Synchronization of technological innovation and regulation in biomass utilization: A bibliometric-systematic study

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Abstract

Purpose: This study aims to synthesize global trends, key themes, and collaboration patterns in biomass energy studies, particularly those related to public policy and regulation. Particular focus is placed on the role of developing countries in this scientific discourse.
Design/methodology/approach: A Bibliometric-Systematic Literature Review (B-SLR) approach was used, analyzing 308 Scopus-indexed articles published between 2010 and 2025. The process involved metadata refining (using biblioMagika® and OpenRefine) and visual mapping (VOSviewer) to illustrate keyword networks, institutional collaborations, and thematic clustering.
Findings: There has been a significant surge in publications and citations related to biomass and energy policy. Dominant themes include sustainability, bioenergy, and energy governance. However, a fragmentation between technical and policy research, as well as an imbalance in contributions between developed and developing countries, was found.
Limitations and Research implications: This study only used data from one database (Scopus), and, therefore, may have missed relevant publications from other sources. Further studies are needed to measure the effectiveness of biomass policies in local contexts.
Practical Implications: These findings can inform policymakers' design of more inclusive and evidence-based biomass energy regulations and encourage collaboration across countries and disciplines.
Originality/value: This paper contributes original value by combining bibliometric methods and systematic reviews to uncover thematic and spatial gaps in the global biomass literature.
Keywords: Renewable Energy; Energy Policy; Bibliometrics; Systematic Review; Energy Transition.

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Introduction

The global transition to sustainable energy systems has prompted countries to reduce their dependence on fossil fuels and shift to cleaner, renewable energy sources (Holechek et al., 2022). Among the various options available, biomass stands out as a key contributor. In 2020, it was estimated that around 60% of total global renewable energy would come from biomass (Scarlat et al., 2015). However, in the ASEAN region, biomass's contribution to the energy mix remains below 2%, indicating a significant gap between potential and actual utilization (Abdul Malek et al., 2020).

Biomass sources such as agricultural and forestry waste are geographically unevenly distributed, creating logistical challenges and high operational costs. Furthermore, the efficiency of biomass-based electricity generation technologies remains relatively low, ranging from 10–25% for small-scale plants and a maximum of 45% for large-scale units without carbon capture technology (Scarlat et al., 2015). Therefore, to increase the adoption of

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biomass as an alternative energy source, synergy between technological advances and targeted policy support is needed (Owen et al., 2013).

Historically, biomass energy consumption, particularly wood, has played a significant role in the electricity and commercial sectors of various countries. Figure 1 illustrates the fluctuating trend in wood energy consumption from 1973 to 2008, reflecting the reliance on traditional energy sources before the global integration of low-carbon energy policies. Meanwhile, Figure 2 presents the diverse forms of biomass feedstock globally, ranging from agricultural waste to forestry industrial residues, reflecting the significant potential of this resource to support renewable energy diversification.

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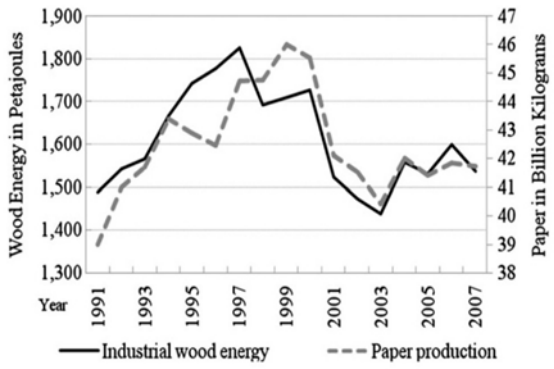

Figure 1
Wood Energy Consumption by Electricity and Commercial Sectors 1973-2008 (Aguilar et al., 2011)

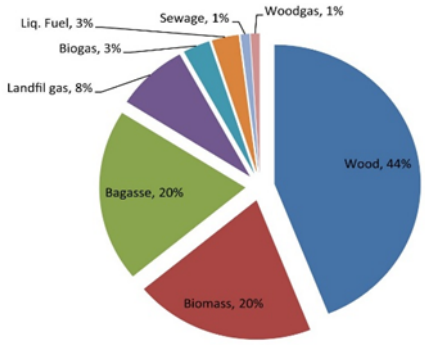

Figure 2
Forms of World Biomass Raw Materials (Abdul Malek et al., 2020)

Over the past two decades, biomass-related research has grown rapidly, particularly in the fields of energy conversion, bioengineering, and thermal processing technologies. However, regulatory and public policy aspects have received little systematic attention in academic studies (Clauser et al., 2021). Findings from bibliometric analysis indicate a lack of integration between topics such as "biomass," "public policy," and "energy governance," indicating conceptual and empirical gaps in the literature (Bisht & Thakur, 2019). Developing countries like Indonesia, which boasts a biomass potential of up to 50 GW, have been recorded as contributing only minimally to global scientific publications (Singh & Setiawan, 2013). In addition to research factors, a lack of regulatory coordination and weak institutional support also hinder optimal biomass development (Falcone, 2023).

Based on this review, the main issue raised in this research is the weak integration between biomass technology innovation and public policy, particularly in developing countries that have significant potential but lack adequate governance and institutional support. This research aims to examine in depth the relationship between technological innovation and public policy in the context of biomass utilization as an alternative energy source, as well as to map the dynamics of global scientific collaboration relevant to this issue.

Theoretically, this research enriches interdisciplinary understanding of the link between technological innovation and energy policy within a sustainability framework. Practically, this study is expected to provide evidence-based recommendations for policymakers, renewable energy practitioners, and research institutions in developing countries to promote more structured and inclusive biomass development.

This paper is organized into five main sections: Introduction, Literature Review, Research Methodology, Results and Discussion, and Conclusions and Implications.

Literature Review

Biomass in the Global Energy Transition

The transition to a low-carbon energy system has driven increased global interest in renewable energy, in which biomass plays a strategic role. Biomass is not only considered a sustainable energy source but also flexible and can support energy security in various regions (Scarlat et al., 2015) noted that by 2020, biomass contributed approximately 60% of the world's total renewable energy. However, the level of biomass utilization and integration into national energy systems is highly dependent on the technological readiness and policy frameworks implemented by each country. In many developing countries, including Indonesia, biomass utilization does not yet reflect its vast resource potential. It tends to lag behind developed countries that have developed adequate infrastructure, research, and supporting policies.

Technological Innovation in Biomass

From a technological perspective, the literature shows significant advances in biomass conversion techniques, including the development of lignocellulose pretreatment, thermophilic fermentation technologies, and integration with hybrid energy systems. Several studies highlight improvements in biofuel production efficiency through the use of ionic liquids and genetically engineered microorganisms (Alazi & Ram, 2018; Woźniak et al., 2025). However, the efficiency of biomass-based power generation systems remains relatively low, particularly at small scales, ranging from 10–25%, and can reach 45% on large scales without carbon capture technology. This underscores the importance of technological innovation to overcome technical barriers to widespread biomass utilization. Furthermore, the successful adoption of this technology is largely determined by policy support that bridges the gap between research and field implementation.

Policies and Regulations in Biomass Energy Development

Policies and regulations play a crucial role in determining the direction and sustainability of biomass development. Countries such as the United States and members of the European Union have adopted policies supporting biomass development through fiscal incentive mechanisms, feed-in tariffs, sustainability certification schemes, and R&D support (Aguilar et al., 2011). Conversely, developing countries face challenges in institutional coordination, minimal investment incentives, and weak implementation of consistent energy policies (Falcone, 2023). In Indonesia, for example, despite its significant biomass potential, policies such as Presidential Regulation No. 5 of 2006 have yet to significantly impact increasing the use of biomass energy in the national energy mix.

To further enrich the contextual understanding, this study elaborates on Indonesia's regulatory and governance experience in the biomass sector. Although Indonesia possesses an estimated 50 GW of biomass potential, actual contributions to the national energy mix remain limited due to fragmented policies, inconsistent incentives, and weak inter-agency coordination. Presidential Regulation No. 5/2006, while an early milestone, has not been supported by consistent downstream implementation. At the regional level, the ASEAN Plan of Action for Energy Cooperation (APAEC) also identifies bioenergy as a strategic focus, yet progress has been hampered by policy harmonization gaps and varying national priorities. These cases illustrate the complex landscape of energy governance in Southeast Asia, emphasizing the importance of adaptive, locally grounded, and collaborative regulatory mechanisms to synchronize technological development with policy frameworks.

Global Scientific Contribution Inequality

The disparity in scientific contributions between countries is also a concern in the literature. A bibliometric analysis using biblioMagika® created by Ahmi (2024) shows that scientific publications on biomass and energy policy are still dominated by Global North countries such as China, the United States, and European countries. Meanwhile, developing countries with

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significant biomass potential, such as Indonesia, India, and other ASEAN countries, still contribute very little to the global literature. This disparity is caused by limited research funding, weak institutional capacity, and limited access to international research collaboration (Mensah & Yankson, 2025). As a result, many energy policies in developing countries are not based on local scientific evidence, but instead follow global policy trends without adequately considering the domestic context.

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Thematic Fragmentation and the Technology-Policy Co-Evolution Framework

One important finding in the literature review is the thematic fragmentation between technology and policy aspects. Co-occurrence analysis in several bibliometric studies reveals that the keyword "biomass" is not closely associated with keywords such as "public policy" or "regulation" (Bisht & Thakur, 2019). This reflects that scientific approaches to biomass technology are often not integrated with policy studies, which should be the foundation for energy technology planning and adoption at the national level. As a result, technical recommendations resulting from research are not always relevant to the prevailing policy realities, often leading to stagnant implementation on the ground.

This thematic disconnect can be further conceptualized using the Technology–Policy Co-Evolution framework, which posits that technological innovation and public policy evolve through reciprocal influence (McLaren & Markusson, 2020). Specifically, the model identifies three core mechanisms: (1) regulatory responses to technological progress (Freij, 2022), (2) policy-driven incentives that shape technological pathways (Breisinger et al., 2023), and (3) institutional learning derived from success and failure in implementation (Dana et al., 2021). In developing countries, this co-evolution is often imbalanced due to weak institutions and limited regulatory adaptability. By introducing this framework, the present study aims to bridge the thematic gap identified in bibliometric findings and propose more synchronized development strategies between technical and policy dimensions.

In this context, a significant research gap emerges. While numerous studies address biomass technology or energy policy separately, very few comprehensively examine the interrelationship between the two, particularly in the context of developing countries. The lack of interdisciplinary approaches that bridge the technical and policy dimensions creates ample scope for new scholarly contributions. Therefore, this study emphasizes the need for studies that not only review publication trends or technological developments but also integrate it with regulatory dynamics, institutions, and evidence-based implementation strategies.

By using a combined Bibliometric-Systematic Literature Review (B-SLR) approach, this study is expected to be able to fill this gap by presenting a comprehensive literature mapping, identifying knowledge gaps, and providing new directions for the development of more integrated, inclusive, and contextual biomass energy policies.

Methodology

This study applies a B-SLR approach to gain a comprehensive understanding of the interaction between technological innovation and policy in the utilization of biomass as an alternative energy source. This approach was chosen because it integrates the strengths of quantitative bibliometric analysis with a qualitative synthesis of selected literature (Marzi et al., 2025; Snyder, 2019), so it is relevant to answer the research objectives, which focus on mapping the relationship between the dimensions of technology and public policy.

Specifically, the B-SLR approach in this study was carried out in two main stages. First, quantitative bibliometric analysis was performed using tools such as VOSviewer and biblioMagika® to explore keyword co-occurrence, co-citation networks, and bibliographic

coupling, thereby identifying publication trends, thematic clusters, and collaboration patterns. Second, a qualitative systematic review was conducted to interpret the core content of selected papers based on thematic relevance, enabling deeper conceptual synthesis between technological innovation and public policy in biomass energy. This dual-track process was guided by the 10-step B-SLR framework proposed by (Marzi et al., 2025), ensuring methodological rigor from data retrieval to theoretical insight.

The data source was obtained from the Scopus database, which was selected for its broad multidisciplinary coverage and credibility as a reputable journal index (Singh et al., 2021). The literature search process was conducted by constructing Boolean queries combining keywords such as *"biomass"*, *"wood pellets"*, *"renewable energy"*, *"technology"*, and *"policy/regulation"*. Inclusion criteria included English-language scientific articles published between 2010 and 2025, focusing on public policy, regulation, or technological innovation related to biomass. Articles that only discussed technical aspects without policy relevance, as well as non-scientific documents such as editorials and letters to the editor, were excluded from the dataset. As part of the Bibliometric-Systematic Literature Review (B-SLR) approach, this study compiles basic bibliometric metrics as presented in Table 1, showing a total of 308 selected publications between 2010 and 2025, with 8,267 total citations, an h-index of 50, and an average of 26.84 citations per article, indicating the strong scholarly relevance of this topic. Table 2 complements this by providing more detailed citation performance, revealing that the majority of documents fall within the h-core, reflecting a high and consistent level of academic influence in this field. Table 3 displays the interdisciplinary spread of the selected studies, with Environmental Science (46.10%) and Energy (42.21%) as the dominant fields, followed by contributions from Agricultural Sciences, Chemistry, Molecular Biology, and Social Sciences, further justifying the need for a cross-sectoral methodological perspective.

Table 1
Basic Information

Start Year	2010
End of Year	2025
Total Publications	308
Number of Contributing Authors	308
Number of Cited Papers	274
Total Citations	8,267
Citation per Paper	26.84
Citation per Author	26.84
Citation sum within h-Core	7,673
Citable Year	16
h-index	50
g-index	78

Source: Generated by the author using biblioMagika ® (Ahmi, 2024)

Table 2
Citation Information

Number of Cited Papers	274
Total Citations	8,267
Citation per Paper	26.84
Citation per Cited Paper	26.84
Citations per Year	0.00
Citation per Author	7673.00
Author per Paper	0.00
Citation sum within h-Core	16
h-index	78
g-index	0
m-index	0,000

Source: Generated by the author using biblioMagika ® (Ahmi, 2024)

Table 3
Subject Area

Subject Area	TP	%
Environmental Science	142	46.10%
Energy	130	42.21%
Agricultural and Biological Sciences	87	28.25%
Engineering	54	17.53%
Chemical Engineering	38	12.34%
Biochemistry, Genetics, and Molecular Biology	28	9.09%
Social Sciences	27	8.77%
Chemistry	21	6.82%
Mathematics	21	6.82%
Immunology and Microbiology	16	5.19%
Economics, Econometrics, and Finance	15	4.87%
Materials Science	15	4.87%
Multidisciplinary	10	3.25%
Computer Science	9	2.92%
Business, Management, and Accounting	8	2.60%
Earth and Planetary Sciences	8	2.60%
Veterinary	7	2.27%
Medicine	6	1.95%
Physics and Astronomy	5	1.62%
Decision Sciences	2	0.65%
Pharmacology, Toxicology, and Pharmaceutics	1	0.32%

Source: Generated by the author using biblioMagika® (Ahmi, 2024)

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Temporally, Figure 3 illustrates a significant rise in publication and citation counts beginning in 2017, with a peak in 2025, indicating growing global attention to the issue of biomass and its energy-related policy dimensions. Meanwhile, Figure 4 reveals the predominance of multi-author publications, suggesting strong tendencies toward collaborative research. This supports the study's emphasis on scientific network mapping and confirms the relevance of co-authorship analysis in understanding the dynamics of knowledge production in this area.

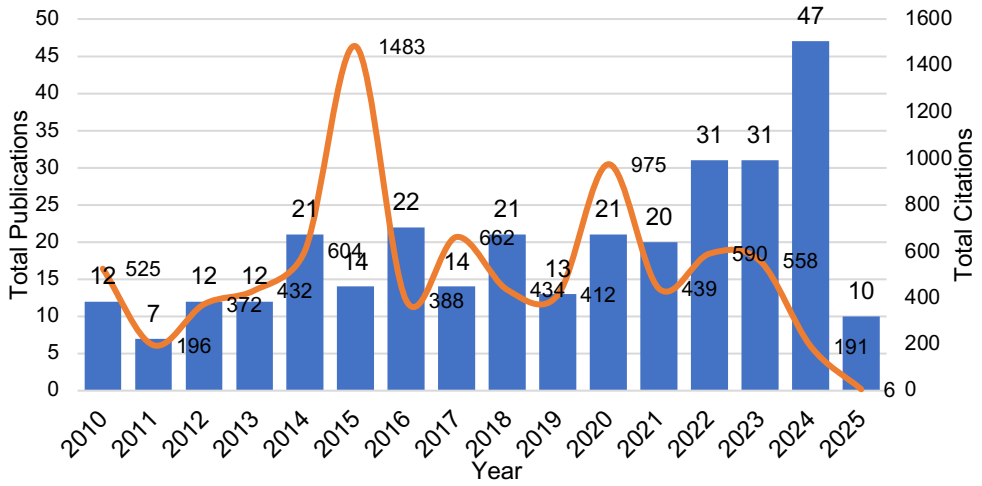

Figure 3
Graph of Total Publications and Citations by Year
Source: Generated by the author using biblioMagika ® (Ahmi, 2024)

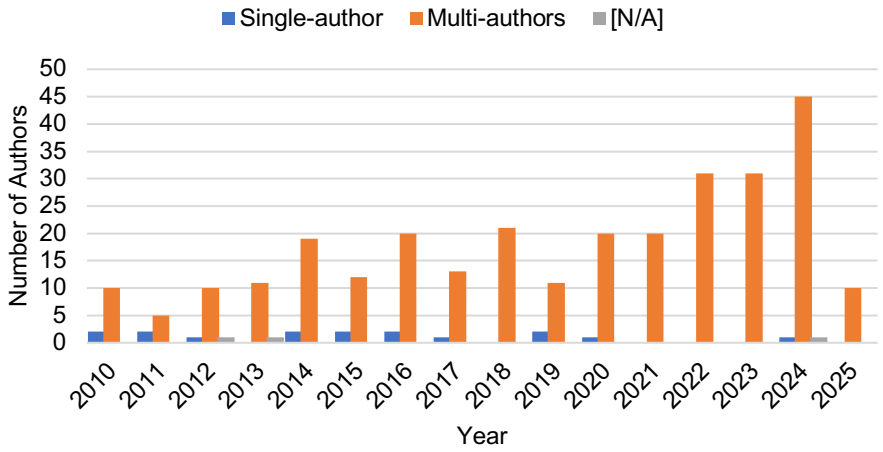

Figure 4
Single Author vs. Multi-Author Graph
Source: Generated by the author using biblioMagika ® (Ahmi, 2024)

This process resulted in 308 publications, which were then filtered using OpenRefine software for data cleaning and biblioMagika® for metadata management. Bibliometric analysis was performed using VOSviewer (Bukar et al., 2023) and biblioMagika® (Ahmi, 2024), with three main approaches: co-citation analysis to see the relationship between reference sources, co-occurrence analysis to map keyword associations, and bibliographic coupling to identify relationships based on shared references between documents. Scopus database and the use of analysis software are widely used in cross-disciplinary bibliometric studies (Donthu et al., 2021). Coherence between objectives and methods was achieved through an explicit focus on mapping the relationship between technology and policy, reflected in the structure of the thematic analysis and data visualization.

Results and Discussion

Thematic Mapping dan Keywords in the Literature

Bibliometric results from 308 publications between 2010 and 2025 show a significant increase in research on biomass as an alternative energy source. Total citations reached 8,267, with an average of 26.84 citations per article and an h-index of 50, reflecting the high scientific quality and influence in this field (Ahmi, 2024). The publication trend consistently increased, with the highest spike occurring in 2025. However, 2016 and 2020 recorded the highest number of citations, indicating the presence of important publications that serve as primary references. Cumulative quadratic regression showed exponential growth with a coefficient of determination (R^2) of 0.9956 (Figure 5), indicating that the theme of biomass and energy policy is increasingly becoming a center of attention in the global scientific community (Perea-Moreno et al., 2019; Mather-Gratton et al., 2021).

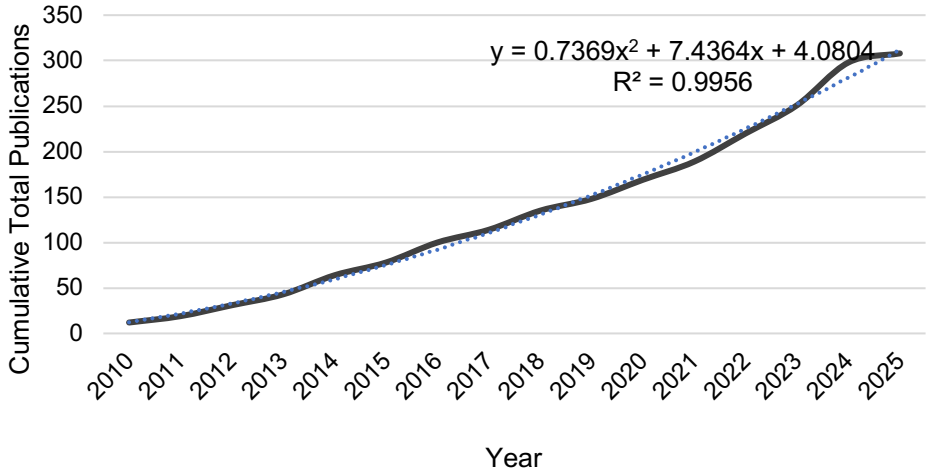

Figure 5
Cumulative Total Publications by Year
Source: Generated by the author using biblioMagika ® (Ahmi, 2024)

Keyword analysis (Figure 6) shows that “biomass” is the most commonly used term by authors (52 documents), followed by “bioenergy” (29 documents) and “policy” (24 documents). In the keyword index (Figure 7), the term “biomass” appears 321 times, followed by “energy policy” (69) and “forestry” (43) (Ahmi, 2024). The presence of words such as “sustainability,” “carbon,” and “biofuel,” which are quite dominant, reflects the strong integration between the environmental and energy dimensions in the literature. The difference between the authors’ keywords and the index indicates the existence of thematic classification dynamics that emphasize the importance of a multidisciplinary approach in understanding biomass utilization. Figure 6 presents the distribution of the fifteen most frequently used author keywords in biomass studies. The terms "biomass," "bioenergy," and "policy" dominate, reflecting the literature's primary focus on resource aspects, energy conversion, and regulatory frameworks. This visualization emphasizes the importance technology and policy dimensions as two main poles in the scientific discourse related to biomass. Meanwhile, Figure 7 shows the most frequently appearing index keywords in the database, with "biomass," "energy policy," and "forestry" as the dominant terms. Unlike author keywords, this distribution reflects a systematic classification of publisher metadata, highlighting policy, sustainability, and the forestry sector within the biomass research landscape. The difference with Figure 6 suggests a perceived duality between researchers' orientation and the formal categorization system.

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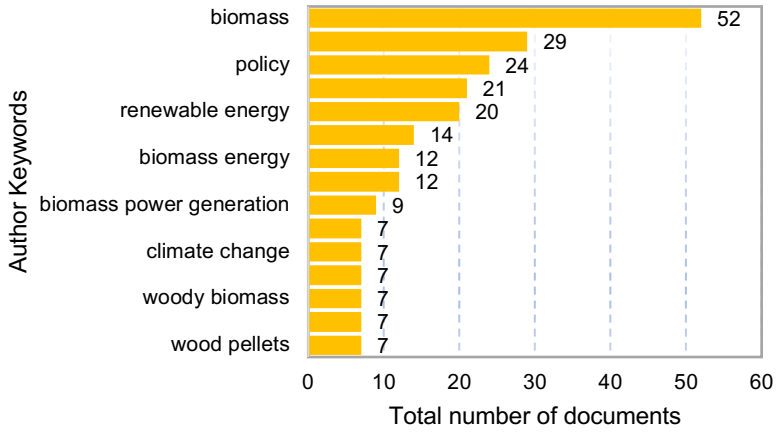

Figure 6

Frequency Distribution of the Top Fifteen Author Keywords

Source: Generated by the author using biblioMagika ® (Ahmi, 2024)

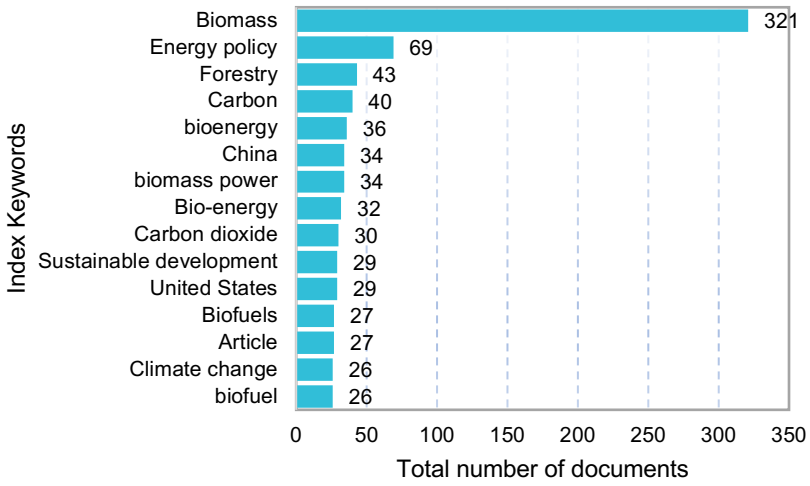

Figure 7

Frequency Distribution of the Top Fifteen Index Keywords

Source: Generated by the author using biblioMagika ® (Ahmi, 2024)

Co-occurrence analysis grouped the topics into two main clusters (Figure 8). The first cluster (Blue) focused on conversion technologies and materials, with topics such as biomass *pretreatment* using ionic liquids, which can significantly improve methane production efficiency (Woźniak et al., 2025). This approach also involves genetic manipulation of lignocellulosic enzymes, such as Clr-1/2 and XlnR, as well as the use of microorganisms such as Mortierella isabellina, which is capable of producing lipids up to 6.81 ± 0.07 g/L (Alazi & Ram, 2018; Zeng et al., 2013).

The second cluster (Red) covers the policy and economic dimensions of bioenergy, including the successful example of the BCAP program in the US, which offers incentives of up to USD 49.60 per ton and long-term financing for 15 years (Aguilar et al., 2011). These clusters show a distinction between technology-related keywords and governance-related terms. Figure 8 visualizes a co-occurrence map that groups topics into two main clusters. The blue cluster contains keywords related to biomass conversion and processing technologies, while the red cluster reflects a focus on bioenergy policy and economics. This visual separation indicates a

conceptual fragmentation between the technical and governance dimensions in the global biomass literature.

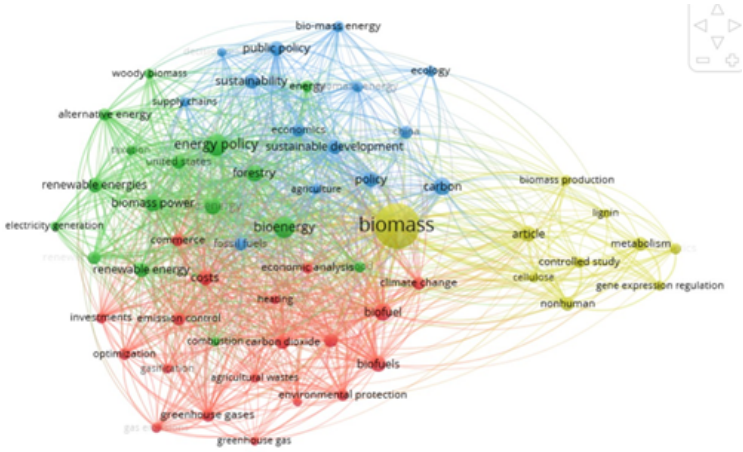

Figure 8
Bibliometric Co-occurrence Analysis
Source: Generated by the author using VOSviewer

Global Contributions and Structure of the Literature

This thematic separation can be interpreted as an indication of weak synergy between research on technological innovation and studies related to policy and governance. Such fragmentation reflects a broader issue in developing countries where scientific advancements are often not well-integrated with policy design. The disconnection suggests a need for interdisciplinary frameworks and cross-sectoral collaboration to bridge the gap. By reflecting on this finding, the study underscores the importance of embedding policy considerations early in technological development and ensuring that regulatory systems adapt dynamically to emerging innovations. The distribution of publications by country shows dominance by China with 116 publications (37.66%), followed by the United States (66 publications or 21.43%), and Italy (5.52%) (Table 4).

Table 4
Top Ten Publications by Country

Country	Continent	TP	%
China	Asia	116	37.66%
United States	North America	66	21.43%
Italy	Europe	17	5.52%
Canada	North America	15	4.87%
Germany	Europe	15	4.87%
Australia	Oceania	13	4.22%
United Kingdom	Europe	13	4.22%
Netherlands	Europe	12	3.90%
Japan	Asia	11	3.57%
Sweden	Europe	11	3.57%

Source: Generated by the author using biblioMagika ® (Ahmi, 2024)

Several other Asian countries, such as Japan and India, have also demonstrated active participation in biomass research (Figure 9). Meanwhile, Indonesia is not yet among the top ten contributing countries, despite its enormous biomass potential—approximately 50 GW, including 15.45 million m^3 of forest waste, 144.5 million tons of agricultural residues, and 11,330 tons of municipal waste per day (Singh & Setiawan, 2013). This indicates a disparity between the availability of natural resources and the capacity to produce scientific knowledge that can be utilized to support the development of the biomass sector. Figure 9 shows the distribution of biomass-related scientific publications by country of origin, with China and the

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United States strongly dominating. While Asian countries such as Japan and India are starting to show activity, Indonesia is not yet among the top ten, despite its significant biomass potential. This disparity reflects the gap between resource capacity and scientific contributions, which needs to be bridged through a more focused national research strategy.

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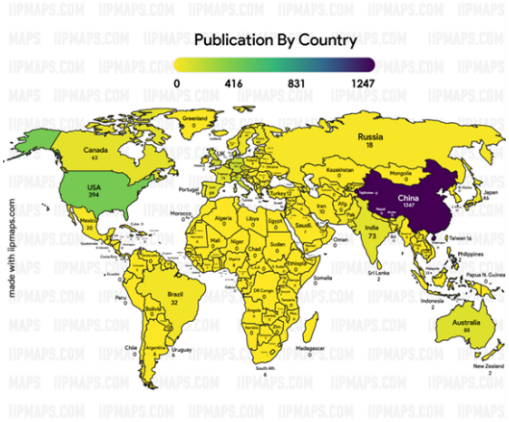

Figure 9
Publications by Country
Source: Generated by the author using biblioMagika ® (Ahmi, 2024)

Conceptual Synthesis and Knowledge Inequality

Co-citation analysis confirms that the journals Energy Policy, Renewable and Sustainable Energy Reviews, and Biomass and Bioenergy are the main sources of references in this field (Figure 10), with 258, 174, and 221 citations, respectively, and a link strength of over 3,900 for each journal (Table 5) (Ahmi, 2024). Figure 10 depicts the co-citation structure in the biomass literature, with journals such as Energy Policy, Renewable and Sustainable Energy Reviews, and Biomass and Bioenergy occupying central positions. These three journals form strong nodes in the reference network, indicating their dominant influence on the direction of scientific development in the field of biomass energy. This visualization reveals authoritative sources that serve as the main conceptual foundation for subsequent studies. Bibliographic coupling analysis also shows that articles with high citation rates form a strong conceptual network and serve as an important foundation for the development of further studies (Table 6). Figure 11 displays a bibliographic coupling network connecting articles with similar references. This visualization reveals interconnected conceptual clusters, where publications with high citation rates form a strong theoretical foundation in biomass studies. This finding indicates a stable intellectual structure that can serve as a strategic reference for further research development.

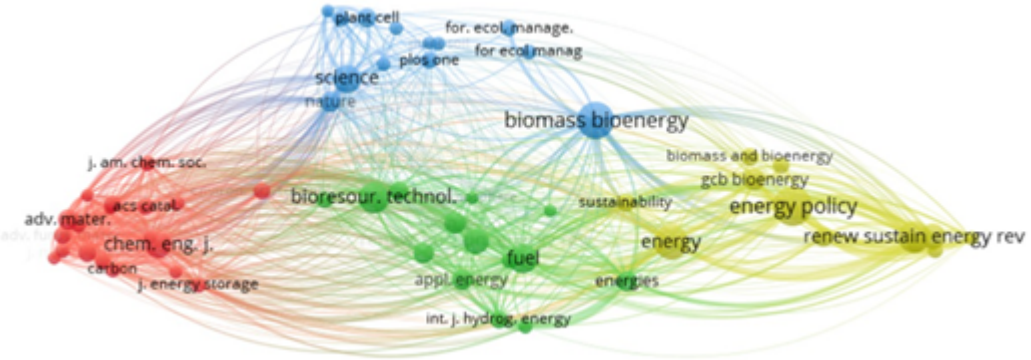

Figure 10
Co-Citation Bibliometric Analysis
Source: Generated by the author using VOSviewer

Figure 11
Bibliometric Analysis of Bibliographic Coupling
Source: Generated by the author using VOSviewer

Table 5
Top Ten Number of Citations and Link Strength in Co-Citations

Source (Journal)	No. of Citations	Total Strength Link
Energy Policy	258	5828
Renew Sustain Energy Rev	174	5530
Energy	200	4836
Chem. Eng. J.	116	4170
Biomass Bioenergy	221	3984
Adv. Mater.	70	3431
Fuel	142	3369
Bioresour. Technol.	153	3170
Apple Energy	106	3031
Science	128	2773

Source: Generated by the author using VOSviewer

Table 6
Top Ten Number of Citations and Link Strength in Bibliographic Merging

Document	No. of Citations	Total Link Strength
Feng (2015)	675	3
Villeneuve (2015)	409	2
Uslu (2017)	256	9
San Miguel (2010)	204	11
Alexopoulou (2017)	199	1
Marchetti (2023)	169	0
Money (2015)	148	0
Esteves (2020)	135	0
Furbank (2020)	124	1
Arentsen (2019)	116	0

Source: Generated by the author using VOSviewer

Conceptually, these findings emphasize that technological advancements in biomass processing need to be accompanied by a clear and sustainable regulatory framework (Lewandowski, 2015). Studies in developed countries show that a combination of policies, such as feed-in tariffs, sustainability certification schemes, and fiscal incentives, can significantly encourage biomass development (Singh et al., 2021). Conversely, in Indonesia, the implementation of regulations such as Presidential Regulation No. 5 of 2006 and the establishment of institutions such as the Directorate of New, Renewable Energy and Energy Conservation (EBTKE) have not had a significant impact on biomass penetration (Singh & Setiawan, 2013). Poor coordination between agencies and limited funding are serious obstacles that need to be addressed immediately.

The importance of collaboration between various actors—government, academia, industry, and civil society—is key to creating a sustainable biomass ecosystem (Trencher et al., 2013). Integration of technology and policies tailored to local contexts is essential for biomass utilization to address the challenges of the energy transition and open up opportunities in a competitive global energy market (Araújo, 2014).

The results of the bibliometric analysis show that research on biomass as an alternative energy has increased significantly during the period 2010–2025. A total of 308 relevant scientific documents were identified in the Scopus database, with a total of 8,267 citations and an h-index value of 50. The publication growth trend shows a very strong quadratic pattern with an R^2 value of 0.9956, which indicates a surge in academic interest in this topic, especially in the context of energy sustainability and the transition to a low-carbon economy.

Keyword distribution analysis revealed that the most dominant themes were related to biomass energy, biofuel, sustainability, and renewable energy policy. Co-occurrence analysis grouped these themes into two large clusters: the first cluster related to conversion technology and bioengineering, while the second cluster focused on energy policy, governance, and

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sustainability. However, the relationship between these two clusters remains structurally weak, indicating a fragmentation in the literature between technology and public policy issues.

This finding is reinforced by co-citation and bibliographic coupling, which demonstrate that technical studies often develop in a separate disciplinary domain from policy studies. This demonstrates that the integration of technical and energy governance dimensions remains an underexplored conceptual gap, particularly in the context of developing countries.

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Implications of the Study and Policy Recommendations

Germany has succeeded in developing its bioenergy sector through long-term policies such as the Feed-in Tariff (FiT) that provide investment certainty and align technology development with national sustainability targets. Meanwhile, South Korea is building a solid biomass innovation ecosystem through integration between government agencies, research institutions, and the industrial sector. These two examples show how strategic alignment between regulation and technology can accelerate biomass adoption. This experience also provides lessons that can be adapted to the Indonesian context, especially in terms of long-term policy planning and strengthening institutional coordination.

The international collaboration map shows that scientific contributions to this topic are still dominated by Global North countries, such as China, the United States, and Western European countries. Meanwhile, Global South countries, including Indonesia, show relatively small contributions, despite their significant biomass potential. The lack of research capacity, policy support, and international collaboration networks is major obstacle to improving the position of developing countries in the global scientific landscape. This imbalance underscores the need for more inclusive and contextual research and policy strategies.

While it was initially assumed that the literature on biomass technology and public policy would be closely interconnected, bibliometric results show that these two themes develop in relatively separate clusters. Keyword co-occurrence patterns indicate a weak integration between technical and policy disciplines in biomass studies, particularly in developing country contexts. This mismatch can be explained by the dominance of technocratic approaches in energy research and the lack of collaboration between technical researchers and policymakers. This also underscores the importance of an interdisciplinary approach capable of bridging technological solutions and institutional realities.

This finding is in line with criticism in previous literature, which emphasizes the limited integrative research between the technology and energy governance dimensions (Donthu et al., 2021; Snyder, 2019). As emphasized by Jain et al. (2022), systematic review-based studies must be able to not only map trends but also identify conceptual structures and knowledge gaps. Thus, this study not only reinforces previous findings regarding the dominance of developed countries in knowledge production but also contributes to broadening the theoretical understanding of thematic fragmentation in global biomass research.

Theoretically, this research contributes to enriching the understanding of the relationship between technological innovation and policy structures in the renewable energy transition, particularly in the context of developing countries. Practically, the resulting international collaboration map and thematic findings can be used by policymakers to design evidence-based national strategies and encourage cross-border research partnerships. The resulting policy implications also emphasize the importance of synergy between the research, private, and government sectors in creating a sustainable and contextual biomass development ecosystem.

While this analysis presents a comprehensive mapping of the biomass literature from both bibliometric and systematic perspectives, several limitations warrant consideration. First, the data used were sourced from only one major database, Scopus, thus leaving out important

literature that might be indexed in other databases such as Web of Science or Dimensions. Second, the English-language selection criteria indirectly excluded potential local-language contributions from developing countries (Turba et al., 2025). This can lead to representational bias in assessing global scientific capacity. Third, the bibliometric approach is quantitative and descriptive, so deeper conceptual linkages or practical implications still require qualitative exploration or complementary field studies (Snyder, 2019; Donthu et al., 2021). Therefore, further research is recommended to expand the data coverage across languages and databases, and combine bibliometric approaches with policy content analysis or national case studies to enrich the interpretation of findings and address the complexities of the relationship between technology, regulation, and sustainable development.

One important limitation lies in the exclusion of non-English language publications, which may inadvertently marginalize relevant knowledge from developing countries. While the use of English-language sources enhances international accessibility and consistency, it potentially overlooks locally grounded insights, especially in countries like Indonesia, India, or many African nations, where valuable case studies and policy documents are often published in national languages and are not indexed in international databases. This introduces a systematic bias in global scientific mapping and may reinforce the knowledge divide between the Global North and Global South. Future research is encouraged to expand the scope to include multilingual databases and to collaborate with local scholars to create a more balanced and context-sensitive synthesis.

Building on the preceding synthesis and international examples, Table 7 outlines practical policy recommendations aimed at strengthening the integration between technology and regulation in biomass development, particularly in the Indonesian context.

Table 7
Policy Recommendations for Synchronizing Technology and Regulation in Biomass Energy Development

Strategic Area	Key Findings	Policy Recommendations
1. Technology–Policy Integration	Thematic fragmentation between technological and policy research	Establish interdisciplinary platforms linking ministries, universities, and industry to coordinate planning (Fonseca et al., 2021; Nawaz & Koç, 2020; Rådberg & Löfsten, 2024).
2. Investment and Incentives	Limited investment in biomass technologies due to policy uncertainty	Implement long-term support schemes such as Feed-in Tariffs and tax incentives for biomass projects (Milad Mousavian et al., 2020; Banja et al., 2019; Ndiritu & Engola, 2020).
3. Institutional Coordination	Lack of coordination between policymaking and implementation bodies	Create a national biomass coordination agency with cross-sectoral responsibilities (Ndlovu, 2025; Bößner et al., 2020).
4. Adaptive Regulatory Frameworks	Regulations are not responsive to technological advancements	Regularly update regulations based on input from technology developers and policy impact assessments (Yu & Wang, 2021; De Almeida et al., 2021).
5. Regional Collaboration	Weak harmonization of bioenergy policies across ASEAN countries	Initiate regional cooperation mechanisms for standardization, joint research, and sustainable financing (Larsen, 2022).
6. Local Inclusion and Publications	Knowledge gaps due to the exclusion of non-English/local-language publications	Encourage collaboration with local researchers and use multilingual databases in policy studies (Duarte et al., 2023).

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Conclusion

This study demonstrates that the literature on biomass as an alternative energy source has grown significantly over the past decade, with a thematic focus on sustainability, conversion technologies, and energy policy. Bibliometric and systematic findings indicate an imbalance in contributions between developed and developing countries, as well as a fragmentation between technological development and regulatory frameworks. This study contributes to strengthening theoretical understanding of the relationship between technological innovation and energy governance in the context of developing countries. Practically, these results provide a basis for more evidence-based and collaborative policy formulation, particularly in the renewable energy sector. However, this study is limited in its data coverage, which only uses Scopus databases and English-language publications, which may affect the generalizability of the findings. Further research is recommended to expand data sources, explore national case-based policy studies, and combine bibliometrics with qualitative analysis to better understand the dynamics of biomass energy policy implementation.

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Reference

Abdul Malek, A. B. M., Hasanuzzaman, M., & Rahim, N. A. (2020). Prospects, progress, challenges and policies for clean power generation from biomass resources. *Clean Technologies and Environmental Policy*, *22*(6), 1229–1253. https://doi.org/10.1007/s10098-020-01873-4

Aguilar, F. X., Song, N., & Shifley, S. (2011). Review of consumption trends and public policies promoting woody biomass as an energy feedstock in the U.S. *Biomass and Bioenergy*, *35*(8), 3708–3718. https://doi.org/10.1016/j.biombioe.2011.05.029

Ahmi, A. (2024). Bibliometric Analysis using biblioMagika®. In *Bibliometric Analysis usingbiblioMagika®*.

Alazi, E., & Ram, A. F. J. (2018). Modulating Transcriptional Regulation of Plant Biomass Degrading Enzyme Networks for Rational Design of Industrial Fungal Strains. *Frontiers in Bioengineering and Biotechnology*, *6*, 133. https://doi.org/10.3389/fbioe.2018.00133

Araújo, K. (2014). The emerging field of energy transitions: Progress, challenges, and opportunities. *Energy Research & Social Science*, *1*, 112–121. https://doi.org/10.1016/j.erss.2014.03.002

Bisht, A. S., & Thakur, N. S. (2019). Small scale biomass gasification plants for electricity generation in India: Resources, installation, technical aspects, sustainability criteria & policy. *Renewable Energy Focus*, *28*, 112–126. https://doi.org/10.1016/j.ref.2018.12.004

Breisinger, C., Keenan, M., & Mbuthia, J. (2023). *A Way Forward: Policy-Driven Transformation*. https://doi.org/10.2499/9780896294561_19

Bukar, U. A., Sayeed, M. S., Razak, S. F. A., Yogarayan, S., Amodu, O. A., & Mahmood, R. A. R. (2023). A method for analyzing text using VOSviewer. *MethodsX*, *11*, 102339. https://doi.org/10.1016/j.mex.2023.102339

Clauser, N. M., González, G., Mendieta, C. M., Kruyeniski, J., Area, M. C., & Vallejos, M. E. (2021). Biomass Waste as Sustainable Raw Material for Energy and Fuels. *Sustainability*, *13*(2), 794. https://doi.org/10.3390/su13020794

Dana, L.-P., Gurău, C., Hoy, F., Ramadani, V., & Alexander, T. (2021). Success factors and challenges of grassroots innovations: Learning from failure. *Technological Forecasting and Social Change*, *164*, 119600. https://doi.org/10.1016/j.techfore.2019.03.009

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Duarte, J., García-Jimenez, E., McMonagle, S., Hansen, A., Gross, B., Szelei, N., & Pinho, A. S. (2023). Research priorities in the field of multilingualism and language education: A cross-national examination. *Journal of Multilingual and Multicultural Development*, *44*(1), 50–64. https://doi.org/10.1080/01434632.2020.1792475

Falcone, P. M. (2023). Sustainable Energy Policies in Developing Countries: A Review of Challenges and Opportunities. *Energies*, *16*(18), 6682. https://doi.org/10.3390/en16186682

Fonseca, L., Rodrigues, C., & Capelleras, J.-L. (2021). The organizational adaptation of universities to smart specialization: The emergence of strategic network interface units. *European Planning Studies*, *29*(8), 1514–1537. https://doi.org/10.1080/09654313.2020.1854188

Freij, Å. (2022). Regulatory change impact on technology and associated mitigation capabilities. *Technology Analysis & Strategic Management*, *34*(12), 1418–1431. https://doi.org/10.1080/09537325.2021.1963426

Holechek, J. L., Geli, H. M. E., Sawalhah, M. N., & Valdez, R. (2022). A Global Assessment: Can Renewable Energy Replace Fossil Fuels by 2050? *Sustainability*, *14*(8), 4792. https://doi.org/10.3390/su14084792

Jain, J., Walia, N., Singh, S., & Jain, E. (2022). Mapping the field of behavioural biases: A literature review using bibliometric analysis. *Management Review Quarterly*, *72*(3), 823–855. https://doi.org/10.1007/s11301-021-00215-y

Kim, S.-Y. (2019). Hybridized industrial ecosystems and the makings of a new developmental infrastructure in East Asia's green energy sector. *Review of International Political Economy*, *26*(1), 158–182. https://doi.org/10.1080/09692290.2018.1554540

Larsen, M. L. (2022). Driving Global Convergence in Green Financial Policies: China as Policy Pioneer and the EU as Standard Setter. *Global Policy*, *13*(3), 358–370. https://doi.org/10.1111/1758-5899.13105

Lewandowski, I. (2015). Securing a sustainable biomass supply in a growing bioeconomy. *Global Food Security*, *6*, 34–42. https://doi.org/10.1016/j.gfs.2015.10.001

Marzi, G., Balzano, M., Caputo, A., & Pellegrini, M. M. (2025). Guidelines for Bibliometric-Systematic Literature Reviews: 10 steps to combine analysis, synthesis and theory development. *International Journal of Management Reviews*, *27*(1), 81–103. https://doi.org/10.1111/ijmr.12381

McLaren, D., & Markusson, N. (2020). The co-evolution of technological promises, modelling, policies and climate change targets. *Nature Climate Change*, *10*(5), 392–397. https://doi.org/10.1038/s41558-020-0740-1

Mensah, P., & Yankson, E. (2025). Biomass energy as a catalyst for achieving global sustainability goals: Technological advancements and policy implications. *Academia Green Energy*, *2*(1). doi.org/10.20935/AcadEnergy7556

Milad Mousavian, H., Hamed Shakouri, G., Mashayekhi, A.-N., & Kazemi, A. (2020). Does the short-term boost of renewable energies guarantee their stable long-term growth? Assessment of the dynamics of feed-in tariff policy. *Renewable Energy*, *159*, 1252–1268. https://doi.org/10.1016/j.renene.2020.06.068

e-ISSN: XXXX-XXXX
DOI: 10.25299/ijbs.2025.22990

Ndlovu, N. P. (2025). Cross-sectoral coordination in the implementation of agroforestry in Malawi. *Frontiers in Forests and Global Change*, *8*. https://doi.org/10.3389/ffgc.2025.1533326

Owen, M., Der Plas, R. V., & Sepp, S. (2013). Can there be energy policy in Sub-Saharan Africa without biomass? *Energy for Sustainable Development*, *17*(2), 146–152. https://doi.org/10.1016/j.esd.2012.10.005

Perea-Moreno, M.-A., Samerón-Manzano, E., & Perea-Moreno, A.-J. (2019). Biomass as Renewable Energy: Worldwide Research Trends. *Sustainability*, *11*(3), 863. https://doi.org/10.3390/su11030863

Rechsteiner, R. (2021). German energy transition (Energiewende) and what politicians can learn for environmental and climate policy. *Clean Technologies and Environmental Policy*, *23*(2), 305–342. https://doi.org/10.1007/s10098-020-01939-3

Scarlat, N., Dallemand, J.-F., Monforti-Ferrario, F., & Nita, V. (2015). The role of biomass and bioenergy in a future bioeconomy: Policies and facts. *Environmental Development*, *15*, 3–34. https://doi.org/10.1016/j.envdev.2015.03.006

Singh, A., Christensen, T., & Panoutsou, C. (2021). Policy review for biomass value chains in the European bioeconomy. *Global Transitions*, *3*, 13–42. https://doi.org/10.1016/j.glt.2020.11.003

Singh, R., & Setiawan, A. D. (2013). Biomass energy policies and strategies: Harvesting potential in India and Indonesia. *Renewable and Sustainable Energy Reviews*, *22*, 332–345. https://doi.org/10.1016/j.rser.2013.01.043

Singh, V. K., Singh, P., Karmakar, M., Leta, J., & Mayr, P. (2021). The journal coverage of Web of Science, Scopus and Dimensions: A comparative analysis. *Scientometrics*, *126*(6), 5113–5142. https://doi.org/10.1007/s11192-021-03948-5

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Trencher, G. P., Yarime, M., & Kharrazi, A. (2013). Co-creating sustainability: Cross-sector university collaborations for driving sustainable urban transformations. *Journal of Cleaner Production*, *50*, 40–55. https://doi.org/10.1016/j.jclepro.2012.11.047

Turba, R., Thoré, E. S. J., Bertram, M. G., Bridg, H., Sabet, S. S., Gamboa, M., Ríos-Orjuela, J. C., Takola, E., Capa Salinas, J., Sampaio Franco, A. C., & Marín, C. (2025). *Global North-South science inequalities due to language and funding barriers*. Zenodo. https://doi.org/10.5281/zenodo.14902146.

Woźniak, A., Kuligowski, K., Świerczek, L., & Cenian, A. (2025). Review of Lignocellulosic Biomass Pretreatment Using Physical, Thermal and Chemical Methods for Higher Yields in Bioethanol Production. *Sustainability*, *17*(1), 287. https://doi.org/10.3390/su17010287

Yu, X., & Wang, P. (2021). Economic effects analysis of environmental regulation policy in the process of industrial structure upgrading: Evidence from Chinese provincial panel data. *Science of The Total Environment*, *753*, 142004. https://doi.org/10.1016/j.scitotenv.2020.142004

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