Sustainable Bio-Waste Management

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Alongside production and consumption, bio-waste management is central to the food systems debate. To achieve sustainable food systems—an essential component of the Sustainable Development Goals and the world they envision—public authorities must address the shortage of current bio-waste-management policies and strive towards a new paradigm of bio-waste management, where environmental justice primarily informs policy design and decision making.

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1. Introduction

There is no shortage of solutions for the sustainable management of bio-waste, such as material recovery by composting or anaerobic digestion, the go-to waste-to-energy method that transforms bio-waste into biogas, a process from which digestate is also created (Gadaleta et al. 2021).

Although the methods for the sustainable management of bio-waste—understood as the “biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants” (European Union 2008, Directive 2008/98/EC)—are well known to the scientific community and practitioners, it largely remains to be understood how to move away from more traditionally linear methods, such as landfilling and incineration—considered as such when not matched with energy recovery (Dhanya et al. 2020)—and towards more circular methods, such as composting and anaerobic digestion. Therefore, understanding which factors determine the development of bio-waste management systems (Contreras et al. 2010) is increasingly essential.

The growing prominence of sustainability and sustainable development has drawn researchers to the theme of waste management and, in particular, to bio-waste management, the food waste portion of which is understood as an essential component of the construction of circular food systems (Jurgilevich et al. 2016). As the interest in this topic has grown, so has the attention given by researchers to the drivers of bio-waste management, as shown by the multiplication of reviews of waste-management drivers over the last decade and a half (Agamuthu et al. 2009; Contreras et al. 2010; Márquez and Rutkowski 2020; Wilson 2007; Zaman 2013).

2. The Role of Bio-Waste Management in Building Circular Food Systems

In the European Union (EU), the Circular Economy Action Plan for a cleaner and more competitive Europe launched in 2020 (European Commission 2020a) constitutes one of the main pillars of the European Green Deal. The aim of the Action Plan is to "accelerate the transition to a regenerative growth model that gives back to the planet more than it takes", "reduce its consumption footprint", and "double its circular material use rate in the coming decade". Similarly, Directive 2018/851 of the European Union (2018), amending Directive 2018/98/EC, establishes in its Article 11 recycling targets, according to which by 2025, a minimum of 55% of municipal waste by weight should be recycled or prepared for reuse, a target that rises to 60% in 2030 and 65% in 2035 (Directive 2018/851). Regarding food, the Farm to Fork Strategy for a fair, healthy, and environmentally friendly food system (European Commission 2020b) states that "The circular bio-based economy is still a largely untapped potential for farmers and their cooperatives. For example, advanced bio-refineries that produce bio-fertilizers, protein feed, bioenergy, and bio-chemicals offer opportunities for the transition to a climate-neutral European economy and the creation of new jobs in primary production".

Food constitutes one of the most important sectors of the economy, accounting for 8.3% of jobs and 4.4% of GDP in Europe (Lemaire and Limbourg 2019). As they consume 79% of the food produced annually (FAO 2019), cities are the main driver of food systems (Calori et al. 2017), thus positioning themselves as an element of the utmost importance for the discussion on food sustainability.

The debate on food sustainability and cities includes the concept of a circular food system, understood by Jurgilevich et al. (2016) as one that "implies reducing the amount of waste generated in the food system, re-use of food, utilization of by-products and food waste, nutrient recycling, and changes in diet towards more diverse and more efficient food patterns" (p. 2). Distinguishable from linear food systems by their concern for reducing emissions and waste at all stages of the food system and by its environmentally responsible treatment of food waste, circular food systems involve action at three stages: production, consumption, and waste management (Jurgilevich et al. 2016).

To this end, the scientific community has focused a great deal of effort on the issue of food waste, defined by the United Nations Environment Programme (UNEP) as food and the associated inedible parts removed from the human food supply chain (to landfill, controlled combustion, sewer, litter/discards/refuse, co/anaerobic digestion, compost/aerobic digestion, or land application) in the sectors of manufacturing of food products, food and grocery retail, food service, and households (UNEP 2021).

This interest can be justified by the data released by UNEP, which indicate annual food waste of around 931 million tons in 2019 (UNEP 2021), corresponding to the waste of one-third of all the food produced globally in a year and whose use would feed two billion people (UNEP 2015). In the European Union, the most recent data indicate food waste of 59 million tons in 2020, corresponding to 131 kg per inhabitant (Eurostat 2023).

Alongside these, the renewal (both in volume and type) of food needs in developing countries (Lemaire and Limbourg 2019; Porter et al. 2016) places growing pressure on global food systems, further justifying the SDG concern with production and consumption (and food waste associated with these stages of the food system), as stated in SDG 12 (Responsible Consumption and Production) and its target 12.3 (“By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses”), as well as in target 2.4 (“By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality”) of SDG 2 (Zero Hunger) (United Nations General Assembly 2017).

Despite different definitions of food waste—from those that understand food waste as the edible material that is ultimately wasted from production to consumption (FAO 1981; Gustavsson et al. 2011; Jurgilevich et al. 2016) to those that also include in their definition the inedible material that is ultimately wasted (Ladele et al. 2021; Östergren et al. 2014)— food waste constitutes a much broader set of losses than just the food itself.

The production of food that ends up wasted has significant impacts on the use of natural resources, fertilizers, and fuels (Krishnan et al. 2020; Sehnem et al. 2021), as well as those arising from water use—with Lemaire and Limbourg (2019) pointing to an expenditure of 306 cubic kilometers of water in the production of food that is eventually wasted—and from greenhouse gas emissions resulting from the landfilling of this food or its treatment in similarly environmentally inefficient ways (Gokarn and Kuthambalayan 2017; Jurgilevich et al. 2016; Sehnem et al. 2021). This set of losses, with an estimated economic impact of USD 490 billion (Esparza et al. 2020), makes food waste equivalent to the third most polluting country in the world (UNEP 2015).

Notwithstanding the importance of acting on production and consumption (and the problem of food waste underlying both these phases), it is on the third phase or element of circular food systems—bio-waste management—that researchers will focus for the remainder of this study.

Papargyropoulou et al. (2014) developed a food waste hierarchy and suggested that action on food waste should be preferred, in the following order: prevention, reuse, recycling, recovery, and finally, disposal. Thus, after efforts to prevent surplus food generation and food waste generation, the focus of food waste management policy should shift to the reuse of excess food produced, namely through surplus food distribution (Garrone et al. 2014). For undistributed food and food rendered inedible, the food waste hierarchy suggests its conversion into animal feed (Esparza et al. 2020) or its composting.

A succeeding option to composting—and in opposition to the understanding that the choice of methodology to be used in food waste management should be dependent on an analysis of the concrete circumstances of the context where the waste is generated (Weidner et al. 2020)—is recovery, understood as the conversion of food waste material into energy, namely through anaerobic digestion (Papargyropoulou et al. 2014).

At the tip of the reverse pyramid suggested by Papargyropoulou et al. (2014)—and with the agreement of the scientific community (Cobo et al. 2018; Greben and Oelofse 2009)—is landfilling. Indeed, while it is possible—and, increasingly, legally required—to recover gases from landfill decomposition (Dhanya et al. 2020; Pearse et al.

2018), that is still not the norm, helping to make waste disposal the third largest human source of methane emissions (Esparza et al. 2020). In addition to occupying large areas and causing unpleasant odors, the impacts of landfilling are, according to Gao et al. (2017), ten times higher than those generated by any of the other available treatment methods, making landfilling the most “linear” solution for managing bio-waste. Nevertheless, landfilling remains the most popular bio-waste conversion method worldwide, particularly in developing countries (Feiz et al. 2020).

For Esparza et al. (2020), there is no one-size-fits-all solution for bio-waste management. Rather, the choice of how to deal with bio-waste should depend on an analysis of several factors, such as population density, volume of waste generated, installed collection practices, expected social acceptance, political–administrative availability for the implementation of projects, and assimilation capacity of generated products (Weidner and Yang 2020). Thus, the ideal bio-waste-management policy is one that adapts and chooses the most appropriate management methods for each reality it faces (Esparza et al. 2020).

3. Bio-Waste Management Drivers

3.1. A Comprehensive Review of Bio-Waste Management Drivers

To improve bio-waste-management policies, it is necessary to understand what pushes them forward or pulls them back (Márquez and Rutkowski 2020). Researchers are dealing with the issue of drivers, understood as the “factors that positively (termed facilitators) or negatively (termed constraints) alter an existing waste management system” (Agamuthu et al. 2009, p. 625), or, according to Wilson (2007), the “mechanisms or factors that significantly impact development in (…) waste management” (p. 198). In fact, current bio-waste management systems have no single raison d’être but, rather, result from the impact of several factors, which vary across space and over time (Contreras et al. 2010).

In turn, Contreras et al. (2010), studying waste management in Yokohama and Boston, analyze the temporal evolution of four distinct categories of drivers: socio-economic drivers, regional and international drivers, technology development and institutional drivers, and legal drivers. Zaman (2013) distinguishes three categories of drivers: social (which he subdivides into personal behavior, local waste management practice, and consumption and generation of waste), economic (where he highlights the resource value of waste, the economic benefit from waste-treatment facilities, and the landfill tax), and environmental (mentioning both global climate change and environmental movement and awareness). Finally, Márquez and Rutkowski (2020), in a historical analysis of waste management in Colombia, suggest the following drivers: public health, decentralization, financial sustainability, environmental protection, free competition, social control, integrated waste management, and inclusive recycling.

In fact, the first driver of bio-waste management was the resource value of waste (UNEP 2015), with waste pickers being at the center of the early stages of waste management generally (Rodić and Wilson 2017). Under the transition from the idea of “waste management” to an idea of “resource management” (UNEP 2015), and particularly in the context of the bio-waste portion of waste, the resource value of waste drivers is completely different in nature today than it was originally. Furthermore, given their impact on the choices made surrounding waste management policy, the costs of inaction on waste and issues related to financing waste management deserve consideration (UNEP 2015).

The second historical driver of waste management (namely bio-waste) was public health. Although it has since been surpassed as the main driver of waste-management policies, public health was one of the first and most important facilitators of these policies, which have evolved with the aim of stopping the spread of diseases in the urban environment resulting from uncontrolled waste disposal (UNEP 2015). Its relevance as a motivator for the adoption of new public policies on these issues remains significant in developing countries (Márquez and Rutkowski 2020), which have not yet overcome these challenges, and it has not yet been forgotten in developed countries either.

Moreover, among the drivers traditionally highlighted in the literature is environmental protection. The environmental movement established in the 1960s and 1970s (UNEP 2015) sharpened focus on the growing concern for waste in discussions about the sustainability of the planet. Nevertheless, the idea of environmental protection as a driver of bio-waste management has been disregarded by authors such as Agamuthu et al. (2009), for whom environmental protection constitutes a natural consequence of the action of other drivers. In fact, some authors have pointed out limitations to the analysis of drivers, highlighting the difficulty of understanding the actual influence of each driver, since they are interconnected (Zaman 2013), interacting in ways that can contaminate the analysis of the individual impact of each driver alone (Agamuthu et al. 2009).

Alongside these, researchers highlight drivers that only more recently have gained prominence. One example is the public awareness driver. Incredibly important for understanding the evolution (and future prospects) of bio-waste management, the public awareness driver can be divided into two components: public acceptance and personal behavior (Esmaeilian et al. 2018). Although initiatives on sustainable and circular bio-waste management have multiplied over the last years (Lemaire and Limbourg 2019), there is still a general lack of public awareness on the subject, which manifests itself both in the weak pressure exerted by citizens on public authorities and in the lack of sustainable practices of citizens themselves in bio-waste management (Weidner et al. 2020). Public acceptance and personal behavior promise to gain renewed importance as the EU pushes towards a brown-bin bio-waste collection system (Directive 2018/851).

Equally worthy of attention is the driver of scientific knowledge. Among its contributions to the design of new and more sustainable bio-waste management systems, it should be highlighted that scientific knowledge has contributed to the perfecting of existing bio-waste management technologies. In addition to the evolution of bio-waste management systems depending on the ability of scientific knowledge to improve existing methodologies through technological development, they also depend on the ability of scientific studies to analyze the efficiency of the different methods available and to propose the most correct solutions for each context. In this sense, the driver of scientific knowledge can be broken down into two dimensions: one theoretical, relating to the accumulation and maturation of the themes studied in the different forums by the literature, and one practical, relating to the creation of methodologies, instruments, and techniques of bio-waste management, and therefore more closely associated with an operational (or technical) dimension.

Finally, the policy and legislation driver should be considered. From political debate are born the legal instruments that seek to concretize the community's vision on each topic, and, in this case, on bio-waste management (Lemaire and Limbourg 2019; UNEP 2015). By establishing the framework within which action on bio-waste must take place and the rules to which it must comply, legislation is both the limit and the guide to action on bio-waste management.

3.2. The "Policy and Legislation" Driver as a Make-or-Break Approach to a More Sustainable Bio-Waste Management

Legislation constitutes one of the main repositories of the secondary objectives associated with bio-waste management, such as public health, environmental protection, or resource value of waste (UNEP 2015), playing an essential role in the evolution of bio-waste-management policies.

In the European context, the influence of this driver on bio-waste-management policies is very closely linked to the European institutions, which have been the leading promoters of innovation in bio-waste management, particularly through the adoption of Directives. The first steps towards sustainable bio-waste management were made by the Landfill Directive (Directive 1999/31/EC) (Buratti et al. 2015), which set targets for a reduction in the volume of bio-waste landfilled and demanded the collection of the gases generated therein. Nine years later, although not addressing bio-waste in particular, Directive 2008/98/EC (Waste Framework Directive) established in the European legislative framework fundamental principles (polluter pays principle)—manifested in "pay-as-you-throw" (Ukkonen and Sahimaa 2021), "pay-as-you-own" (Messina et al. 2023), and "pay-as-you-differentiate" (Le Pera et al. 2023) schemes which have been studied and have proposed to encourage sorting at the household level (Chua and Yau 2022)—and concepts (producer extended responsibility and waste hierarchy) of current waste management (Taelman et al. 2018).

The next significant step in the field of waste management—and particularly in the field of bio-waste management—was taken by Directive 2018/851, which, amending the Waste Framework Directive approved ten years earlier, reinforced the need for Member States to take measures to reduce waste generation (Directive 2018/851). As it concerns bio-waste management, Directive 2018/851 highlighted the need to carry out selective collection of bio-waste, indicating that, to this end, by 31 December 2023, Member States should ensure the selective collection of bio-waste and its separation from other types of waste. This measure constitutes, for all intents and purposes, an obligation to implement a brown-bin system (Weidner et al. 2020).

Although the Waste Framework Directive (and amending Directive 2018/851) are recognized as being largely responsible for the significant advances recognized in waste management (and, in particular, bio-waste management) in Europe (Grosso et al. 2010; Zorpas et al. 2015), there is still much progress to be made in terms of sustainable bio-waste management. In addition to suggesting, given its specific characteristics, the development of a separate Directive for bio-waste, shortcomings are attributed to the European Directives approach to the subject of bio-waste.

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