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Harnessing Biomass Waste for Value-Added Products in Achieving Sustainable Development Goals (SDGs): A Systematic Review of Low-Carbon Transition, Bibliometric, Technical Insights, and Challenges

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Abstract: This study aims to systematically examine the utilization of biomass waste in the production of value-added products, supporting the achievement of the Sustainable Development Goals (SDGs), particularly in the context of transitioning to a low-carbon society and a circular economy. The Systematic Literature Review (SLR) method was used. Biomass can be converted into various products, including bioenergy, bioplastics, briquettes, biochar, biofertilizers, and automotive composites. Conversion technologies such as pyrolysis, fermentation, and biorefinery support the principles of circularity and emission mitigation. This study also reveals challenges in technical, social, and policy aspects. The implication is that cross-sector synergy is needed to encourage the utilization of biomass as a strategic solution for sustainable development and to strengthen the green industry in the future.

Keywords: *Attached growth; Biomass waste; Challenges; Low-carbon transition; SDGs; Technical insights; Value-added products.*

1. Introduction

In the last two decades, global awareness of the environmental crisis, climate change, and the limitations of natural resources has increased significantly. Increasingly complex and multidimensional environmental changes have reduced the capacity of nation-states to perform their basic functions independently, driving the need for cross-sectoral and cross-national cooperation (Kapsa and Trempała, 2020; Kazakova *et al.,* 2020). Unsustainable rates of resource consumption, population growth, and economic pressures have exacerbated social inequalities and accelerated the degradation of the Earth's ecosystems. As a result, the world now faces a significant challenge in striking a balance between human development needs and the planet's limited carrying capacity (Motesharrei *et al.,* 2016; Monserand, 2022).

Bibliometric analysis is a quantitative method for analyzing academic publications related to the SDGs. It helps researchers understand research trends, identify influential authors and publications, map the intellectual structure of the field, and pinpoint knowledge gaps (Arora *et al.,* 2025; Davim *et* *al.,* 2025; Hammouti *et al.,* 2025; Mishra *et al.*, 2024; Payumo *et al.,* 2021; Nandiyanto *et al.,* 2020; Pozzi *et al.,* 2020).

In response to these conditions, the United Nations launched the 2030 Agenda for Sustainable Development in 2015, which contains 17 Sustainable Development Goals (SDGs), as shown in **Figure 1**. Many reports regarding the SDGs have been well-reported (**Table 1**).

Table 1. Previous studies on SDGs

No	Title	Reference
1	Safe food treatment technology: The key to realizing the sustainable development goals (SDGs) zero hunger and optimal health	Rahmah *et al*. (2024)
2	Analysis of student's awareness of sustainable diet in reducing carbon footprint to support sustainable development goals (SDGs) 2030	Keisyafa *et al*. (2024)
3	Analysis of the application of mediterranean diet patterns on sustainability to support the achievement of sustainable development goals (SDGs): Zero hunger, good health and well beings, responsible consumption, and production	Nurnabila *et al*. (2023)
4	Efforts to improve sustainable development goals (SDGs) through education on diversification of food using infographic: Animal and vegetable protein	Awalussillmi *et al.* (2023)
5	Implementation of sustainable development goals (SDGs) no. 12: Responsible production and consumption by optimizing lemon commodities and community empowerment to reduce household waste	Maulana *et al*. (2023)
6	The influence of environmentally friendly packaging on consumer interest in implementing zero waste in the food industry to meet sustainable development goals (SDGs) needs	Haq *et al*. (2024)
7	The relationship of vocational education skills in agribusiness processing agricultural products in achieving sustainable development goals (SDGs)	Gemil *et al*. (2024)
8	Smart learning as transformative impact of technology: A paradigm for accomplishing sustainable development goals (SDGs) in education	Makinde *et al*. (2024)
9	Techno-economic analysis of production ecobrick from plastic waste to support sustainable development goals (SDGs)	Syahrudin *et al*. (2026)
10	Techno-economic analysis of sawdust-based trash cans and their contribution to indonesia's green tourism policy and the sustainable development goals (SDGs)	Apriliani *et al*. (2026)
11	Production of wet organic waste ecoenzymes as an alternative solution for environmental conservation supporting sustainable development goals (SDGs): A techno-economic and bibliometric analysis	Sesrita *et al*. (2025)
12	Hazard identification, risk assessment, and determining control (HIRADC) for workplace safety in manufacturing industry: A risk-control framework complete with bibliometric literature review analysis to support sustainable development goals (SDGs)	Henny *et al*., (2025)
13	Sustainable packaging: Bioplastics as a low-carbon future step for the sustainable development goals (SDGs)	Basnur *et al*., (2024)
14	Contributing factors to greenhouse gas emissions in agriculture for supporting sustainable development goals (SDGs): Insights from a systematic literature review completed by computational bibliometric analysis	Soegoto *et al*., (2025)
15	Characteristics of jengkol peel (Pithecellobium jiringa) biochar produced at various pyrolysis temperatures for enhanced agricultural waste management and supporting sustainable development goals (SDGs)	Rahmat *et al*., (2025)
16	Effect of substrate and water on cultivation of Sumba seaworm (nyale) and experimental practicum design for improving critical and creative thinking skills of prospective science teacher in biology and supporting sustainable development goals (SDGs)	Kerans *et al*., (2024)

17	Innovative nanofluid encapsulation in solar stills: Boosting water yield and efficiency under extreme climate supporting sustainable development goals (SDGs)	Namoussa *et al*. (2025)
18	Modernization of Submersible Pump Designs for Sustainable Irrigation: A Bibliometric and Experimental Contribution to Sustainable Development Goals (SDGs)	Glovatskii *et al*. (2025)
19	Sustainable development goals (SDGs) in engineering education: Definitions, research trends, bibliometric insights, and strategic approaches	Ragadhita *et al*. (2026)
20	Integrating multi-stakeholder governance, engineering approaches, and bibliometric literature review insights for sustainable regional road maintenance: Contribution to sustainable development goals (SDGs) 9, 11, and 16	Yustiarini *et al*. (2025)
21	Computational engineering of malonate and tetrazole derivatives targeting SARS-CoV-2 main protease: Pharmacokinetics, docking, and molecular dynamics insights to support the sustainable development goals (SDGs), with a bibliometric analysis	Merzouki *et al*. (2025)
22	A study on sustainable eggshell-derived hydroxyapatite/CMC membranes: Enhancing flexibility and thermal stability for sustainable development goals (SDGs)	Waardhani *et al*., (2025)
23	Towards sustainable wind energy: A systematic review of airfoil and blade technologies over the past 25 years for supporting sustainable development goals (SDGs)	Krishnan *et al*. (2024)
24	Assessment of student awareness and application of eco-friendly curriculum and technologies in Indonesian higher education for supporting sustainable development goals (SDGs): A case study on environmental challenges	Djirong *et al*. (2024)
25	Low-carbon food consumption for solving climate change mitigation: Literature review with bibliometric and simple calculation application for cultivating sustainability consciousness in facing sustainable development goals (SDGs)	Nurramadhani *et al*. (2024)
26	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis	Maryanti *et al*. (2022)

This agenda is a global collective framework for building a better and more sustainable future for all (Ragadhita *et al*., 2026). The SDGs emphasize the importance of human development that is able to realize a harmonious relationship between humans and nature, by integrating economic growth, social justice, and environmental preservation. One of the key approaches in implementing the SDGs is strengthening the concept of a low-carbon society, a circular society, and a natural symbiotic society, a social system designed to reduce emissions, recycle resources, and maintain ecological balance (Di *et al*., 2023).

In this context, innovative and sustainable waste management, particularly for biomass waste, is a key strategy. Biomass encompasses a range of organic materials derived from the agricultural, forestry, food industry, and organic-based household waste sectors (Chew *et al*., 2019). As a renewable resource, biomass has enormous potential across various sectors, supporting the food, energy, materials, and chemical industries (Melliti *et al*., 2013; Yana *et al*., 2022; Salim *et al*., 2024). However, the reality shows that most global biomass waste is still disposed of inefficiently (through open burning or landfill), which increases greenhouse gas emissions and worsens environmental pollution. To fully understand the potential of biomass and encourage its optimal use, an integrated approach is needed that considers the sustainability dimension and its contribution to supporting the transition to a low-carbon society (Kobayashi & Nakajima, 2021) The use of biomass to substitute fossil fuels, reduce greenhouse gas emissions, and produce clean energy and renewable materials is a key element in the global economic decarbonization strategy (Romasheva & Cherepovitsyna, 2023).

Integrated biomass utilization can produce various value-added products such as bioenergy (biogas, bioethanol, briquettes), organic fertilizer, compost, bioplastics, and environmentally friendly building materials (Ashokkumar *et al*., 2022). Conversion technologies such as pyrolysis, gasification, fermentation, and anaerobic digestion have shown their effectiveness in increasing the utility value of biomass while supporting the principles of a circular economy (Kumari *et al*., 2024). These innovations are in line with the achievement of SDGs, especially SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), SDG 13 (Addressing Climate Change), and SDG 15 (Terrestrial Ecosystems) (Torres *et al*., 2022).

Figure 1. The 17 Sustainable developments goals (Ragadhita *et al*., 2026)

Several previous studies have examined the contribution of biomass to sustainable development in various contexts (Nandiyanto *et al*., 2023; Hamidah *et al*., 2023; Utami *et al*., 2024; Harahap *et al*., 2025). Several studies highlight the potential of the bioeconomy in supporting the transition to a more sustainable energy system, although there are still limitations in the integration of social and governance dimensions in its implementation (Zabaniotou, 2018; D'Amico *et al*., 2022). Bibliometric studies show that the focus of biomass research is generally still centered on goals such as SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), and SDG 12 (Responsible Consumption and Production), while attention to social SDGs such as SDG 4 (Quality Education), SDG 5 (Gender Equality), and SDG 17 (Partnerships for the Goals) is still limited (Mao *et al*., 2015; Sertolli *et al*., 2022; Maoi *et al*., 2018). Several other studies underline that the effectiveness of biomass utilization in supporting the achievement of SDGs is greatly influenced by contextual factors, including national policies, community participation, and supply chain sustainability (Hiloidhari *et al*., 2023; Zahraeee *et al*., 2022; Blair *et al*., 2021). However, to date, there are still limited studies that systematically map the relationship between types of biomass waste, their derivative products, and their contribution to achieving the SDGs in a comprehensive and cross-sectoral manner. Although biomass issues have been implicitly reflected in several SDGs (such as food security, renewable energy, and ecosystem conservation), the approach used in most studies is still sectoral or thematic. This results in a lack of comprehensive synthesis on the role of biomass in sustainable development. In addition, there are not many studies that integrate technical, social, and policy aspects simultaneously, even though these three aspects are crucial to understanding the contribution of biomass to sustainable production and consumption systems, especially in supporting the transition to a low-carbon society.

Based on this urgency and potential, this article aims to present a systematic review of various studies that discuss the utilization of biomass waste into value-added products within the framework of sustainable development. This study not only classifies the types of biomass waste and products but also evaluates the contribution of each product to achieving the SDGs, as well as identifies challenges and knowledge gaps that still exist. The novelty of this article lies in its cross-sectoral and comprehensive approach. Unlike previous studies that tend to be sectoral, this article integrates waste type classification, derivative product analysis, and explicit contribution mapping to the SDGs as a whole. This article also directly links the role of biomass in supporting decarbonization strategies and low-carbon society development by highlighting the transformative potential of biomass in strengthening the circular economy, creating green jobs, and reducing dependence on fossil fuels. This approach is expected to be a strategic reference for the formulation of evidence-based policies, the development of biomass technology, and the integration of sustainability principles in the future industrial and energy sectors.

2. Methodology

This study used the Systematic Literature Review (SLR) approach as the main method to comprehensively evaluate the role of biomass in supporting sustainable development. This method is not only used to examine the contribution of biomass to the transition to a low-carbon economy but also to identify and classify various value-added products that can be produced from biomass waste, such as bioenergy, organic fertilizers, bioplastics, and other environmentally friendly materials. To ensure the quality and accountability of the literature selection process, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework is used as a reference in every stage of the study, from literature identification to screening and final analysis.

The literature search strategy was carried out systematically through Scopus data. The search process used a combination of keywords that were designed to capture relevant thematic coverage, including: (TITLE-ABS-KEY (biomass AND utilization) OR TITLE-ABS-KEY (sustainable AND development AND goals) AND TITLE-ABS-KEY (value AND added AND products AND from AND biomass). These keywords were selected to ensure that the collected literature reflects interrelated technical, environmental, and policy dimensions. Detailed information regarding the use of bibliometric is explained elsewhere (Rochaman *et al*, 2024; Al Husaeni & Nandiyanto, 2022; Al Husaeni & Al Husaeni, 2022).

The literature selection process was carried out systematically based on the inclusion and exclusion criteria as presented in **Table 2**. The articles included were scientific journals (both research articles and review articles) published between 2020 and 2025, in English, with full access to the full text. The selected studies explicitly discussed biomass utilization, value-added products, and their relevance to achieving the SDGs or a low-carbon economy. Conversely, articles that were only available in abstract form, were not relevant to the topic, or were in the form of technical reports, conference proceedings, and opinion articles, were excluded from the analysis. From the initial search results of 200 articles, 139 articles were eliminated because they did not meet one or more selection criteria. After going through a strict screening process based on the PRISMA principle, 36 articles were obtained that met all criteria and were further analyzed in this study.

The data analysis technique was carried out through two approaches: descriptive analysis and thematic analysis. Descriptive analysis includes identifying publication trends by year, country, and topic coverage. Meanwhile, thematic analysis aims to explore the main focus of the study, group the types of biomass and their derivative products, and analyze their contribution to achieving SDGs across sectors. The results of this analysis form the basis for developing a conceptual synthesis on the strategic role of biomass in supporting sustainable development and the transition to a low-carbon society.

Table 2. Previous studies on SDGs

Aspect	Inclusion criteria	Exclusion criteria
Document type	Scientific articles published in accredited journals, including review articles	Rahmah *et al*. (2024)
Language	English	Keisyafa *et al*. (2024)
Year of publication	2020–2025	Nurnabila *et al*. (2023)
Focus of discussion	Available in full text form	Awalussillmi *et al*. (2023)
Contextual relevance	Studies that explicitly address biomass, SDGs, a low-carbon economy, or value-added products from biomass	Maulana *et al*. (2023)

3. Results and Discussion

3.1 Descriptive Quantitative Selected Literature

Figure 2 illustrates the distribution of publications related to biomass utilization in support of sustainable development and the transition to a low-carbon economy, by publication year, from 2020 to 2025. In general, there has been an increasing trend of academic attention to this topic over the past five years, although fluctuations have occurred from year to year. In 2020 and 2021, the number of publications was relatively low, with 3 and 4 papers, respectively, reflecting the early stage of interest in this topic as the global discourse on the circular economy and bioenergy began to develop after the adoption of the 2030 Agenda. However, in 2022, the number of publications decreased to only 2, possibly due to the continued impact of the COVID-19 pandemic, which shifted the focus of research to health and other crises.

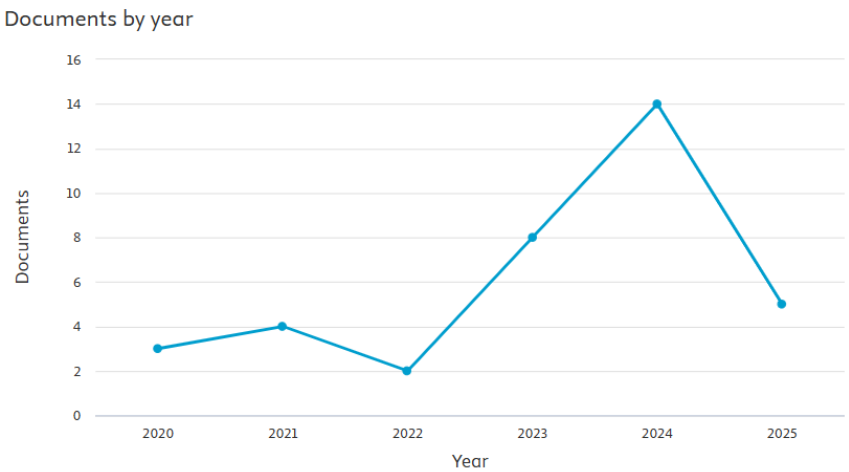

Figure 2. The distribution of the reviewed documents across publication years from 2020 to 2025.

The trend began to show a significant increase in 2023 with 8 documents, and peaked in 2024 with a total of 14 documents. This spike indicates the increasing global urgency of biomass utilization as part of climate change mitigation strategies, carbon emission reductions, and the substitution of fossil fuels with renewable energy and materials. 2024 is a point of research intensification, which is in line with the growing commitment of various countries to support decarbonization and green recovery policies. Meanwhile, the number of publications in 2025 was recorded to have decreased to 5 documents. This decrease is most likely due to data that is not yet fully available, considering that the year was still ongoing when the analysis was conducted.

Figure 3 illustrates the distribution of scientific articles based on scientific fields related to the topic of biomass utilization in supporting sustainable development and the transition to a low-carbon economy. Based on Figure 3, it can be seen that the topic is multidisciplinary, with significant contributions from various branches of science. The field with the largest proportion is Energy (17.7%), which shows that most research focuses on the development and utilization of biomass as an alternative energy source, such as biofuel, biogas, or biochar. The second position is occupied by Environmental Science (16.7%), which reflects great attention to environmental impacts, carbon emission reduction, waste management, and the role of biomass in decarbonization efforts and the clean energy transition.

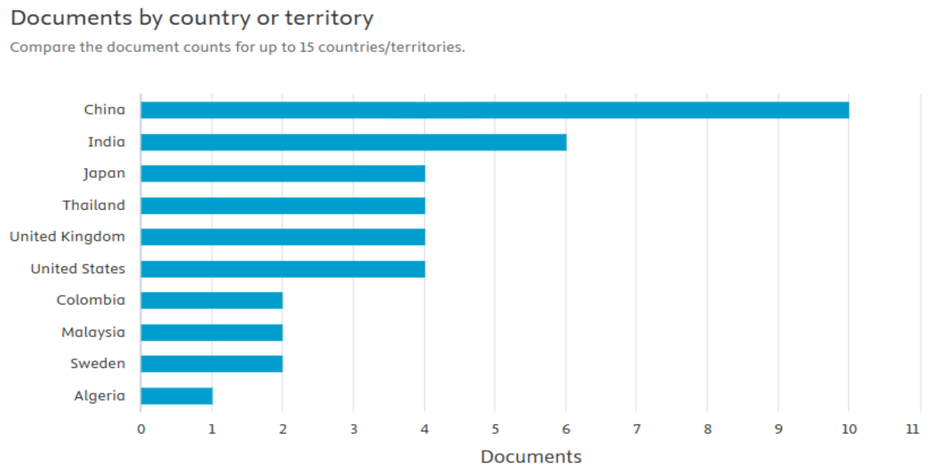

Figure 3. Distribution of scientific documents by country of origin, based on the top 10 countries with the most publications.

Furthermore, Chemical Engineering contributed 14.6% of the documents, showing the importance of engineering approaches in biomass conversion processes such as pyrolysis, gasification, and fermentation. The field of Chemistry (10.4%) also plays an important role, especially in analyzing chemical reactions, converting compounds, and characterizing bio-products such as bio-oil and biochar. Engineering in general contributed 9.4% of the total, indicating involvement in the design and development of technology and equipment for biomass processing.

In terms of resources, Agricultural and Biological Sciences (7.3%) describe studies on biomass raw materials such as agricultural waste, energy crops, and other organic waste. Meanwhile, Computer Science (5.2%) shows the involvement of digital technology in this research, such as the use of modeling, simulation, and artificial intelligence for process optimization. Other disciplines, such as Biochemistry, Genetics, and Molecular Biology (4.2%) and Immunology and Microbiology (3.1%), show research involving microorganisms or biological processes in biomass conversion. Social Sciences (4.2%) contribute to understanding the socio-economic aspects, energy policy, and sustainability of biomass-based technologies.

Finally, the other categories (7.3%) include other disciplines that may be cross-sectoral, such as law, energy economics, or environmental education. Overall, this diagram reflects that biomass research is not only limited to science and technology but also involves various interdisciplinary dimensions to realize sustainable and environmentally friendly energy solutions.

Figure 4 presents the distribution of scientific documents by country or region, indicating the level of contribution of each country in research related to the topic of biomass utilization in supporting sustainable development and the transition to a low-carbon economy. Based on **Figure 4**, China is the country with the largest contribution, producing 10 documents, followed by India with 6 documents.

This shows that these two Asian countries have a large focus on biomass research, which may be influenced by the high demand for renewable energy, large population, and the potential for biomass waste from the agricultural and industrial sectors. Japan, Thailand, the United Kingdom, and the United States each contributed 4 documents, indicating a balanced attention from developed and developing countries to the issue of biomass conversion. Japan and Thailand, for example, have a strong history in waste conversion technology and energy efficiency, while the United Kingdom and the United States are known to be active in technological innovation and green energy policies.

Meanwhile, countries such as Colombia, Malaysia, and Sweden contributed 2 documents each, indicating moderate but potential involvement in biomass energy development. Algeria, with 1 document, is at the bottom of the chart, but still shows the contribution of the North African region to this research. The presence of countries such as Malaysia is also important to note because it has abundant biomass sources from palm oil and agricultural waste.

Figure 4 shows that research on biomass as an energy source is not only of interest to developed countries but also to developing countries that see biomass as a solution for energy diversification, carbon emission reduction, and sustainable waste management. Asia's dominance in this chart in Figure 4 also shows that this region plays an important role in the development and application of renewable energy technologies sourced from biomass. This reflects the global trend towards a cleaner and more sustainable energy transition, with increasing international involvement.

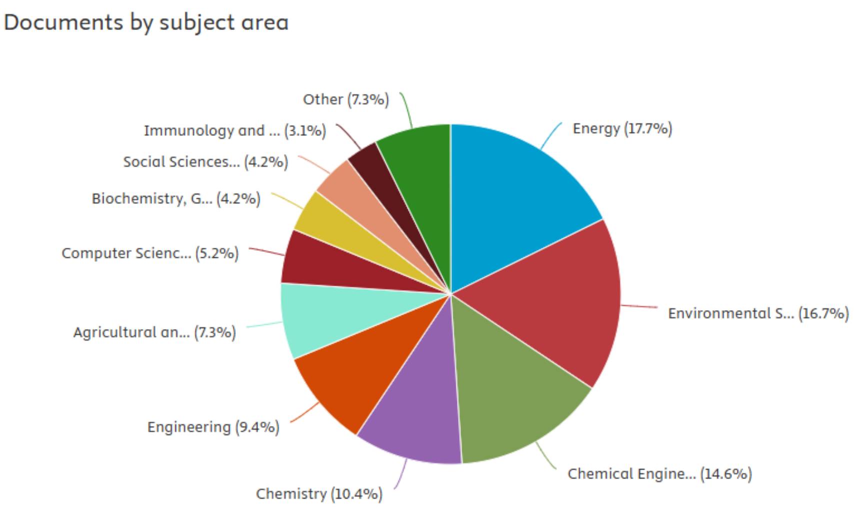

Figure 4. Distribution of subject areas in the reviewed articles.

Table 3 shows the top 10 articles with the highest number of citations based on the results of the analysis in this study. Of all the articles analyzed, the work of Solarte-Toro *et al*. (2021) is in first place with 85 citations, indicating its very significant role in explaining the relationship between biorefinery and the shift towards a sustainable bioeconomy. This article discusses the technical aspects and challenges in implementing the bioeconomy concept widely.

In second place, the article by Ubukata *et al*. (2020) entitled "The Future is Garbage" raises an important issue regarding the utilization of food waste into bioenergy through a biorefinery approach, and has been cited 58 times. This reflects the increasing attention to the management of food waste as a valuable resource. Furthermore, the article by Guo *et al*. (2020) on multilevel system modeling concerning the interrelationships between food, energy, and water in the global south obtained 31 citations, indicating that spatial and systemic aspects are also of concern in global bioenergy studies.

Another article that is also widely cited is the work of Pekkoh *et al*. (2023) and Hoyos-Seba et al. (2024), with 26 and 24 citations, respectively, which examine the potential for utilizing CO_2 waste using photosynthetic microorganisms and animal waste as energy sources and value-added products. Meanwhile, other articles such as those by Wichaphian *et al*. (2023) and Tumma *et al*. (2022) have lower citations (13 and 7), but are still relevant because they discuss innovative technologies such as DES pretreatment and biocircular platforms.

The bottom three articles on this list, respectively by Xi *et al*. (2024), Yuldirim and Acar (2024), and Kumar *et al*. (2025), still have very low citation counts (3, 1, and 0, respectively). This can be attributed to two main reasons: first, their publication year is still very recent, thus they have not had enough time to gain many citations; second, the scope of the topic or the scientific community that accesses them is likely still limited.

Based on this analysis, it shows that articles with the topic of biorefinery that are applicable, based on organic waste, and supporting the transition to bioeconomy, receive high attention and influence in the scientific community. The high number of citations also indicates the relevance of these topics to global issues such as energy security, waste management, and environmental sustainability. This table is an important indicator to identify the main references and research trends that dominate the scientific discourse in the field of biomass-based renewable energy.

Table 3. The top ten articles with the most citations are based on the analysis results in this study.

No	Year	Citation	Author
1	Biorefineries as the base for accomplishing the sustainable development goals (SDGs) and the transition to bioeconomy: Technical aspects, challenges, and perspectives	2021	Solarte-Toro *et al*., 2021
2	The Future is Garbage: Repurposing of food waste to an integrated biorefinery	2020	Ebikade *et al*., 2020
3	Multi-level system modelling of the resource-food-bioenergy nexus in the global south	2020	Guo *et al*., 2020
4	Turning waste CO_2 into value-added biorefinery co-products using cyanobacterium Leptolyngbya sp. KC45 as a highly efficient living photocatalyst	2023	Pekkoh *et al*. 2023
5	Animal manure in the context of renewable energy and value-added products: A review	2024	Hoyos-Sebá *et al*., 2024
6	Value-added green biorefinery co-products from ultrasonically assisted DES-pretreated Chlorella biomass	2023	Wichaphian *et al*., 2023
7	Biocircular platform for renewable energy production: Valorization of waste cooking oil mixed with agricultural wastes into biosolid fuels	2022	Tumma *et al*., 2022
8	Production of α-olefins from biomass gasification: Process development and multi-objective optimization for techno-economic and environmental goals	2024	Xi *et al*., 2024
9	Value of horse manure for renewable energy production: anaerobic digestion, biogas generation, and contributions to sustainable development	2024	Yuldirim and Acar, 2024
10	Valorizing banana peel waste into mesoporous biogenic nanosilica and novel nano-biofertilizer formulation thereof via nano-biopriming inspired tripartite interaction studies	2025	Kumar *et al*., 2025

3.2 Definition and Classification of Biomass

Biomass is defined as renewable organic material derived from plant photosynthesis, agricultural/forestry waste, or animal by-products, containing lignocellulosic components (cellulose, hemicellulose, lignin), lipids, or proteins that can be converted into energy, chemicals, or functional materials (Li *et al.,* 2017; Kobayashi and Nakajima, 2021). Unlike fossil fuels, biomass is carbon-neutral because the CO_2 emissions released during conversion are balanced by the CO_2 absorbed during its growth. Biomass is classified into two categories (Fantini, 2017) based on its origin shown in **Figure 5**:

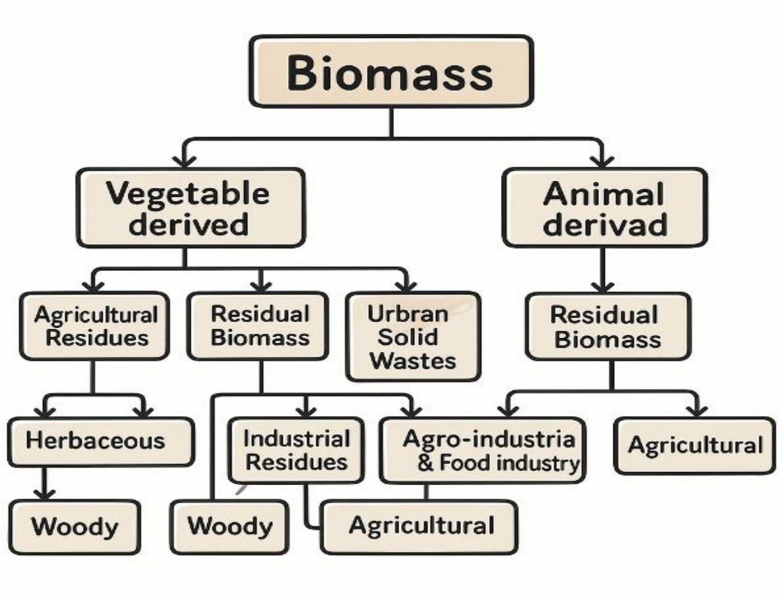

Figure 5. Classification of biomass.

(i) Vegetable-derived biomass is derived from plant residues or parts, whether from agriculture, industry, or municipal waste. This category has the following sub-classifications:

a) Agricultural Residues are biomass produced from the remaining agricultural crop yields that are not used directly for human consumption or animal feed. Generally, it is used for the production of bioethanol, wood pellets, and compost. Agricultural waste is divided into two sub-categories:
   - Herbaceous: Non-woody plants such as rice straw, wheat, corn, or elephant grass.
   - Woody: Woody plants such as twigs, small branches, young tree trunks, or waste from pruning.

b) Residual Biomass is organic waste from industrial processes that still has high energy content and can be reused. It is divided into two sub-categories:
   - Industrial Residues: Waste from plant-based industries such as sawmills (sawdust, wood chips), paper processing, etc.
   - Woody: All types of industrial wood waste fall into this sub-category. Residual biomass can be converted into briquettes, pellets, or biochar through pyrolysis.

c) Urban Solid Waste is organic waste that comes from urban community activities. This category has sub-classifications:
   - Agro-industria and Food Industry: Food waste and agricultural-based industrial waste such as fruit peels, sugarcane pulp, and industrial kitchen waste.
   - Agricultural (Urban): City garden waste, including leaves, twigs, and waste from urban farming.

(ii) Animal-derived biomass is derived from organic waste from animals and the livestock industry. This category has the following sub-classifications:

a) Residual is a source of biomass that comes from animal organic waste that is not used in food consumption or production. It is divided into two sub-categories:
   - Agro-industrial: Waste from the livestock industry, such as animal waste, blood, bones, and slaughterhouse waste.
   - Agricultural: Livestock manure and waste reused in agricultural activities as manure or as biodigester input.

3.3 Biomass Conversion Technology

Biomass conversion is a technological process that converts organic materials, such as agricultural waste, crop residues, animal waste, food waste, and forestry waste, into various forms of energy that can be used, either directly or indirectly. The energy produced from this process includes heat, electricity, liquid fuels such as bioethanol and biodiesel, and gases such as biogas and syngas (Walker *et al.,* 2019). Biomass is considered a carbon-neutral energy source because the carbon dioxide released during its use is comparable to the amount of carbon absorbed by plants during photosynthesis (Gouveia and Passarianho, 2017). Thus, biomass conversion is not only a solution to reduce greenhouse gas emissions, but also plays an important role in encouraging a circular economy by utilizing previously unused organic waste into energy and value-added products (Kataya *et al*., 2023).

The results of biomass conversion vary greatly depending on the technology used. For example, direct combustion produces heat energy that can be used for space or water heating (Jha *et al*., 2022). The fermentation process produces bioethanol from sugar and starch, while transesterification produces biodiesel from vegetable oils or animal fats. In addition, the anaerobic digestion process by microorganisms produces biogas, which can be used for cooking, lighting, or small-scale electricity generation. Meanwhile, the pyrolysis and gasification process of solid biomass can produce bio-oil, biochar, and synthetic gas (syngas), which can be further converted into fuel or electrical energy (Yılmaz and Selim, 2013; Lee *et al*., 2019). Not only energy, biomass conversion can also produce high-value derivative products such as biochar (for soil fertility and carbon storage), digestate (as organic fertilizer), bioplastic (a substitute for conventional plastic), and various bioactive compounds and industrial enzymes used in the food, textile, and pharmaceutical sectors (Motesharrei *et al*., 2020). In brief, the discussion related to the types of biomass conversion technology, along with the main products produced, the advantages of each technology, and their relationship to the SDGs, is presented in **Table 4.**

3.4 Value Added Products from Biomass

Biomass, as a renewable resource, has tremendous potential to be converted into various environmentally friendly, value-added products. This product diversification not only supports decarbonization and waste reduction efforts but also expands the contribution of biomass to the industrial, energy, agricultural, and automotive sectors. With the right technological approach, biomass can serve as a crucial foundation in the transition to a circular and low-carbon economy. The following are some of the main categories of value-added products that have been widely developed from biomass:

3.4.1. Bioplastic

The use of lignocellulose as a raw material for bioplastics not only reduces dependence on fossil fuels but also supports the principle of circular bioeconomy. In the context of the global environmental crisis, lignocellulose waste from the agricultural and forestry sectors—such as straw, sugarcane bagasse, and wood fiber waste—has been identified as a very abundant and potential biomass resource (Kobayashi and Nakajima, 2021) This residual biomass is not only widely available, but also has the characteristics of raw materials that are suitable for development into environmentally friendly products, such as bioplastics. This is relevant to efforts to fulfill the SDGs, especially SDG 3, SDG 12 (Responsible Consumption and Production), SDG 14 (Marine Ecosystem), and SDG 15 (Land Ecosystems), which encourage the reduction of food waste and optimization of recycling.

Table 4. Summary of biomass conversion technologies.

No	Conversion technology	Main products	Advantage	SDGs linkages
1	Combustion	Heat, steam, electricity	Simple technology, high efficiency for large-scale	SDG 7 (Clean energy), SDG 13 (Climate change)
2	Pyrolysis	Bio-oil, biochar, syngas	Minimal waste, producing solid, liquid, and gas products at the same time	SDG 9 (Industrial innovation), SDG 12 (Sustainable consumption and production), SDG 15 (land ecosystem)
3	Gasification	Synthesis gas (syngas)	Can be used to generate electricity or chemicals	SDG 7, SDG 9, and SDG 13
4	Fermentation	Bioethanol, biobutanol	Using sugar/flour waste, suitable for transportation fuel	SDG 2 (food security), SDGs 7, and SDG 12
5	Anaerobic	Biogas (CH_4 + CO_2) digestate (organic fertilizer)	Processing wet waste and dirt, producing energy and fertilizer	SDG 6 (Clean water), SDG 7, SDG 13
6	Transesterification	Biodiesel	Converting vegetable oil/animal fat into fuel	SDG 7, SDG 12, SDG 15 (land ecosystem), SDG 13
7	Hydrolysis and Fermentation	Bioethanol from lignocellulose	Processing non-food biomass (wood waste, straw) into fuel	SDG 2, SDG 9, SDG 13
8	Advanced Biochemical Technology	Bioplastics, industrial enzymes, biosurfactants	High-value, environmentally friendly products	SDG 3 (Health & well-being), SDG 12, SDG 14 (Marine ecosystems), SDG 15

Bioplastics derived from cellulose and chitin (two organic compounds found in abundance in plant waste and food waste) have been developed as a solution to various environmental problems, such as plastic pollution and carbon emissions. This biomass is a carbon-neutral source, as the carbon released during the degradation of bioplastic products is reabsorbed by plants through photosynthesis, thereby not increasing the burden of greenhouse gas emissions (Kobayashi and Nakajima, 2021; Lei *et al.*, 2022). This aligns bioplastics with the concept of a low-carbon society. In addition, lignocellulose bioplastics have broad prospects for development into advanced materials such as biodegradable films, carbon fibers, and composites for the medical, packaging, and automotive industries (Nandiyanto *et al.*, 2020; Triawan *et al.*, 2020; Anggraeni *et al.*, 2021). An example of an innovative application is the regeneration of cellulose from sugarcane bagasse and agave waste in the food industry, which produces a hydrogel film with high flexibility and strong water retention capabilities. This material not only possesses good mechanical properties but also decomposes naturally without combustion, supporting the principle of circularity and reducing pollution from non-degradable microplastics (Triawan *et al.*, 2020).

In addition, lignocellulose bioplastics have broad prospects for development into advanced materials, such as biodegradable films, carbon fibers, and composites, for the medical, packaging, and automotive industries. Examples of innovative applications are the regeneration of cellulose from sugarcane bagasse and agave waste in the food industry, which produces hydrogel films with high flexibility and strong water retention capabilities. This material not only possesses good mechanical properties but also decomposes naturally without combustion, supporting the principle of circularity and reducing pollution from non-degradable microplastics (Nandiyanto *et al.*, 2020; Triawan *et al.*, 2020).

3.4.2. Automotive Brake Pads and Composites

In the modern automotive industry, innovation with biomass-based materials is a key strategy in supporting the transition to a sustainable transportation system. One of the significant uses of biomass is in the production of brake pad composites and automotive interior components. Natural materials, such as coconut fiber, hemp fiber, kenaf, and sisal fiber, have been widely studied and applied as reinforcement materials in composite formulations to replace synthetic materials like asbestos and fiberglass (Yavuz *et al.,* 2025; Nandiyanto *et al.,* 2024a, 2024b).

The main advantages of this biomass-based material are that it is lightweight, heat-resistant, wear-resistant, and readily biodegradable, making it a superior choice in efforts to reduce carbon emissions in the automotive industry. The use of natural fiber-based composites can reduce vehicle weight, thereby increasing fuel efficiency and reducing carbon dioxide (CO_2) emissions during vehicle operation. This aligns with the goal of a low-carbon society, where reducing greenhouse gas emissions is a top priority for addressing climate change (related to SDG 13: Addressing Climate Change and SDG 9: Industry, Innovation, and Infrastructure) (Mohammed *et al*., 2018).

From a circular economy perspective, the use of biomass waste as raw material for the automotive industry supports the principle of recycling and reusing resources. Agricultural waste, such as coconut fiber and kenaf stalks that were previously discarded, can now have new economic value in the form of environmentally friendly automotive components. This not only reduces dependence on non-renewable raw materials, but also creates new economic opportunities for the agricultural sector and creative industries based on bioresources. This approach strongly supports SDG 12: Responsible Consumption and Production and SDG 8: Decent Work and Economic Growth (Selvaraj *et al*., 2021).

In the context of natural symbiosis, the use of natural fibers in vehicles not only imitates the design principles of nature (biomimicry) but also strengthens the harmonious relationship between technology and the environment. Plant fibers come from renewable resources, are biodegradable after the end of their product life cycle, and do not pollute the environment like microplastics or synthetic fibers. This is in line with SDG 15: Land Ecosystems, where the preservation and restoration of ecological functions are an important part of the development strategy.

3.4.3. Bio composite, Biochar, Briquette

The use of biomass as an alternative raw material in the development of value-added products is a strategic step in supporting sustainable development, particularly in the context of transitioning to a low-carbon economy. Three leading products developed from biomass are biocomposites, biochar, and biomass briquettes (Minugu *et al*., 2021). All three not only offer technical solutions to environmental and energy problems, but also make a significant contribution to achieving various SDG targets. Biocomposites are composite materials comprising a polymer matrix (either synthetic or biodegradable) reinforced with natural fibers derived from biomass waste, such as coconut fiber, kenaf fiber, bamboo, or straw. This combination produces a material that is lightweight, strong, and easily biodegradable, making it highly suitable for applications in the automotive, construction, and household equipment sectors. The production process typically involves mixing natural fibers with polymers, then processing them through hot molding or other composite methods (Hadey et al., 2022). Biocomposites support the principle of a circular economy because they can extend the life cycle of materials, reduce waste, and reduce dependence on petrochemical-based materials. In terms of SDGs, biocomposites are closely related to SDG 9 (Industry, Innovation, and Infrastructure) and SDG 12 (Responsible Consumption and Production) (Kobayashi and Nakajima, 2021).

Meanwhile, biochar is solid charcoal produced from the pyrolysis process of biomass under oxygen-limited conditions. This product has an excellent microporous structure and is chemically stable, making it effective for improving soil quality, absorbing heavy metals, and increasing water retention capacity. In addition, biochar also functions as a long-term carbon store because the carbon contained in it is not easily released into the atmosphere, thus supporting climate change mitigation strategies (Khan *et al*, 2023; Olugbade and Mohammed, 2019). Thus, biochar contributes directly to SDG 13 (Addressing Climate Change), SDG 2 (Zero Hunger), and SDG 15 (Ecosystems on Land), especially in terms of sustainable agriculture and soil conservation.

Biomass briquettes are solid fuels made from agricultural waste such as rice husks, coconut shells, straw, and sawdust. The manufacturing process includes drying, grinding, and compaction using high pressure without additional chemicals. This briquette is a clean, efficient, and affordable renewable energy solution, especially for household and small industry needs. Its main advantages are its high calorific value and cleaner combustion compared to conventional firewood or charcoal. The use of briquettes not only helps reduce carbon emissions and deforestation, but also empowers rural communities through the creation of green businesses and jobs, thus supporting the achievement of SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), and SDG 11 (Sustainable Cities and Human Settlements).

3.4.4. Biofuel, Biogas, Bioethanol

Conversion of biomass into bioenergy is one of the most extensive and strategic forms of biomass utilization in supporting the transition to a sustainable energy system. Bioenergy includes various forms of biofuels, such as biofuels, bioethanol and biogas, which are produced from renewable organic sources. Biofuels, especially biodiesel, are generally produced through the transesterification process of vegetable oils (e.g., palm oil, castor oil) or animal fats, and are a potential substitute for conventional diesel fuel (Pilarski *et al*., 2021; Sofokleous *et al*., 2022; Alrefai *et al*., 2017). Meanwhile, bioethanol is obtained through the fermentation process of sugar or starch from plants such as sugar cane, corn, or cassava, which is then purified and can be used as transportation fuel, either purely or mixed (blended) with gasoline. In addition, biomass can also be converted into biogas through the anaerobic fermentation process of organic waste, such as agricultural waste, livestock waste, or household organic waste (Sofokleius *et al*. 2022; Kalay *et al*, 2020; Sutarman *et al*., 2018).

This biogas contains quite high methane (CH_4) and can be used as an energy source for power plants, heating, or vehicle fuel. This process not only produces clean energy but also reduces greenhouse gas emissions and helps manage waste in an environmentally friendly manner. The utilization of renewable energy from biomass through the bioenergy pathway is very relevant in supporting the achievement of the Sustainable Development Goals, especially SDG 7 (Affordable and Clean Energy) and SDG 13 (Addressing Climate Change). By replacing fossil fuels, bioenergy can reduce dependence on non-renewable energy and significantly reduce carbon footprints (Kobayashi and Nakajima, 2021).

Furthermore, community-based bioenergy systems also have the potential to increase local energy independence, expand energy access in remote areas, and create new economic opportunities based on local resources. Therefore, the development of technology and supporting policies for bioenergy needs to be continuously improved so that its benefits can be felt widely, fairly, and sustainably.

3.4.5. Enzymes, Biofertilizers, and Biopesticides

In addition to being used for energy and materials, biomass also has great potential in producing functional biological products such as enzymes, biofertilizers, and biopesticides, which are very relevant in supporting sustainable agriculture and environmentally friendly food production systems. These three products not only offer an alternative to synthetic chemical inputs that risk polluting the environment but also play an important role in soil regeneration, natural pest control, and increasing the efficiency of agricultural production (Sutarman and Putra, 2018; Seenivasagan and Babalola, 2021). Enzymes, produced from microorganisms or biomass fermentation, are widely used in various industries such as food, textiles, detergents, and waste processing. In the context of agriculture and the environment, enzymes function to accelerate the decomposition process of organic matter, increase nutrient absorption by plants, and accelerate the biodegradation process. The production of enzymes from biomass waste, such as bagasse or fruit peels, supports the principle of a circular economy and reduces organic waste (Abey *et al*., 2019; Avishek *et al*, 2017).

Biofertilizers, or biological fertilizers, are formulations containing living microorganisms that can increase the availability of nutrients in the soil, such as nitrogen-fixing bacteria (Rhizobium, Azospirillum), phosphate-solubilizing bacteria, or mycorrhiza. Biofertilizers from biomass not only increase land productivity naturally but also help improve soil structure, maintain long-term fertility, and reduce dependence on chemical fertilizers that have the potential to pollute water and soil (Ongsakul and Sen, 2019).

Meanwhile, biopesticides are natural pesticides made from biological materials, such as plant extracts or microbes (fungi, bacteria), which are able to control plant-disturbing organisms without damaging the ecosystem. For example, Bacillus thuringiensis (Bt) is used to specifically control pest caterpillars without killing non-target insects. The use of biopesticides from biomass waste, such as fruit peels or medicinal plant leaves, expands the benefits of biomass in sustainable agricultural systems.

The development of enzymes, biofertilizers, and biopesticides from biomass is very much in line with SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 15 (Ecosystems on Land), because it supports sustainable food systems, maintains soil fertility, and protects biodiversity. In addition, this approach contributes to SDG 13 (Climate Change) by reducing emissions from chemical fertilizers and synthetic pesticides.

3.5. Fundamental Principles: Concept of Low Carbon, Circulation, and Natural Symbiosis in Biomass Utilization

In the framework of sustainable development, the concepts of low carbon, circulation, and natural symbiosis are three fundamental principles that are interrelated and reinforce each other as presented in **Figure 6**. The three form the main pillars in the transition to a society that is not only environmentally friendly but also competitive, resilient, and inclusive of future global challenges. The use of biomass as an organic renewable resource has great potential to bridge the three concepts, especially in supporting the targets of the SDGs (Kobayashi and Nakajima, 2021).

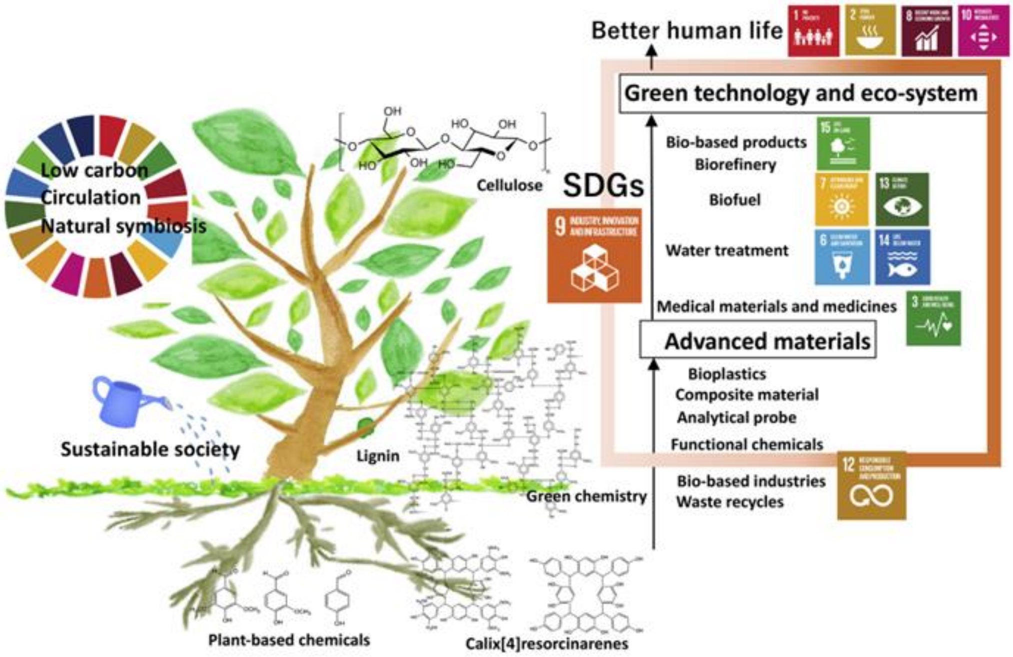

Figure 6. Fundamental principles: concept of low carbon, circulation, and natural symbiosis adopted from Kobayashi and Nakajima (2021).

The low-carbon concept refers to a development strategy that minimizes greenhouse gas emissions, especially carbon dioxide (CO_2), which is the main cause of the global climate crisis. In this context, the transition to a low-carbon society does not only involve replacing fossil fuels with renewable energy sources, but also requires systemic changes in production patterns, consumption, transportation, and people's lifestyles. Biomass plays an important role through its conversion into bioenergy (bioethanol, biogas, briquettes), which simultaneously supports emission reduction and fossil fuel substitution. Thus, this approach directly contributes to SDG 7 (Affordable and Clean Energy), SDG 13 (Addressing Climate Change), and SDG 9 (Industrial Innovation and Infrastructure) and is part of the global economic decarbonization strategy (Robert, 2000; Tan *et al*., 2017).

Meanwhile, the concept of circulation or circular economy emphasizes the importance of reducing waste, recycling resources, and extending the life of materials in the economic cycle. Biomass, as a renewable and biodegradable raw material, can be converted into various value-added products through technologies such as pyrolysis, fermentation, and biorefinery (Hariram *et al.,* 2023). These products include compost, organic fertilizer, bioplastics, and environmentally friendly building materials. This approach not only strengthens local economic resilience and resource efficiency but is also in line with SDG 12 (Responsible Consumption and Production), SDG 11 (Sustainable Cities and Human Settlements), and SDG 8 (Decent Work and Economic Growth) (Kobayashi and Nakajima, 2021).

The concept of natural symbiosis emphasizes the importance of a harmonious relationship between human activities and ecological systems, where both support each other to maintain mutual survival (Kobayashi and Nakajima, 2021). In this context, biomass utilization must be carried out sustainably without damaging the ecological balance. These practices include land conservation, biodiversity protection, fair supply chain management, and avoidance of environmentally damaging exploitation. This approach is in line with SDG 15 (Protecting Terrestrial Ecosystems), SDG 14 (Marine

Ecosystems), and SDG 6 (Clean Water and Sanitation), and supports the creation of a more ethical and environmentally friendly production system (Tan *et al*., 2017; Kobayashi and Nakajima, 2021).

These three principles do not stand alone, but are intertwined in forming the foundation towards a sustainable bio-based economy. In this framework, biomass becomes the meeting point between the needs of economic development, environmental conservation, and social justice (Kobayashi and Nakajima *et al*., 2021). Strategic utilization of biomass enables the achievement of three important things: (1) reducing carbon emissions, (2) resource circulation through recycling and waste conversion processes, and (3) ecological sustainability through a symbiotic relationship between humans and nature. This integration opens up great opportunities to support the SDGs agenda in a multidimensional manner, encouraging the formation of an innovative, inclusive, and resilient green industry (Hiloidhari *et al.,* 2023; Cambero and Sowlati, 2014).

3.6. Integration of Social, Economic, and Environmental Dimensions in Biomass Utilization for Sustainable Development

Figure 7 illustrates the importance of an integrative approach in realizing sustainable development through synergies between three main dimensions: environment, economy, and society. These three dimensions are interrelated and mutually reinforcing, forming a conceptual framework that supports the realization of a low-carbon society, a circular society, and natural symbiosis. This approach reflects the essence of the transformation towards a sustainable and inclusive bio-based economy (Kobayashi and Nakjima, 2021; Cambero and Sowlati, 2014).

As shown in **Figure 7**, the environmental aspect focuses on the formation of an environmentally civilized society. This concept emphasizes the importance of maintaining ecological integrity through the application of green technology and sustainable chemistry principles. The use of biomass as a renewable energy source and environmentally friendly raw material contributes significantly to climate change mitigation and pollution reduction, supporting the achievement of SDG 13 (addressing climate change) and SDG 15 (terrestrial ecosystems) (Kobayashi and Nakjima, 2021; Ahmed *et al.,* 2021)

On the economic side, there is an emphasis on economic activities that support the transition to a low-carbon society. This includes investment and consumption directed at low-emission products and technologies and sustainable production practices. The use of biomass in this sector not only functions as an alternative energy source but also as a catalyst in encouraging green industrial innovation and increasing resource efficiency. This approach is in line with the achievement of SDG 7 (affordable and clean energy), SDG 8 (decent work and economic growth), and SDG 9 (industry, innovation, and infrastructure).

Meanwhile, the social dimension emphasizes the harmonious relationship between humans and nature (symbiosis with humans and nature). This concept of natural symbiosis encourages an approach that places nature as a partner in development, not just an object of exploitation. Ethical and responsible use of biomass strengthens the carrying capacity of ecosystems, protects biodiversity, and promotes social justice and local community participation. This dimension contributes to the achievement of SDG 6 (clean water and sanitation), SDG 14 (marine ecosystems), and SDG 11 (sustainable cities and communities) (Kaczmarcyk *et al*, 2020).

These three dimensions intersect and form an integration point that is the foundation for creating a resilient, inclusive, and sustainable society. The use of biomass is a key strategy because it is able to respond to these three pillars simultaneously: reducing carbon emissions (low carbon), encouraging efficiency and recycling (circulation), and maintaining ecological balance (natural symbiosis). Therefore, the integration of social, economic, and environmental dimensions is not only a strategic choice but also a fundamental prerequisite in designing policies and innovations that support the achievement of the 2030 Sustainable Development Agenda (Kaczmarcyk *et al*, 2020).

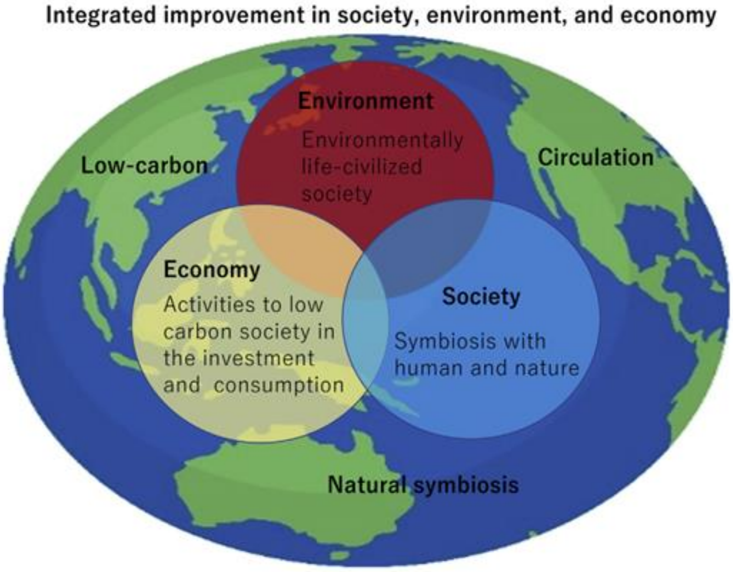

Figure 7. Integration of social, economic, and environmental dimensions in biomass utilization for sustainable development, adopted from Kobayashi and Nakajima (2021).

3.7 Challenges and Opportunities in Biomass Utilization

The use of biomass as a renewable resource plays a crucial role in supporting the transition to a sustainable energy system and a low-carbon economy. However, despite its great potential, the implementation and optimization of biomass still face various multidimensional challenges, both in terms of technical, economic, social, and environmental aspects.

On the other hand, the global dynamics towards decarbonization, circularity, and symbiosis with nature also open up space for innovation and strategic opportunities to make biomass an integral part of 21st-century sustainability solutions. One of the main obstacles to the use of biomass is the limited availability of efficient, economical, and sustainable conversion technologies. Processes such as pyrolysis, gasification, anaerobic fermentation, and biorefinery technology still require further development to produce output with high efficiency and low emissions. In addition, variations in the composition of biomass raw materials (e.g., water content, lignocellulose, or nutrient content) often require specific technology adjustments, which can increase operational costs and engineering complexity.

From an economic perspective, key challenges include high initial costs, dependence on government incentives, and the lack of a stable commercial market for biomass products such as biofuels, bioplastics, or organic fertilizers. Uncertainty in the biomass raw material supply chain (both in terms of quantity and continuity) is a serious obstacle, especially in areas that do not yet have adequate organic waste collection and logistics systems. This is exacerbated by the suboptimal infrastructure for storage, transportation, and distribution of biomass products, which has the potential to hinder production scale and market penetration.

Social and environmental aspects also cannot be ignored. Large-scale use of biomass, especially from energy crops, has the potential to trigger land use conflicts with the agricultural and food sectors, cause forest conversion, and threaten biodiversity. On the social side, unequal access to technology and capital—especially in developing countries—creates a gap in biomass utilization capacity, both for household energy needs and on an industrial scale.

Despite facing many challenges, opportunities for biomass development are increasingly wide open. Technological advances have enabled the diversification of biomass-based products into bioenergy, bioplastics, organic composites, green building materials, and even pharmaceutical and cosmetic ingredients. The concept of a biorefinery (which mimics the oil refinery system to process biological materials into various end products) allows for the comprehensive and integrative optimization of biomass waste. In addition, advances in biotechnology and nanotechnology open up new prospects for significantly improving the quality and performance of biomass products.

In the context of a circular economy, biomass plays an important role in changing the paradigm of waste into a resource. Utilization of agricultural waste, food waste, and forestry residues can support the reduction of GHG emissions, strengthen energy security, and create new jobs in the green sector. Integration of biomass into national energy policies and global decarbonization strategies also encourages opportunities for financing innovation through green incentive schemes, energy transition funding, and public-private partnerships that support sustainable projects.

The right policies and regulatory support are important catalysts in strengthening the position of biomass in sustainable development. Opportunities lie in the harmonization of cross-sector regulations, the integration of biomass into energy and environmental policy frameworks, and strengthening the role of local governments and local communities in encouraging the use of biomass. Public education, strengthening human resource capacity, and research collaboration between institutions are the foundations for encouraging an innovation ecosystem that supports the use of biomass inclusively and equitably.

Conclusion

The results of this systematic review confirm that biomass waste has great potential as a renewable resource to be converted into various value-added products, which not only support sustainable waste management but also contribute directly to the achievement of various SDGs. Bioenergy, such as biogas and bioethanol, support SDG 7 (Affordable and Clean Energy) and SDG 13 (Addressing Climate Change) by reducing dependence on fossil fuels and reducing carbon emissions. Bioplastics, biochar, and briquettes support SDG 12 (Responsible Consumption and Production) and SDG 15 (Ecosystems on Land) with the principles of circular economy and resource conservation. Meanwhile, biotechnology-based products such as biofertilizers and biopesticides contribute to SDG 2 (Zero Hunger), SDG 3 (Healthy Lives and Well-Being), and SDG 6 (Clean Water and Sanitation) because they encourage healthy, productive, and chemical-free agricultural practices. In the manufacturing and automotive sectors, biomass biocomposites contribute to SDG 9 (Industry, Innovation and Infrastructure) and support energy efficiency and emission reduction in the transportation industry.

All forms of biomass utilization have a common thread, namely supporting the transition to a low-carbon economy through reducing greenhouse gas emissions, substituting fossil fuels, and promoting resource efficiency. However, the broad implementation of this strategy still faces challenges from technical, policy, social, and sustainable supply chain aspects.

Therefore, an integrative cross-sectoral approach is needed that involves technological innovation, supportive regulations, multi-stakeholder collaboration, and community empowerment. Biomass must be positioned not only as a technical raw material but also as a catalyst for the transformation of economic, social, and environmental systems towards a greener, more resilient, and more inclusive direction.

The co-conversion cost, high biochar yield and no electrical power requirement. The study has been able to successfully achieve the co-conversion of biomass and plastics (as typologies of MSW major components valuable products with a twin goal of waste management and product development.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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