stem, peanut shell, coffee husk, coconut shell	[10, 26, 48]

Indonesia, being the largest producer and exporter of palm oil along with Malaysia, generates massive quantities of solid residues like empty fruit bunches (EFB), palm kernel shells (PKS), mesocarp fiber, fronds, and trunks [14,15,33]. Other major residues include rice straw, rice husk, sugarcane bagasse, cocoa pod waste, coconut shells/husks, and residues from banana and pineapple cultivation [1,10,12,34]. The availability of these diverse residue streams presents opportunities for valorization into bioenergy, biorefinery products, and soil amendments. Malaysia, the second-largest palm oil producer [35], faces waste management challenges [36] from the oil palm industry's EFB, PKS, fronds, and trunks [37–39]. It also generates residues from rice, coconut, pineapple, banana, durian, and sago starch production [22,34,40,41]. The government aims to capitalize on bioenergy from these abundant residues to reduce greenhouse gas emissions [42]. Thailand is a major producer of residues from sugarcane (bagasse, tops, leaves), rice (straw, husk), palm oil (kernels, EFB, trunks), rubber, teak, cassava, and tobacco cultivation [1,32,43]. Open burning of crop residues like rice straw and sugarcane trash is widespread, causing air pollution and transboundary haze events [26,32,44–46]. Valorization pathways like bioethanol production from molasses, cassava, and tobacco stalks are being explored [1,43,47]. Vietnam faces challenges with the open burning of rice straw, a common crop residue disposal practice [26,27,48]. Other residues include rice husks, bagasse, maize trash, cassava stems, peanut shells, coffee husks, and coconut shells [10]. Developing sustainable valorization routes for these residues can mitigate emissions and provide economic benefits. The Philippines generates abundant rice residues (straw, husk, bran) as a major producer, along with corn residues, coconut biomass, and sugarcane bagasse [1,13,49,50]. Open burning of residues like rice straw is prevalent, leading to emissions and health hazards [13,50]. Valorization into biochar, particle boards, and bioenergy represents potential solutions [13,51,52]. Cambodia heavily relies on rice cultivation, generating rice straw, husk, and other residues like corn cobs, cassava stalks, groundnut shells, and coconut shells [4,10,19]. Open burning of post-harvest straws is a traditional practice requiring sustainable residue management approaches [4]. Smaller nations like Brunei, Laos, and Myanmar have relatively lower biomass potential compared to regional agricultural giants [5,10,19]. However, residues from coconut, rice, corn, and cassava cultivation present opportunities for localized valorization efforts aligned with their largely agrarian economies. Singapore, being a compact island nation with negligible domestic agricultural production, can potentially import and utilize regional biomass residues like EFB from neighboring palm oil producers are biorefinery feedstock, leveraging its strategic location and status as a major oil refining hub [18].

3. Challenges

Despite the abundance of diverse agricultural residues across Southeast Asia, several challenges hinder their effective valorization into value-added products, bioenergy, and soil amendments. These challenges span technological, economic, social, institutional, and environmental domains. From a technical standpoint, issues related to biomass supply, including availability, scattered locations, and high moisture content, pose hurdles [12,56]. Logistical challenges, such as storage and transportation due to the low density and high volume of biomass residues, further compound the problem [56,58,59]. Additionally, the lack of accessible and reliable technologies, especially those tailored for tropical biomass feedstocks, and the shortage of technical expertise, particularly in small and medium enterprises (SMEs), impede progress [10,56]. Social awareness and responsibility barriers, such as the failure to raise public awareness about the importance of the biomass industry and its potential socio-economic benefits, hinder development [56,60].

Moreover, misconceptions about the benefits and losses from crop burning, along with long-standing established norms, contribute to the prevalence of open burning practices [4]. Institutional and policy barriers include gaps between academia and industry players, the absence of biomass monitoring and tracking systems, and the lack of agreement between policymakers and departments [1,56]. Additionally, the lack of preferential regulatory frameworks and institutional barriers impede the bioenergy transition in some countries [1,61]. Environmental considerations, such as the need to assess the full environmental impacts of biomass conversion technologies from cradle-to-grave, must also be addressed [56]. Furthermore, the open burning of agricultural residues contributes significantly to air pollution, particulate matter emissions, and the release of greenhouse gases, posing a significant environmental challenge [5,26,32].

4. Future directions

Several authors highlight the importance of integrating circular and sustainable agricultural practices as paramount for addressing agricultural waste and associated greenhouse gas emissions. Promoting alternative practices and technologies to replace open burning is crucial, including developing incentive policies and treatment/ recycling technologies [4,28], supporting smallholder farms to transition to sustainable practices, and improving residue collection and valorization technologies [28,58,62].

Embracing circular and sustainable agricultural practices, such as implementing good agricultural practices emphasizing waste minimization, reuse, recycling, and proper disposal; adopting circular agriculture principles; increasing emphasis on organic, bio-, and bioorganic fertilizers; and conducting field trials to explore biomass/fertilizers' potential for increasing soil carbon sequestration [12,37,63,64].

Effectively communicating and enforcing existing regulations prohibiting open burning, and developing databases and GIS maps to track residue availability and distribution [4], investigating residue conversion into energy through various processes, developing integrated biorefineries for efficient lignocellulosic biomass conversion, overcoming technical barriers in thermochemical and biochemical conversion of rice residues, and exploring the production of high-value products from rice biomass [1,4,65].

Table 3 summarizes valorization pathways for agricultural wastes in Southeast Asia.

Table 3. Valorization pathways for agricultural wastes in Southeast Asia.

Country	Agricultural waste	Valorization	Reference
Brunei	Coconut shell, coconut fiber, corn fiber, rice husk	Bioenergy	[19]
Cambodia	Rice straw	Cattle silage	[4]
	Rice husk, livestock manure	Bioenergy	
Indonesia	Rice husk, cocoa pods, coconut shells, oil palm shells, corn cobs	Biochar	[33]
	Oil palm residues such as palm kernels, EFB, fronds, and trunks	Bioenergy, value-added products	[15]
	Palm kernel shells, EFB, old trunks, rice husks, rice straw, sugarcane residues (bagasse, tops, leaves)	Bioenergy	[19, 34]
	Cassava pulp	Biogas	[1]
	Cocoa pod waste, rice straw & husk, coconut waste	Bioenergy	[34]
Malaysia	Oil palm residues	Bioenergy	[37]
	Sago wastes	Value-added products	[40]
	Rice and palm oil residues	Biocoke	[34]
	Palm oil residues	Value-added products	[39]
	Oil palm residues	Biofuel	[42]
Philippines	Rice husks	Value-added products	[13]
	Rice husks, sawdust, starch	Particle board	[49]
	Corn stover, coconut shell	Cattle feed, activated carbon, charcoal	[50]

Table 3 continued

Country	Agricultural waste	Valorization	Reference
Thailand	Sugarcane residues	Bioenergy	[32]
	Sugarcane bagasse, rice straw, rice husks, palm kernel shell, EFB, and trunks	Bioenergy	[1]
	Cassava starch and chips	Biofuel	[1]
	Tobacco waste	Bioethanol	[43]
	Sugarcane leaves and trash	Electricity, biochar	[57]
	Sugarcane, cassava, rice, palm residues	Biofuel	[47]
Vietnam	Rice straw	Biochar, animal feed, mushroom cultivation	[48]
	Rice straw, rice husk, sugarcane bagasse, cane trash, maize trash, cassava stem, peanut shell, coffee husk, coconut shell, manure	Bioenergy, biogas	[19]

5. Conclusions

The Southeast Asian region generates abundant agricultural residues from major commodity crops like rice, palm oil, sugarcane, coconut, and corn, which present opportunities for valorization to offset greenhouse gas emissions. The reviewed literature has shown that countries like Indonesia, Malaysia, and Thailand have conducted numerous studies on various valorization pathways, including bioenergy, value-added products, and soil amendments; yet, research is limited for some countries in the region, especially those with high residue valorization potential, such as Vietnam and the Philippines. The available studies have indicated a relationship between agricultural waste valorization and emissions that could contribute to air pollution. Nevertheless, this review could not draw specific conclusions, as the studies did not establish a direct association with the related GHG emissions. Valorization of agricultural wastes is hindered by open burning practices, logistical issues, and a lack of sustainable waste management strategies. Overcoming these barriers could lead to significant environmental and economic benefits for the region. Moreover, further research is needed to better understand the direct relationship between agricultural waste valorization and greenhouse gas emissions reduction in SEA. Region-wide assessments and cross-country comparisons would provide insights to guide policymakers and stakeholders in developing strategies for sustainable agricultural waste valorization.

Author Contributions

Conceptualization, methodology, original draft. Z.N.; Review and supervision, G.L..

Conflict of Interest

The authors agreed to the publication of this manuscript version and declare that there are no conflicts of interest.

Data Availability Statement

The data analyzed in this review are studies available from cited published online sources. The review synthesized information from sixty-five (65) research articles and reports from Google Scholar, including those indexed in Scopus and Clarivate databases by searching for the following keywords: “agricultural waste”, “valorization”, “agricultural residues”, “biomass”, “Southeast Asia” for the period of 2015 to 2024. The specific sources are appropriately referenced throughout the manuscript and no new datasets were generated in this review.

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References

[1] International Renewable Energy Agency [Internet]. Scaling up Biomass for The Energy

Transition: Untapped Opportunities in Southeast Asia [cited 2024 May 1]. Available from: https://www.irena.org/Publications/2022/Feb/Scaling-up-biomass-for-the-energy-transition-Untapped-opportunities-in-Southeast-Asia#:~:text=Copy%20url%20Copied-,Scaling%20Up%20Biomass%20for%20the%20Energy%20Transition%3A%20Untapped%20Opportunities%20in-,%2C%20Myanmar%2C%20Thailand%20and%20Vietnam

[2] Dedicatoria, R.M.M., Diomampo, C.B., 2019. Chapter 8—Status of climate change adaptation in Southeast Asia region. Status of Climate Change Adaptation in Asia and the Pacific. 153–182.
DOI: https://doi.org/10.1007/978-3-319-99347-8_8

[3] Chaturvedi, S., 2022. Types of biomass burning in South East Asia and its impact on health. EQA—International Journal of Environmental Quality. 50(1), 55–79.
DOI: https://doi.org/10.6092/issn.2281-4485/15539

[4] Economic and Social Commission for Asia and the Pacific [Internet]. Air Pollution and Greenhouse Gas Emissions From The Agricultural Sector in South and Southeast Asia [cited 2024 May 1]. Available from: https://hdl.handle.net/20.500.12870/6383

[5] Zain, S.M.S., Latif, M.T., Baharudin, N.F., et al., 2021. Atmospheric PCDDs/PCDFs levels and occurrences in Southeast Asia: A review. Science of the Total Environment. 783, 146929.
DOI: https://doi.org/10.1016/j.scitotenv.2021.146929

[6] Bacudo, I., Lui, R., 2022. Carbon trading and smallholder rice farmers in Southeast Asia. Discussion Paper: Opportunities and Challenges of Carbon Trading for Smallholder Farmers. ASEAN Climate Resilience Network.

[7] Sundram, P., 2023. Food security in ASEAN: Progress, challenges and future. Frontier in Sustainable Food Systems. 7, 1260619.
DOI: https://doi.org/10.3389/fsufs.2023.1260619

[8] Chataut, G., Bhatta, B., Joshi., et al., 2023. Greenhouse gases emission from agricultural soil: A review. Journal of Agriculture and Food Research. 11.
DOI: https://doi.org/10.1016/j.jafr.2023.100533

[9] Ramachandran, S., 2021. Emission reduction potential of energy from biomass residues in Southeast Asia's Road Transport [PhD Thesis]. München: Technical University of Munich.

[10] Tun, M.M., Juchelkova, D., Win, M.M., et al., 2019. Biomass energy: an overview of biomass sources, energy potential, and management in Southeast Asian countries. Resources. 8, 81.
DOI: https://doi.org/10.3390/resources8020081

[11] World Agricultural Production [Internet]. Circular Series WAP 5–24 May 2024 [cited 2024 May 1]. Available from: https://apps.fas.usda.gov/psdonline/circulars/production.pdf

[12] Susanti, W.I., Cholida, S.N., Agus, F., 2024. Agroecological nutrient management strategy for attaining sustainable rice self-sufficiency in Indonesia. Sustainability. 16, 845.
DOI: https://doi.org/10.3390/su16020845

[13] Sarong, M.M., Orge, R.F., Eugenio, P.J., et al., 2020. Utilization of rice husks into biochar and nanosilica: for clean energy, soil fertility and green nanotechnology. International Journal of Design and Nature and Ecodynamics. 15(1), 97–102.
DOI: https://doi.org/10.18280/ijdne.150113

[14] Nabila, R., Hidayat, W., Haryanto, A., et al., 2023. Oil palm biomass in Indonesia: Thermochemical upgrading and its utilization. Renewable and Sustainable Energy Reviews. 176, 113193.
DOI: https://doi.org/10.1016/j.rser.2023.113193

[15] Suhartini, S., Hidayat, N., Rohma, N.A., et al., 2022. Sustainable strategies for anaerobic digestion of oil palm empty fruit bunches in Indonesia: a review. International Journal of Sustainable Energy. 41(11), 2044–2096.
DOI: https://doi.org/10.1080/14786451.2022.2130923

[16] Teh, J.S., Teoh, Y.H., How, H.G., et al., 2021. The Potential of sustainable biomass producer gas as a waste-to-energy alternative in Malay-

sia. Sustainability. 13(7), 3877.
DOI: https://doi.org/10.3390/su13073877

[17] Sharma, R., Wahono, J., Baral, H., 2018. Bamboo as an alternative bioenergy crop and powerful ally for land restoration in Indonesia. Sustainability. 10(12), 4367.
DOI: https://doi.org/10.3390/su10124367

[18] Isoni, V., Kumbang, D., Sharatt, P.N., et al., 2018. Biomass to levulinic acid: A techno-economic analysis and sustainability of biorefinery processes in Southeast Asia. Journal of Environmental Management. 214, 267-275.
DOI: https://doi.org/10.1016/j.jenvman.2018.03.012

[19] FAO. 2022. Agricultural production statistics. 2000–2021. FAOSTAT Analytical Brief Series No. 60. Rome.
DOI: https://doi.org/10.4060/cc3751en

[20] Amran, M.A., Palaniveloo, K., Fauzi, R., 2021. Value-added metabolites from agricultural waste and application of green extraction techniques. Sustainability. 13, 11432.
DOI: https://doi.org/10.3390/su132011432

[21] Panda, A., Yamano, T., 2023. Asia's Transition to Net Zero: Opportunities and Challenges in Agriculture. ADB Economics Working Paper Series. 694.
DOI: http://dx.doi.org/10.22617/WPS230360-2

[22] Development of Renewable Resources Based on Biomass Waste in Malaysia [Internet] [cited 2024 May 1]. Available from: https://www.jstage.jst.go.jp/article/jspmee/8/6/8_243/_pdf/-char/ja

[23] Oanh, N.T., Permadi, D.A., Hopke, P., et al., 2018. Annual emissions of air toxics emitted from crop residue open burning in Southeast Asia over the period of 2010–2015. Atmospheric Environment. 187, 163–173.
DOI: https://doi.org/10.1016/j.atmosenv.2018.05.061

[24] Contribution of Agriculture to Climate Change and Low-Emission Agricultural Development in Asia and the Pacific [Internet] [cited 2024 May 1]. Available: https://doi.org/10.56506/WDBC4659

[25] Fajrini, R., 2022. Environmental harm and decriminalization of traditional slash-and-burn practices in Indonesia. International Journal for Crime, Justice and Social Democracy. 11(1), 28–43.
DOI: https://doi.org/10.5204/ijcjsd.2034

[26] Krishna, V.V., Mkondiwa, M., 2023. Economics of crop residue management. Annual Review Resource Economics. 15, 19–39.
DOI: https://doi.org/10.1146/annurev-resource-101422-090019

[27] Lasko, K., Vadrevu, K.P., Bandaru, V., et al., 2021. PM2.5 emissions from biomass burning in South/Southeast Asia—uncertainties and trade-offs. Biomass Burning in South and Southeast Asia. CRC Press: Boca Raton, Florida, USA.
DOI: https://doi.org/10.1201/9780429022036-12

[28] Actions Needed to Reduce Open Biomass Burning and Associated PM2.5 Pollution in Southeast Asia Countries [Internet] [cited 2024 May 1]. Available from: https://huce.edu.vn

[29] IPCC, 2022. Summary for policymakers. Climate Change 2022: Mitigation of Climate Change. Cambridge University Press: Cambridge, UK and New York, NY, USA.
DOI: https://doi.org/10.1017/9781009157926.001

[30] Rhofita, E.I, Rachmat, R., Meyer, M., 2022. Mapping analysis of biomass residue valorization as the future green energy generation in Indonesia. Journal of Cleaner Production. 354, 131667.
DOI: https://doi.org/10.1016/j.jclepro.2022.131667

[31] Gao, Z., Alshehri, K., Li, Y., et al., 2022. Advances in biological techniques for sustainable lignocellulosic waste utilization in Biogas production. Renewable and Sustainable Energy Reviews. 170, 112995.
DOI: https://doi.org/10.1016/j.rser.2022.112995

[32] Suriyawong, P., Chuetor, S., Samae, H., et al., 2023. Airborne particulate matter from biomass burning in Thailand: Recent issues, challenges,

and options. Heliyon. 9(3), E14261.
DOI: https://doi.org/10.1016/j.heliyon.2023.e14261

[33] Susilawati, A., Maftuah, E., Fahmi, A., 2020. The utilization of agricultural waste as biochar for optimizing swampland: a review. IOP Conference Series: Materials Science and Engineering. 980, 012065.
DOI: https://doi.org/10.1088/1757-899X/980/1/012065

[34] Gani, A., Erdiwansyah, Munawar, E., et al., 2023. Investigation of the potential biomass waste source for biocoke production in Indonesia: A review. Energy Reports. 10, 2417–2438.
DOI: https://doi.org/10.1016/j.egyr.2023.09.065

[35] Kaniapan, S., Hassan, S., Ya, H., et al., 2021. The utilisation of palm oil and oil palm residues and the related challenges as a sustainable alternative in biofuel, bioenergy, and transportation sector: A review. Sustainability. 13(6), 3110.
DOI: https://doi.org/10.3390/su13063110

[36] Singh, G., Gupta, M.K., Chaurasiya, S., et al., 2021. Rice straw burning: a review on its global prevalence and the sustainable alternatives for its effective mitigation. Environmental Science and Pollution Research. 28, 32125–32155.
DOI: https://doi.org/10.1007/s11356-021-14163-3

[37] Daud, N.N., Chinenyenwa, A.S., Rhys, T.H., et al., 2019. Carbon sequestration in malaysian palm oil plantations—an overview. Proceedings of the 8th International Congress on Environmental Geotechnics. 3, 49–56.
DOI: https://doi.org/10.1007/978-981-13-2227-3_6

[38] Sentian, J., Herman, F., Yee, V.K., et al., 2021. Biomass burning in Malaysia: Sources and impacts. Biomass Burning in South and Southeast Asia. CRC Press: Boca Raton, Florida, USA.
DOI: https://doi.org/10.1201/9780429022258-10

[39] Azman, N.F., Katahira, T., Nakanishi, Y., et al., 2023. Sustainable oil palm biomass waste utilization in Southeast Asia: Cascade recycling for mushroom growing, animal feedstock production, and composting animal excrement as fertilizer. Cleaner and Circular Bioeconomy. 6, 100058.
DOI: https://doi.org/10.1016/j.clcb.2023.100058

[40] Amin, N., Sabli, N., Izhar, S., 2019. Sago wastes and its applications. Pertanika Journal of Science and Technology. 27(4), 1841–1862.

[41] Amin, M.A., Shukor, H., Yin, L.S., et al., 2022. Methane Biogas production in Malaysia: Challenge and future plan. International Journal of Chemical Engineering. 2278211.
DOI: https://doi.org/10.1155/2022/2278211

[42] Rashidi, N.A., Chai, Y.H., Yusup, S., 2022. Biomass energy in Malaysia: Current scenario, policies, and implementation challenges. BioEnergy Research. 15, 1371–1386.
DOI: https://doi.org/10.1007/s12155-022-10392-7

[43] Sophanodorn, K., Unpaprom, Y. Whangchai, K., et al., 2020. A biorefinery approach for the production of bioethanol from alkaline-pretreated, enzymatically hydrolyzed Nicotiana tabacum stalks as feedstock for the bio-based industry. Biomass Conversion and Biorefinery. 12, 891–899.
DOI: https://doi.org/10.1007/s13399-020-01177-z

[44] ChooChuay, C., Pongpiachan, S., Tipmanee, D., et al., 2020. Effects of agricultural waste burning on pm2.5-bound polycyclic aromatic hydrocarbons, carbonaceous compositions, and water-soluble ionic species in the ambient air of Chiang-Mai, Thailand. Polycyclic Aromatic Compounds. 42(3), 749–770.
DOI: https://doi.org/10.1080/10406638.2020.1750436

[45] Country Report Scoping Study Climate Smart Rice Thailand [Internet]. Promoting Global Best Practices and Scaling of Low Emissions Technologies by Engaging the Private and Public Sectors in the Paddy Rice Sector [cited 2024 May 1]. Available from: https://www.ccacoalition.org/sites/default/files/resources/2021_Thailand-Country%20Report-Scoping-Study_CCAC.pdf

[46] World Food and Agriculture—Statistical Year-

book 2023 [Internet] [cite 2024 May 1]. Available from: https://doi.org/10.4060/cc8166en
[47] Jusakulvijit, P., Bezama, A., Thran, D., 2022. An integrated assessment of GIS-MCA with logistics analysis for an assessment of a potential decentralized bioethanol production system using distributed agricultural residues in Thailand. Sustainability. 14(16), 9885. DOI: https://doi.org/10.3390/su14169885
[48] Hung, N.T.Q., Thong, L.K., Nguyen, M.K., et al., 2018. Potential of biochar production from agriculture residues at Household scale: A case study in Go Cong Tay District, Tien Giang Province, Vietnam. Environment and Natural Resources Journal. 16(2), 68–78.
[49] Jabile, L.M., Tuyor, M.P., Salcedo, A., et al., 2022. Utilization of sawdust and rice husk for particle board application. ARPN Journal of Engineering and Applied Sciences. 17(2), 257–261.
[50] Demafelis, R.B. Elepaño, A.R., Dorado, M.A., et al., 2015. Potential bioenergy production from major agricultural residues in the Philippines. Philippine Journal of Crop Science (PJCS), Special Issue 40, 49–61.
[51] Kamaruzaman, N., Manaf, N.A., Milani, et al., 2023. Assessing the current state of biomass gasification technology in advancing circular economies: A holistic analysis from techno-economic-policy perspective in Malaysia and beyond. Chemical Engineering Research and Design. 199, 593–619. DOI: https://doi.org/10.1016/j.cherd.2023.10.023
[52] Raihan, A., 2023. The dynamic nexus between economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, forest area, and carbon dioxide emissions in the Philippines. Energy Nexus. 9, 100180. DOI: https://doi.org/10.1016/j.nexus.2023.100180
[53] Chua, J.Y., Pen, K.M., Poi, J.V., et al., 2023. Upcycling of biomass waste from durian industry for green and sustainable applications: An analysis review in the Malaysia context. Energy Nexus. 10, 100203. DOI: https://doi.org/10.1016/j.nexus.2023.100203
[54] Ukaejiofo, R.U., 2020. Examining climate adaptation policies and strategies in agricultural livelihoods in Sarawak, Malaysian Borneo [Master's Thesis]. New York: Cornell University.
[55] Singh, A., Gill, A., Lim, D., et al., 2022. Feasibility of Bio-Coal production from Hydrothermal Carbonization (HTC) technology using food waste in Malaysia. Sustainability. 14, 4534. DOI: https://doi.org/10.3390/su14084534
[56] How, B.S., Ngan, S.L., Hong, B.H., et al., 2019. An outlook of Malaysian biomass industry commercialisation: Perspectives and challenges. Renewable and Sustainable Energy Reviews. 113, 109277. DOI: https://doi.org/10.1016/j.rser.2019.109277
[57] Silalertruksa, T., Wirodcharuskul, C., Gheewala, S., 2022. Environmental sustainability of waste circulation models for sugarcane biorefinery system in Thailand. Energies. 15(24), 9515. DOI: https://doi.org/10.3390/en15249515
[58] Go, A.W., Conag, A.T., Igdon, M.B., et al., 2019. Potentials of agricultural and agro-industrial crop residues for the displacement of fossil fuels: A Philippine context. Energy Strategy Reviews. 23, 100–113. DOI: https://doi.org/10.1016/j.esr.2018.12.010
[59] Waste Management Practices for Food and Agricultural By-Products: Case Studies of Public Markets in Zamboanga City [Internet] [cited 2024 May 1]. Available from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4518764
[60] Adewuyi A., 2022. Underutilized lignocellulosic waste as source of feedstock for biofuel production in developing countries. Frontiers in Energy Research. 10, 741570. DOI: https://doi.org/10.3389/fenrg.2022.741570
[61] Cuong, T.T., Lee, H.A., Khai, N.M, et al., 2021. Renewable energy from biomass surplus resource: potential of power generation from rice straw in Vietnam. Scientific Reports. 11, 792.

DOI: https://doi.org/10.1038/s41598-020-80678-3

[62] Building and Enhancing Sustainable Agriculture and Food Systems in ASEAN: A Preliminary Scoping Study [Internet] [cited 2024 May 1]. Available from: https://www.eria.org/publications/building-and-enhancing-sustainable-agriculture-and-food-systems-in-asean-a-preliminary-scoping-study

[63] Kumar, P., Raj, A., Kumar, V.A., 2024. Approach to reduce agricultural wastes via sustainable agricultural practices. Valorization of Biomass Wastes for Environmental Sustainability. Springer Nature: Switzerland. pp. 21–50.
DOI: https://doi.org/10.1007/978-3-031-52485-1_2

[64] Chieng, S., Kuan, S.H., 2020. Harnessing bioenergy and high value-added products from rice residues: A review. Biomass Conversion and Biorefinery. 12, 3547–3571.
DOI: https://doi.org/10.1007/s13399-020-00891-y

[65] Ullah, K., Sharma, V.K., Dhingra, S., et al., 2015. Assessing the lignocellulosic biomass resources potential in developing countries: A critical review. Renewable and Sustainable Energy Reviews. 51, 682–698.
DOI: http://dx.doi.org/10.1016/j.rser.2015.06.044