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Review

Organic Waste Management and Circular Bioeconomy: A Literature Review Comparison between Latin America and the European Union

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Abstract: Worldwide, organic waste represents one of the most significant shares in the waste management system. Within the framework of circular bioeconomy, new and cutting-edge infrastructure has been developed at the European level to turn organic waste into valuable resources. The present paper aims to provide an exhaustive comparison between the European Union and Latin America regarding organic waste valorization. To this end, an introductive analysis about the state of the art circular bioeconomy in Latin America and Caribbean countries was developed. Subsequently, a systematic literature review in the context of South and Central America was conducted to detect differences and similarities in technologies and best practices for treating biowaste. The results show that the Latin American region is home to numerous bio-based infrastructures: biogas recovery, composting facilities and bioremediation strategies. Nevertheless, a conclusive remark underlines that some social, economic and political barriers are still encountered in the region, and therefore, new and locally-based studies are of paramount importance.

Keywords: biowaste; bioresources; composting; organic waste to energy; circular bioeconomy

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1. Introduction

The birth of the bioeconomy, conceived as "the process of transforming life-science knowledge into new, sustainable, eco-efficient and competitive products" [1], has been the result of chance, necessity and evolution of several societies [2]. This evolution and concern for sustainability also involves anthropological issues as ethics, an increasing delimiting factor in the modern context, as already mentioned by the Romanian economist and mathematician Nicholas Georgescu-Roegen on his treatise on bioeconomic and degrowth in 1975. For Georgescu-Roegen, it was clear that an unequal appropriation of natural resources (even for economic development) could trigger a social fracture and eventual economic degrowth [3].

In the same line, there is consensus that the transition towards a bioeconomy is often associated with a number of economic, environmental and social benefits; however, the bioeconomy is not sustainable per se. Various environmental and socio-economic risks could undermine the sustainability of the bioeconomy, such as increased competition for land between food crops and fuel crops, direct and indirect changes in land use, marginal land use with negative effects on the biodiversity and greenhouse gas emissions, among others [4]. At the Latin American level, in 2014, around 4.6 giga tons of CO_2 were registered, of which 50% were associated with agricultural activities and land use. On the other hand, only in Central America between 1990 and 2017, about 20 million hectares of forests have been lost due to changes in land use [1].

For full bioeconomy application, ethics and other social rules have to be set in order to achieve sustainability. This is especially true in developing countries, where bioeconomy can enhance the dichotomy between food safety and industrial development, considering that there is consensus in the global scientific community that conventional technology will not, on its own, increase or diversify food production in sufficient quantity and quality to feed a population that will almost double in 50 years. This will directly influence the food security of several countries, especially those developing countries, where demands will be higher [5].

In terms of global bioeconomy development, while it is true that the European Union is one of the pioneers in the world in terms of application of the bioeconomy [6], the bioeconomy has found a niche of opportunities in other parts of the world including Latin American and the Caribbean (LAC).

In terms of a literature review, the state of maturity and development level of the bioeconomy in Europe is well documented, mainly by institutional organisms, while in LAC and especially in Central America (CA), the number of specialized publications is currently limited and rarely diffused. Additionally, the mentioned publications are mainly performed by international organisms that respond to its own necessities and agendas.

However, some actors have analyzed the current state of the technological context in LAC and CA also based on the number of scientific publications, where Brazil rose to first place with the highest number of scientific publications, accounting for 37% of the analyzed available documents [7]. The number of scientific publications—especially for Central American countries—regarding bioeconomy issues, including biofuels and enhancement of crops, is very limited; thus, one of the main objectives of the present paper is to contribute to the systematization of state of the art biowaste valorization.

The following lines are intended to show a qualitative overview between the development level of bioeconomy at the European Union (EU) and the Latin America and Caribbean region (LAC).

1.1. Legal Framework for the Bioeconomy in EU and Latin America

As far as public policies are concerned, one of the biggest differences between the EU, LAC and CA is the common legal structure and framework. While at the EU levels, it counts with a formal bioeconomy strategy that groups many sectors of the economy as agriculture, fishing and forestry [8], the LAC and CA structures are rarely united. In the specific case of the Central America region, through the so-called Central America Integration System (SICA), the system counts with some regional mechanism that enforce bioeconomy application as a "Agricultural Policy," a "Common energy strategy" and other regional instrument, but there is still no cohesion between them and binding force in all the state members [9].

It can be seen that, although there are triggering elements, the state of public policies in terms of circular economy, biotechnology and bioeconomy are still incipient [10]. In particular, limitations are observed in the absence of harmonization in the classification criteria for new products related to the bioeconomy, including by-products that, due to their lack of analytical classification, cannot be used in a timely manner as inputs for recovery and recovery processes [11].

1.2. Main Drivers of Bioeconomy Development in EU and Latin America

In terms of biodiversity, conceived as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" [12], the LAC region presents 20% of the key biodiversity areas identified worldwide [13]. The specific case of Central America is classified as a hotspot of biodiversity, with about 7% of the world biological patrimony [14]. Moreover, the United Nations points to Latin America as one of the most forest-covered areas in the world; in particular, Central America enjoys a land cover of about 19.499.000 ha, 38% of its total surface [15]. Moreover, 42.7% of LAC land is dedicated to biotech, consisting of a total of 191.7 million hectares in 2018 [5].

The region of Central America possesses structural factors linked to the agricultural vocation that may favor the successful application of bio-based economical models, especially for the generation of subproducts in high quantities as rice husks, postmortem waste from a bovine, mucilage, pulp and lees from coffee and cocoa, sugar cane residues, citrus peel, potato waste and pineapple waste, [11]. This last factor, considered a problem from the traditional and linear economy standpoint, can be of great importance in the creation of new value chains [15].

On the other hand, there is significant potential for water resources in all countries in the region. In measurable terms of water stress (relationship between quantity, quality and access to water)—with the exception of Guatemala and El Salvador, which present "medium-high" and "medium-low" stress levels, respectively—the rest of the CA countries experience levels of water stress considered "low," indicating average good "water health" [1].

Additionally, a social factor of opportunity to be considered is the native indigenous population present in the Central American Region. Indigenous communities, according to various studies, amount to almost 8 million people [1] who can contribute, through their historical richness, to understanding the potential of existing crops in the region and their potential use in the value chains of the bioeconomy [11].

1.3. Limitation of Bioeconomy Development in Latin America

Other remarked difference in the application of the bioeconomy in Latin America and the European Union is the level of maturity of governance, which can be understood as the process by which societies adapt their rules to new challenges [5]. This rule, as mentioned before, constitutes the framework through which bioeconomy or any other economic model can be set and runed. It is valid to mention that there are also significant limitations by the absence of harmonization in the classification criteria for new products related to the bioeconomy, including by-products that, due to their lack of analytical classification, cannot be used in a timely manner as inputs for recovery and recovery processes [11].

In terms of funding, the main difference between the UE, LAC and CA is the origin of funding. Midence Diaz and García Gómez [16] stated the main sources of funding in the LAC and CA come from international cooperation agencies as the Green Climate Fund, the United Nations Development Program and the World Bank [16], in contrast with the public funding provided by the EU as the well-known European Green Deal.

Regarding bioenergy development, the main difference between LAC, but especially CA, and the European Union is that ono one hand, the European Union predicts the direct diminution of the significance of bioenergy and the increase of the relevance of biomaterials by 2050 [17], while on the other hand, in the case of Central America, sugarcane bagasse and straw are currently agricultural residues that produce energy on a large scale with a positive trend, especially in Nicaragua, Guatemala and Honduras. At the LAC scale, Brazil counts with different sources of bioenergy coming from agricultural waste with significant level of power; for example, black liquor (1.7 GW), wood residues (371 MW), rice husk (36 MW), charcoal (35 MW), elephant grass (32 MW) and palm oil (4 MW) [7]. On the other hand, bioeconomy applied for environmental remediation can have a place in LAC and CA. In the particular case of Nicaragua, there is experience with the use of autochthonous microorganisms, in particular fungi, to propitiate bioleaching to extract heavy metals from tailings derived from mining activities [16].

Within the aforementioned framework of bioeconomy, the present study aims to draw a comparison analysis about biowaste recovery and treatment between the European and the Latin American contexts. To this end, the paper proposes a structural literature review of the current trends to turn organic waste into bioresources in the Latin American region.

The presentation of the work is divided into two main sections: the materials and methods that will describe the methodology performed to collect valid material and the results and discussion part will show the outcoming information grouped in three approaches. The groups cover composting technologies, biogas generation and other biowaste valorization solutions.

2. Materials and Methods

A literature-based review was conducted in order to frame a comprehensive picture of biowaste remediation in Latin American.

The methodology follows the structure adopted by [18]. The research was developed using the Scopus database and facilitated by the filter TITLE-ABS-KEY. The keywords assumed for the review were: "Latin America" AND "organic waste" OR "bioeconomy" OR "composting" OR "biogas". A total number of 66 entries were initially obtained. Afterwards, the field was restricted to only English and Spanish languages and within a time window between 1990 and 2002, which led to a total of 61 potential papers. Given the specific topic of choice, the remaining articles could potentially all be suitable for the research; however, to collect only highly relevant contributions, a further screening was also conducted and a final sample of 17 relevant manuscripts was obtained. The selection process is summarized and shown in Figure 1.

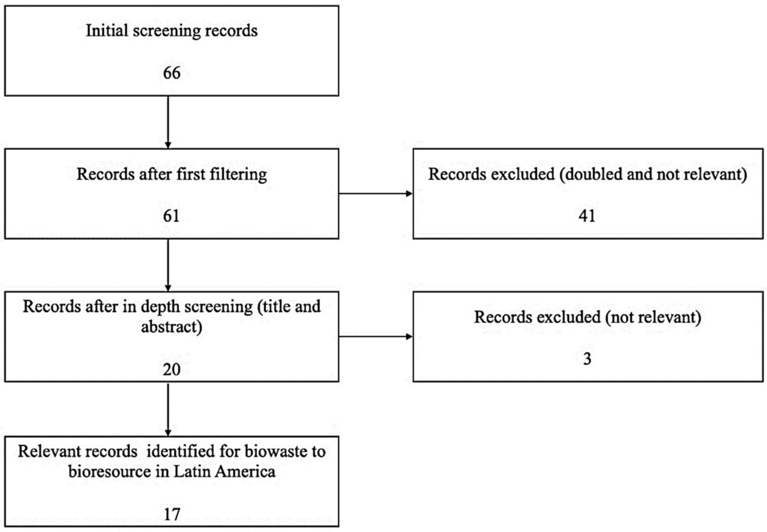

Figure 1. Overview of the selection process (own representation).

Regarding the geographical representation of the selected papers, Spain was the most popular country (5) followed by Italy, Colombia and Germany (3) (Figure 2).

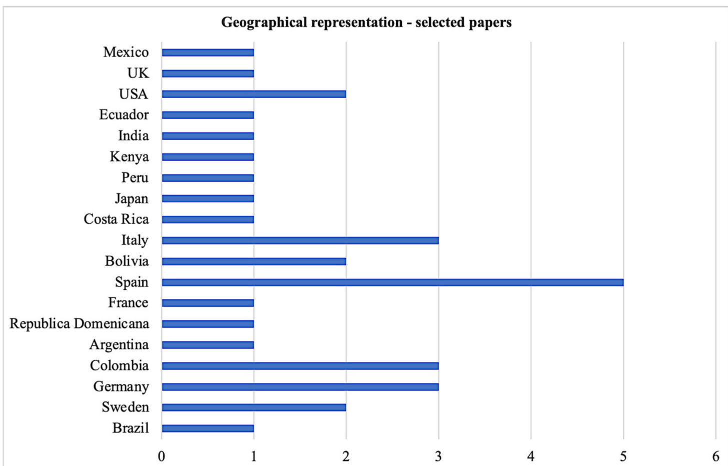

Figure 2. Geographical coverage. Source: own representation.

As far as the research method is concerned, 29% of articles analyzed were specific case studies, followed by theoretical model applications and literature reviews (Figure 3).

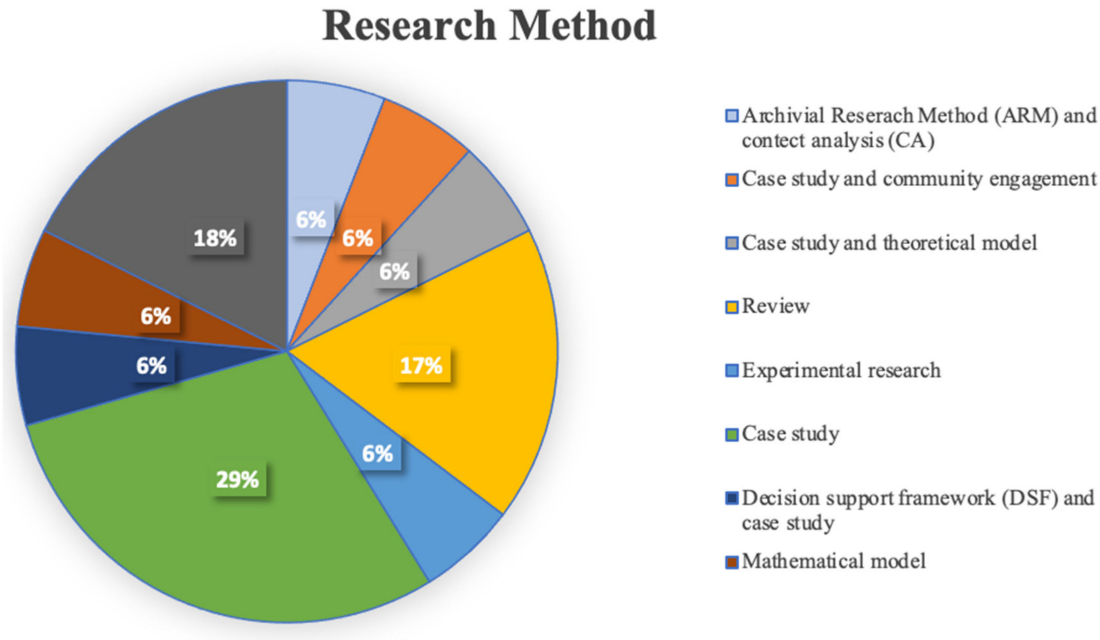

Figure 3. Research methodology (own representation).

Concerning the temporal representation, a peak of publication was encountered in 2020 (Figure 4).

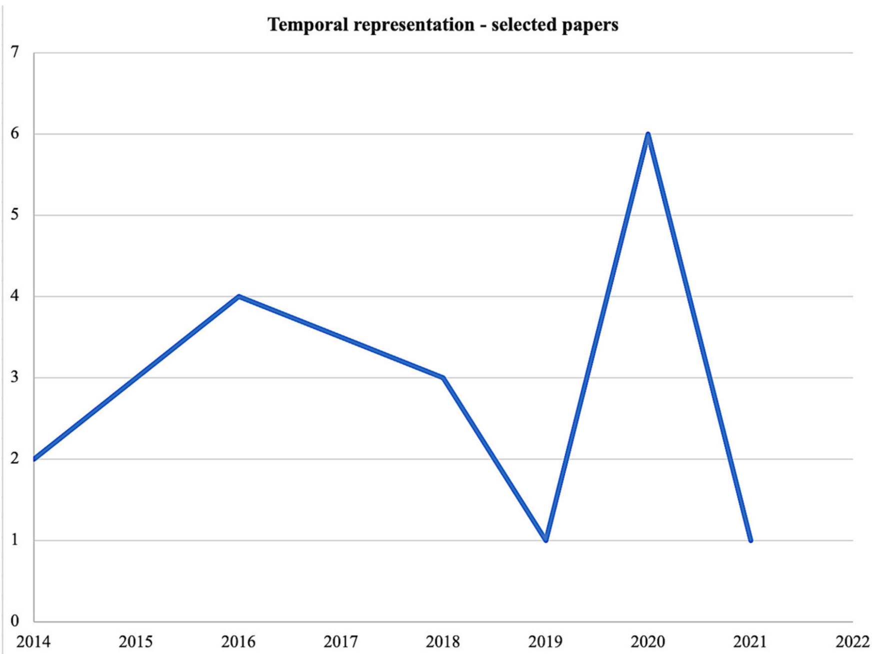

Figure 4. Temporal coverage (own representation).

3. Results

From the literature analysis described, it was possible to divide the obtaining sample in three main groups due to consistent analogies among the information gathered. The papers, indeed, tackle the topic considering three main different bio technologies recovery solutions. Some focused on diverse composting technologies, others on biogas generation and a small percentage on different biowaste valorization alternatives. This section divides the papers into three main recovery groups and aims to systematically describe current practices in the Latin American region for turning biowaste into bioresources. The manuscript grouping is summarized in Table 1.

Table 1. Literature review group analysis.

Composting Alternative	Biogas Generation	Other Biowaste Valorisation Solutions
(Sandoval Duarte, Osuna, Jenny, Rodríguez, & Juan, 2020) [19]	(Silva-Martínez, Sanches-Pereira, Ortiz, Gomez Galindo, & Teixeira Coelho, 2020) [7]	(Sasson & Malpica, Bioeconomy in Latin America, 2017) [20]
(Ferronato, Pineto, & Torretta, Assessment of Used Baby Diapers Composting in Bolivia, 2020) [21]	(Colombo & Rodriguez Cuevas, 2020) [22]	(Acevedo, Díaz Carrillo, Flórez-López, & Grande-Tovar, 2021) [23]
(Brenes-Peralta, Jiménez-Morales, Campos-Rodríguez, De Menna, & Vittuari, 2020) [24]	(Ferrer-Martí, Ferrer, Sánchez, & Garfí) [25]	(Ziegler-Rodriguez, Margallo, Aldaco, Ian, & Kahhat, 2019) [26]
(Ferrans, et al., 2018) [27]	(Garfí, Martí-Herrero, Garwood, & Ferrer) [28]	(Sharma, et al., 2016) [29]
(Ferronato, et al., 2018) [30]	(Kinyua, Rowse, & Ergas, 2014) [31]	
(Diaz & Otoma, 2013) [32]	(Meneses-Jácome, et al., 2015) [33]	
	(Pérez, Garfí, Cadena, & Ferrer, 2013) [34]	

3.1. Composting Alternative

The Latin America and the Caribbean (LAC) region still relies on open dumpsters for the disposal of more than 30% of municipal solid waste (MSW), and only in better circumstances is the landfill solution adopted [26]. When it comes to organic waste recovery, one of the main alternatives to open dumpsite or landfill is undoubtedly compost production, especially in regions in which the amount of biowaste is intensely generated both at domestic and industrial levels.

In the context of Latin America and, in general, of low-and middle-income countries, besides the commitment of developing bigger waste treatment infrastructures, the presence and the importance of small-scale technologies is predominant [20]. Ferrans et al. [27], for instance, considered composting process as a complementary stabilizer solution for sewage sludge treatment. Through composting it is indeed possible to eliminate pathogens and obtain good quality organic fertilizers when the sludge is mixed with organic waste.

However, when it comes to developing regions, composting solutions are not only identified in literature to solve organic waste generation problems but also to actively involve local communities. For instance, two interesting Latin American examples were given by Ferronato et al. [21] and Duarte et al. [19].

Ferronato et al. [21] explored the context of Bolivia, considering the specific issue of recycling used baby diapers (UBDs) waste fraction. Because of the wide generation in the territory of UBDs and the common discharge in open dumps, this specific waste fraction represents an issue in the country, and proper management should be addressed. The novelty of the case study was to attempt to treat disposable used baby diapers (UBDs) through a vermicomposting process. Scouting for innovative recycling solutions can support the low-income context to reduce uncontrolled waste disposal and achieve a more recycling and circular bioeconomy [21].

The experimental work proposed by [21] sought to evaluate the degradation of the biomass with a combination of different composting agents as cow dung, earthworms and activated bacteria. The UBDs samples were collected from different areas; they were then opened and last the plastic part was removed. At the end of those stages, composting experimental trials were performed following correct and specific timings and locations. To finally compare the process, [21] identified four main parameters: acidity (pH), decomposition time, earthworm growth and compost production. The research demonstrated that vermicomposting can be implemented to treat UBDs waste mixed with cow dung over a period of 60 days. The main finding was that without the presence of cow dung the waste substrate could not decompose because of the generation of algae and fungi. On the other hand, if cow dung is combined with earthworms as well, good final compost can be obtained.

The described case study is an example of a contribution to boost circularity in low-income territories by proposing low-cost and appropriate alternatives to specific waste that otherwise would end up in open dumpsites. This is a particular need, especially when proper selective collections and good pre-treatment solutions are not developed and applied in the study area.

A complementary contribution in the Bolivian context was proposed by Ferronato et al. in [30]. The mentioned paper analyses the main strengths and difficulties for implementing a sustainable MSWM. Within this framework, it also describes the commonly used vermicomposting process to treat organic fractions in developing economies. The study considers a specific composting plant located at an old open dumb situated in the south of La Paz. The small but functioning composting facility is used for producing compost that will consequently be utilized to reclaim the old open dump and create a new green area. Additionally, the final compost is used as fertilizer and as a new soil to plant trees.

Duarte et al. [19], on the other hand, considers an even more societal-based aspect by involving recycling picker organizations. The informal recycling waste sector is a real and deep issue in developing countries, and many studies have explored potential solutions to turn informal activities into legal recycling organizations [35–37]. Duarte et al. [19] explain that in the city of Bogotà, according to [38], 55.22% of the waste generated in a year are organic fractions which generally end up in open dumpsites or—in the best cases—sanitary landfills. However, in developing countries, besides environmental damages and economic losses, an ever more touchable issue is the informal recycling sector. Based on [39], it was found that in the city of Bogotà, there are approximately 13,700 informal waste recyclers who make their livelihood through the collection and the sale of recyclable materials and therefore, integrating these informal organizations into a formal organic waste management system might represent a win–win opportunity [19]. The case study considers a specific landfill named Donña Juana. In particular, [19] aims to propose a theoretical model based on a series of strategies. It consists of developing a structural management plan for organic waste that could involve: separation at the source, collection, transport and final use with a vermiculture composting system. Duarte et al. [19] concluded that with the development of this kind of integration system, the city of Bogotà can reduce up to 50% of the waste weight discharged in the Doña Juana landfill. Moreover, composting and vermiculture technologies have shown to be a valuable choice due to their economic accessibility, easy applicability and feasible administrative duties. Another key aspect that the experiment addresses is that including waste picker organizations promotes the generation of employment and consequently, the generation of higher and legal economical incomes to vulnerable families.

In addition to the previous study, another supporting case study is the one proposed by [24], who also compared the business-as-usual scenario of adopting landfilling with two food waste (FW) valorization alternatives: anaerobic digestion (AD) and composting (CP). The case study, specifically, focuses on the FW generated from a consortium of five different universities in Costa Rica. It was calculated that the universities generated a total amount of 2.607 tons of FW per week, with an operating service of 45 weeks of the academic year. The project was facilitated by a combination of Life Cycle Thinking (in which both life cycle assessment and life cycle cost were performed), linear programming and a multicriteria decision analysis method such as the Analytic Hierarchy Process. Regarding the environmental dimension, the main findings show that FW valorization alternatives would reduce both Global Warming Potential and Freshwater Eutrophication but, clearly, the anaerobic digestion would cause lower land use than composting. On the other hand, from the economic and social standpoints, the results show that alternative scenarios as AD and CP would have higher costs than landfills that, however, in the long term will probably be reversed. In addition, the paper aims to frame a complete circular economy-oriented scenario in the decision-making process and, within this prospective, it must be noted that initial investments will likely prevent future expenses. Furthermore, the valorization of FW would require more labor, which means higher costs but also new job opportunities.

A more economical prospective was explored by [32]. Diaz and Otomo address the Peruvian context by adding a further contribution aimed towards involving and systematizing informal recycling activities. To this end, the paper investigates a mathematical model able to calculate yields and costs of separate waste collection and of recycling alternative improvements. In Peru, current recycling and composting programs barely represent the 0.5% of national waste generation, but informal recycling, on the other hand, contributes to a reduction of almost 13% of waste and of 2.6% of food waste for pig feeding. As a consequence, in this case study, improving and formalizing the current informal recycling sector set the basis for a structural waste reduction system. To confirm this, the paper was developed in two sections: on one hand, it proposes a methodology to simulate separate collection, and on the other hand, it presents a more integrated analysis of the recycling and composting business by addressing cooperation risks that influence the collection. When it comes to recycling solutions, given good community cooperation, it was demonstrated that inorganic waste recycling has a wider margin of acceptance than composting. Recycling may indeed lead to attractive incomes that can potentially reach minimum wage. On the other hand, the case of composting is a bit more difficult and is even more dependent on good cooperation. Diaz and Otomo [32] demonstrated that with good cooperation only, the net cost of composting is lower than the usual landfill business scenario. The author also suggests that an interesting strategy to reduce the risks of a bad cooperation with waste pickers and the community is to locate composting facilities close to city markets, parks, clusters of restaurants and hotels and occasionally provide the service to the nearby residential area as well. Moreover, another key measure may be to give compost equivalents for tax incentives and grants.

3.2. Waste-To-Energy Alternative: Biogas Production

Besides compost production, first-generation biofuels are another growing industry in tropical and subtropical climates in LAC [22,33]. Although organic waste to energy (OWtE) technologies have been implemented in Latin America, they are insufficient, not only for the amount of waste volume but also to significantly supply the regional energy demand and meet national sustainability goals [7]. This phenomenon is due to a series of factors: the technological difficulties that this kind of infrastructure requires, along with a lack of research and education, unaffordable economic investment and weak political legislation. Silva-Martínez et al. [7], based on the Archival Research Method, presents research of state-of-the-art OWtE technologies in the context of Latin America and also addresses challenges and opportunities for improving adequate infrastructures. Silva-Martínez et al. [7] underlines that every year, millions of tons of agricultural, forest and urban waste are generated in LAC. The paper aims to provide a full and comprehensive understanding of the OWtE situation in LAC and divides the study in two main technological classification: thermochemical and biochemical processes.

As far as thermochemical processes are concerned, the main findings demonstrated that incineration is the most commonly used treatment in LAC. Because of low costs, combustion technologies are largely applied for agricultural and forest residues to produce electricity and, in particular, sugar cane bagasse and straw are the main combusted residues [7]. Countries such as Argentina, Brazil, Chile, Costa Rica, Honduras, Mexico and Uruguay also explored some densification techniques as pelletizing and torrefaction. On the other hand, gasification systems have been implemented in Cuba and Brazil, proving valuable experiences. Lastly, pyrolysis remains one of the least favorable practices especially in the Central America region.

Regarding biochemical solutions, recent years of studies have been focused on small-scale anaerobic digesters and landfilling in the Latin American context. Large-scale anaerobic digesters (AD) are not widely applied, primarily due to their high investment costs. On the other hand, important studies have been accomplished in LAC to explore the benefit of a combination of technologies, between co-digestion and biochemical methane potential. Fermentation industries aiming to produce first-generation (1G) biofuel are growing in the region, especially in Argentina, Brazil and Colombia. On the contrary, second-generation (2G) biofuels are not yet widely implemented but are getting more attention, especially from specific crops as sugarcane, coffee, corn, banana and palm oil. Likewise, biohydrogen production from dark fermentation is gaining ground in the region.

Above all, in LAC, low-cost household biodigesters are one of the most adopted technologies in rural areas to produce fertilizers and energy from agricultural residuals. Nevertheless, there are still some difficulties better identified in Garfi et al. [28], who provided an overview of household biogas digester developed in rural areas in Latin America. The authors stated that significant improvements have been achieved in the regions, including also the creation of a Network for Biodigesters in Latin America and the Caribbean (RedBioLAC), which aims to coordinate research programs throughout the continent.

The urgent need of turning organic waste into a valuable energy resource is also demonstrated by the fact that 31 million people in Latin America lack access to electricity, of which 87% in rural areas and 13% in urban areas. The authors explain that the design of household digesters mainly depend on climate conditions and available organic waste, skills and local materials. Commonly, the most used types are fixed dome, floating drum and tubular digesters. The fixed-dome digester is one of the most used in developing countries and it consists of a cylindrical chamber, a feedstock inlet and an outlet also used as a tank. Biogas is accumulated in the upper part of the chamber, as described in Figure 5a. The size of household digesters depends generally on local conditions such as biogas needs, organic waste and water availability. As far as the operation and maintenance aspect is concerned, Garfi et al. remind that the digester should be fed semi-continuously with organic waste that generally consists of manure diluted with water. The removing of the sludge is a challenging step, and it happens no more than once a year. Another example is the floating drum digester, which also consists of a cylindrical shape digester and a floating drum, generally made of steel or polyvinyl chloride (PVC), where the gas is accumulated. The drum also acts as a storage tank. It is built underground from concrete and steel. Through a pipeline, biogas is transported to a specific reservoir and used for cooking, heating and also lighting (Figure 5b). This case requires higher skilled labor for installation and also higher investment costs because of expensive construction materials such as concrete and steel, and sometimes, construction materials are not even available in rural areas. This system is fed daily with organic waste diluted with water. Its lifespan is shorter than the fixed-dome digester due to potential drum corrosion. The last most used digesters in LAC are tubular digesters (Figure 5c), which consist of a tubular plastic bag, generally made from polyethylene or PVC, though which the diluted feedstock flows from the inlet to the outlet. The biogas in this case is also transported from the digester to the reservoir by means of a proper pipeline. As mentioned above, the size depends on a number of different factors, but in poor rural areas of LAC—where families rely on agriculture and farming—a tubular digester volume is about 6–10 m^3.

The main findings of the paper illustrate that digester design vary according to a series of conditions such as water and waste availability, biogas and fertilizers needs, climatic conditions, local skills, raw materials availability, transportation feasibility and economic affordability. Moreover, it was demonstrated that in rural communities in LAC, biogas produces sufficient fuels for cooking and in the best cases, for electricity generation as well. From an environmental standpoint, biogas production is an environmentally sustainable system in rural areas of LCA; however, further improvements can be accomplished by researching and investing in more durable and sustainable materials to reduce the environmental impact but at the same time, maintain low costs. Nevertheless, the most significant barrier is initial investment costs for rural communities. From a social perspective, the authors stated that household can obviously improve health and quality of life, but trainings are nonetheless recommended for better community acceptance.

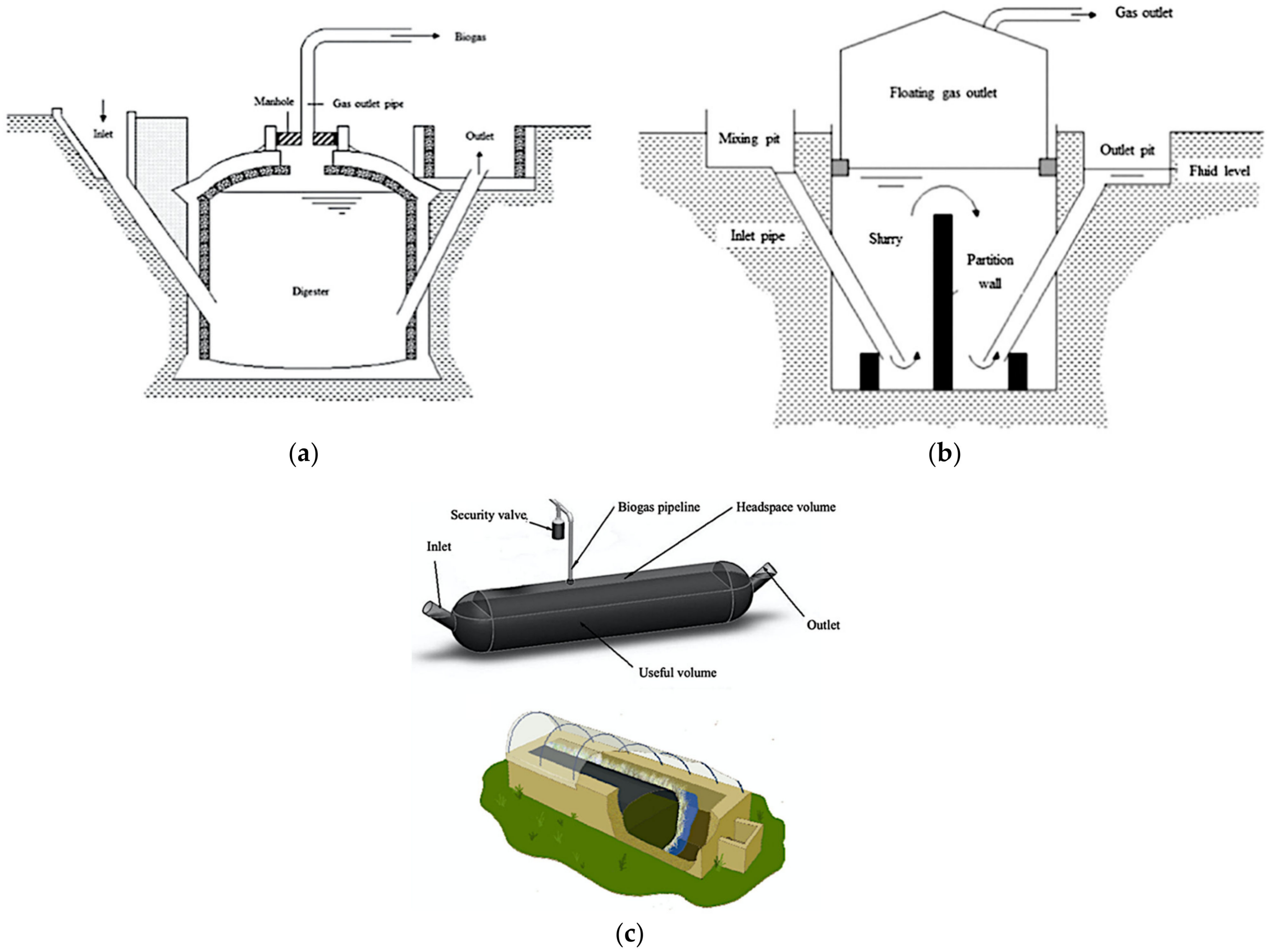

Figure 5. Schematic diagram of type of digesters. (**a**) fixed-dome digesters; (**b**) Floating digesters model. (**c**) Tubular digester model [28]. ©Elsevier, 2016.

This research was further complemented by the study of [25], whose aim was to validate and develop a multi-criteria decision support tools for the assessment of household digester programs in rural areas in LA. To this end, the methods consisted of three levels of decision: the local community, the digester model and the digester design selection. A set of evaluation criteria was established and weighted. The most significant criteria were those related to socio-economic aspects and digester reliability and durability. The methodology was then validated considering three case studies from rural Peruvian areas. To conclude, the multi-criteria decision analysis was suitable in a decision-making process for designing sustainable and reliable biogas programs, but the authors suggest that it should be introduced by specific training to help stakeholders become familiar with the applicability of new methodologies.

More specifically, [34] developed a life cycle comparison between a fixed-dome and a plastic tubular digester in the rural Andean communities. Over a span of 20 years, the plastic tubular digester were shown to be the more affordable alternative. For instance, capital costs for the plastic tubular digester were 12% lower than the fixed-dome digester, and also initial investment costs for a plastic tubular digester were also 1/3 of the fixed-dome digester. However, some maintenance costs were higher due to the plastic materials that require a replacement approximately every five years. From the environmental life cycle prospective, on the other hand, tubular digester generates the highest impacts because of the short life of plastic materials. In the fixed-dome model, high impacts are imputable to the use of concrete and bricks.

The specific case of tubular digester was also explored by [31] as it is widely used in developing countries for the treatment of livestock waste. Kinyua et al. [31], through a systematic review, list a series of potential benefits from the use of tubular digesters. First, anaerobic digestion produces net energy. Second, as far as the agricultural aspect is concerned, the digester effluent contains a large number of nutrients to be used such as soil enriching. Moreover, it contributes to decreasing deforestation, mitigating water contamination from the livestock sector and lowering air emissions if compared with combustion of firewood and other organic waste. It is also a social-oriented solution, due to important benefits for human health and gender inequality issues. Gender inequality-related concerns are not yet well tackled in poor contexts, but have been present since former generations. Due to traditional rules, women are assigned to intense and exhausting activities such as the collection of firewood and water as well as the food preparation. This means that women spend about nine hours per day in survival activities, in harsh and complicated conditions. If anaerobic digestion systems are installed, women would also be able to save energy and time.

3.3. Other Biowaste Valorizations

Besides composting and biogas production, other interesting examples are given by [29]. The paper describes the multiple benefits a correct bioeconomy system might have. For instance, it focuses on smart agroforestry systems, considering its contribution to sustainable rural development. They provide, indeed, clear energy from bioenergy (as biodiesel, bioethanol and biogas) but also a reliable level of food security due to a simultaneous system production. They also have important social advantages thanks to the creation of new jobs and therefore to additional incomes. Another significant aspect is the mitigation of climate change because of a strong reduction in GHG emissions, the absence of land-use change phenomena, a structural water protection and biodiversity conservation programs due to the application of multi-culture plantations.

Nevertheless, in developing contexts, if not properly well-design, bioenergy programs and solution still have some negative repercussions on forest degradation, indoor pollution and food insecurity; therefore, innovative system and project need to be correctly addressed in order to gain all the potential benefits that bioenergy can embrace.

A touchable example of food waste valorization is the numerous strategies to fight banana waste loss. Acevedo et al. [23], for instance, states that in 2019, 51.227 hectares of bananas were planted in Colombia and often, after harvesting, almost 60% of banana biomass was wasted. Consequently, almost 115 million metric tons of banana waste loss are generated in the world. Acevedo et al. [23] delineated a comprehensive review to demonstrate the potential of banana waste loss valorization towards a stronger circular economy in Latin America. Among others, the paper argues that thanks to the high content of carbon, compound banana peels are used in diverse applications: mainly to obtain bioplastic materials, but also to produce biofuels as diesel and ethanol. Moreover, banana leaves are used to produce biodegradable packaging, utensils and organic fertilizers. Cellulose and hemicellulose from banana waste content can also be useful for nanotechnologies.

To conclude, [20] through a series of practical examples, we dove into a more general understanding of the essence of bioeconomy in Latin America.

4. Conclusions

The study stresses the difficulties that the LAC region still encounters in its transition towards a new bioeconomy, which is particularly clear in biofuels and bioproducts sectors. In the region, local specific and small-scale solutions were shown to be more appropriate for the geographical area (widely rich in biodiversity and natural ecosystems) and also better welcomed by the community.

From the present review, it appeared clear that organic waste management and circular bioeconomy are sectors in which new technologies still need to be consolidated, in opposition to the European context. This highlights the importance of developing public and business policies that prioritize waste reduction in production and organic waste recovery and valorization.

Additionally, it is important to heed the great potential LAC region has in boosting circular economy strategies and policies. The case examples described emphasize this strong potential but also shed light on the difficulties the region is still encountering. In most of the cases, economic dependence should be reduced; this is likely, especially with the help of international cooperation. Therefore, it is necessary to advance in experimental studies to better develop more circular solutions for organic waste management to reduce huge organic fraction volumes and reduce potential environmental burdens.

As a final recommendation, the authors stated that future research should address tailored training and participatory programs to maximize social acceptance and economic revenues from innovative bio-based alternative solutions.

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