



Harnessing Seaweed for Bioplastics: Unveiling South Sulawesi's Blue-Green Economy to Address Waste Issues.

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Abstract. The bio-based plastic industry, particularly the development of seaweed-based bioplastics, offers significant opportunities for sustainable development within the blue-green economy of South Sulawesi. This paper explores the untapped potential of bio-based plastics to address critical waste management challenges, providing targeted recommendations for the South Sulawesi government. We assess the current landscape of the bio-based plastic sector, identifying key areas for innovation and growth that align with circular and green economy principles and contribute to the Sustainable Development Goals (SDGs). We analyze factors driving industry development, including local resources like seaweed, market demand, and effective government support, while addressing barriers such as limited awareness and infrastructure deficits. The downstream processes for transforming raw seaweed into bioplastics are highlighted as essential actions for enhancing this sector. Through qualitative insights and a comprehensive literature review, our findings offer actionable guidance for improving waste management practices and promoting ecological sustainability within the blue economy framework. This research aims to equip policy-makers with strategies to harness the potential of bio-based and seaweed-based plastics, fostering a sustainable and circular future for South Sulawesi and advancing progress toward the SDGs.

Keywords: Seaweed-based Plastic, Blue-Green Economy, Circular Economy, Downstreaming, SDGs

1 Introduction

The global climate crisis has affected every region of the world, prompting countries to collaborate and commit to achieving the Sustainable Development Goals (SDGs). These goals build upon the earlier Millennium Development Goals (MDGs), which were successfully met in 2015. The consequences of the climate crisis, particularly global warming, stem from economic activities that neglect environmental sustainability, such as air pollution, extensive use of non-renewable resources, and waste issues that contaminate air, land, and water, particularly in the form of plastic waste. Global plastic production has surged over the past two decades, doubling to reach 460 million tons in 2019 [1]. Projections indicate that by 2025, greenhouse gas emissions associated with the production, use, and disposal of plastics will constitute 15 percent of overall emissions [2].

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M. Nohong et al. (eds.), *Proceedings of the 9th International Conference on Accounting, Management, and Economics 2024 (ICAME 2024)*, Advances in Economics, Business and Management Research 331,
https://doi.org/10.2991/978-94-6463-758-8_87

Plastic waste pollution is considered a significant threat to terrestrial life, including plants, animals, and humans, as it can take thousands of years to decompose. During this prolonged degradation process, toxic substances are released into the soil and water, further exacerbating environmental harm [3]. In the ocean, plastic stands as one of the predominant sources of pollution, particularly in the form of microplastics, which are frequently detected in marine organisms consumed by humans. When ingested, these microplastics can travel to vital organs, including the liver, kidneys, spleen, heart, and brain, potentially leading to serious health issues such as infertility, obesity, cancer, and a range of other diseases [4]. Consequently, the issue of plastic waste has garnered significant attention from countries around the globe.

In March 2022, 175 countries reached an agreement to combat plastic pollution by 2024 during a meeting of the UN Environment Assembly, which centered on addressing the challenges posed by single-use plastics [5]. The resulting resolution aims to address the entire lifecycle of plastic, encompassing its production, design, and disposal [2]. Concrete actions from each country to address plastic waste issues are essential, as these efforts align with and support the attainment of specific targets within the Sustainable Development Goals (SDGs). Some of these points include Goal 13: Climate Action, Goal 14: Life Below Water, and Goal 12: Responsible Consumption and Production.

Goal 13 should be successfully pursued in conjunction with the achievements of Goal 14 and Goal 12. The actions associated with these three goals will significantly contribute to the overall success of Goal 8: Decent Work and Economic Growth, which addresses target 8.1 Sustainable economic growth; target 8.2 diversify, innovate, and upgrade for economic productivity; target 8.3 promote policies to support job creation and growing enterprises; and target 8.4 improve resource efficiency in consumption and production. Goal 14 focuses on "Life Below Water," urging countries to conserve and sustainably utilize the oceans, seas, and marine resources to promote sustainable development [6]. This is because the ocean offers a wealth of natural resources, including food, materials, and energy. The sustainable exploitation of these resources is anticipated to enable governments to alleviate poverty by increasing income and generating new jobs, thereby driving economic growth in targeted regions. Furthermore, its impact on wealth enhancement aligns with Goal 8 of the SDGs, which emphasizes decent work and economic growth. Balancing resource exploitation with environmental preservation is crucial for fostering sustainable growth, as well as supporting other SDGs, such as Goal 12, which focuses on responsible consumption and production that aims to minimize waste and pollution, particularly in terrestrial and marine ecosystems.

Indonesia, recognized as a country dedicated to minimizing plastic waste, ranks as the second largest contributor to plastic pollution, following China [7], where 59% of its rivers have been classified as severely polluted [8]. In 2020, Indonesia generated approximately 67.8 million tons [9] and is expected to rise in line with the growing population. In 2022, Indonesia generated around 68.5 million tons of waste, with 18% of that being plastic waste [10]. To tackle the waste challenge, the government must assume a key role in the management of plastic waste. Policies and regulations established by the central government should be effectively adapted and endorsed by local governments, including provincial administrations. The UN General Assembly highlighted the significance of provincial governments in its resolution,

"Transforming Our World: The 2030 Agenda for Sustainable Development." This resolution underscores the importance of collaboration and engagement among society, entrepreneurs, academics, the People's Representative Council, the central government, and provincial authorities (Badan KSAP DPR RI, 2019).

A research study carried out by Subekti [12] demonstrates that Indonesia's management of plastic waste is heavily reliant on government involvement. Policies that impact various sectors necessitate collaborative participation from relevant stakeholders, including employers, investors, academics, and civil society. Previously, The Government of Indonesia released Law No. 18/ 2008 regarding Rubbish Management, Government Regulation No. 81 of 2012 regulates the domestic waste management and similar waste [10]. As a participant in the pursuit of the Sustainable Development Goals (SDGs), Indonesia is dedicated to the 2030 Agenda, demonstrated by the implementation of Presidential Regulation No. 59 of 2017 regarding the execution of the Sustainable Development Goals [13] and through Government Regulation No. 27 of 2020, which delineates the criteria for specialized waste management practices [10]. To attain the Sustainable Development Goals, it is essential to harmonize planning policies across different levels of government, spanning from national to provincial, district, and city levels, including South Sulawesi Province. Tackling the issue of plastic waste at the governmental level can advance sustainable development efforts, incorporating initiatives related to a blue-green economy and the principles of a circular economy.

Transitioning to a circular economy is anticipated to lower the influx of plastics into oceans by more than 80%, decrease the production of virgin plastics by 55%, and reduce greenhouse gas emissions by 25% by 2040. In addition, this paradigm shift could potentially save governments approximately \$70 billion while generating 700,000 new jobs, predominantly in the Global South [2]. Unfortunately, policies addressing plastic waste have not been prioritized by provincial governments, particularly in South Sulawesi, which ranked as the 10th highest waste-producing province in Indonesia in 2022 [14] and ranked first among the provinces on the island of Sulawesi. The 2021 SDGs report for South Sulawesi Province revealed that there are significant challenges and issues in implementing sustainable production and consumption patterns, particularly regarding waste management. Efforts to reduce waste in South Sulawesi remain inadequate [15]. Furthermore, the 2022 report highlights additional challenges, particularly the low level of public awareness concerning waste management [16].

2 Literature Review

2.1 Blue-Green Economy

The term Blue Economy is becoming increasingly prominent in various research efforts and is being examined by countries around the globe. The World Bank defines Blue Economy as the sustainable use of ocean resources to drive economic growth, enhance livelihoods and employment, and maintain the health of ocean ecosystems [17] The notion of the blue economy was initially articulated at the 2012 United Nations Conference held in Rio de Janeiro, Brazil, where it underscored the

imperative of sustainable development as a fundamental objective [18]. Martínez-Vázquez et al. [19] identified that the Blue Economy represents a contemporary field of research focusing on economic activities linked to marine resources, often intersecting with other sectors such as tourism, maritime transport, energy, and fishing. In their research, Lee, et al. [20] describe that the blue economy aims to harmonize marine resource development with ecological preservation, fostering sustainable practices while unlocking economic opportunities from ocean assets. This research is also supported by [21] which demonstrated that ocean commodities, particularly seaweed, can be leveraged to advance the blue economy and bolster national economic growth, highlighting their potential as valuable resources for a coastal country.

Furthermore, the Blue Economy is inherently connected to the green economy, as it seeks to both sustainably utilize and safeguard the marine environment. Another research by Olteanu & Stinga [22] stated for a sustainable blue economy to thrive, each nation must determine the most effective strategies to harmonize sustainability with economic development, ensuring that marine resources are utilized optimally while also prioritizing environmental well-being. The blue economy is the principled use of marine resources that supports environmental sustainability alongside economic growth and improved livelihoods [22]. Blue economy has the potential to optimize its activities by responsibly harnessing ocean resources in an environmentally sustainable way as demonstrated by [23] where blue economy emphasizes the implementation of strategies for phosphorus recovery from marine ecosystems, aligning economic growth with ecological sustainability. This framework acknowledges the capacity to utilize marine resources in a sustainable way, focusing on mitigating harmful environmental impacts while aiming to enhance economic prosperity.

Khan, et al. [24] similarly indicated that maritime nations possess significant potential to more extensively explore their territories and water resources for the development of the Blue Economy. The Blue Economy emphasizes the importance of sustainable business processes and corporate activities, encompassing all stages from production to disposal. This framework prioritizes the generation of products that do not harm marine ecosystems or contribute to pollution, thereby safeguarding the livelihoods of marine organisms [25]. The Deputy Minister for Maritime and Natural Resources at the Ministry of National Development Planning stated that the Blue Economy has the potential to empower countries like Indonesia to promote the sustainable development of the marine economy, thereby delivering social and economic benefits for future generations without compromising the oceans' capacity. She emphasized that it is not possible to achieve green initiatives without considering blue resources, asserting that a low-carbon terrestrial strategy must be complemented by the Blue Economy. This approach aims to foster economic growth while safeguarding environmental integrity, effectively embodying the principles of a Green Economy [26]. The Blue Economy encompasses the management and utilization of non-terrestrial resources within the framework of a Green Economy [27]. Consequently, activities within the Blue Economy will ultimately bolster the effectiveness of the Green Economy.

In spite of its potential, the blue economy faces several practical challenges as stated by Turschwell, et al. [28], the blue economy represents a domain in which

various ocean sectors compete for space and resources, creating both challenges and opportunities for collaborative planning that can benefit a range of stakeholders. The blue economy's development is hindered by a complex and fragmented policy environment that restricts investment in co-located projects, highlighting the need for integrated governance to support sustainable growth [29]. Consequently, the advancement of the blue economy cannot rely solely on government efforts; other stakeholders must also play a role in its development, as noted by Dijkstra, et al. [30] that the blue economy is bolstered by entrepreneurs creating innovative business models to address marine plastic pollution, offering significant environmental benefits while facing challenges such as competition from unsustainable practices and the need for supportive policies to foster sustainable growth.

2.2 Circular Economy

Circular economy is a sustainable approach focused on minimizing waste and enhancing resource efficiency, which helps reduce environmental damage, encourages global cooperation on sustainability, and addresses issues such as income inequality and industrial emissions [31]. The circular economy makes the most of resources by promoting practices such as recycling, reuse, and regeneration, ultimately creating closed-loop systems where products and materials are continuously cycled back into the economy [32]. The important part in executing a circular economy is the sustainable utilization of resources through innovative methodologies and collaborative partnerships, while recognizing significant growth opportunities despite various logistical, economic, and regulatory challenges [33].

Several advantages of the circular economy were highlighted by Kolade, et al. [34], including the potential for job creation through a newly empowered workforce and the promotion of a sharing economy that optimizes resource use via collaborative consumption, all facilitated by innovative, digitally enabled business models. However, Balsalobre-Lorente, et al. [31] defined obstacles such as limited consumer acceptance of circular products and the need for strong public-private partnerships and carbon policies hinder the transition. Similar to them, Kolade, et al. [34] also identified the challenge of limited consumer adoption of circular products as a significant barrier to transitioning to a circular economy. Other challenges to advance the circular economy are also highlighted by Gallego-Schmid, et al. [35] including limited government incentives, inadequate waste management infrastructure, high transition costs, and low public awareness.

2.3 Downstreaming

Downstream activities have historically been an integral component of industrial processes. Ika [36] stated that downstreaming, or value-adding, as defined by Patunru (2015), is a measure designed to limit the export of raw materials to promote their use in domestic industries, thereby enhancing local value and creating employment opportunities. Adenekan Olanrewaju, et al. [37] refer downstream as the activities associated with the distribution and management of products, including refining, storage, and waste management, as they progress through the supply chain to reach

end consumers. They also emphasized that downstream activities help sustain production and manage environmental challenges effectively, enabling countries to improve supply chain efficiency and reduce costs through focused waste management and loss evaluation strategies. Other benefits of downstreaming include an increased supply of products, enhanced operational efficiency, attraction of private investment, stabilized pricing, and a reduction in corruption, all of which contribute to a more functional and sustainable industry [38].

2.4 Bioplastics and Seaweed-Based Bioplastics

At the global scale, fossil-based plastic production ranked first in 2021, experiencing a year-on-year growth of 3.62%. This was followed by recycled plastic production, which saw a year-on-year increase of 2.85%. In contrast, the production of bio-based plastics exhibited a remarkable surge, achieving a year-on-year growth rate of 51.28% [39]. This data suggests a growing global demand for bio-based plastics. These materials are considered a vital solution for mitigating plastic waste both on land and in oceans, as they are biodegradable and compostable, generating no harmful by-products. By prioritizing the reduction of plastic waste while maintaining revenue streams from plastic production—of which 50% comprises single-use plastics [40]—the production of bio-based plastics emerges as a viable option. Bioplastics, derived from plant sources, are safe for use and can decompose naturally within a relatively short timeframe, without leaving behind harmful residues that could negatively impact living organisms and the environment.

Not only should the products themselves be sustainable, but the production processes must also prioritize energy efficiency and minimize pollution, ideally achieving a completely clean operation. The negative impacts associated with bioplastics are significantly less pronounced than those of conventional plastics [41]. Nevertheless, the advancement of bioplastic production in the coming years will be heavily influenced by fluctuations in the prices of traditional plastics [42]. The volume of research and development focused on creating bio-based plastics as sustainable alternatives to fossil-fuel-derived plastics continues to increase, with the aim of producing higher-quality and more durable products that do not compromise environmental integrity while remaining economically viable.

Several ministries and government agencies in Indonesia have undertaken the development and research of seaweed as a bio-based plastic material. The Agricultural Research and Development Center of the Ministry of Agriculture has introduced nano-cellulose bioplastics and bio-based materials derived from cassava starch, incorporating agricultural waste such as straw. These innovations have demonstrated enhanced strength in load-bearing capacity while maintaining biodegradability within approximately 60 days [43]. The National Research and Innovation Agency (BRIN), in conjunction with the Biomass and Bioproducts Research Center (PRBB) and PT Evogaia Karya Indonesia, has successfully developed the inaugural generation of seaweed-based plastic formulations [44]. The Ministry of Maritime Affairs and Fisheries (KKP) is actively enhancing its innovation efforts. The Center for Testing the Application of Marine and Fishery Products (BBP3KP), a unit under the Directorate General of Marine and Fisheries Product Processing and Marketing (Ditjen PDSPKP), is collaborating with a research team

from the Faculty of Fisheries and Marine Science at Padjadjaran University (FPIK Unpad) [45]. This demonstrates that collaboration between government entities and other institutions or organizations will expedite the research and development process for bioplastics.

Moreover, extensive research within the academic sector, particularly at the university level, is being actively pursued across Indonesia. Several studies indicate that plastics can be produced from organic materials or natural ingredients, with key commodities such as cassava, corn, and agricultural by-products identified as viable primary feedstocks for this production (see Table 1).

Table 1. Local Academic Research on Bioplastics

No	Title	Author	Main Ingredient	Description
1	Pembuatan dan Karakterisasi Bioplastik Berbahan Dasar Biomassa dengan Plasticizer Gliserol	[46]	Cassava starch	The characterization results show that bioplastics with a combination of cassava starch + glycerol + water + acetic acid (vinegar) + alcohol have a high degree of degradation
2	Pembuatan Bioplastik Berbahan Dasar Pati Kulit Singkong (Manihot utilissima) dengan Selulosa Jerami Padi, Polivinil Alkohol dan Bio-Compatible Zink Oksida	[47]	Cassava peel starch	The results of the best mechanical properties of tensile strength from bioplastics are in the D4 sample of 1.2 g cellulose equals 37.38 MPa.
3	Sintesis Bioplastik Dari Kitosan-Pati Kulit Pisang Kepok dengan Penambahan Zat Aditif	[48]	Kepok banana peel starch	The result showed the optimum composition of bioplastic is kitosan 4%-30% starch-5 ml Glycerol-5% ZnO
4	Pembuatan Bioplastik Dari Tepung Ubi Jalar (Ipomoea Batatas) dengan Pengaruh Penambahan Ampas Tebu (Saccharum officinarum) dan	[49]	Sweet potato starch	The results showed the highest biodegradation value occurred in the variation of sweet potato starch and sugarcane bagasse

- Gliserol mass, namely (80:20)% and (90:10)% with the addition of 7 ml, 5 ml, and 3 ml of glycerol.
- 5 Karakterisasi Material [50] Cellulose from rice straw The research results were obtained in the form of test data results where in the thickness test the highest thickness value was found in 45 ml solution with a value of 9.28×10^{-2} mm
- 6 Pembuatan dan [51] Avocado seed starch The results demonstrated that a mass ratio of starch from avocado seeds to chitosan of 3:2 yielded bioplastic with the optimal mechanical properties. Additionally, the inclusion of 3 mL of sorbitol resulted in bioplastic exhibiting the most favorable mechanical characteristics.
- 7 Development of [52] Yam starch The findings indicated that the concentrations of chitosan and clove oil notably influenced the thickness and water vapor transmission rate of the film; however, they had minimal impact on its solubility and compressive strength.
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Another study revealed that seaweed serves as the primary component for producing bio-based plastics, a fishery product that is predominantly found in Indonesia. In the realm of global aquaculture production, Indonesia ranks as the second-largest seaweed farming nation, accounting for 28.6% of worldwide cultivation, with significant contributions from species such as *Eucheuma* (*Eucheuma* spp.) and *Gracilaria* (*Gracilaria* spp.) [53]. As indicated in numerous studies, *Eucheuma* seaweeds are particularly well-suited as a primary commodity for bioplastics, closely followed by *Gracilaria*, which has also been highlighted in various research efforts. Notably, some local studies have discovered that seaweed can be effectively combined with plant-derived materials, potentially enhancing the quality of the resultant bioplastics (See Table 2).

Table 2. Local Research on Seaweed-based Bioplastics

No	Title	Author	Combined Ingredient	Description
1	Karakterisasi Bioplastik Rumput Laut (<i>Eucheuma Cottonii</i>) dan Pati Singkong dengan Penambahan Pati Biji Alpukat	[54] Dari Laut	Cassava starch, avocado seed starch, durian seed starch	The bioplastic film composite mixed with avocado seeds and has shown promising characteristics for bioplastic applications in the packaging industry.
2	Karakteristik Bioplastik Berbasis Rumput Laut Yang Dimodifikasi Dengan Monogliserida Minyak Jagung	[55]	Cassava starch and corn oil	The more monoglycerides added, the thicker the bioplastic, the more water resistance it has, and the smoother the surface.
3	Aplikasi Rumput Laut <i>Eucheuma Cottonii</i> Pada Sintesis Bioplastik Berbasis Sorgum Dengan Plasticizer Gliserol	[56]	Sorghum starch and sorghum powder filler rod	The formulation of adding <i>Eucheuma cottonii</i> cellulose and glycerol plasticizer concentration in the manufacture of sorghum-based bioplastics has met the HDPE plastic standards for mechanical properties, but has not met the

4	Karakterisasi Bioplastik dari Rumput Laut (Eucheuma Cottonii) dan Pati Singkong Dengan Penambahan	[57]	Cassava starch and durian seed starch	standards for physical properties. Bioplastic films from durian seed waste have shown promising characteristics for bioplastic applications in the packaging industry based on functional group, mechanical and biodegradability characteristics.
5	Karakterisasi Bioplastik Dari Beberapa Jenis Tumbuhan Penghasil Selulosa	[58]	Peanut shells, rice straw, pineapple leaves, mango seeds, palm fronds and pineapple leaves	Plants that meet quality standards are peanut skins, rice straw, pineapple leaves, mango seeds, oil palm fronds and pineapple leaves.

Bioplastic products are not a recent innovation; numerous local companies are already engaged in their production and sale (see Table 3). In the context of this research on the blue economy, the focus of this paper will be on bioplastics derived from seaweed. Therefore, the conversion of seaweed into bioplastics through value-added processes can be categorized as an economic activity related to downstreaming.

Table 3. Local Companies on Sustainable Packaging Product

No	Brand	Product	Online Profile
1	Avani	Cassava Bag, Bagasse Foodware	https://www.instagram.com/avanieco/
2	Evoware	Edible foodware from seaweed, Cassava Bag	https://www.instagram.com/evowareworld/
3	Plépah	Areca nut midrib package	https://www.instagram.com/plepah_id/
4	Ecoplease	Bagasse, sugarcane, bamboo foodware	https://www.instagram.com/ecoplease/

3 **Methodology**

This study adopts a qualitative literature review approach to investigate the underexplored potential of seaweed-based bioplastics in South Sulawesi. A thorough search was carried out across various academic databases, including Science Direct, utilizing specific keywords such as "bioplastics," "seaweed-based bioplastics," "green economy," "blue economy," and "circular economy." The criteria for inclusion centered on peer-reviewed articles published within the past decade, excluding studies that were irrelevant or lacked empirical data. Critical information was meticulously extracted from the selected literature, encompassing authorship, publication dates, research aims, and notable findings. A thematic analysis was employed to discern and categorize recurring themes related to the production of seaweed-based bioplastics, environmental advantages, and economic opportunities in the region. While ethical concerns were minimal due to the dependence on existing literature, all sources were meticulously cited to maintain academic rigor. The review also addresses limitations, including potential publication bias and subjective interpretations of data, which were managed through a transparent and systematic review process, ensuring a thorough and credible examination of the potential for seaweed-based bioplastics in South Sulawesi.

4 **Discussion**

4.1 **Blue-green economy, circular economy, and downstreaming—the trinity solution to solve plastic waste problem in Indonesia**

The concept of blue-green economy is closely associated with the circular economy which represents a production and consumption model that emphasizes sharing, lending, reusing, repairing, refurbishing, and recycling materials and products to maximize their lifespan. The primary objective of a circular economy is to minimize waste generation. Currently, one of the most significant challenges related to waste in the industrial sector is the generation of plastic waste. Annually, over 300 million tons of plastic are produced worldwide, with approximately half of that volume consisting of single-use plastics, which include items such as water and soda bottles, plastic grocery bags, product packaging, straws, coffee cups, and single-use plastic bags [59]. Approximately 50% of plastic waste is disposed of in landfills, while an estimated 30 million tons of plastic waste currently pollute seas and oceans. Additionally, around 109 million tons have accumulated in rivers [60]. Plastic waste not only contaminates terrestrial and aquatic environments, but it also fragments into microplastics that are inadvertently ingested by various organisms, including fish, which subsequently enter the human food chain. On land, these plastic particles infiltrate the soil and remain persistently present, as they decompose at rates spanning hundreds to thousands of years. Unfortunately, numerous industries continue to heavily depend on plastic, both in their production processes and in the packaging and formulation of their products.

Waste management can be effectively approached through the principles of Reduce, Reuse, and Recycle, commonly referred to as the 3Rs, which are widely acknowledged by the public. In recent years, recycling has emerged as the most

emphasized process. For instance, in Indonesia, a bottled water company has intensified its recycling initiatives by forming partnerships with various organizations and institutions, including the recycling sector and waste picker associations. Additionally, the company collaborates with local industries, such as clothing brands, to foster a consumer mindset that prioritizes their products while alleviating concerns about waste generation. Furthermore, a plastic manufacturing facility in Makassar introduced a line of home furnishings and furniture created from recycled plastic waste in 2022 [61], however, this initiative has struggled to swiftly meet market demand and preferences. Additionally, the volume of recycled plastic waste is insufficient to address the total quantity of plastic waste generated, as the recycling process remains neither economically viable nor environmentally sustainable.

A significant local recycling initiative involves a collaborative effort between the City Government of Makassar and the companies SUS Shanghai and Sarana Utama Synergy, focused on expediting the development of a Waste-to-Energy Processing Installation (PSEL) that employs eco-friendly technology. This initiative is additionally supported by Presidential Regulation No. 35 of 2018 [62]. The Indonesian Forum for the Environment (WALHI) has noted that the implementation of plastic waste reduction measures outlined in Mayoral Regulation (Perwali) No. 70 of 2019, which addresses the regulation of plastic bag usage, has not been effectively maximized to curb both community and industrial consumption of plastic bags. Their research indicates that Waste-to-Energy facilities are highly inefficient, with approximately 70 percent of the waste incinerated for electricity production classified as fly ash and bottom ash (FABA), which is deemed hazardous (B3) due to its dioxin content [63]. While the pyrolysis of mixed plastic waste in China has recently emerged as an environmentally friendly method for energy and material recovery [64], it is crucial to recognize that the recycling process is energy-intensive and involves the use of specific chemicals that can result in water and air pollution. Consequently, prioritizing reduction strategies—especially by eliminating single-use conventional plastics—should be regarded as the most effective solution to mitigate plastic pollution.

In practice, the circular economy extends beyond mere recycling; it also encompasses reduction strategies. The primary objective of the circular economy is to minimize environmental impact by establishing a closed-loop system that incorporates recycling, reusing, and remanufacturing. Additionally, it promotes a more resilient and sustainable approach to industrial processes [65]. Consequently, the circular economy framework is perceived as an advantageous business model for the production of biodegradable and compostable plastics. Suharsono Monoarfa, Indonesia's Minister of National Planning and Development, articulated that the circular economy operates as a closed-loop system that strives to keep raw materials, components, and products in continuous use, thereby minimizing the volume of waste that is neither repurposed nor directed to landfills [66]. An additional perspective on the circular economy is presented by Norimasa Shimomura, the UNDP Indonesia Resident Representative, who emphasized that within this framework, companies and manufacturers can achieve success by adopting practices that lead to zero waste and the repurposing of any by-products generated during their production processes [66]. Lars Bo Larsen, the Danish Ambassador to Indonesia, noted that investing in a more circular economy is essential not only from an environmental perspective but also as a

prudent economic investment. He highlighted that such initiatives can enhance employment opportunities while simultaneously reducing the carbon footprint [66]. There is optimism that the circular economy will propel Indonesia toward economic transformation by implementing green economy principles and strategies focused on low-carbon development. The environmental challenges posed by plastics have expedited research and policy initiatives aimed at facilitating the transition to a sustainable circular economy for plastics [67].

Amid efforts to enhance the circular economy for plastics, the concept of downstreaming has recently emerged as a key focus in the presidential campaign of Prabowo Subianto for the 2024-2029 term in Indonesia. This program is an extension of the initiatives undertaken by President Joko Widodo in recent years, which have primarily focused on mining commodities. The Ministry of Finance has developed the 2025 Draft State Budget to bolster economic growth in alignment with the government's objective of downstreaming seaweed commodities [68]. This program aligns with the mandate of the 1945 Constitution, specifically Article 33, Paragraph 3, which asserts that all mineral and coal resources are to be utilized for the maximum welfare of the Indonesian people [69]. The objective of downstreaming, as a component of government strategy, is to transform the export composition from primary raw commodities to higher value-added products. This government policy paves the way for the downstream processing of extensively studied seaweed, a key organic material for producing bioplastics, offering a viable solution to replace conventional plastics currently available in the market.

This shift is particularly relevant for seaweed, which has consistently ranked as one of Indonesia's top fishery export commodities by volume. In 2021, seaweed contributed 225,612.16 tonnes (18.5%) to total exports; in 2022, this figure rose to 253,680.06 tonnes (20.7%), and by 2023, it further increased to 265,843.76 tonnes [70]. However, despite Indonesia being the largest seaweed exporter in 2018, a significant portion—205.76 thousand tonnes—was exported as raw commodities. China emerged as the largest importer, purchasing seaweed worth 149.3 million USD, which amounted to 148.3 thousand tonnes [71]. Moreover, the value of seaweed exports does not rank among the top three contributors, often placing in the fourth or fifth position compared to other commodities. In 2021, the export value was 345,114.33 thousand USD (6.0%), which increased to 600,356.45 thousand USD (9.6%) in 2022, but then declined to 433,715.44 thousand USD (7.7%) in 2023 [70]. Once again, this situation arises because seaweed is primarily exported as raw commodities. The anticipated decline in seaweed prices on the international market to IDR 6,000 by June 2024 [72] serves as a stark reminder of Indonesia's limited bargaining power, which adversely affects the economic value of its seaweed commodities. Ultimately, it is the buyers or importers who reap greater benefits by processing Indonesian seaweed and adding further value.

4.2 The prospects and challenges of South Sulawesi in the bioplastics industry

The global bioplastics market was valued at USD 7.49 billion in 2023 and is anticipated to expand from USD 7.41 billion in 2024 to an impressive USD 56.99 billion by 2032 [73]. Establishing a new industry capitalizing on this potential will not only create job opportunities, particularly for marine-based communities, but also

foster local sustainable economic growth. Among the provinces in Indonesia, South Sulawesi is uniquely positioned to capitalize on this opportunity. According to 2020 data from BPS, South Sulawesi emerged as the foremost province in Indonesia for seaweed production, with a remarkable output of 1.63 million tons [74]. In both 2022 and 2023, South Sulawesi consistently accounted for over half of Indonesia's national seaweed export volume, contributing 55.98% or 142 thousand tons in 2022 and 57.34% or 152.4 thousand tons in 2023 [75]. A significant opportunity awaits South Sulawesi, given its strategic coastal location, where nearly every district or city engages in seaweed production (See Figure.1).

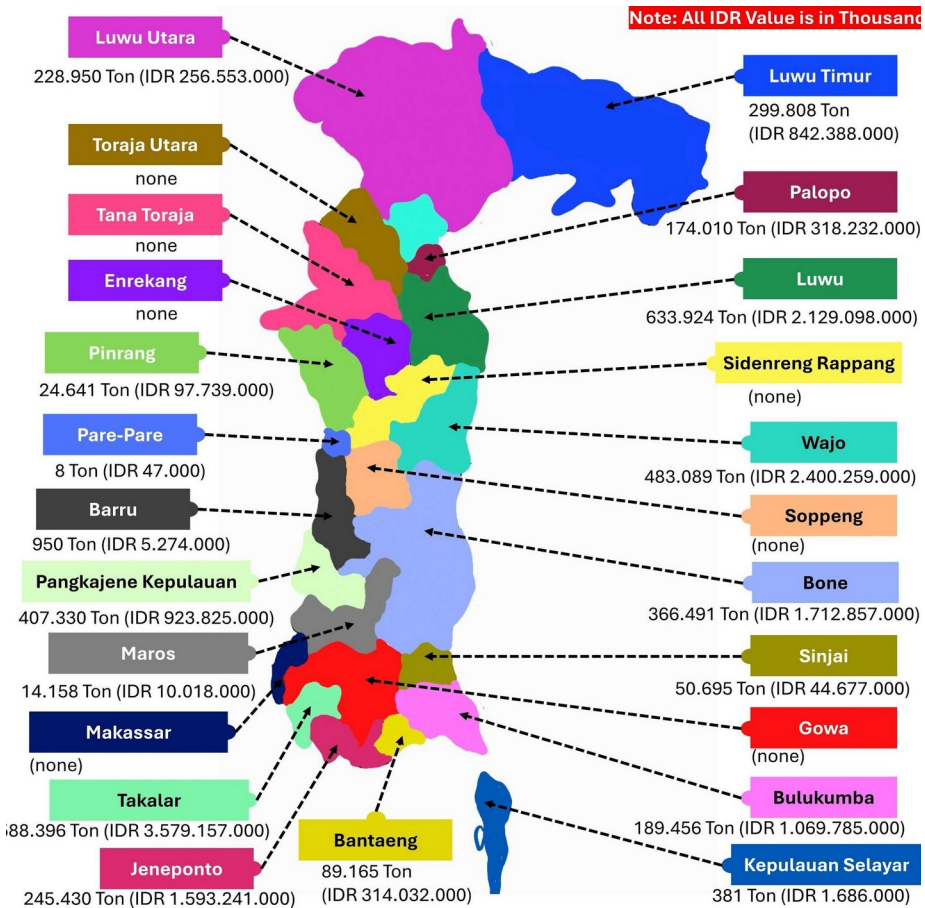


Fig. 1. Production and Value of Aquaculture Fisheries (Seaweed) by District/City and Major Commodities in South Sulawesi Province, 2022 (Source: Author’s Image)

By leveraging the downstream potential of seaweed to produce bioplastics, the South Sulawesi government can promote a more equitable economic development in the region. This initiative will lead to the establishment of new factories and the creation of numerous job opportunities. Moreover, since bio-based plastics can be produced

not only from seaweed but also from agricultural and plantation by-products, these sectors stand to benefit significantly as well. South Sulawesi is known for its large production of various agricultural goods, including rice, corn, cassava, and sugarcane. The combined use of seaweed with these agricultural commodities is backed by extensive research conducted both nationally and internationally. Additionally, various ministries and governmental bodies are actively engaged in ongoing studies related to bio-based plastics.

Another factor bolstering the South Sulawesi government's optimism about advancing this industry is the growing demand for eco-friendly products. Research published in the *Harvard Business Review* highlights a significant shift in consumer behavior towards sustainable products. It indicates that brands genuinely committed to sustainability are likely to outperform those that have not made adequate investments in this area. This trend is notably influenced by younger generations in the United States, who possess increasing purchasing power and demonstrate a stronger preference for sustainable choices [76]. A similar trend can be observed in Indonesia. According to a 2022 survey on Generation Z and Millennials, there is a growing awareness among younger generations regarding environmental issues, with 69.8% of respondents indicating that they purchase eco-friendly products [77]. Conversely, a 2023 study conducted by Bain & Company reveals that as many as 20% of Indonesian consumers are willing to pay a premium for eco-friendly products [78].

This moment presents a prime opportunity to explore the potential of the bio-based plastic industry in South Sulawesi, particularly with the regional elections for governors and mayors scheduled for 2024. As the foremost local authority, the government must meticulously plan the timeline, action plan, and budget necessary for the industry's establishment and growth. This forward-thinking strategy would far surpass the existing initiative by the Makassar city government, which has focused on a partnership for waste-to-energy plants (PLTSa), a deal officially signed by the mayor in 2024 [79]. Waste processing is energy-intensive, and the combustion process, along with its byproducts, can lead to pollution of land, sea, and air. Research conducted by Lim, et al. [80] presents findings showing that while recycling plastic waste can minimize environmental damage, it does not completely eliminate it. The adverse effects on health are inevitable, as noted by ipen.org [81] that plastic recycling uncontrollably disperses toxic chemicals and fails to provide a viable solution to the plastics crisis, and Toxics Link [82] highlighted various health issues associated with chemicals in recycled plastics, including impacts on reproductive health, pregnancy, fetal development, respiratory illnesses, and even cardiovascular problems. While the industry advocates for a circular plastics economy, it is evident that the toxic chemicals in plastics undermine the viability of this approach, effectively poisoning the circular economy [83].

The same applies to the recycling of plastic waste into products such as furniture and household goods. Although South Sulawesi hosts several plastic processing facilities in regions like Gowa and Takalar ([84], [85], [61]), the quantity of waste processed falls short of the total waste generated in a short timeframe. Consequently, not all plastics are recyclable due to the diversity of plastic types involved [86]. Recycled plastics, when transformed into new products, require significant energy consumption, given that 99% of plastics are derived from fossil fuels [83].

Furthermore, products created from recycled materials struggle to gain quick market absorption, as demand does not keep pace with production output. While consumers typically express a favorable view towards these items, they frequently choose not to purchase them [87].

Aligned with the strategic framework for developing seaweed-based bioplastics in South Sulawesi, the production of these materials presents distinct challenges. Currently, seaweed cultivation in the region generates approximately 16,000 tons of plastic waste from bottles utilized as floats during the farming process [88]. In response, it is imperative for local governments to proactively establish regulations addressing this issue to ensure that the entire supply chain, from upstream to downstream, upholds a core tenet of the blue-green economy: the reduction of environmental pollution. One viable approach involves the implementation of HDPE pipes and seaweed bags, practices that have already been successfully adopted in Maluku [89].

Another significant challenge is the insufficient public awareness and engagement regarding waste management practices. The government of South Sulawesi must persist in addressing these obstacles, as indicated in the annual Sustainable Development Goals (SDGs) report, by actively promoting awareness about waste management issues. This initiative is crucial for cultivating community concern and prompting tangible actions toward more effective waste management strategies. To date, initiatives aimed at decreasing the reliance on single-use plastic bags through the introduction of paid plastic policies have demonstrated limited success. For example, in the provincial capital of Makassar, the volume of plastic waste rose from 258 tons per day in 2019 to 294 tons per day in 2020 [90]. Additionally, the provision of waste disposal facilities in various public areas has not yielded the desired outcomes. The community continues to show a lack of engagement in waste sorting practices, with many individuals opting to pay for plastic bags instead of utilizing their own reusable alternatives. Consequently, it is imperative that all policies enacted by the provincial government receive robust support, implementation, and oversight from both city and regency administrations to ensure their effective execution.

4.3 Suggestions

This paper presents a series of actionable steps that the South Sulawesi regional government can consider for establishing and advancing a seaweed-based bioplastics industry:

1. Providing environmental-friendly equipment that does not generate plastic waste. This equipment is intended to replace the used bottles currently utilized in seaweed cultivation, which contribute to marine pollution.
2. Undertake a comprehensive mapping of seaweed farmers, categorizing them by the scale of their operations. Assess the potential for selected farmers to serve as pilot projects that could evolve into bio-based plastic production enterprises.
3. Perform a mapping of relevant agricultural and plantation farmers to identify potential collaborators for future partnerships aimed at supplying the necessary materials for the seaweed-based bioplastics industry.

4. Compile and analyze data relevant to the advancement of the bio-based plastic industry by collaborating with ministries, research institutions, organizations, and universities. This cooperation should facilitate continuous research focused on improving the quality of bio-based plastic production, with an emphasis on developing environmentally sustainable biodegradable products that are competitively priced and capable of mass production to satisfy the needs of various industries.
5. Facilitate knowledge and technology transfer to local companies, particularly small and medium-sized enterprises (SMEs).
6. Establish collaborations and partnerships with larger corporations to ensure a steady supply of required materials, facilitating knowledge transfer while also supporting the bioplastics industries of SMEs.
7. Seek support from the central government to be integrated into the regional budget draft, specifically earmarked for the regional action plan associated with the Sustainable Development Goals (SDGs) initiative.
8. Allocate financial resources to support specialized research focused on developing seaweed-based bioplastics, while also remaining open to advancements in other types of bioplastics, that meet functionality and strength specifications comparable to conventional plastics currently on the market.
9. Coordinate and delegate specific responsibilities to mayors and regents to ensure the smooth development of the bio-based plastic industry, minimizing obstacles in the process.
10. Enact regulations to systematically phase out the use of single-use plastics across all industries in South Sulawesi, incorporating enforcement mechanisms that impose fines on non-compliant businesses.
11. Implement a comprehensive outreach strategy to advocate for effective waste management and the benefits of bioplastics across multiple communication channels. This should involve engaging relevant stakeholders and local media, both digital and traditional, to strengthen support for this initiative.

5 Conclusion

Through the development of seaweed-based bioplastics, Indonesia, particularly South Sulawesi, can make a significant contribution to achieving the Sustainable Development Goals (SDGs), namely Goal 13: Climate Action, Goal 14: Life Below Water, Goal 12: Responsible Consumption and Production, and Goal 8: Decent Work and Economic Growth. Hence, in the foreseeable future, South Sulawesi has the potential to transition from a mere exporter of raw seaweed to a prominent producer of bioplastics for the domestic market, while simultaneously positioning itself as a key exporter to the global market—one that is progressively attuned to environmental challenges associated with the palpable threats of climate change to human livelihoods.

This aspiration can be achieved if the current and predicted challenges in developing the bioplastics industry are effectively tackled through strategic initiatives led by the provincial government. Once again, the primary role must be orchestrated by the provincial government. Moreover, it requires collaboration, cooperation, and

active engagement from all stakeholders in South Sulawesi, including local governments, communities, businesses, relevant government agencies, educational institutions, and other involved parties.

This study has several limitations that future research could address. Firstly, the data utilized primarily consists of general statistics sourced from the references provided. Future investigations could benefit from incorporating more detailed datasets, such as financial information, customer insights, observational findings, and survey responses. Secondly, the analysis encompasses a broad geographic area, specifically the entirety of South Sulawesi. Future studies might focus on a specific regency or city to gather more targeted data that better elucidates the performance and strategic requirements for the sustainable development of the seaweed-based bioplastic industry.

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