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Biological valorization of urban solid biowaste: A study among circular bioeconomy start-ups in France

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1. Introduction

Cities face many challenges, among which is solid-waste management, which raises particular difficulties in an urban context, such as the dispersion of the source of household waste, heterogeneity of its composition, “Not In My Back Yard” (NIMBY) syndrome, or access to land for its treatment. These challenges will become even greater in the long run due to the increasing urbanization: 7 out of 10 people will live in cities in 2050, and the annual world municipal solid-waste (MSW) amount is thus expected to increase from 2.88 billion tons in 2020 (284 kg/person/year) to 3.88 billion tons in 2050 (Kaza et al., 2018). Therefore, waste management in cities must urgently become more efficient and sustainable to improve the environmental quality, protect human health, use natural resources efficiently and rationally, provide renewable energy, and offer new job opportunities (Brás et al., 2022). Current waste-management challenges differ according to countries’ income levels (Kaza et al., 2018). Specifically, at the European level, almost all the MSW (249 million tons in 2017) is collected, and some concerns mainly arise from its treatment and recovery as 50% of MSW is still sent to landfill or incineration (Eurostat, 2023). Incineration, even with energy recovery, and landfilling are positioned at the very bottom of the hierarchy of waste-management strategies, after waste prevention and reuse and recycling (Teigiserova et al., 2020). This hierarchy, introduced formally in the European waste regulation in 1991 by Directive 91/156/EEC (Duquennoi and Martinez, 2022), has since been reaffirmed and reinforced several times, particularly in the European Circular Economy Action Plan (EC, 2020). The European regulations currently in force provide that a maximum of 10% MSW should be landfilled by 2035 (Directive 31/1999/EC) and that at least 65% of MSW should be recycled by 2035 (Directive, 2018/851/EU on waste management). To facilitate recycling, Directive 2018/851/EU also added the obligation to separately collect textile and household hazardous waste, as well as biowaste for all producers, including both households and professionals. Consequently, municipalities must set up separate collection schemes before December 31, 2023 (for biowaste) and January 1, 2025 (for textile and hazardous waste), which will not be easy for many of them.

This study focuses on biowaste, which includes garden- and park-biodegradable waste, household food waste, food waste from restaurants, canteens, offices, and retail, as well as food processing (see Directive 2018/851/EU). In 2017, 86 million tons of biowaste were produced in Europe (EEA, 2020), comprising 60% food waste and 35% garden waste. Only 43% (37 million tons) of this biowaste was separately collected in 2017 (Brusselaers and Van Der Linden, 2020). However, the composition of municipal biowaste varies greatly from country to country—from 20% of food waste in Hungary to more than 90% of food waste in Denmark. The same holds for the biowaste-capture rate, i.e., the share of biowaste produced that is separately collected: from less than 10% for Portugal,

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Turkey, Spain, and Cyprus to more than 80% in Austria and Slovenia in 2017 (Brusselaers and Van Der Linden, 2020). Consequently, the type of separate collection schemes and ease of implementing them will differ greatly from country to country.

Individual household composting of biowaste could be an environment-friendly solution; however, it requires consumer awareness, a positive attitude, the right knowledge, a careful selection of materials, and control (Kunszabó et al., 2022; Voukkali et al., 2023), and it is therefore rather recommended by researchers in rural and sparsely populated regions (Martínez-Blanco et al., 2010).

In France, approximately half of the biowaste is separately collected (Brusselaers and Van Der Linden, 2020); however, most of it comprises garden waste collected in waste-disposal centers. Indeed, only 175 cities have door-to-door separate collection schemes for household biowaste, which covers only 6% of the French population. France is thus far away from the target of separate collection for all biowaste by December 2023, which was introduced in the 2020 French law against waste and for a circular economy (Loi du 10 février 2020 relative à la lutte contre le gaspillage et à l'économie circulaire). This law specifies that cities must establish source separation of biowaste and ensure that the biowaste collected will be recovered and not landfilled. This is a major challenge for many local authorities, particularly because of the significant costs involved in establishing new collection systems.

To help communities meet these new obligations and to contribute to more efficient, sustainable, and circular waste management and resource use in cities, an increasing number of private start-ups with new circular and bioeconomy business models are emerging. Circular business models have been defined in various ways; however, they mostly combine the value creation, proposition, delivery, and capture concept proposed by Osterwalder and Pigneur (2010) with circular-economy principles such as recycling, use-time extension, or substitution of products by services (Geissdoerfer et al., 2020). Circular business models aim at more sustainable and regenerative economic systems (Salvador et al., 2020) by maintaining the value of products and materials in the economy as long as possible and closing or narrowing resource loops (Bocken et al., 2016). Bioeconomy business models convert biomass (e.g., waste and co-products from agriculture, food production, and forestry) into diverse new value-added products such as bioenergy, biofertilizers, biomaterials, or food ingredients by applying circular strategies such as recovering, recycling, upcycling, and cascading the biomass (Donner et al., 2022). Developing and implementing bioeconomy business models is generally challenging due to several external macro-environmental market, political, legal, cultural, as well as internal technical, organizational, and financial-management factors (Donner et al., 2021). Especially for bioeconomy start-ups, the different viewpoints between academics and industries can impede the necessary technology transfer (Ocampo-López et al., 2019).

The entrepreneurship literature also provides insights for better understanding the emergence and role of new business models (start-ups) for the transition to a bioeconomy (Kuckertz et al., 2020; Wilde and Hermans, 2021). The concept of entrepreneurship refers to an individual who recognizes, evaluates, and exploits a business opportunity (Venkataraman, 1997). Key questions of entrepreneurship include the "*why, when, and how*" opportunities for developing new (sustainable) products and/or services, and "why, when, and how" entrepreneurs discover and exploit these opportunities (Shane and Venkataraman, 2000). Thus, considering the specific temporal, spatial, institutional, and social context is crucial for understanding the emergence and persistence of entrepreneurship (Welter, 2011). Wilde and Hermans (2021) stated that innovative bioeconomy entrepreneurship was based on entrepreneurs' *innovation willingness* (i.e., individuals' or organizations' learning and performance orientation), its *innovation capability* (i.e., the ability to combine resources and knowledge that result in new products, services, or markets), and *perceived innovation opportunities* (individuals who perceive, imagine, and interpret their external environments, which are subject to change); however, innovation success also depends on sectoral, regional, and national innovation systems and value-chain configurations, and it can be hindered by national and international institutions.

While solid-biowaste conversion in cities has until now been researched from a technological (e.g., Yaashikaa et al., 2020; Lohri et al., 2017), a life-cycle (e.g., Zeller et al., 2020), or an urban-metabolism (Zeller et al., 2019) perspective, a business and entrepreneurial viewpoint remains lacking. The objective of this study is to identify the different types and value propositions of these private initiatives of biowaste management in France, and to understand the enablers of and barriers to their development. To the best of our knowledge, this type of emerging, small-scale, and urban circular-bioeconomy business model has not yet been presented in the academic literature. Following a description of the prevailing biowaste-transformation processes (Section 2), the methodology is specified (Section 3). Section 4 presents the results, detailing the different types of start-ups observed, and discusses their characteristics, the enablers and barriers, and their contribution to the literature.

2. Prevailing biological valorization processes of urban solid biowaste

The core components of the circular-bioeconomy sector rely on biowaste-transformation processes. Biological processes, also known as bioprocesses, appear particularly well adapted to small-scale biowaste-valorization initiatives. Presently, three families of biological processes are readily available for the valorization of biowaste in urban contexts: composting, vermicomposting, and anaerobic digestion. All three can be considered as the intensification of natural processes.

2.1. Composting

Composting is a strictly aerobic process involving living organisms that all require unlimited access to oxygen for their maintenance and growth. This living biomass transforms residual organic matter into a humus-like product called compost, generally readily eligible for soil amendment. It must be underlined that, as natural as it may appear, composting is a technological, human-controlled process requiring optimal operating conditions and a good understanding of its core biological drivers. The overall action of the living organisms all along the composting process can be understood as the consumption of simple, easily degradable organic compounds, leading to the concentration of more complex and less degradable ones. The organisms responsible for this action are principally bacteria, as they are the most adapted to the rapidly changing physico-chemical conditions of the process.

When conducted efficiently in terms of oxygenation, the composting process emits gas comprising carbon dioxide (CO_2), volatile organic compounds (VOC), and ammonia, the latter two compounds being responsible for odors. CO_2 emission from composting is considered neutral in terms of global warming because it is biogenic. Nonetheless, whenever anaerobic conditions appear during the composting process because of a lack of aeration, potent greenhouse gases (GHGs) such as methane (CH_4) and nitrous oxide (N_20) can be emitted (Sánchez et al., 2015).

The initiatives included in our study use three different types of composting technologies, using Makan and Fadili's (2020) terminology:

- Turned open heaps or windrows: windrows are outstretched piles of organic substrate. Both windrows and heaps are passively aerated and regularly turned, usually by mechanical equipment. The system is operated outdoors and thus tagged as “open.”
- Home/foot-of-the-building/neighborhood bin-type composters, more or less regularly turned. Such composters are generally open and more seldom equipped with a lid.
- Dynamic closed composters: quadrangular or cylindrical reactors with a built-in mixing device, either with or without forced aeration.

Open heaps and windrows may be indifferently used for small (converting up to 150 tons of waste per year, according to Plana (2015)) and medium- to large-scale (from 150 t/y upward) operations. Meanwhile, bin-type composters and dynamic closed composters are generally devoted to small-scale operations.

Other technologies are available, essentially for large-scale facilities, such as agitated bays/channels, in-vessel tunnels, rotating drums, etc. (Makan and Fadili, 2020); however, none of them were encountered in our study.

Open composting systems (Open heaps/windrows and bin-type composters) are simpler to operate and less costly than closed systems (dynamic closed composters); however, they require more land space, more time to obtain the final product and, as the process is less controlled, often lead to a greater variability of the end-product. Moreover, as suggested by Makan and Fadili (2020), closed composting systems release less GHGs and odors than open systems. Leachate production and management must also be considered when assessing the impact of composting systems on the environment.

Dynamic closed composters can be automated, with control of some of the main parameters governing the composting process.

Because of the complex biological drivers of the composting process, the final quality of compost as a manufactured product depends both on the composition of the organic residual matter entering the process and on the operating conditions and parameters (moisture content, oxygen availability, process technology, and duration). Therefore, whereas they are all tagged by the same term “compost,” there exists a very large array of products resulting from the composting process, exhibiting a large variety of physical, chemical, and biological characteristics and soil-amending properties.

2.2. Vermicomposting

Vermicomposting is another type of biological process used to treat biowaste in households, small-scale proximity, and even industrial systems. It entails the decomposition of organic waste by earthworms (mainly *Eisenia fetida* sp.) and is biologically more related to anaerobic digestion than composting, the organic matter being transformed by worms' anaerobic digestive tracts. The products of transformation are the worms’ feces.

The ideal waste for vermicomposting has a high organic content ($>50\%$) and a fairly high moisture content, between 70% and 90% (Edwards and Bohlen, 1996). Meat and dairy products are to be avoided in feeding the worms, as well as fats and salted food waste, either because they disturb the worms’ digestive process or because they attract pests. A pre-treatment shredding process is often necessary to reduce the particle size of the waste and facilitate its ingestion.

Whereas different technologies exist for the vermicomposting process (bins, windrows, silos/reactors, channels, etc.), the initiative included in our study uses only windrows.

It has been suggested (Komakech et al., 2015) that the environmental impact of vermicomposting is lower than that of composting, especially due to less GHG emissions and lower energy consumption because no regular turning of the waste/compost is required.

2.3. Anaerobic digestion/methanization

Anaerobic digestion, as its name suggests, involves strictly anaerobic micro-organisms growing only in the total absence of oxygen. Whereas anaerobic digestion is generally considered a complex and sensitive process (Amani et al., 2010), it has been applied to a large array of liquid waste, such as sludge or wastewater, for decades and more recently to solid organic waste.

When aiming at producing biogas, anaerobic-digestion processes progress through different phases, finally leading to the production of the CH_4 and CO_2 mix called biogas. The optimal temperature for anaerobic digestion ranges from 20 °C to 60 °C, i.e., in mesophilic as well as thermophilic conditions. Below 20 °C and above, gas production is considerably lowered and the process may even be stopped.

Anaerobic-digestion technologies vary considerably depending on the physical state of the raw organic materials to be treated. In the following, we focus on technologies adapted to solid biowaste. In this case, the two principal families of technologies differ by the total solids content of the treated waste mixture:

- “Wet” digestion: in this process category, the concentration of solids has to be lowered down to below 20%, giving way to a slurry-type material. It can be done either by adding water or by mixing solid biowaste with sludge or manure. The latter procedure is called co-digestion. Wet-digestion technologies vary essentially with the technique used for stirring the waste mixture.

- “Dry” digestion: the process is considered “dry” when the solids concentration is higher than 20% and usually lower than 40% (Rocamora et al., 2020). More recent and less generalized than its counterpart, dry digestion is generally conducted in batch (discontinuous) reactors and then technologically resembles in-vessel composting. As the mixing of solids inside the reactor is very limited, thus reducing the potential for biogas production, some recent dry-digestion technologies rely on the in-vessel recirculation of liquids percolating through the waste.

Small-scale anaerobic digestion is a recent tendency that has mainly been applied to agricultural waste. The micro-scale anaerobic digestion (mAD) of urban biowaste can still be considered to be in an experimental phase, and it uses either wet (González et al., 2020) or dry (Degueurce et al., 2022) digestion in micro-scale reactors treating from 5 tons to 200 tons of biowaste per year (Thiriet et al., 2020).

3. Methodology

As the development of solid-biowaste collection and valorization companies in urban contexts is very recent and still ongoing, the existing examples are too limited to consider quantitative studies. In addition, one is dealing with a type of start-up company that has until now been largely unexplored. Therefore, a qualitative exploratory-research approach was adopted. The main method for collecting data was based on case studies as this represents one of the most suitable qualitative methods in organizational studies, and it helps us understand how a complex contemporary phenomenon occurs (Voss et al., 2010; De Massis and Kotlar, 2014). A case study is based on an intensive study of a single unit (or several) to understand a wider range of similar units (Gerring, 2004). Cases were selected according to the following criteria: the geographical boundary of metropolitan France (overseas territories were excluded as they are not subject to the same legislative regulation for biowaste); private small companies or associations that collect and/or valorize biowaste in cities; and companies that offer technical solutions for biowaste management or that develop and support these activities.

As the companies are still small and emerging, they are often not well referenced or do not yet have their websites. Therefore, the search was conducted in various ways. Some of the initiatives could be found in local or regional newspapers (e.g., the EUROPRESSE database) because pro-environmental actions are often promoted there. Moreover, the SHIFT YOUR JOB website, which lists companies in the field of ecological transitions, allowed identifying initiatives. Last, the snowball method helped us find more enterprises, which means companies could provide contacts of other initiatives with whom they collaborated. In total, 37 initiatives could be found across France. They were all contacted and asked for an interview, and 17 responded positively and were available. As shown in Table 1, the 17 cases studied are located in different regions in France and operate in different cities. Among the cases, nine are micro-enterprises, six have the status of an association, and only one is a small enterprise with more than ten employees.

Semi-structured interviews were conducted with each initiative, as this allows the interviewer to follow predefined guided questions while simultaneously the interviewee can further develop and address specific points that would not have been thought of before. The interviews were conducted with the enterprise managers via telephone or online conference tools in June and July 2022, and they lasted from 30 to 90 min.

The analytical framework used was based on the business-model canvas components (Osterwalder and Pigneur, 2010) and Antikainen and Valkokari's (2016) enlarged framework for sustainable circular business-model analysis, which has been adapted to the specific agrifood sector in earlier studies (Donner et al., 2020, 2022). Herein, the following categories are defined to analyze and understand the larger business eco-system and context, different components and functioning of a (circular and bioeconomy) business model, its value creation, proposition, delivery, and value-capture strategy, and its requirements and impact on the environment:

Table 1
Overview of the 17 cases studied.

Case No	Year of creation	Type of initiative	Region	Area of action
1	2019	Micro-enterprise	Auvergne-Rhône-Alpes	Lyon
2	2019	Micro-enterprise		
3	2017	Association		Clermont-Ferrand
4	2021	Association	Bretagne	Rennes
5	2021	Micro-enterprise	Centre-Val de Loire	Chateauroux/Indre
6	2020	Association		Orleans
7	2019	Association	Grand-Est	Strasbourg
8	2021	Association	Hauts-de-France	Lille
9	2018	Micro-enterprise	Ile-de-France	
10	2019	Association	Nouvelle-Aquitaine	Bayonne
11	2020	Micro-enterprise		Bordeaux
12	2017	Cooperative	Occitanie	Montpellier
13	2022	Micro-enterprise		
14	2020	Micro-enterprise	Provence-Alpes-Côte d'Azur	Marseille
15	2015	Micro-enterprise	Several sites in France	
16	2020	Micro-enterprise		
17	2018	Small enterprise		

- the general macro-environmental trends and drivers (PESTLE analysis: political, economic, social, technological, legal, and environmental factors)
- the larger stakeholders concerned
- the individual firm-development and business-model components, including key partners, activities, and resources; the value proposition; the customers, customer relationships, and channels; and the costs and revenue streams
- the sustainability or circularity requirements and impacts

The interview guide from Donner et al. (2020, 2022) was adapted to the specific context of biowaste valorization by small start-up enterprises in cities (cf. Annex 1). All interviews were recorded, and based on the records as well as the notes taken during the interviews, detailed summaries were written. The written summaries were verified and approved by the interviewees. The collected data were then coded and analyzed according to the main themes, first for each single case and thereafter comparatively.

4. Results and discussion

From the data analysis, five different types of businesses could be identified.

The different types of business models are presented and characterized mainly according to their value propositions and technologies used, but also considering their value creation (activities, resources, and partnerships), distribution (customers and distribution channels), and value capture (costs and revenues) (cf Annex 2).

4.1. Type 1 – local biowaste collection and composting

This type is represented by ten companies whose key value proposition comprises local biowaste collection and a processing service, with collection by bicycle (and electric vehicle for some of them) and processing essentially by composting. Only occasionally, additional biowaste quantities are given to an external biogas-production unit. The value proposition also includes complementary activities for some of these start-ups: support services for installing composters and raising user awareness; training (composting site referent); various workshops in the case of start-up number 3, who organizes *do-it-yourself* and gardening workshops; or sales of fruit and vegetables (case number 9).

Table 2 shows the technical models used and scales of the biowaste treated. Most start-ups use open heaps/windrows composting.

Revenues mainly stem from the collection service offered to customers. These customers are typically companies that produce biowaste (restaurants, catering services, florists, etc.); however, they can also be local authorities in the case of household biowaste. One start-up (case 3) is subsidized by the local authority that hosts it to collect restaurant biowaste in addition to household waste. This company receives a subsidy calculated based on the quantity of biowaste collected.

For all these companies, whether they process a small or medium volume of waste, the planned technical developments include expansion, to benefit from economies of scale, in a context of increasing demand. Cases 1 and 4 are planning to automate/mechanize their processes to reduce labor. All other cases are planning to expand while keeping the same process. Economies of scale are essentially linked to collection and the labor required to turn the compost. Last, they all point to the high costs of collection equipment (mainly electric cargo bikes), whose purchase was only possible with subsidies.

Most of these start-ups distribute compost free of charge because their compost does not conform to the French standard for soil improvers, NF U44-051 (AFNOR, 2006), and consequently cannot be sold. The NF standard sets limit levels for trace-metal elements (TME), organic trace compounds (OTC), micro-organisms, as well as the maximum annual flux of TME and OTC, which should be used to prescribe the maximal dose of soil improver to be applied. Only four of the ten companies in the category sell their compost. In these cases, the company owners point out that the selling price is low, and that the revenue from sales represents only a very small proportion of their business income.

Overall, few companies refer to the quality of the compost in the interview, apart from one start-up (case 10), who analyzes the quality of its compost in relation to its practices in order to readjust the latter; case 1, who has been selling a product meeting the French standard for a long time; and case 9, who sells potting soil rather than compost to gain added value.

This raises questions about the quality of composts that do not meet the standard for soil improvers and the environmental impact of composting. The objective of returning organic matter to the soil that most of these companies pursue is not necessarily fully achieved if the compost is of poor quality.

Table 2
Technical models and scales of the enterprises of type 1.

Technical model	Company	Scale (waste flow)
Open heaps/windrows composting	11	Medium (200 t/y)
	1	Medium (200 t/y)
	7	Medium (157 t/y)
	10	Small (104 t/y)
	4	Small (52 t/y)
	6	Small (20 t/y)
Neighborhood-type open-bin composters	13	Small (3 t/y)
	3	Small (35 t/y)
Dynamic closed composters	8	Small (15 t/y)
	9	Small (50 t/y)

There is no real difference in the business models for the different technical models, except perhaps for one start-up (case 8). This company has a very clear objective of re-integrating long-term unemployed people and only hires them on fixed-term contracts, with fully subsidized salaries.

Among the companies' partners, local authorities or urban farmers often provide them with working space or land to install composters or windrow composting. Local authorities or public agencies also help finance the purchase of equipment. Some partners are customers of the firms' services and products, and may include restaurants, florists, gardeners, catering services, etc. Last, partnerships often provide part of the service. Regulations require biowaste to be sorted and recycled, and partner companies can provide the entire biowaste-transformation chain. Competition at territorial level varies greatly from one town to another; however, the start-ups feel threatened by the big players in the market (Suez and Veolia) and are uncertain about their future commercial strategy. They often highlight that bicycle collection represents a competitive advantage in relation to city-traffic conditions (small or pedestrian streets), although the costs of this collection mode are higher than those of truck collection.

In terms of prospects, business case number 11 is aiming to set up operations in different cities using this business model, while case 10 is in the process of changing its business model to focus more on composting and support instead of biowaste collection.

4.2. Type 2 – innovative processing

This type comprises companies with a value proposition focused on biowaste processing and a high level of technical expertise. The three related companies have developed a specific processing technology, either through patent registration on methanization (case 15) and on dynamic-closed composters (case 17) or through scientific experimentation on vermicomposting for company number 2. They sell equipment and associated services, such as design for biogas units, audit, software and training for dynamic-closed composters, or vermicomposting training. Business numbers 2 and 15 also offer biowaste collection and processing services. These two companies collect biowaste by trucks. However, start-up number 2 has a dual activity: it conducts the processing itself but also provides a service to private individuals, in which case the customer performs the processing independently.

From a financial viewpoint, these enterprises have all been subsidized for their research and development (R&D) activities.

Cases 2 and 15 build long-term relationships with their customers as they sell processing and collection services. Case 17 “only” performs audits and then installs the equipment and trains the customer. It is then up to the customer to manage the processing and collection.

In terms of resources, these companies rely on their own know-how. They call on partners to build the equipment, install the biogas-production unit (for start-up 15), or establish the vermicomposting platforms (case 2). This know-how affords them a technical and operational advantage over their competitors.

Moreover, the quality of the vermicompost is extremely high, allowing high sales prices as soon as it is authorized for sale. Currently, a major obstacle to the development of biowaste vermicomposting is the regulation prohibiting the sale of vermicompost, which cannot withstand sufficiently high temperatures to guarantee the destruction of pathogens.

4.3. Type 3 – training and advice services

This type of business model includes only one case (number 12).

The value proposition comprises composting expertise, with two types of service offered: training of professionals and auditing to support companies or local authorities in local composting. This company is very similar to type 2 businesses in terms of technical expertise. The essential differences are that start-up 12 sells neither equipment nor collection-processing services and has not been innovative in its process.

Revenues thus comprise income from the services sold; the resources mobilized are solely labor and technological know-how. The essential partner for this activity is a network that lists all training courses to promote them.

4.4. Types 4 and 5 – innovative equipment for biowaste collection and storage

The value proposition of the companies belonging to these two types is centered on technological innovations that allow the management of the perishability of organic waste. The companies sell innovative equipment (biowaste collection and storage equipment) as well as collection and processing services associated with the proposed equipment. The innovative equipment include refrigerated containers for one company, dehydrators for another, and airtight tanks for the third. All these companies collect biowaste by trucks.

None of these companies received any subsidies.

Two sub-types can be distinguished here: type 4 represented by business 16, who developed the innovation and filed a patent, and type 5, including cases 5 and 14, who sell equipment developed by other enterprises.

Company 16 (type 4) has long-term contracts with its customers and has built a partnership with Gaz Réseau Distribution France (GRDF). It has managed to obtain a public-funding loan and to raise private funds. Start-ups of type 5 have considerable difficulties in finding customers and neither have funding partners.

4.5. Synthesis and discussion

As a synthesis, the following Fig. 1 shows the various types of companies on a diagram, with their level of technical expertise on the x-axis and their core value proposition between collection and processing on the y-axis.

All these companies mention a strong environmental motivation for the biological recovery of bio-waste, with the choice between composting, methanization, and vermicomposting responding to different viewpoints on these processes.

Several composting initiatives (6 companies) emphasized that they preferred this process because the organic matter returns to the soil. Two of these companies were highly critical of the environmental impact of methanization due to lorry traffic to supply the

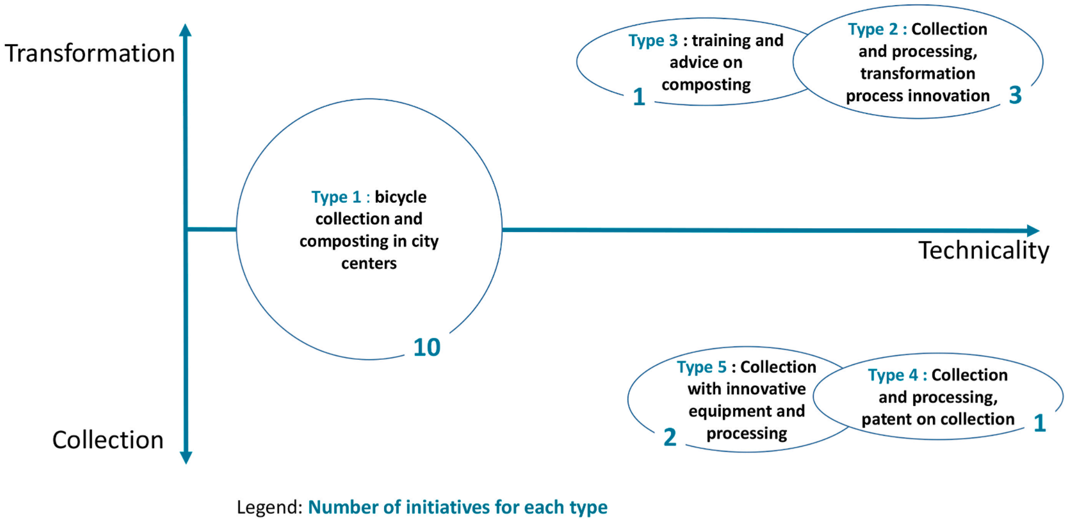

Fig. 1. Value proposition and technical level of the different business model types.

plant and the fact that the process produces CH_4. Others consider that anaerobic digestion and composting are complementary. They chose composting for financial reasons, as the investment cost was much higher for anaerobic digestion, and because of the technological knowledge required to implement the process.

The two businesses involved in methanization point out that composting emits gases that are harmful to the environment while methanization recovers all the carbon contained in bio-waste.

Comparing the advantages and drawbacks of composting, vermicomposting, or anaerobic digestion and confronting these processes is an arduous task that will not be conducted herein. For example, some types of organic waste (e.g., fats and animal products) are hardly compostable in non-industrial, small-scale processes as well as with vermicomposting, either because they disturb the biological processes or because they attract pests. Meanwhile, fats, meat, and dairy products are perfectly susceptible to anaerobic digestion. However, the anaerobic digestion of urban biowaste requires specific procedures for the temporary storage of waste prior to treatment in order to prevent the aerobic degradation of easily degradable organic matter, which may lead to an important loss of biogas-production potential. Types 4 and 5 initiatives develop and/or use specific technologies to prevent this degradation of organic matter during transport from collection points to valorization facilities. Start-up 16 (type 4) has developed a collection technology for processing by methanization. Type 5 companies have chosen preservation processes (dehydration and refrigeration) mainly to reduce the inconvenience of biowaste storage, and they recover the biowaste collected through composting and vermicomposting.

Despite their differences, all these companies emphasize the highly favorable regulatory context for sorting and recycling biowaste, increasing general awareness for environmental issues, and resulting increase in demand for biowaste collection and processing services. Customer-tailored value propositions corresponding to individual needs, waste collection within well-defined geographical limits, and transformation near the city's centers are important for success. Meanwhile, companies stress the constraints associated with biowaste management as storage and processing can generate nuisances. Another barrier is that customers are sometimes still difficult to find and often hesitate to pay for the collection of biowaste.

The start-ups are all recent, fast-growing businesses, many of which are not yet profitable. Moreover, these companies operate in a highly uncertain context, both from an economic viewpoint, as the biowaste collection and recovery market is highly dynamic, with the emergence of many new companies and competition from existing large-scale companies, and from a political viewpoint, as it depends on the political choices made by the major players in the market, i.e., local authorities.

Regarding the “why, when, and how” opportunities of entrepreneurship (Shane and Venkataraman, 2000), these start-ups recognize well the “why”—the urgent need for solutions for environmental challenges as well as new business opportunities—and the “when”—the current favorable institutional-legal conditions. However, the “how”—here, concerning the most suitable technological, organizational, and customer responses to biowaste collection and valorization, is still at a rather experimental stage, as witnessed by the diversity of their individual activities and value propositions.

In this sense, the innovation capabilities (Wilde and Hermans, 2021) based on combined technological, financial, and human resources and knowledge must be reinforced to further develop and establish their business models toward new markets. This could, for example, allow improving the quality of the compost, meeting the requirements of the French standard for soil improvers (AFNOR, 2006), and selling the product with value-added instead of giving it away for free.

The question of the persistence and resilience of these companies arises but is difficult to address given the highly changing economic environment, uncertainty about regulations, and subsidies for circular and bioeconomy businesses. It would be relevant to conduct a longitudinal study of these companies to better understand and monitor their strategies and develop well-founded recommendations.

Only three families of processes (composting, vermicomposting, and methanization) are represented in our study, whereas considerably more biomass-transformation processes are technologically available and increasingly operated at medium and large scales in industrial biorefineries. In this regard, it is often thought that the larger investment cost of these biorefinery technologies hampers their implementation in small-scale initiatives. Nevertheless, the high added value of the products they potentially deliver could be a driver for innovative initiatives in the near future, especially if innovative process designs could lower their cost; a combination of a business-and a technological-model analysis could then serve to monitor those innovative trends.

5. Conclusion

With increasing urbanization globally, collecting and valorizing (bio)waste in efficient, sustainable, and circular ways becomes urgent. Innovative business models are required to deal with specific customer needs, public regulatory demands, and citizens' wellbeing while creating sustainable added value. This study has offered novel insights into the business types and value-creation mechanism via an empirical analysis of 17 circular bioeconomy start-ups in French cities and contributes to the scientific literature, combining management and bio-based sciences.

The results showed that five major types of circular bioeconomy start-ups currently exist in France: the most common type, whose central value proposition is local biowaste collection and valorization via composting; the second type, which focuses on innovative processing technologies such as biogas production via anaerobic digestion or vermicomposting; the third type, which offers training and advice services; and types 4 and 5, which either develop (type 4) or propose (type 5) innovative equipment on the markets for biowaste collection and storage as well as a processing service.

The findings from this study indicate the importance of customer-oriented value propositions at small scale: in our examples, biowaste is collected by bikes or e-vehicles within a restricted area and converted close to the city center. We could also highlight such enabling factors of the start-ups as (1) an increasing demand for environmentally responsible business activities as well as, more directly, for energy and soil-amendment products; and (2) more drastic public regulations of separate biowaste collection. In parallel, some barriers could be identified: (1) the difficulty of identifying all the potential customers; (2) the reluctance of some of the customers to pay for biowaste collection; (3) the high initial costs related to investment in technological equipment and/or costs of starting a business; (4) the low income from the small amounts of compost, which is furthermore often given away; (5) the difficulty of raising public financing; and (6) competition from larger-scale, well established companies.

The main conclusion is that most of the small-scale business models that have recently emerged in France in the field of urban biowaste encounter difficulties in entering the market and still depend largely on public financing. The upcoming regulation of household-biowaste separate collection is thought to result in an increasing demand for such services but is simultaneously expected to create more competition. In this context, it is conceivable that small-scale businesses might develop partnerships for joint responses to upcoming calls for tenders from local authorities. As these insights are derived from the exploration of cases in a single country, a larger-scale survey should be performed in Europe among urban biowaste-valorization start-ups to corroborate and supplement the present study and provide scientifically grounded business and policy recommendations.

CRediT authorship contribution statement

Sandrine Costa: Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Mechthild Donner:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Christian Duquennoi:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization. **Valentin Savary:** Methodology, Investigation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Annex 1. The interview guide used

1) INITIATIVE

When and how was your company created? What were the main objectives of the project? Why did you settle in an urban environment? Was it a public or private initiative?

2) VALUE PROPOSITION

What are your main services/products offered? What benefits and value do you bring to consumers and users of your service/product? What types of bio-waste do you recover (food waste, green waste, solid/liquid)? What elements made it possible to decide your choice of valorization (composting/methanization)?

3) CLIENTS

Who buys the electricity/heat/compost that you produce or that your partners produce? How are the products of recovery (compost/biogas, …) recovered? How do you find new customers? Are your customers loyal or do they stop using your service/product after a while?

4) RELATION CLIENTS

Would it be difficult for your customers to switch companies providing the same service/product? Are there any problems with residents (odor emission, noise, etc.)? Do you have a long-term relationship with your customers?

5) CHANNELS

How is the (reverse) supply chain/bio-waste collection organized? What are your distribution channels? What are your communication channels?

6) CLE PARTNERS

Do you have public partners? Private? Do you have equipment shared with your partners?

7) KEY ACTIVITIES

What are your key activities? Do you outsource certain activities? How do you manage the variability (quantity and quality) of biowaste? How do you optimize processes? Why did you choose this means of collection? Does it create jobs?

8) KEY RESOURCES

What are your technological resources? Do you have patents and/or other intellectual property? How many people are employed in your company?

9) COSTS

Is the technology investment a major cost for you? How long is your ROI? Does the size of your equipment allow you to make economies of scale?

10) REVENUE STREAM

What is your pricing strategy? Do you receive public subsidies? If it's not confidential: estimate the percentage of electricity/heat/digestate used as input. How do you create value? How does this pay your employees?

11) STAKEHOLDERS

Who are the different stakeholders related to your activity? How do you take their expectations into account? Are you involved in a business group or network?

12) IMPACTS OF CIRCULARITY

Do you analyze your environmental impact? If so, how? How many tons of biowaste do you recover? What are your final waste streams? What method or indicator do you use (tons of bio-waste, carbon footprint, life cycle assessment)?

13) TRENDS AND DRIVERS

What is the regulation on the treatment of bio-waste? How are green energy/compost prices evolving?

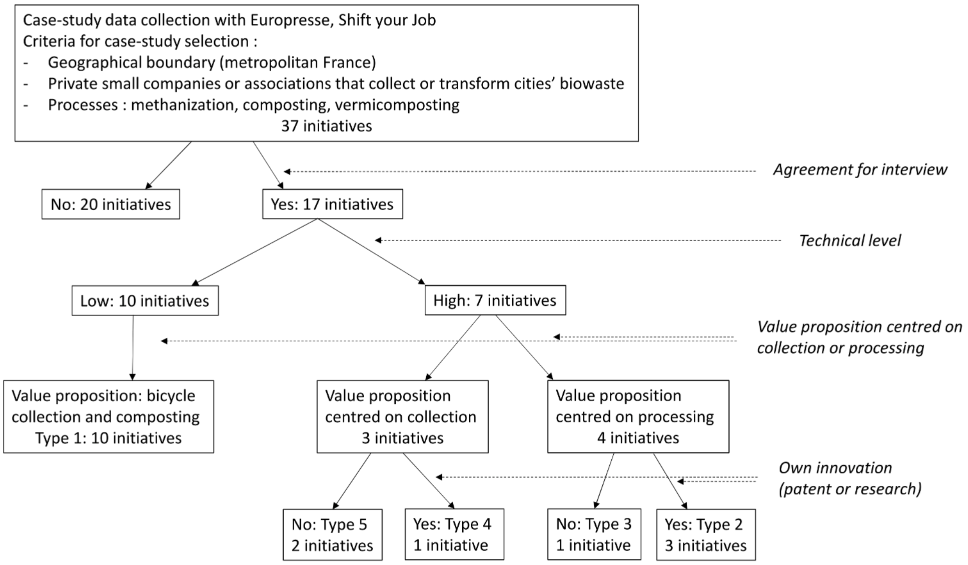
14) INSTITUTIONAL ELEMENTS

Are there any political, economic, social, technological, ecological or legislative aspects that have a positive/negative impact on your activity?

15) LESSONS LEARNED

What have you learned from the past and what is your vision for the future (opportunities/threats)? Do you have any future development plans?

Annex 2. logic diagram of start-ups analysis



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