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The Potential of Sustainable Biogas Production from Macroalgae in Indonesia

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Abstract. Indonesia is the second world's major macroalgae producer after China, contributing to 28% of the global macroalgae production. Indonesia increased its macroalgae farming output from less than 4 million tons in 2010 to over 9.9 million tons in 2019. It is expected to continue rising to 13 million tons by 2024. The contribution of macroalgal products is quite significant, 60.7% of the total national aquaculture production. To achieve sustainable energy development goals in many developing countries, including Indonesia, biomass to energy technology such as the production of biogas form macroalgae has been considered one of the best options. Therefore, we aim to investigate the potential application of biomass to energy technology via the production of biogas from macroalgae as an alternative source of local power generation. Indonesia's energy mix and several issues regarding macroalgae production are comprehensively reviewed. Additionally, we also discussed the process of macroalgal biogas production.

1. Introduction

Indonesia is the largest archipelagic country with 6.3 million km^2 of water area, in which 2.7 million km^2 sea zones, covering about two-thirds of the nation. With this vast area, Indonesia has abundant aquatic resources, including macroalgae or more popularly called seaweed. Macroalgae are primarily being utilized for food, feed, fertilizer, cosmetics, and pharmaceuticals [1]. This is due to the unique macroalgae composition with a wide variety of nutrient and bioactive compounds [2]. In general, they contain water (90%), protein (7–31%), carbohydrate (32–60%), and low lipid contents (1–5%) depending on the species, also the cultivation condition such as habitat, water salinity, temperature, light intensity, and harvesting timing [3]. Macroalgae is also rich in micronutrients such as vitamin B, A, and E (tocopherol) as well as minerals such as potassium, magnesium, and calcium [2].

To improve the production of macroalgae and have a more substantial positive impact on the Indonesian economy, higher value and diversification of macroalgae products are immensely necessary. Besides the applications aforementioned, macroalgae with their hydrocarbon composition are very potential for bioenergy production [3]. Their renewable and carbon-neutral characteristic will support the mitigation of carbon dioxide emission by using them as fossil fuel substitution or termed as third-generation biofuels [4]. As aquatic organisms, macroalgae is very attractive for energy feedstock because they excel in growth rate. The land-use competition and changes will likely be minimal compared to terrestrial biomass. Another advantage of using macroalgae is zero freshwater requirement when mass-cultivated in the oceans [5].

One of the promising pathways to harvest energy from macroalgae is via the biological process of anaerobic digestion to generate biogas [5]. Biogas application ranges from cooking fuel, heating fuel, electricity, and transportation fuels. The exploration of macroalgae for bioenergy has been done since the 1970s in the USA by Wilcox with its ocean farms to cultivate giant kelp *Macrocystis sp* as reviewed by Kelly and Dworjanyn [6]. In Japan, where macroalgae are consumed in massive amounts, macroalgae have been experimented with to generate methane. The Tokyo Gas Company chose methane fermentation with 1 ton per day capacity over gasification of seaweed (*Laminaria japonica*) to generate electricity because it is the most suitable process, considering the high water content of macroalgae [6]. In Africa's Atlantic coast, where *Ulva lactuca* and *Codium tomentosum* cause an environmental problem, these macroalgae showed excellent biogas yield compared to cow manure and *Jatropha curcas* cake [7]. Further understanding on biogas production from macroalgae has been explored in various studies for the last decades, extending from the pretreatment options [8], the effect of process condition [9,10], type of reactors [11], biorefinery approach [12], co-digestion strategy [13], to the techno-economy feasibilities [14]. One of the most recent research is exploring feedstock source that is not only fresh macroalgae but also the wastes to obtain biogas [15].

As a maritime country, it is intriguing that the discussion of Indonesian macroalgae potential for biogas energy is still limitedly found in the kinds of literature. On the other hand, Indonesia is committed to increasing its ambitious share of new and renewable energy (NRE) by 23% in 2025 [16]. Currently, the energy supply in Indonesia is primarily relied on coal (39%) and oil (30.3%), with a small portion (12%) from NRE (Figure 1). Biogas plays a vital role in increasing the portion of NRE since the feedstock is abundantly available in Indonesia. Consequently, a discussion on macroalgal biogas prospect is crucial for Indonesia. For that reason, this study sincerely reviewed the potential of biogas production from macroalgae in Indonesia, intending to present the prospect of valorization of this commodity via the energy sector.

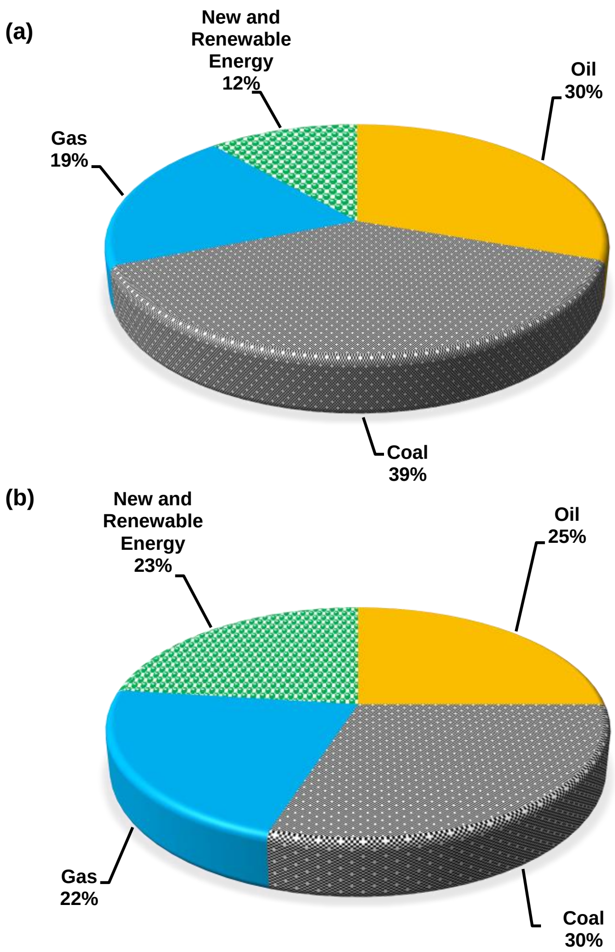

Figure 1. (a) current energy mix in Indonesia and (b) targeted energy mix in 2025.

2. Potential of Macroalgae in Indonesia

The world's macroalgal production significantly increases year by year. According to FAO, the production of macroalgae in in 2019 (35.76 million wet tones) was twice of 2009. China and Indonesia are the largest macroalgal producers with over 30 million tones production capacity in 2019 (Figure 2). Most macroalgae in China are brown algae (*Saccharina japonica* and *Undaria pinnatifida*) and red seaweed (the genera *Gracilaria* and *Pyropia*). Meanwhile, the primary macroalgae found in Indonesia are *Eucheuma* and *Kappaphycus*. In 2019, Indonesian seaweed production achieved 9.9 million tons and occupied the second largest global producer. Considering the increasing trend of global production, Indonesia, which has more than 500 macroalgal species identified, should be more active in being the key player of macroalgae production and use in the world.

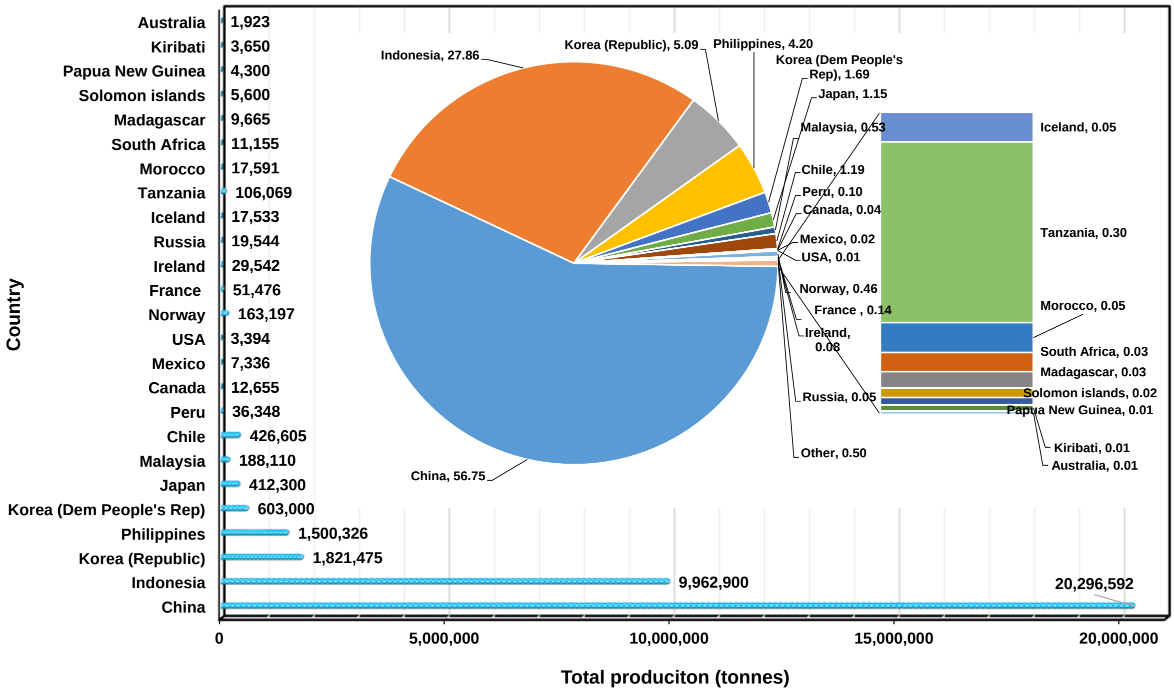

Figure 2. Global macroalgae production in 2019 [17].

Currently, Indonesia's three significant seaweed producers are located in South Sulawesi, East Nusa Tenggara (NTT), and Central Sulawesi, with a production capacity of around 2.615, 1.994, and 1.331 million wet tones, respectively (Figure 3). All three types of seaweed, namely Rhodophyceae (red algae), Chlorophyceae (green algae), and Phaeophyceae (brown algae), are found in Indonesia. The red seaweed (*Eucheuma* and *Kappaphycus* sp.) are the most found species in Indonesia since these are the primary raw materials for carrageenan extraction.

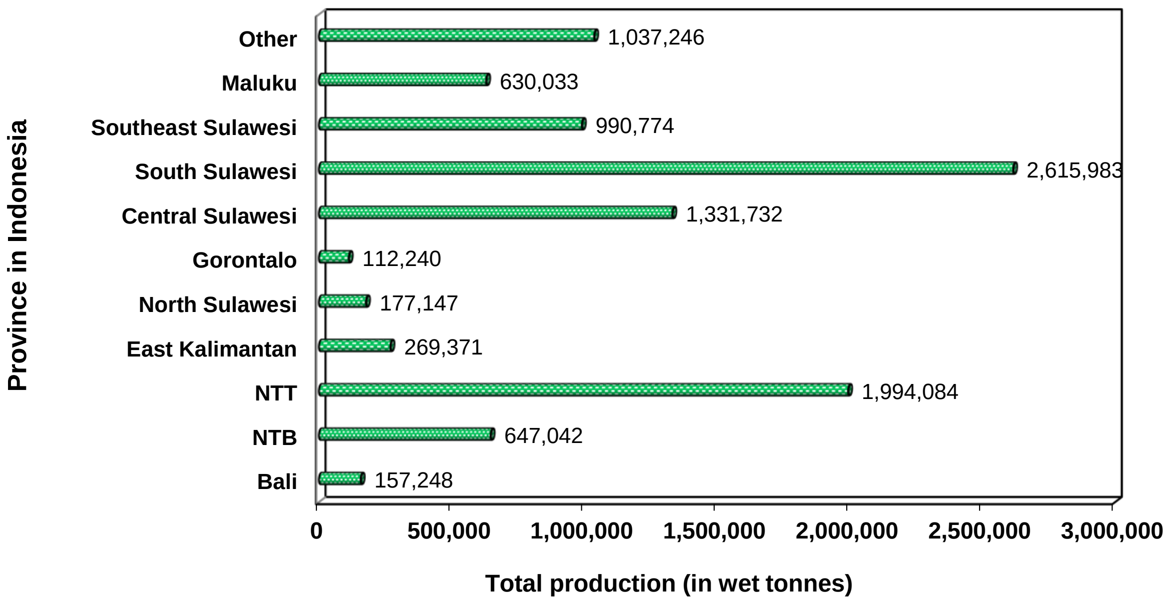

Figure 3. Total production of Indonesian macroalgae in 2019

3. Biogas Production and Its Potential from Indonesian Macroalgae

The chemical composition in macroalgae is utterly different from terrestrial plants. Macroalgae have higher contents of nitrogen and sulfur and lower contents of carbon, hydrogen, and oxygen than terrestrial plants [3]. Interestingly, macroalgae have a large number of carbohydrates and a low amount of lignin and cellulose. Since macroalgae contain a considerable amount of water content (80-90%) makes them more suitable for biogas production through microbial conversion than for conventional thermochemical processes that requires drying [18].

Apart from that, due to macroalgal low lignin content and high digestible carbohydrate content, biogas (bio-methane) production from macroalga is more promising than that from terrestrial plants. Several studies have reported biogas production from macroalgae. The methane production from macroalgae is presented in Table 1.

Table 1. Methane yield obtained from anaerobic digestion of macroalgae

Macroalgae Species	Digestion temperature [°C]	Time [day]	CH_4 production	Ref.
Ulva sp.	35	15	203 L/kg VS	[19]
Ulva lactuca	50	22	157.6 L/kg VS	[20]
Ascophyllum nodosum	35	24	110 L/kg VS	[21]
Laminaria hyperborea	35	24	280 L/kg VS	[21]
Laminaria sp.	50	22	185.7 L/kg VS	[20]
Laminaria sp.	35	22	139 L/kg VS	[20]

As shown in Table 1, the methane yields of macroalgae are in the range from 110 to 280 L CH_4/kg VS. The potential of methane production from Indonesian macroalgae can be calculated using Eq. 1.

$$PMP = MP \times MY \quad (1)$$

where, *PMP* is potential methane production (L/year), *MP* is the total amount of macroalgae production (kg), and *MY* is the methane yield (L/kg algae). Please note that the value of a volatile amount of macroalgae is around 500 g VS/kg algae [7]. By employing Eq. 1, methane production potential from Indonesian macroalgae in each province is summarized in Table 2.

Table 2. Estimation of methane production from Indonesian macroalgae

Province in Indonesia	Macroalgae production in 2019 [ton]	Estimation of potential CH_4 production [kL]
Bali	157,248	8,648,651–22,014,747
West Nusa Tenggara	647,042	35,587,317–90,585,898
East Nusa Tenggara	1,994,084	109,674,634–279,171,796
East Kalimantan	269,371	14,815,396–37,711,918
North Sulawesi	177,147	9,743,060–24,800,517
Gorontalo	112,240	6,173,220–15,713,652
Central Sulawesi	1,331,732	73,245,244–186,442,440
South Sulawesi	2,615,983	143,879,089–366,237,681
Southeast Sulawesi	990,774	54,492,552–138,708,314
Maluku	630,033	34,651,806–88,204,597
Other	1,037,246	57,048,530–145,214,441

4. Conclusion

Indonesia has a great potential of macroalgae to be utilized as sustainable energy. One of the most promising sustainable energies from macroalgae is biogas since macroalgae contains huge amount of carbohydrate and water content. This work reviews the potential of biogas production from Indonesian macroalgae. Indonesia's three significant seaweed producers in 2019 are located in South Sulawesi, East Nusa Tenggara (NTT), and Central Sulawesi, with a production capacity of around 2.615, 1.994, and 1.331 million wet tones, respectively. The potential of methane production from Indonesian macroalga is also estimated. Based on the calculation, the highest potential amount of methane that can be generated from macroalgae in Indonesia are found in South Sulawesi with the range of 143,879,089–366,237,681 kL.

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