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Smart and Sustainable Bioeconomy Platform: A New Approach towards Sustainability

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Abstract: The smart and sustainable bioeconomy represents a comprehensive perspective, in which economic, social, environmental, and technological dimensions are considered simultaneously in the planning, monitoring, evaluating, and redefining of processes and operations. In this context of profound transformation driven by rapid urbanization and digitalization, participatory and interactive strategies and practices have become fundamental to support policymakers, entrepreneurs, and citizens in the transition towards a smart and sustainable bioeconomy. This approach is applied by numerous countries around the world in order to redefine their strategy of sustainable and technology-assisted development. Specifically, real-time monitoring stations, sensors, Internet of Things (IoT), smart grids, GPS tracking systems, and Blockchain aim to develop and strengthen the quality and efficiency of the circularity of economic, social, and environmental resources. In this sense, this study proposes a systematic review of the literature of smart and sustainable bioeconomy strategies and practices implemented worldwide in order to develop a platform capable of integrating holistically the following phases: (1) planning and stakeholder management; (2) identification of social, economic, environmental, and technological dimensions; and (3) goals. The results of this analysis emphasise an innovative and under-treated perspective, further stimulating knowledge in the theoretical and managerial debate on the smart and sustainable aspects of the bioeconomy, which mainly concern the following: (a) the proactive involvement of stakeholders in planning; (b) the improvement of efficiency and quality of economic, social, environmental, and technological flows; and (c) the reinforcement of the integration between smartness and sustainability.

Keywords: bioeconomy; digitalization; platform-based bioeconomy; smart and sustainable development; governance

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1. Introduction

Current rates of urbanization and industrialization generate a wide range of issues that affect bioeconomy, such as waste recycling [1,2], energy conservation [3], water dissipation [4], traffic congestion [5], social disparities [6], healthcare emergencies [7], loss of biodiversity [8], land utilization difficulties [9], atmospheric and acoustic pollution [10], infrastructure and facilities obsolescence [11,12], food valorisation [13], forest management [14], safety and cyber-security [15,16], sustainable economic development [17], and so on. Consequently, the social, economic, and environmental challenges that emerge from urbanization and industrialization and the opportunities to address these issues more adequately through technology place the bioeconomy at the centre of the academic and managerial debate, as it plays a crucial role in supporting a smart and sustainable transition [18–22].

According to the summit [23], the term smart and sustainable bioeconomy used in this article refers to a centre of "production, utilization, conservation and transformation of biological resources which—through digital technologies—aim to provide real time and continuous data and information that contribute to improve the circularity and efficiency of waste, water, energy, agriculture, health, education, mobility, telecommunications, and governance." In fact, bioeconomy strategies and practices are at the centre of several international frameworks, such as the report on "challenges, visions and ways forward of the cities of the future" implemented by [24], the study on "new perspectives on urbanization of cities in the world" [25], and the 2030 UN Agenda for Sustainable Development [26]. In [27,28], authors identified a wide range of bioeconomy strategies and practices in line with diverse goals and targets of the UN 2030 Agenda on Sustainable Development, such as food security (Goals 1 and 2), water quality (Goal 6), energy efficiency (Goal 7), inclusive economic development (Goal 8), waste prevention and reuse (Goal 12), and prevention of life below water and on land (Goals 14 and 15). Likewise, the report [29] recommends policymakers, urban planners, and managers to strengthen "the sustainable management of resources, facilitating ecosystem conservation, regeneration, restoration and resilience in the face of new and emerging challenges".

Therefore, policymakers, entrepreneurs, and citizens are required to rethink the bioeconomy paradigm through the implementation of smart and sustainable initiatives in order to optimize the social, economic, and environmental processes and operations [30–33]. To this end, it is essential to enhance the understanding and awareness of bioeconomic flows and reorient their circulation in order to support a forward-looking and dynamic vision of the bioeconomy as the engine of smart and sustainable solutions [34–37].

The transition towards a smart and sustainable bioeconomy strives to address through a data-based approach the ever-increasing quantity of renewable biological resources, such as plant resources, agri-food production, forests, marine and livestock resources, microorganisms, algae, as well as waste, by-products and wastewater of agro-industrial origin, and the consequent congestion, in order to reduce the anthropogenic pressure on built and natural settlements [38–41]. Specifically, this new form of smart and sustainable bioeconomy, through the utilization of digital platforms and dashboards [18,42,43], holistically combines a wide range of information and communication technologies (ICTs), such as sensors [44,45], real-time monitoring stations [46], cameras [47], GPS tracking systems [48], big-data analysis techniques [49], artificial intelligence [50], augmented reality [51], blockchain [52], Internet of Things (IoT) [53], cloud computing [54], smart grids [55], satellites [56], nanotechnologies [57], advanced biotechnologies [58], and drones [59].

The information and communication technologies (ICTs) listed above ensure a real time and fully transparent authentication, traceability, treatment, analysis and evaluation of data, and information on bioeconomic resources from source to customer while providing agility, security, and efficiency along the production and distribution processes [60,61]. Consequently, the pervasive and intensive dissemination of fixed and mobile digital devices is revolutionizing the circularity of raw materials and secondary raw materials, by-products, chemicals, biofuels, bioplastics, urban and industrial waste, and wastewater, generating a wide and diversified range of data and information useful for policymakers, planners, managers, agricultural entrepreneurs, scientists, growers, logistics companies, biorefinery workers, chemical and technological companies, etc., able to optimize the use of natural and non-natural resources and improve the quality of their interactions [62,63]. In this regard, information and communication technologies (ICTs) allow a proactive and holistic approach capable of improving the mechanization and commercialization of practices along the bioeconomy chain through innovations, such as precision farming [64], precision livestock [65], sustainable packaging [66], and industry 4.0 [67].

Conversely, the lack of detailed and real-time data and information determines a wide range of uncertainties related, for example, to the timing of procurement, production, distribution and transformation, quality, location, and consumption, which leads to an under-optimization of bioeconomic flows [68]. Hence, the connectivity, variety, proximity, flexibility, coordination capacity, diversity, foresight, interdependence, collaboration, adaptability, creativity, efficiency, agility, self-organization, robustness, and resourcefulness of bioeconomy data and information provided by fixed and mobile digital equipment are therefore essential not only to minimize economic, social, and environmental costs but also as tools to refurbish other dimensions, such as mobility, telecommunications, health, education, and safety.

According to the "Future transitions for the Bioeconomy into Sustainable Development and a Climate-Neutral Economy report," elaborated by the European Commission's Knowledge Centre for Bioeconomy, the bioeconomy employs around 17.5 million people (almost 9% of its workforce), generating 614 billion euros of added value (about 5% of its GDP). Furthermore, if we include the tertiary bioeconomy sector based on digital services, which amounts to 872 billion euros, we reach an overall European extent of the bioeconomy of 1.5 trillion euros (almost 10% of its GDP) [69].

This growing importance of bioeconomy has provided a wide range of strategies and practices at the global level [23]. In this sense, the development of bioeconomy policies has become increasingly complex and varied [70]. In general, the strategies and practices of the bioeconomy tend to differ on the basis of factors related for example to technological advances [71], the availability of natural resources [72], cultural and institutional progress [73], and the development of the economic system [74]. In Germany, for example, the bioeconomy is clearly recognized as an inter-sectoral concept and refers not only to biological resources but also embraces social aspects, such as multi-level governance, stakeholders' management, and people empowerment [75,76]. Otherwise, Japan prioritizes the "biotechnological" vision, emphasizing the role of digital technologies such as Big Data, Artificial Intelligence, and Internet of Things [77]. On the other hand, the United States focuses more on the safety and security aspects, such as the cyber protection from biological threats, the development of biotechnologies for military use, and the preservation of sensitive infrastructure and biological data [78]. Given their significant and varied availability of biological resources, Costa Rica [79] and South Africa [80] embrace sustainable bioprospecting practices for scientific and commercial purposes, while Thailand [81], Italy [82], and Nordic Council of Ministers [83] are committed to the conservation of biodiversity and natural ecosystems for tourism activities.

Therefore, the current theoretical and managerial discussion is increasingly focused on the role of biotechnology, nanotechnology, and information and communication technologies (ICTs) in the bioeconomy [84]. In this regard, Costa Rica [79] coined the term "advanced bioeconomy" in order to highlight the importance of digitalization in improving the circularity of natural and non-natural resources. At the same time, the intensive and pervasive use of digital technologies in the bioeconomy highlights a wide range of challenges and issues within the social, economic, and environmental spheres [85].

On the basis of reports, master plans, and documents elaborated by governments, ministries, departments, agencies, and research centres, the following article provides a detailed overview of the bioeconomy strategies and practices implemented globally in order to develop a multidimensional platform able to holistically integrate the phases that characterize the smart and sustainable bioeconomy decision-making process. In summary, the proposed overview aims to explain the different approaches developed at a global level and to strengthen the understanding of (a) planning and stakeholder management; (b) identification of the social, economic, environmental, and technological dimensions; and (c) setting of the goals to be pursued. To do this, an in-depth analysis was conducted on a wide range of countries, such as South Africa, Costa Rica, USA, Japan, Malaysia, Thailand, Austria, Finland, France, Germany, Ireland, Italy, and so on, which have developed a plethora of smart and sustainable bioeconomy initiatives in order to improve the planning, collection, monitoring, and analysis of economic, social, environmental, and technological flows. In this sense, by identifying and analysing a wide range of smart and sustainable strategies and practices, the study fills a gap in the theoretical and managerial literature of the bioeconomy, providing a further piece in the debate between policymakers, entrepreneurs, scientists, planners, and citizens.

Hence, the study is structured in this manner: Section 2 outlines the methodology. Section 3 proposes the smart and sustainable bioeconomy platform, identifying and analysing the phases that characterize the smart and sustainable bioeconomy at a global level. Section 4 offers considerations on the role of smart and sustainable bioeconomy in future challenges. Finally, Section 5 provides the conclusions.

2. Materials and Methods

This paper provides a systematic review of the literature of strategies and practices implemented worldwide in order to develop a multidimensional platform capable of analysing and integrating the phases that characterize the smart and sustainable bioeconomy decision-making process. To do this, a wide range of globally implemented bioeconomy strategies and practices was investigated. The research took place in three different phases: identification, operational, and results (see Figure 1).

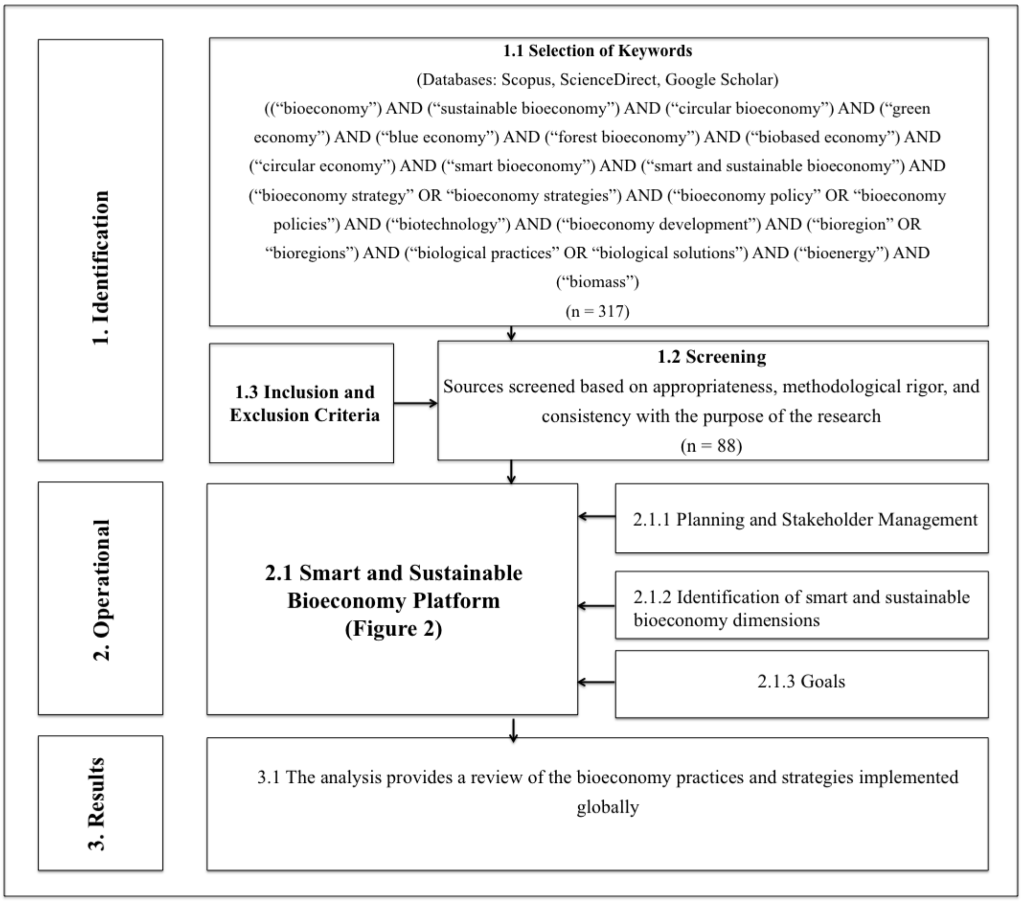

Figure 1. Methodology. Source: Authors.

In Phase 1—Identification, the search question, the keywords, a series of inclusion and exclusion criteria, and the search databases are outlined. With regard to the aim and research question of this paper, the study aims to provide a clear and exhaustive analysis, developing a platform capable of integrating in a systemic and holistic way the aspects of each operational phase of the smart and sustainable bioeconomy decision-making process. Therefore, the study focuses on the following research question: with which strategies and practices is the global context facing the transition towards the smart and sustainable bioeconomy? In this regard, the study of the smart and sustainable bioeconomy offers a multidisciplinary perspective of circular economy. Specifically, the scientific areas embrace agricultural, forest and marine economics, logistics, industrial organization, strategic management, technology and innovation management, data science, information and communication technologies, environmental and IT engineering, energy management, sustainable development, public policy analysis, geography, urban governance, territorial planning, etc.

In terms of sources, the investigation was based on the exploration and integration of a wide range of sources, such as urban and industrial reports and master plans, government documents, non-academic research, official websites, publications of ministries, departments, divisions, agencies, committees, research institutes, universities, etc. In parallel, scientific literature, such as peer-reviewed journal articles, book chapters, conference proceedings, and any other source in line with the development of the smart and sustainable bioeconomy, was used to verify and integrate basic information. As for the databases, ScienceDirect, Google Scholar, Scopus, and institutional websites were used. To do this, the following keywords were used: ("bioeconomy") AND ("sustainable bioeconomy") AND ("circular bioeconomy") AND ("circular bioeconomy") AND ("green economy") AND ("blue economy") AND ("forest bioeconomy") AND ("biobased economy") AND ("circular economy") AND ("smart bioeconomy") AND ("smart and sustainable bioeconomy") AND ("bioeconomy strategy" OR "bioeconomy strategies") AND ("bioeconomy policy" OR "bioeconomy policies") AND ("biotechnology") AND ("bioeconomy development") AND ("bioregion" OR "bioregions") AND ("biological practices" OR "biological solutions") AND ("bioenergy") AND ("biomass").

In order to further refine the search, all the selected sources (n = 317) were screened following different inclusion and exclusion criteria, in line with the objective and the research question. Specifically, the inclusion criteria include (1) appropriateness with the purpose of the study; (2) theoretical and managerial robustness; (3) scientific rigor; and (4) consistency with the long-term and novel perspective of the study. As exclusion criteria, sources with partial information and inconsistent with the research topic were not included in the search. The screening generated a detailed and complete overview (n = 88) that encompasses the strategies and policies of smart and sustainable bioeconomy implemented by Ethiopia, Ghana, Kenya, Malawi, Mali, Mauritius, Mozambique, Namibia, Nigeria, Rwanda, Senegal, South Africa, Tanzania, Uganda, Argentina, Brazil, Canada, Colombia, Costa Rica, Ecuador, Mexico, Paraguay, Uruguay, the United States of America, Australia, China, India, Indonesia, Japan, Malaysia, New Zealand, Russia, South Korea, Sri Lanka, Thailand, Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Latvia, Lithuania, the Netherlands, Norway, Portugal, Slovenia, Spain, Sweden, and the UK (see Table A1 in Appendix A). The large number and varied typology of countries taken into consideration undoubtedly constitutes a strength of the study, as it represents almost all the countries involved in the transition towards the smart and sustainable bioeconomy. In this regard, the plurality of bioeconomy strategies and practices highlights the difference, the gap, and the prevailing focus between countries with diverse social, economic, environmental, and technological infrastructures. In this sense, a large number of countries around the world are not equipped to collect, monitor, analyse, and evaluate bioeconomic flows through real-time monitoring stations, sensors, digital tracking systems, artificial intelligence, blockchain, cloud computing, etc.

In Phase 2—Operational. Based on the analysis of the previous phase, a platform was created, capable of providing a theoretical and managerial approach to the development of the smart and sustainable bioeconomy. Specifically, the platform for the smart and sustainable bioeconomy represented in Figure 2 is characterized by the three following phases: (1) planning and stakeholder management; (2) identification of smart and sustainable bioeconomy dimensions; and (3) goals. Furthermore, each phase provided a holistic perspective, emphasizing aspects related to smartness and sustainability.

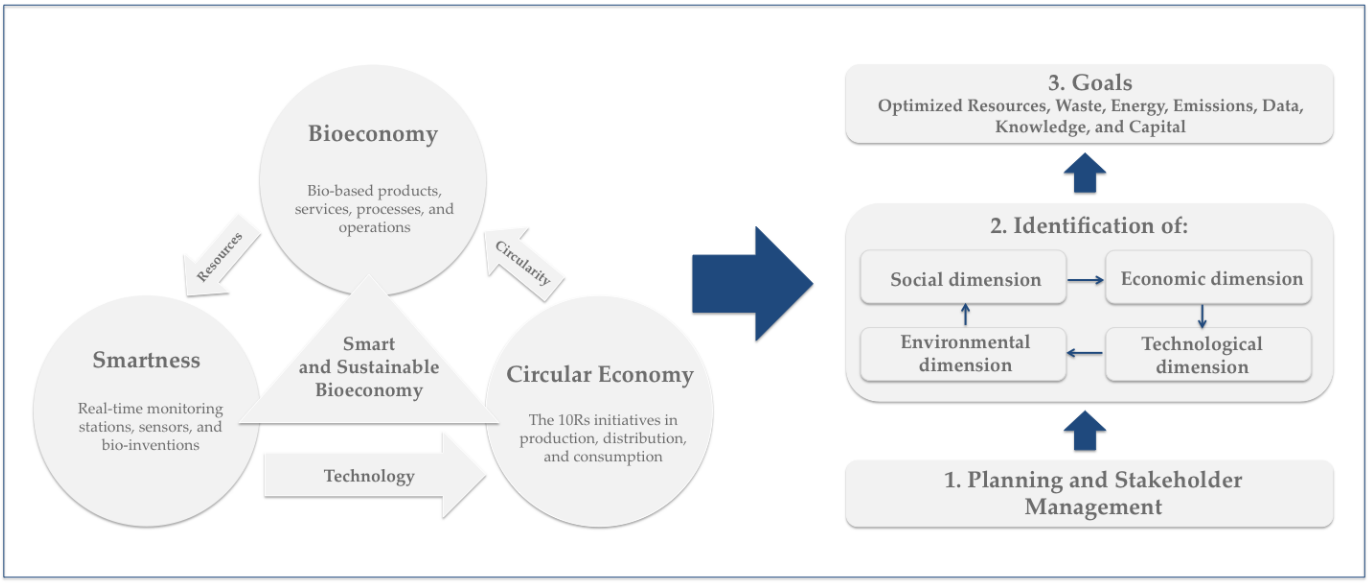

Figure 2. Smart and sustainable bioeconomy platform. Source: Authors.

In Phase 3—Results. The grouping of the initiatives developed by the countries taken into consideration in the investigation around the phases that characterize the smart and sustainable bioeconomy platform provides a framework capable of providing a review of the bioeconomy practices and strategies implemented globally.

3. Results

Based on the literature, the strategies and practices of the bioeconomy implemented globally were considered, analysed, and grouped. The result is a multidimensional platform illustrated in Figure 2 able to describe the smart and sustainable development in the bioeconomy in a holistic perspective. In detail, the phases that characterize the proposed smart and sustainable bioeconomy platform are divided into: (1) planning and stakeholder management; (2) identification of smart and sustainable bioeconomy dimensions; and (3) goals (Figure 2, vertical reading).

3.1. Planning and Stakeholder Management

Regarding the first phase (as represented in Figure 2), most of the bioeconomy strategies and practices investigated involve a wide range of stakeholders coordinated by government institutions. In general, these co-design activities take various forms, such as inter-ministerial committees, working groups, expert and public consultations, inter-ministerial collaborations, and partnerships. At the same time, bioeconomy policies planning are delegated to representatives of ministries, departments, agencies, committees, executive offices, councils, cabinets, associations, research centres, and steering groups. For example, the Bio-Circular-Green Economy (BCG) strategy in Thailand is characterized by an expert consultation process coordinated by the Thai minister of science and technology [81]. Similarly, South Africa [80], Costa Rica [79], Japan [86], Malaysia [87], Austria [88], and Latvia [89] involve in the strategy the ministries and departments of science, innovation, and technology. In the USA, the President of the United States has coordinated the Office of Science and Technology Policy of the White House in the elaboration of the Bioeconomy Blueprint [78]. Otherwise, the Council of Science, Technology, and Innovation of Japan has decentralized to the Japan Science and Technology Agency (JST), the New Energy and Industrial Technology Development Organization (NEDO), the National Institute of Technology and Evaluation (NITE), and the Japan Agency for Medical Research and Development (AMED) [86]. Likewise, the Finnish Technical Research Centre VTT, which operates under the mandate from the ministry of economic affairs and labour and the

Finnish innovation fund SITRA, were involved in the planning activities [90]. In Malaysia, the bioeconomy is entrusted to the Bioeconomy Corporation owned by the Malaysian ministry of finance, administered by the National Bioeconomy Council (NBC), supported by the Bioeconomy International Advisory Panel, and chaired by the Malaysian Prime Minister [87]. Differently, the Austrian inter-ministerial collaboration involves the federal ministry of transport, innovation, and technology and the federal ministry of sustainability and tourism [88,91]. In general, the ministry of economy coordinates bioeconomy strategies and practices in Finland, France, Italy, Latvia, Spain, and the UK. Industry and trade ministries have been involved in South Africa, Costa Rica, Japan, Malaysia, and Norway. Specifically, Japan embraces the Japan External Trade Organization (JETRO) and the Japan International Cooperation Agency (JICA).

The ministries and departments of agriculture, forestry, and fisheries are active in most of the countries considered. South Africa also integrates the department of environmental affairs [80]. Costa Rica includes the ministry of agriculture and livestock and the ministry of environment and energy [79]. Japan involves the National Agriculture and Food Research Organization (NARO) [86]. In addition to the ministry of agriculture, agrifood, and forests, France includes the ministry of ecology, sustainable development, and energy [92]. The Presidency of the Italian Council of Ministers has delegated the minister of the environment, land, and sea; the committee of the Italian regions; the Territorial Cohesion Agency; and the Italian Technology Clusters for Green Chemistry, Agrifood, and Blue Growth, the former drafting of the BIT I strategy [93]. Similarly, the strategy adopted by Latvia is characterized by an inter-ministerial group formed by the ministry of agriculture, economy, environmental protection, and regional development [89]. Otherwise, the Austrian bioeconomy strategy was implemented through a public consultation supervised by the Vienna University of Natural Resources and Life Sciences [91]. Furthermore, South Africa, Japan, Finland, France, Germany, Italy, and Latvia involve ministries from health, education, research, and welfare. In this regard, Norway has established a wide range of partnerships between the ministries of education, research, local government, modernization, and foreign affairs [94,95].

3.2. Identification of Smart and Sustainable Bioeconomy Dimensions

The investigation of the dimensions of the smart and sustainable bioeconomy involves a wide range of sectors, such as energy, waste, water, education, governance, and health, which mainly depend on environmental, social, economic, and technological characteristics of the context in which they circulate. However, the analysis of the countries taken into consideration and engaged in the transition towards the smart and sustainable bioeconomy shows a predominance of the fields of automated agriculture, industrial biotechnology and nanotechnology, smart grids for the optimized circulation of biomass, genetics, genomics, chemistry, medicine, marine and terrestrial biodiversity, and biorefinery.

The strategies and practices of smart and sustainable bioeconomy shared among the countries analysed emphasise the importance of industrial districts and knowledge-sharing centres in the fields of biotechnology, nanotechnology, genomics, genetics, and precision automation. In this regard, the UK is characterised as a thriving environment for innovation, entrepreneurship, and scientific research. In recent years, through the Synbio for Growth program, start-ups related to biology have received nearly 500 million pounds of funding in order to develop increasingly innovative bioeconomic products and processes [96,97]. At the same time, the economic initiatives adopted in Spain and Malaysia include digital technologies as centralised refrigeration systems, temperature tracking sensors, and prediction systems able to ensure greater nutritional quality and to reduce waste during the processing, packaging, storage, and distribution phases of the cold chain. Furthermore, in the economic dimension, it is interesting to specify the role of sustainable and virtual tourism within the naturalistic areas of Costa Rica, Finland, and Thailand.

Regarding the agricultural dimension, South Africa ranks first among African countries in agricultural biotechnology, producing more than 85% of genetically modified corn and soybeans. In this sense, by strengthening native crops (e.g., fortified sorghum, rooibos, and shrub honey), the bioeconomy strategy aims to satisfy the market demand for niche natural products [80]. At the same time, agriculture 4.0 initiatives, such as real-time monitoring of fertilizer and water use, precision automation, innovative plant selection methods to cope with drought, flood and insect resistance, and systems of vertical and modular agriculture, are present in Costa Rica, Thailand, Austria, France, Germany, Ireland, Italy, Latvia, Spain, and the UK. Differently, Malaysia has implemented a wide range of initiatives covering the development of animal vaccines, biological fertilizers and pesticides, plant micropropagation, and livestock farming through tracking systems [87]. Austria and Finland focus on how to improve forest resource management. As nearly 80% of Finland's total area is characterised by forests, the Finnish forestry industry is a leader in wood processing, implementing a multitude of low-water consumption processes [90]. Likewise, Austria and Japan promote forestry in the sustainable construction sector in order to minimise environmental impacts, using bio-based chemicals, bioplastics, and compostable and biodegradable materials. Regarding the energy dimension, the strategic axes of the bioeconomy plans of Austria, Costa Rica, and France focus on the production of bioenergy derived from the residual biomass from urban and industrial processes and operations in order to replace fossil fuels with high environmental impact for powering public transport, heating homes, biofertilizers, animal feed, etc. In this sense, Japan aims to use biomaterials with high performance in terms of weight, durability, and safety [86]. In Malaysia, the National Biomass Strategy focuses on the reuse of palm oil to generate bioenergy, biofuels, and bio-based organic products. On the other hand, Thailand has created a capillary system of power plants connected through blockchain-enabled smart grids with the aim of producing clear energy from renewable resources. At the same time, the strategy aims to convert biomass and agricultural by-products into bioplastics, fibres and pharmaceutical products. In general, most countries that include the energy component in the bioeconomy strategy integrate digital technologies such as smart grids, weather forecasting and monitoring systems, and so on. Within the energy dimension, the biorefinery initiatives are adopted by a multitude of countries globally. Indeed, Ireland, Latvia, Norway, Spain, and the UK dedicate great attention to the development of biorefineries in order to ensure a sustainable conversion of residual biomass (e.g., biolubricants, bioplastics, food additives, cosmetics, solvents, chemicals, etc.). Specifically, in Ireland, we highlight the AgriChemWhey project led by Glandia integrated with the dairy processing industry; the BioMarine Ingredients marine biorefinery, which converts raw materials into proteins, oil, and calcium; and the Biorefinery Glas project, which optimises the circularity of glass. In the UK, other examples include the alliance of several biorefineries as BioPilotsUK and the regional innovation cluster, BioVale, in Yorkshire and the Humber, which focus on bio-waste reuse and advanced biorefining. In order to address water scarcity in numerous areas of the country, South Africa is promoting improvements in wastewater treatment through computerized management of water flows. In Europe, the Finnish forestry industry is already leading in this sector by developing technologies for water recycling in its processes. Likewise, the Italian government has launched several projects, such as the PRIMA and BLUEMED initiatives, in order to promote sustainable management of water in the Mediterranean region [82]. The Spanish bioeconomic strategy summarizes the importance of the efficient use of water resources, promoting adequate water management and its reuse in other dimensions, such as construction, logistics, and health. Regarding waste management, Costa Rica intends develops the sustainable management and valorisation of residual solid waste, interurban biological corridors, and urban design approaches inspired by biological principles, processes, and systems. Given the increase in global marine plastic pollution, the Japanese strategy focuses on organic waste and wastewater, converting waste into high-value substances. Similarly, in Ireland, particular emphasis is placed on management and the valorisation of marine waste. The bioeconomy strategy in Germany further focuses on waste streams (e.g., organic waste, urban and industrial wastewater, carbon dioxide and synthesis gas). Furthermore, the strategy highlights the need for innovative methods and processes for the efficient processing and recycling of challenging resources, such as metals or phosphorus.

In the health dimension, South Africa focuses on supporting research and development initiatives of bio-based chemicals and industrial biotechnology in order to better tackle infant mortality, HIV, tuberculosis, and malaria infections. At the same time, bioprospection plays a crucial role in the development of new drugs, vaccines, diagnostics, and medical devices. On the other hand, in European countries, such as Austria, Italy, Germany, Latvia, and the UK, the health dimension mainly encompasses healthy diets and eating habits and psycho-physical well-being. The USA, through the Bioeconomy Blueprint, underlines the positive impacts of genetic engineering, synthetic biology, and bioinformatics on public health. To this end, U.S. federal agencies are incentivized to prioritise bio-based and sustainable materials in public procurement and their implementation and dissemination through technology transfer and easier market access. France, Japan, and Malaysia mainly focus on biopharmaceuticals, regenerative and precision medicine, omics technologies, nutrition, sport, and digital healthcare. Specifically, the digital health strategies and practices aim to generate personalized and categorised nutrition plans through a detailed research of consumer behaviours and preferences.

3.3. Goals

From an economic perspective, the smart and sustainable bioeconomy strategies and practices adopted aim to increase the competitiveness of the agricultural and industrial sectors in national and international markets. Specifically, the increase of the employment rate is the goal set by South Africa, the USA, Malaysia, France, Germany, Ireland, and Latvia. At the same time, the USA has mainly focused on the elaboration of training programs and career updating. Differently, Germany aims to increase employment rate in rural areas. The Latvian strategy intends to address the structural changes in agriculture such as the reduction of small and medium-sized enterprises and the decrease in the workforce due to the progressive digitalisation of processes. Therefore, the development of the smart and sustainable bioeconomy aims to decarbonise the production and consumption processes. In this sense, Costa Rican and Italian strategies have coined the term "circular bioeconomy" to emphasise the circularity of biological resources. According to Costa Rica, the circular bioeconomy contributes to reducing the carbon footprint of production processes and generates new market niches for consumers interested in minimizing their impacts on the environment. Similarly, Japan integrates circularity into the bioeconomy strategy in order to meet diversified needs. Furthermore, a key aspect recalled in a multitude of strategies is the development of public-private partnerships. Specifically, the USA, Japan, Austria, and the UK underline the need for a collaborative environment where industry and government interact dynamically in the implementation of regulatory processes that favour investment in research and development and commercialization of bio-inventions. Japan, for example, encourages the evolvement of international hubs capable of attracting the best start-ups in the field of biotechnology. Conversely, Austria focuses on how to mobilise private capital and the financial systems in the development of smart and sustainable bioeconomy initiatives.

From an environmental point of view, the smart and sustainable bioeconomy strategies and practices investigated aim to address climate change and environmental conservation through a plethora of initiatives related to waste and water management, renewable energy, and land-use optimization. In this sense, the reports of Austria and France refer to the achievement of the targets of the Paris Agreement on the climate. According to the Austrian guidelines, the smart and sustainable bioeconomy will significantly contribute to the reduction of greenhouse gas emissions by 2030. At the same time, Japan, Latvia, and Thailand expressly recall the Sustainable Development Goals (SDGs) of the United Nations 2030 Agenda. Differently, South Africa, Norway, and Spain do not explicitly indicate the Sustainable Development Goals among their objectives, but various initiatives lead to reducing greenhouse gas emissions and contributing to a more sustainable use of biological resources. Japan includes CO_2 reduction, land-use improvement, water management optimization, and food security. In this sense, the Irish bioeconomic strategy is based on the principles of sustainability, cascade, precaution, and food first. Likewise, Italy envisages the three following macro-areas: (1) certifications and quality standards; (2) agri-food, forestry, and marine pilot initiatives at local level; and (3) safeguarding biodiversity and ecosystem services.

Finally, the social dimension includes a wide range of ethical and legal issues. For example, Costa Rica and Japan prioritise social inclusion and equity aspects. In addition, Costa Rica takes into account the creation of opportunities for country's youth and indigenous communities. Conversely, Malaysia focuses primarily on people's health and well-being through reduced health care costs, early disease detection, and cheaper and more accessible medicines. Italy, on the other hand, promotes various initiatives in order to increase awareness, updating of skills, education, attitude, training, and entrepreneurship throughout the bioeconomy. Finally, Germany considers the importance of systems thinking and holistic approaches capable of creating synergies, identifying such conflicts, and minimizing them on the basis of scientific knowledge.

4. Discussion

The strategies and practices of smart and sustainable bioeconomy developed globally and investigated in this study confirm the advances in the scientific literature on the role of technology in the circularity of social, environmental, and economic flows of industrial and urban processes and operations [98]. At the same time, the initiatives identified and analysed support the observations of [99] on the smart and sustainable bioeconomy, where they emphasise the contribution of biotechnology, omics technologies, nanotechnology, precision mechanics, blockchain, and smart grids. Therefore, the theoretical and managerial debate demonstrates the significance assigned to the smart and sustainable bioeconomy [100]. In this sense, the smart and sustainable bioeconomy platform certifies that the planning and stakeholders management; the identification of social economic, environmental, and technological dimensions; and the definition of the goals is a challenging and complex issue that requires a multidimensional and holistic approach, in which a wide range of aspects must be taken into account simultaneously.

However, the stakeholders involved; the economic, social, environmental, and technological dimensions; and the goals of the smart and sustainable bioeconomy argue that the context in which the countries perform is much more hybrid and multi-layered with respect to the reductive conception that the economic, social, environmental, and technological pillars are important and to be pursued. Therefore, we do not claim that these issues have not been previously described and emphasized in the literature, but we declare that the proposed platform holistically highlights the actors engaged, the activated smart and sustainable dimensions of bioeconomy, and the goals to be achieved of a wide range of countries involved globally in this transition.

Firstly, the scientific literature on smart and sustainable bioeconomy underlines the crucial role of proactive, participatory and multi-level governance [101–103]. The authors [33,104] affirm that a distributed governance of the bioeconomy characterized by scalable coordination, consensus transmission protocols, and flexibility in decision-making processes is necessary for greater adaptability and efficiency of processes and operations. In this regard, Section 3.1 'Planning and Stakeholder Management', confirms the necessary bottom-up approach, specifying the role of a plethora of actors, such as ministries, departments and councils of science, innovation and technology, ministries of economy and trade, agriculture, fisheries and forests, foreign trade organizations, international cooperation agencies, research centres, universities, and biotechnology and nanotechnology companies.

In accordance with Section 3.2 'Identifications of the dimensions of the smart and sustainable bioeconomy', digital technologies, such as real-time monitoring stations, smart grids, weather forecasting systems, automatic irrigation systems, precision machinery, etc., improve the fluidity and timeless of flows that circulate in agriculture, fisheries, forests, logistics, health, education, waste, and water. In this sense, the theoretical literature on smart and sustainable bioeconomy emphasises the pre-eminent role of technology in the extraction, tracking, and evaluation phases [105,106]. However, the development of digital technologies in the bioeconomy can encounter criticalities in underdeveloped or developing countries not equipped with adequate economic, technological, social, and environmental structures [107].

Section 3.3 'Goals' highlights a multitude of purposes that confirm and support the current theoretical literature. In summary, from an economic point of view, smart and sustainable bioeconomy strategies and practices embrace the following: (a) the planning and development of agricultural processes and operations with low environmental impacts; (b) the design of industrial parks, international hubs, and start-up clusters in order to share knowledge; (c) the competitiveness of industrial sectors in national and international markets; (d) the creation and enhancement of highly skilled employment in the fields of biotechnology, genetics, and nanotechnology; and (e) the ability to attract and mobilise private capital and funding for the development of digital technologies and bio-inventions. However, the significant investments in planning, installation, integration, maintenance, and redefinition of digital technologies for the smart and sustainable bioeconomy undoubtedly represent a barrier to entry for underdeveloped countries [108]. In this regard, the search for national and international funding is crucial in the transition towards the smart and sustainable bioeconomy [109]. At European level, the European Structural and Investment Funds (ESIF) [110], which embrace regional funds (ERDF) [111] and agriculture and rural development funds (EAFRD) [112], and Smart Specialization Strategies (RIS3) [113,114] aim to facilitate the modernization of the bioeconomy throughout the Europe.

Regarding the environmental perspective, the identified smart and sustainable bioeconomy strategies and practices confirm relevant issues, such as waste, water and wastewater management, energy efficiency, and land use [115,116]. In this sense, Austria and France based their goals with the Paris Agreement on Climate, while Japan, Latvia, and Thailand recall the environmental goals of the United Nations 2030 Agenda on Sustainable Development.

Finally, the social dimension of the smart and sustainable bioeconomy includes several aspects, such as social inclusion, ethics, and legality [117,118]. Regarding the social sphere, the balance of governance between the various ministries, departments, cabinets, agencies, committees, municipal, regional or state owned utilities, divisions, universities, and research centres involved in planning, monitoring, and evaluating smart and sustainable bioeconomy policies emphasizes the need for multidimensional and participatory decision-making processes [101,119–121]. In this regard, the term "orchestration" is coined as a fundamental aspect for understanding the evolution of complex systems towards inclusive and participatory models [122–125]. At the same time, motivational, behavioural, and cognitive issues persist, such as the lack of (a) awareness of the benefits of proactive co-participation of the stakeholders involved; (b) knowledge of technological devices functioning; (c) citizens', entrepreneurs', and businesses' understanding of the practices of production, distribution, and consumption of sustainable bioeconomic products and services; and (d) trust in safeguarding the privacy and security of sensitive data. In this regard, the smart and sustainable bioeconomy highlights technical challenges relating to the quality and robustness of the data and information collected, their degree of security, and their ability to be converted into useful feedback [126]. Furthermore, various countries investigated embrace the health and psycho-physical well-being of people, focusing on reducing healthcare costs through personalized medicine, prevention, nutrition, and more accessible medicines.

Therefore, the proposed platform indicates that the planning and stakeholders management, the identification of the smart and sustainable dimensions of the bioeconomy, and the definition of the goals to be pursued must be carried out taking into consideration the social, economic, environmental, and technological factors holistically. This bottom-up and multidimensional approach is confirmed and emphasised by the theoretical literature on bioeconomy and our investigation of strategies and practices adopted globally.

5. Conclusions

The era of growing urbanization and datafication pushes us to rethink how to tackle sustainable development. In this context, smart and sustainable bioeconomy offers a renewed perspective towards resilient and intelligent future. In recent years, smart and sustainable bioeconomy initiatives are gaining increasing importance in the technical-spatial context in order to collect, monitor, process, and evaluate a large amount of data and to improve the quality and efficiency of industrial and urban processes and operations and therefore the functioning of our countries. In this regard, the importance of smart and sustainable bioeconomy is demonstrated by the numerous strategies and practices implemented by countries, such as Austria, Costa Rica, Finland, Germany, Ireland, Latvia, Malaysia, South Africa, Thailand, and so on. Therefore, the bioeconomy enabled by sensors, real-time monitoring stations, tracking systems, Internet of Things, smart grids, precision mechanics, automation, etc., have the potential to improve the circularity of dimensions, such as waste, water and wastewater, energy, land, biodiversity, economy, health, safety, education, and agriculture. The aim of this study is to provide a clear and comprehensive overview of the concept of smart and sustainable bioeconomy, developing a platform capable of integrating a wide range of bio-initiatives implemented at a global level. Specifically, the smart and sustainable bioeconomy platform illustrated in Figure 2 describes the phases of planning and stakeholder management; identification of economic, social, environmental, and technological dimensions; and the definition of the goals that characterise the smart and sustainable bioeconomy decision-making process. In this sense, the proposed platform improves the understanding of the functioning of smart and sustainable bioeconomy. At the same time, the exploration of the smart and sustainable bioeconomy requires not only a qualitative perspective of the strategies and practices as proposed in this study but also further quantitative research to assess and interpret their social, economic, environmental, and technological impacts. However, the difficulties encountered in obtaining quantitative data on the initiatives investigated undoubtedly represent a limitation to our research. Therefore, the future perspective of this paper is to enrich it with a quantitative approach in order to provide a complete and exhaustive point of view for future analyses.

Hence, in order to summarise the results of this study, we underline and list the following highlights: (a) the effective and efficient implementation of the smart and sustainable bioeconomy requires continuous planning, monitoring, and analysis of the social, economic, technological, and environmental dimensions; (b) the smart and sustainable bioeconomy can improve the participation, accountability, and comprehension of citizens, local authorities, and companies; and (c) the smart and sustainable bioeconomy generates a multitude of social, economic, and environmental challenges still under observation by the scientific and managerial community today.

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Appendix A

Table A1. Summary of sources grouped in the geographical areas. Source: Authors.

Africa														
	Ethiopia	**Ghana**	**Kenya**	**Malawi**	**Mali**	**Mauritius**	**Mozambique**	**Namibia**	**Nigeria**	**Rwanda**	**Senegal**	**South Africa**	**Tanzania**	**Uganda**
Source	[127–129]	[130]	[131–134]	[135]	[136,137]	[138]	[139]	[140]	[141]	[142]	[143]	[80]	[144]	[145]
Americas														
	Argentina	**Brazil**	**Canada**	**Colombia**	**Costa Rica**	**Ecuador**	**Mexico**	**Paraguay**	**Uruguay**	**USA**				
Source	[146]	[147,148]	[149,150]	[151–154]	[79]	[155]	[156]	[157]	[158–160]	[78]				
Asia/Pacific														
	Australia	**China**	**India**	**Indonesia**	**Japan**	**Malaysia**	**New Zealand**	**Russia**	**South Korea**	**Sri Lanka**	**Thailand**			
Source	[161–163]	[164–167]	[168–170]	[171,172]	[86]	[87]	[173,174]	[175,176]	[177,178]	[179,180]	[81]			
Europe														
	Austria	**Belgium**	**Croatia**	**Czech Republic**	**Denmark**	**Finland**	**France**	**Germany**	**Ireland**	**Italy**	**Latvia**	**Lithuania**	**Netherlands**	
Source	[88,91]	[181]	[182]	[183]	[184–186]	[90]	[92]	[75,187]	[188]	[82,93]	[89]	[189]	[190]	
	Norway	**Portugal**	**Slovenia**	**Spain**	**Sweden**	**UK**								
Source	[94,95]	[191,192]	[193]	[194,195]	[196]	[96,97]								

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