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ASSESSING THE ROLE OF BIOECONOMY IN ADVANCING EU'S SUSTAINABLE DEVELOPMENT GOALS – A LITERATURE REVIEW

Dadiana DABIJA
„Ștefan cel Mare" University of Suceava, Romania
dadiana.dabija@usm.ro

Abstract:
As the European Union (EU) countries strive to achieve the United Nations' Sustainable Development Goals (SDGs), a stronger focus needs to be placed on the effectiveness of current bioeconomy strategies and their corresponding initiatives. Drawing upon a systematic review of existing literature and official reports that have studied the alignment of bioeconomy with SDGs, this article pursues two main objectives: firstly, it analyses the main contributions that bioeconomy offers in advancing specific goals, notably SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), and secondly, it explores how countries have integrated bioeconomy principles into their sustainable development policies, determining different stages of transition to a bioeconomy-driven model of sustainability across all members of the EU. This paper highlights potential gaps, such as the lack of relevant indicators that can accurately measure the relationship between bioeconomy strategy implementation to compare the progress across all member countries towards EU's sustainable development goals. Among these gaps are requirements for more reliable indicators that can fully represent the variety of bioeconomy activities, as well as their sectoral and regional variations, and their connection to larger socioeconomic environments. Moreover, there is an urgent need for integrated assessment models that can take into consideration dynamics and trade-offs within the economy. By summarizing and identifying the disparities in implementation, this review expands the existing knowledge of the role of the bioeconomy in pursuing the SDGs in the European Union, and present a current snapshot of progress made so far.

Key words: bioeconomy, Sustainable Development Goals, SDGs, strategy implementation, literature review.

JEL classification: F64, N54, Q28, Q50, Q56, Q57

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1. INTRODUCTION

Human use of natural resources continues to outpace their growth, reproduction, and regeneration rates, putting an unsustainable burden on ecosystems, habitats, biodiversity, and the climate (Global Footprint Network, 2016). The bioeconomy represents a paradigm shift towards sustainable, effective and resilient economic systems (Stegmann et al., 2020 ; Siegel et al., 2022 ; Dietz et al., 2023). The bioeconomy, also known as the bio-based economy, is a mode of economic production that aims to replace fossil-based raw materials with bio-based resources in all sectors of the economy, achieving Sustainable Development Goals (SDGs) and improving social, economic, and ecological living conditions (Dietz et al., 2023 ; Ferraz & Pyka, 2023). Over the past 15 years, nearly **sixty** countries and macro-regions – including Costa Rica, the EU, Japan, Malaysia, South Africa, Thailand, the UK, the US, and East Africa – have adopted dedicated bioeconomy strategies and policies (Global Bioeconomy Summit, 2020; Gould et al., 2023). Nonetheless, there are technological, financial, and social requirements for a successful and long-lasting bioeconomy. The potential for sustainability of the bioeconomy and its relationship to the Sustainable Development Goals (SDGs) in particular are the subject of numerous, occasionally divergent points of view (Heimann, 2019 ; Gottinger et al., 2020 ; Siegel et al., 2022). Previous research focuses on case studies, but a broader global or European focused perspective is needed to provide a comparative overview of national bioeconomy politics (Dietz et al., 2018).

The bioeconomy has a great deal of potential for sustainable developments that lead to the achievement of the SDGs, as the current literature on the subject often emphasizes (Dietz et al., 2018). However, there are significant obstacles in the way of realizing this potential. The core cause of the issue, according to some researchers, is the dependence on both political and economic development (Kleinschmit et al., 2017 ; Ramcilovic-Suominen & Pülzl, 2018 ; Siegel et al., 2022).

This means that even though a bio-based economy has the potential to significantly improve sustainability, the economic system was shaped by past political, economic, and social decisions made prior to the emergence of the bio-based transformation paradigm (Gottinger et al., 2020 ; Dietz et al., 2023). According to Kleinschmit et al. (2017), national political discourses on the bioeconomy take the environment into account, but do not consider it a priority. Thus, the bioeconomy approaches begin from an anthropocentric (human focused) viewpoint, where economic growth is misguidedky believed to be "part of the solution to environmental problems, not as part of the problem" (Baker 2006, p. 138 in Kleinschmit et al., 2017). Research on the relationship between sustainability and the bioeconomy has demonstrated that the bioeconomy is not inherently sustainable (D'amato & Korhonen, 2021 ; Holden et al., 2023), and it has been argued that the idea of sustainable development has been used as a 'selling point' for EU bioeconomy strategies, which have a tendecy to focus extensively on economic efficiencies through technical solutions (Ramcilovic-Suominen & Pülzl, 2018).

In terms of increasing awareness, securing funding, and bolstering research networks, the bioeconomy initiatives have already proven effective (Meyer, 2017 ; Aguilar et al., 2019 ; Fava et al., 2021 ; Vogelpohl, 2023). An example is the The EU Bioeconomy Panel, a participatory dialogue forum, consisting of four stakeholder groups: producers, enterprises, universities, research organizations, public administrations, and civil society, reflecting a gradual shift towards participative dialogues. According to Stark et al. (2020), the bioeconomy is one of several transformative pathways toward achieving multiple SDGs. The 2030 Agenda and the bioeconomy have been connected to accomplish a number of SDGs through the "biologization" of the traditional economy (Lokko et al., 2018 ; Gawel et al., 2019 ; Ashukem, 2020 ; Dietz et. Al., 2023).

Through a systematic literature review of 34 highly cited articles between 2018-2023 this article adds to the discussion surrounding the implementation of a sustainable and effective bioeconomy. Additionally, through a separate analysis of official European Commission progress status reports, our research presents a comprehensive analysis of the national bioeconomy strategies of the 27 EU member states at the time of the study.

2. LITERATURE REVIEW / THEORETICAL BACKGROUND

The term 'bioeconomics' was initially introduced in the 1970s by Nicholas Georgescu-Roegen, a Romanian mathematician and economist, who emphasized the interconnectedness between economic systems and biological processes (Vogelpohl & Töller, 2021; Eversberg et al., 2023). He criticized neoclassical economics for its failure to account for thermodynamic laws, and argued all economic activities need to be understood as eventually degrading the physical environment, according to the laws of entropy (Vogelpohl & Töller, 2021). The concept of bioeconomy, however, still remains undefined 50 years later and its meaning is constantly evolving.

According to the European Union (EU) "the bioeconomy encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy" (European Commission, 2012, p.5), whereas the Organisation for Economic Co-operation and Development thinks of a bioeconomy "as a world where biotechnology contributes to a significant share of economic output" (OECD, 2009, p. 22). The definition of the bioeconomy for the purposes of this article is as follows: "the production, utilization and conservation of biological resources, including related knowledge, science, technology, and innovation, to provide sustainable solutions (information, products, processes, and services) within and across all economic sectors and enable a transformation to a sustainable economy" (Global Bioeconomy Summit, 2020). As a result, the bioeconomy includes the traditional bioeconomy sectors, such as agriculture, forestry, fisheries, and aquaculture, in addition to related processing and service industries, such as food, paper, textiles, building and construction, chemistry, and bio-pharma.

The bioeconomy gained prominence in the 1980s and 1990s due to biotechnology's impact on industry transformations. The term "knowledge-based bioeconomy" was adopted in the EU in 2005, emphasizing innovation policy (Ramcilovic-Suominen & Pülzl, 2018). Knowledge-based

bioeconomy leverages bio-, nano-, and information technologies (Global Bioeconomy Summit, 2020). The EU's Cologne Paper introduced two perspectives on the bioeconomy: biotechnology innovation and resource substitution (Meyer, 2017). In 2012, the European Commission published its first bioeconomy strategy, focusing on renewable biological resource production and conversion into value-added products (Stegman et al., 2020; Kardung et al., 2021; Firoiu et al., 2023). The European Commission established the Bioeconomy Knowledge Centre (BKC) in 2017 to offer a centralized platform for evidence-based knowledge, promoting informed decision-making and sustainable bioeconomy strategies across member states (Hetemäki et al., 2017, p.52).

National bioeconomy strategy development in Europe saw an upturn in 2012 with the introduction of the official EU Bioeconomy Strategy. By integrating national approaches, facilitating macro-regional collaboration, and offering a common regional vision for the development of the bioeconomy, macro-regional policy strategies not only add value and support national policy efforts but also aid in the creation of synergies (McCormick & Kautto, 2013; Global Bioeconomy Summit, 2020 ; Firoiu et al., 2023). A few nations, like Finland, Canada, and Portugal, have opted to focus on particular facets of the bioeconomy, like the "blue bioeconomy" or the "forest-based bioeconomy," in order to capitalize on their national comparative advantages (Global Bioeconomy Summit, 2020). The growth of the bioeconomy is becoming more closely associated with the idea of the "circular bioeconomy," particularly in European nations but also in Asian and Latin American nations (Global Bioeconomy Summit, 2020). However, the connection between these two concepts has not been researched enough (Gottinger et al., 2020 ; Stegmann et al., 2020 ; Kardung et al., 2021 ; Holden et al, 2023 ; Ferraz & Pyka, 2023).

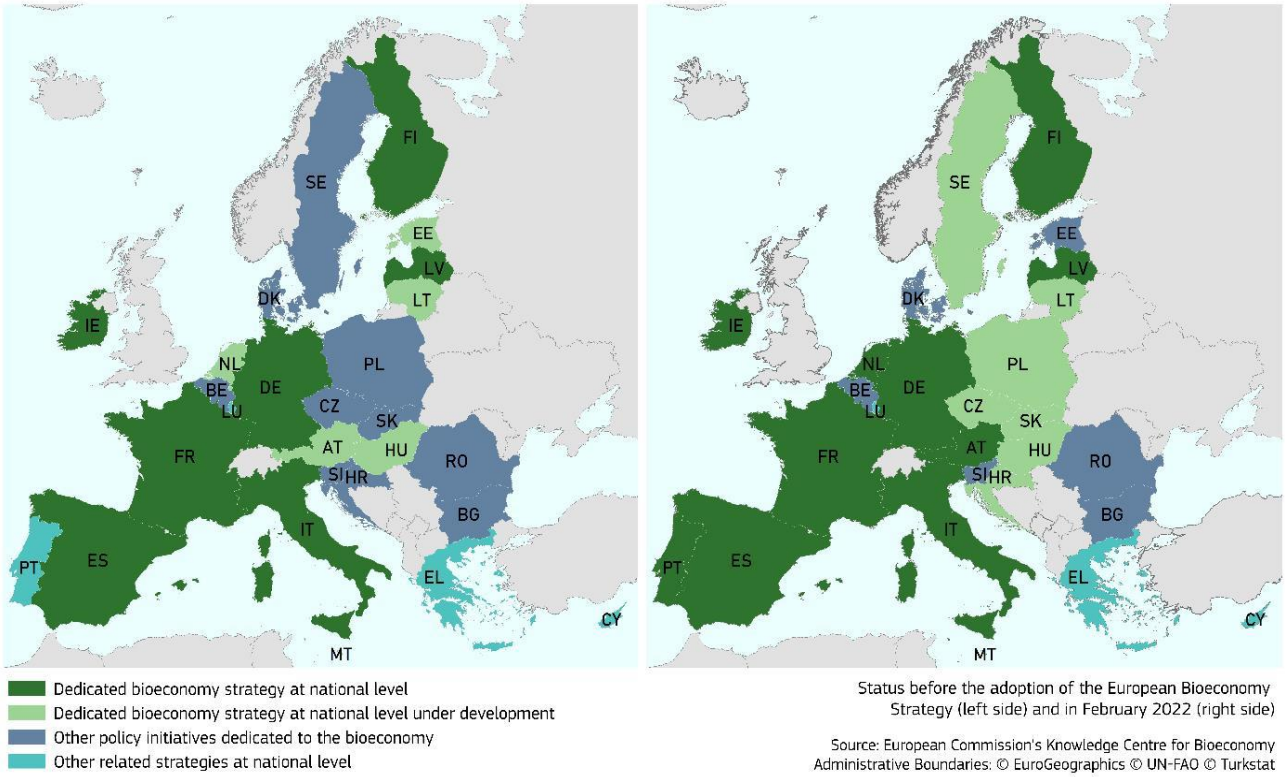

Figure no 1. National bioeconomy strategies before the adoption of the European Bioeconomy Strategy in 2018 (left) and in February 2022 EU progress report (right)

Source: EU Bioeconomy Strategy Progress Report (2022), p.10.

The initial EU bioeconomy strategy which envisaged a shift towards a full bioeconomy by 2020 is no longer accurate. The EU Bioeconomy Strategy was updated in 2018 to accelerate the deployment of a sustainable European bioeconomy (European Commission, 2018 ; Gould et al., 2023). This updated strategy aligns with UN Sustainable Development Goals (SDGs) and the Paris Agreement's climate objectives and integrates new European policy priorities such as the Circular

Economy Action Plan and the Communication on Accelerating Clean Energy Innovation. The European Commission's revised their plan for 2050, "A Clean Planet for All", which highlights the significance of bioeconomy, circular materials and sustainable biomass production and processing as critical strategic areas for attaining a climate-neutral economy (European Commission, 2018).

Figure 1 shows that significant progress in several countries (such as Portugal, Sweden, Poland, Czech Republic and Slovakia) has been made since the 2018 strategy update, but the initial goal of achieving a full bioeconomy by 2020 was ambitious and could not be fully realized (EU Bioeconomy Strategy Progress Report, 2022). A comprehensive progress report published in 2022 assessed the implementation of the strategy and highlighted areas needing further action, particularly regarding land and biomass management and sustainable consumption patterns (EU Bioeconomy Strategy Progress Report, 2022). Furthermore, in April 2023, the EU Council adopted conclusions emphasizing the continued development of a sustainable and circular bioeconomy, reflecting its importance for the European Green Deal and broader environmental, economic, and social goals (EU Council, 2023).

According to Heimann (2019), the bioeconomy scenario affects the SDG targets in both positive and negative ways. The bioeconomy may hinder rather than help achieve the SDGs if there are no laws, policies, and investments that ensure sustainability, or if the increased positive effect of bioeconomy activities cannot balance the increased negative effect.

3. RESEARCH METHODOLOGY

Utilizing techniques from Systematic Literature Review and Bibliometric Analysis methodologies, the research on SDG and the bioeconomy was performed using the Web of Science (WoS) database in March 2024. We chose a bibliometric approach because it facilitates the rapid analysis of a sizable body of scientific literature and offers quantitative information about well-known authors, keywords, trends, and research topics (Ferraz & Pyka, 2023). In order to identify pertinent concepts, research areas, and potential knowledge / research gaps, Lim and Kumar (2024) contend that a systematic literature review should be conducted in addition to the bibliometric methodology. Additional internet-based desk research on officially adopted policy strategies, European Commision reports and EU member countries roadmaps between early 2010 to January 2024 were used to enhance the systematic literature review insigths and determine country-level progress status.

By utilizing the WoS database, we were able to access a total 26,046 articles that were released between January 1st 2018_and January 1st 2024. The selection procress, which resulted in our final 34 articles chosen for the systematic literature review conducted, is presented in **Table 1.**

Table no. 1. Description of article selection process on the topic of bioeconomy and SDG

No. of articles	Description
26046	Articles between Jan 2018-Jan 2024
3046	Remain after filtering by WoS Categories: Economics, Business, Management
677	Remain after filtering by SDGs: 7, 12 and 13
49	Remain after filtering by Highly cited papers
34	Remain after abstract screening → used in the systematic literature review

Source: Own elaboration.

The initial number or articles were identified through simple search on the topic of bioeconomy and using keywords for bioeconomy and Suststainable Develepment Goals or SDGs. The starting period of 2018 was chosen based on the last EU Bioeconomy official update. As part of

next steps, the WoS platform analysis tool allows for extensive filtering based on research category and even based on individual SDGs. We purposely selected only 3,046 articles in the category of Economics, Business and Management as they were the most relevant to our field of study.

Figure 2 below shows the distribution of the 17 sustainable development goals (SDGs) accross the 3,046 filtered articles. We noted that SDG 17 (Partnerships for the Goals) returned zero results in our query and is therefore not included in the figure. Althought other goals such as SDG 01 (No Poverty) or SDG 02 (Zero Hunger) were more prevalently researched, we further filtered the list by selecting **SDG 7** (Affordable and Clean Energy), **SDG 12** (Responsible Consumption and Production), and **SDG 13** (Climate Action), as they had been advocated as the main goals where bioeconomy has a significant contribution (EU Bioeconomy Strategy Progress Report, 2022).

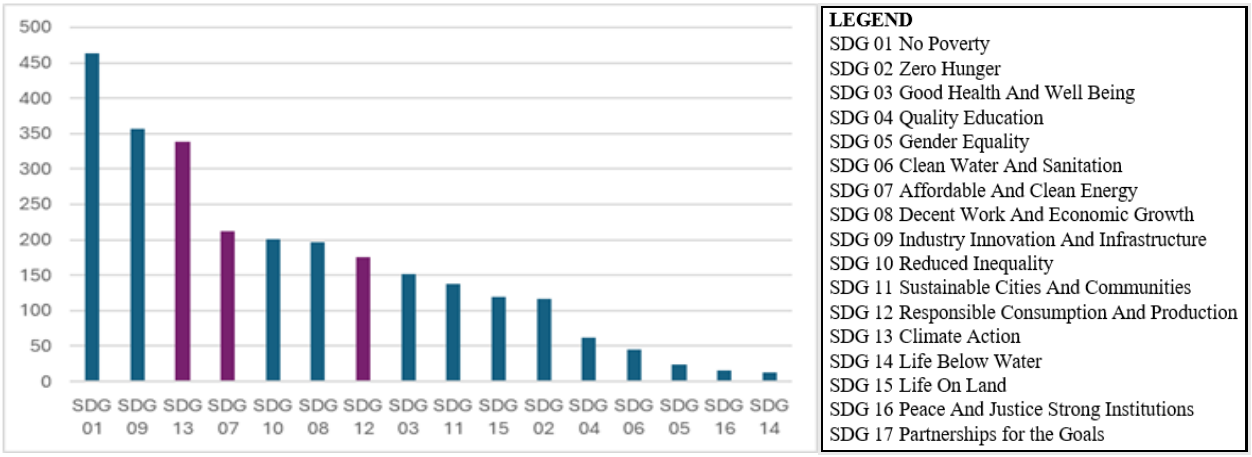

Figure no 2. Distribution of the 17 SDGs accross the 3046 bioeconomy articles
Source: Own elaboration using data from www.webofscience.com

To ensure that the final sample consists only of pertinent literature, the articles selected satisfy the following requirements: i) to be marked as a highly cited paper by WoS database (a difficult criteria to be achived by recent works published in the past 5 years; and ii) to be centered around a EU member country, therefore excluding other regions such as China or Brazil.

Analytical Steps		Research Questions
Systematic Literature review and analysis of bioeconomy strategies across EU member states	Analysing (a) main objectives; (b) country specific approach to each SDG enablement; (c) key Bioeconomy strategy highlights	1) How does the bioeconomy contribute to achieving specific Sustainable Development Goals (SDGs) within the European Union?
	Observing common themes	
Review different stages of transition to a bioeconomy-driven model of sustainability based on official reports	Identifying and categorizing country level phase of bioeconomy policy adoption	2) What are the different stages of transitioning to a bioeconomy-driven model of sustainability?
	Identifying progress status to achieving bioeconomy driven SDGs	

Figure no 3. Analytical steps and research questions.
Source: Own elaboration – Adapted from Gottinger et al. (2020)

The approach we used to address the research questions is depicted in **Figure 3.** The first part of the review process aimed at gaining an overview of the research field by conducting a quantitative systematic review of studies related to bioeconomy in EU member countries, which

also involved a country specific approach to each SDG enablement of key bioeconomy strategy highlights, and observing common themes. The second part included a summary of different stages of bioeconomy transition and progress status based on official reports and BKC database.

4. RESULTS AND DISCUSSIONS

a. BIBLIOMETRIC ANALYSIS

The number of publications on the circular economic model has experienced an exponential growth since 2020, with an average annual growth rate of 26.68% from 2020 to 2023. Key inflection points include a 95% growth in 2020 and 30% growth in 2022. As seen in **Figure 4**, the research in bioeconomy strategy and the SDG has also experienced a significant increase in citations since 2018, reaching 2,000 in 2021 and almost 5,000 citations in 2023, indicating increased recognition and use of research outputs in the academic community.

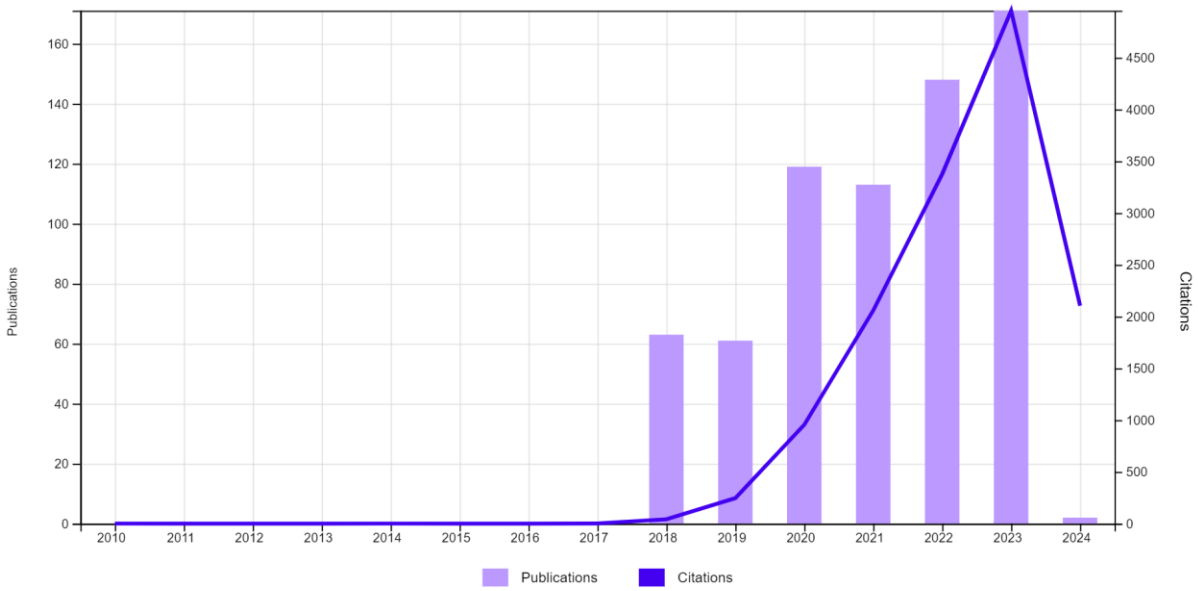

Figure no 4. Publication volume and citation report accross 677 bioeconomy articles
Source: Own elaboration using data from www.webofscience.com

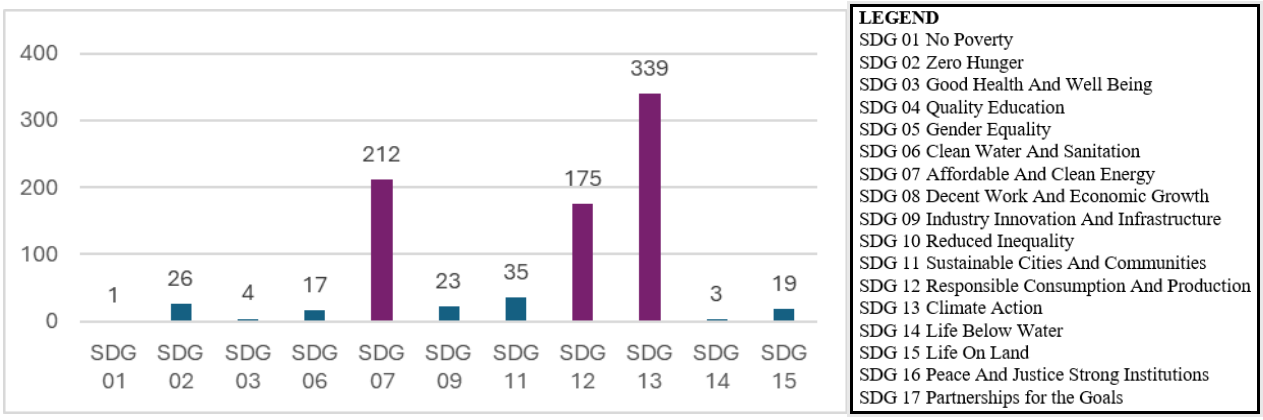

Figure no 5. Distribution of the 17 SDGs accross the 677 bioeconomy articles
Source: Own elaboration using data from www.webofscience.com

The bibliometric analysis is performed on the initial 677 articles identified after filtering in WoS database on **SDG 7** (Affordable and Clean Energy), **SDG 12** (Responsible Consumption and Production), and **SDG 13** (Climate Action). **Figure 5** shows that the remaining articles also touch upon and overlap with other sustainable development goals. The interconnectedness of the SDGs means that actions taken to achieve one goal often have positive (or sometimes negative) impacts

on other goals. In the context of bioeconomy articles, the themes of clean energy, responsible consumption, and climate action naturally overlap with broader sustainable development efforts. This reflects the integrated approach required to achieve the SDGs, recognizing that sustainable development involves complex and interrelated social, economic, and environmental dimensions.

b. SYSTEMATIC LITERATURE REVIEW DISCUSSION

The systematic literature review has identified four main phases of bioeconomy adoption based on recent official policy reports from EU countries such as national bioeconomy strategies, progress reports, and related sustainability reports. The below framework used to interpret the bioeconomy policy adoption phases:

- Initiation: Countries in the early stages of developing or considering a bioeconomy strategy.
- Development: Countries actively formalizing bioeconomy policies and strategies.
- Implementation: Countries with established bioeconomy policies that are actively implementing projects and initiatives.
- Maturity: Countries with well-established bioeconomy frameworks that are monitoring, evaluating, and refining their policies based on outcomes.

The initiation phase involves countries exploring and developing bioeconomy strategies, focusing on a wide range of areas such as agro-bioeconomy, marine bioeconomy, bio-innovation, sustainable tourism, and agriculture.

The development phase involves countries actively developing and formalizing bioeconomy policies, transitioning from exploration to creating structured policies and projects. Key Bioeconomy Strategy Highlights include diverse and broad focus areas, such as agro-bioeconomy, marine bioeconomy, bio-innovation, sustainable tourism, and agriculture.

The implementation phase involves countries establishing bioeconomy policies and actively implementing specific projects and initiatives. Key Bioeconomy Strategy Highlights include significant bioenergy projects, advanced circular economy initiatives, and comprehensive climate policies. Key Bioeconomy Strategy Highlights include deploying well-developed bioeconomy projects and integrating them into the national economy.

The maturity phase involves countries with well-established bioeconomy frameworks, leading in bioenergy technology and implementation, advanced circular economy practices, and ambitious climate action goals. Key Bioeconomy Strategy Highlights include optimizing and refining bioeconomy practices, including biomaterials, bio-based chemicals, sustainable farming, and sustainable forestry. These reflect a sophisticated and mature approach to integrating the bioeconomy into national strategies.

Table 2 in Appendix A below presents a high-level summary of our findings on EU member countries bioeconomy adoption phase and contributors to main identified SDGs.

5. CONCLUSIONS

The systematic review and analysis of bioeconomy strategies across the EU highlight the significant potential and diverse approaches that member states are taking to align with the Sustainable Development Goals (SDGs). This study focuses on the roles of bioeconomy in advancing SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), identifying various stages of bioeconomy adoption among EU countries: initiation, development, implementation, and maturity.

The EU's bioeconomy adoption is advancing in various phases. In the Initiation Phase, countries like Cyprus, Greece, Luxembourg, and Malta are exploring and establishing strategies for agro-bioeconomy, marine bioeconomy, and sustainable tourism. In the Development Phase, countries like Belgium, Bulgaria, and Croatia are formalizing policies focusing on renewable energy, resource efficiency, and climate resilience. In the Implementation Phase, countries like Austria, France, and the Netherlands are implementing advanced circular economy initiatives and

climate policies. In the Maturity Phase, countries like Denmark, Finland, Germany, and Sweden are leading in bioenergy technology and climate action.

The study has confirmed several gaps in bioeconomy strategy implementation and progress towards SDGs, that require reliable indicators and integrated assessment models. Addressing these issues will improve the effectiveness of bioeconomy strategies for sustainable development.

Appendix A

Table no. 2. EU member countries bioeconomy adoption phase and contributors to main identified SDGs

Bioeconomy Adoption Phase	Country	SDG 7: Affordable and Clean Energy	SDG 12: Responsible Consumption and Production	SDG 13: Climate Action	Key Bioeconomy Strategy Highlights
Initiation	Cyprus	Exploring bioenergy options	Sustainable resource use	Coastal and marine climate plans	Agro-bioeconomy, bioenergy, bio-based industries, bio-innovation, marine bioeconomy, sustainable tourism & agriculture
	Greece	Developing bioenergy capacity	Waste reduction initiatives	Climate adaptation strategies	
	Luxembourg	Bioenergy advancements	Resource efficiency programs	Ambitious climate plans	
	Malta	Exploring bioenergy options	Waste management initiatives	Climate adaptation measures	
Development	Belgium	Renewable energy focus	Waste reduction and recycling targets	National climate plan	Biorefineries, bio-waste conversion, green chemistry Biomass energy, sustainable forestry, bio-based products Bioenergy, sustainable fisheries, eco-tourism, Biofuel production, bio-based materials, eco-innovation hubs, Bio-based industries, biomass energy, sustainable agriculture
	Bulgaria	Developing bioenergy	Resource efficiency programs	Mitigation and adaptation measures	
	Croatia	Bioenergy investments	Eco-labeling, waste management	Climate resilience projects	
	Czech Republic	Bioenergy advancements	Circular economy practices	National emissions targets	
	Hungary	Exploring bioenergy	Resource efficiency	Climate action plans	
	Italy	Bioenergy initiatives	Eco-labeling, waste management	Climate resilience projects	
	Latvia	Bioenergy potential	Circular resource use	Climate action efforts	
	Lithuania	Developing bioenergy	Waste-to-resource initiatives	National climate goals	
	Poland	Bioenergy potential	Circular economy initiatives	Climate action initiatives	
	Romania	Bioenergy initiatives	Circular resource use	National climate action plans	
	Slovakia	Developing bioenergy	Resource efficiency	Climate action plans	
	Estonia	Bioenergy potential	Focus on waste management	Climate action initiatives	
Implementation	Austria	Significant bioenergy projects	Circular economy initiatives	Emission reduction goals	Bio-based industries, sustainable agriculture & forestry, biorefineries, bio-based chemicals, bioenergy, bio-based products, sustainable fisheries, sustainable farming, marine bioeconomy
	France	Bioenergy projects	Eco-design, circular economy	Comprehensive climate policy	
	Ireland	Expanding bioenergy	Circular economy practices	National climate action plans	
	Netherlands	Leading in bioenergy	Advanced circular economy practices	Ambitious climate goals	
	Portugal	Expanding bioenergy	Eco-labeling, waste management	Climate resilience efforts	
	Slovenia	Bioenergy projects	Circular economy practices	National climate goals	
	Spain	Bioenergy sector growth	Advanced waste-to-resource systems	Comprehensive climate policy	
Maturity	Denmark	Leading in bioenergy	Advanced waste-to-resource systems	Ambitious climate action goals	Biomaterials, bioenergy, sustainable farming, bio-based chemicals, sustainable forestry, sustainable forestry
	Finland	Bioenergy leader	Advanced recycling systems	Carbon neutrality target	
	Germany	Significant bioenergy sector	Circular economy leader	Ambitious climate targets	
	Sweden	Bioenergy leader	Advanced circular economy	Carbon neutrality target	

Source: Own elaboration from systematic literature review and mutiple official reports.
Source: www.knowledge4policy.ec.europa.eu/bioeconomy/bioeconomy-strategy_en

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