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Implementing Decentralized Composting in Urban Areas in Romania - between European Models and Local Initiatives

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ABSTRACT

Managing bio-waste in urban areas poses significant challenges for local governments, particularly in countries with underdeveloped waste management systems. However, decentralized composting has emerged as a viable solution in various cities and regions worldwide. This paper examines the potential for implementing decentralized bio-waste management systems in urban areas in Romania, a European Union member state with notably low performance in municipal waste management. We analysed three decentralized composting systems from EU countries, focusing on system design, circularity, and household participation. From these case studies, we identified several transferable best practices, including analysing local waste generation patterns, designing circular models, using modular units for rapid implementation, training composting specialists, tailoring behavioural change tools to local contexts, and ensuring continuous performance monitoring. In addition, we explored local bottom-up initiatives for decentralized composting in urban areas in Romania such as green NGOs, informal composting networks, networks of local food producers and consumers, urban gardening practices rooted in the Communist era, and entrepreneurial initiatives offering household bio-waste collection services. We argue that policymakers should adapt these best practices to local conditions and actively engage with bottom-up initiatives to co-create tailored solutions and support behavioural change. The study concludes with policy recommendations for implementing decentralized composting systems. These findings offer a practical framework to guide the development of context-specific composting solutions in Romania and other Central and Eastern European countries with similar urban characteristics and public attitudes towards waste management.

1. INTRODUCTION

Bio-waste is the largest single component of the municipal waste in developing and developed countries alike (Kaza et al., 2018). In the European Union (EU) it represents 34% of all collected municipal waste, and a large share of if (50% on average) remains embedded in the residual waste being landfilled or incinerated (European Environment Agency, 2020). The term bio-waste refers to "biodegradable garden and park waste, food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers and retail premises and comparable waste from food-processing plants" (Directive 2018/851/EC, Article 1). Because of the natural decaying processes of organic matter, landfilling it contributes to increased emissions of greenhouse gases (Smith et al., 2001) and to environmental pollution by leachate production (Ma et

al., 2022). Moreover, bio-waste could be used for producing natural fertilizers and/or biogas, while landfilling or incinerating it may be perceived as wasting valuable resources (Favoino and Giavini, 2020).

The EU policy on waste tried to divert as much bio-waste as possible from landfills - the Landfill Directive specifically requested member states to implement such measures (Directive 1999/31/EC, Article 5). The revised 2018 Waste Framework Directive went further and required the separate collection and treatment of bio-waste or the recycling at source (e.g., home composting), and that all member states should implement such separate collection streams by the 31st of December 2023 (Directive 2018/851/EC, Article 22). However, there are large differences among the member states in what concerns the efficiency of its management (Eurostat, 2021): while the EU's annual average for recycling bio-waste is of 95 kg/capita, the values for different member states vary from more than 150 kg/capita (Danmark, Luxembourg, Austria, Switzerland, Netherlands, and Belgium) to less than 20 kg/capita (Romania, Estonia, Bulgaria, Cyprus and Malta). In this context, there is an urgent need for identifying ways of dealing with bio-waste in both a circular and economically efficient manner in European member states which perform poorly in this field.

There are many available technologies for bio-waste treatment (Lohri et al., 2017 reviewed them), but, in the EU, the most commonly used are composting and anaerobic digestion (European Environment Agency, 2020). Because it is a rather simple technology, composting is a very popular solution for dealing with separately collected municipal bio-waste all over the world, and it is the dominant one in the EU, as well (Kaza et al., 2016). It can be done in both rural and urban areas, at various scales, in centralized or decentralized ways. The scientific and grey literature on waste management uses the term "decentralized composting" with many different models, but the main common aspect is composting bio-waste in the proximity of the place where it was generated. Depending on factors such as population density, the volume of the generated bio-waste, local economic activities, etc., decentralized composting can take various forms. These include home-composting, on-site composting at farms (using crop residues, manure, etc.), at public or commercial institutions (such as schools, campuses, hotels, hospitals, restaurants, etc.), and in public gardens and parks. It also encompasses community composting (small-scale initiatives involving groups of households) and urban-rural partnerships, where bio-waste collected from urban areas is composted in nearby farms.

In terms of implementation and operational costs, a decentralized composting system may be the first choice for diverting large amounts of bio-waste from landfills in countries with low labour costs and low investment in technologies (Rothenberger et al., 2006). However, its multiple benefits have also been demonstrated in urban areas of developed countries - Pai et al. (2019) list them under four categories: logistic (reduced transportation of the bio-waste and of the produced compost), ecological (through locally reuse of the organic matter, by providing a substitute for artificial fertilizers and by increasing the citizens' awareness on the food-waste and, thereby reducing it), economic (reduced cost related to the separate collection and processing of the food-waste, reduced cost with landfill taxes, extending the life of the existing landfills, and economic benefits to the municipalities from meeting their waste diversion and zero-waste targets), and social (stimulating the creation of small local business, supporting the urban farms by increasing their income in cases in which the decentralized composting system includes them as partners, and by the reduced cost of the fertilizer purchases).

Souza and Drumond's (2022) systematic review highlighted several key insights into the implementation of decentralized composting systems - centralized and decentralized approaches are not mutually exclusive and can complement each other; decentralized systems often produce higher-quality compost (particularly in low- and middle-income countries); most decentralized composting initiatives are not financially self-sustaining and typically require support from local governments; community composting sites can serve as hubs for educational activity and community engagement. They also emphasized that the success of decentralized composting involves shifting the focus from purely technological aspects to educational aspects aimed at shaping public attitudes and encouraging community participation.

For municipalities wanting to implement a decentralized bio-waste treatment system there are various technical solutions that fit different spatial, socio-economic and climate characteristics of the urban areas: open-air onsite composting, in-vessel composting systems (static composters, rotating drums, rotating containers with forced aeration, etc.), vermicomposting systems, windrows composting systems (static or revolving windrows, with or without aeration systems, encapsulated or not in semi-permeable materials), etc. (Souza and Drumond, 2022; Weidner et al., 2020; Plana et al., 2019; Rothenberger et al., 2006). However, an efficient decentralized composting system relies the most on public participation and correct segregation of the bio-waste. So, besides the technical design and the specific infrastructure, finding adequate ways of achieving behavioural change (based on a good knowledge of the local population's attitudes and practices) is equally important. But Celestino et al.

(2022) found that most articles on household bio-waste management primarily focus on infrastructural issues (only 23% of the articles selected for their review addressed psychosocial factors). These authors further examined how sociodemographic characteristics (income, age and education), psychosocial factors (convenience and social norms), and communication and education campaigns influence waste management practices aligned with circular economy principles. Their findings indicate that individuals with higher education levels are more likely to engage in proactive recycling behaviours, while those with higher incomes are more willing to pay for food-waste management services. Convenience emerged as the most significant factor influencing participation in waste prevention and bio-waste separation programs, while recycling behaviours were shown to be shaped not only by personal intention but also by the influence of neighbours and peers. Moreover, the authors concluded that in the analysed studies there was not sufficient evidence to determine whether communication and education campaigns effectively impacted recycling behaviour. Other authors, however, argued that local bottom-up initiatives can be more effective in promoting social change – for example, by enhancing the social acceptability of decentralized waste-management (Souza et al., 2023), or by "infiltrating" the mainstream institutions and challenging the prevailing perspectives on waste management (Zapata Campos and Zapata, 2017).

These findings suggest that the most effective approaches for implementing successful decentralized composting in a given area are highly dependent on the local context, and, while "importing" solutions that worked well elsewhere may make the implementation faster, pairing them with the already existing practices and local initiatives may increase their public acceptance and household participation. Based on this assumption, in this paper we explore the decentralized composting as a solution for bio-waste management in urban areas in Romania from two perspectives: as best practices to be transferred from successful cases in Europe, and as local initiatives to build upon in order to achieve the behavioural change needed for the system to function properly. Thereafter, the objectives of this study were:

- to identify best practices of implementing decentralized composting in urban areas in European Union that can be transferred to Romania (or other member states lagging behind in terms of bio-waste management) and,
- to identify local bottom-up initiatives that may support the implementation of decentralized composting in urban areas in Romania.

We chose Romania as an illustrative European case for a country that urgently needs to improve its bio-waste management system – it has both a large share of bio-waste in the collected municipal waste (57% according to PNGD, 2017, p. 27), and poor overall waste management performance, ranking last among EU member states, with a municipal recycling rate of just 12.3%, significantly below the EU average of 48.7% (Eurostat, 2022).

Our research builds on existing literature on decentralized bio-waste management in Romania. Home composting has been examined as a response to the loss of organic matter resulting from wild waste dumping in rural areas (Mihai and Ingrao, 2018), and as a tool to support Zero-Waste municipalities initiatives (Bodog et al., 2018). It is also recognized in policy frameworks, such as the National Waste Management Plan (PNGD, 2017), where it is identified as a key instrument for reducing waste sent to landfills. Moreover, many county-level waste management plans incorporate home-composting as a means of diverting bio-waste from landfilling (Drăgan, 2021). However, beyond home-composing and door-to-door collection of the municipal bio-waste for centralized treatment (at the composting facilities within integrated municipal waste management centres), medium-scale solutions such as community composting have not been incorporated into urban waste-management strategies planned for implementation in Romania. This omission represents a clear research gap that the present study aims to address. In addition, to the best of our knowledge, no prior comparative analysis that includes both best practices and bottom-up initiatives has been undertaken, underscoring this study's contribution to the Romanian waste-management literature.

The present paper is organized into four main sections. The first section provides an overview of the European and Romanian contexts for municipal bio-waste treatment, identifies a gap in the existing research, and outlines the study's objectives. The second section briefly describes the research methods employed. The third section presents best practices in bio-waste management from three European countries and analyses local initiatives for decentralized composting in urban areas in Romania. By comparing these approaches, the paper advances a framework for implementing decentralized composting in Romanian cities. The final section offers policy recommendations for stakeholders interested in promoting decentralized composting systems in urban settings.

2. METHODOLOGY

This paper primarily draws on case study research focused on successful decentralized composting systems in Europe, complemented by an analysis of best practices.

We approached this study by searching scientific and grey literature and the Zero Waste Europe NGO's webpage (www.zerowasteeurope.eu) for

successful decentralized composting models in Europe. We selected (by purposive sampling) three case studies that were different in terms of the system design and were implemented for a long enough period of time in order to prove their efficiency. We browsed through scientific and grey literature (waste management plans, waste management organizations webpages, reports, guidelines, etc.) on those case studies and used document analysis to gather information and data related to them. We conducted a comparative analysis to identify similarities and differences among them based on three specific criteria: the decentralized composting system's design, the circularity of the system, and the household participation (mostly the ways of engaging households into the bio-waste segregation and decentralized composting). Based on this information we identified best practices for designing and implementing decentralized composting systems in urban areas in Europe.

We identified decentralized composting activities in Romania through an online search for composting projects and community initiatives promoting composting in urban areas. This included a general web search and a query using the Share Waste app conducted in January 2021. The search revealed 18 composting sites registered on Share Waste within the Cluj-Napoca Metropolitan Area, seven of which were located within the city itself. This represented the highest concentration of listed sites among all metropolitan areas in Romania (it was followed by the Bucharest Metropolitan Area which had 11 sites). Given the predominance of results related to Cluj-Napoca, we chose to focus our investigation on decentralized composting initiatives in its metropolitan area. Further information on local initiatives was gathered from local media, social media platforms (including groups dedicated to composting and local producer-consumer networks), and the websites of environmental NGOs. Additionally, we attended, as an observer, the webinar "Compostul în oraş / The compost in the city" (April 27th, 2021) organized by a local environmental NGO (Clujul Sustenabil, 2021) with the participation of several composting enthusiasts and a representative from a waste-management company.

The methodology employed in this study presents several limitations. Firstly, the small number of selected European case studies, and the way we selected them, constrained both the scope and diversity of the identified best practices. Consequently, other relevant case studies that may have implemented valuable technological innovations, activities, and measures were likely overlooked. Secondly, the inventory of local initiatives is limited due to the sparse documentation in Romanian scientific literature on the topic, and the reduced online availability of relevant data. However, the aim of the current paper was not to provide an exhaustive catalogue of best practices or local initiatives, but rather to offer a framework to guide policymakers in developing context-specific solutions.

3. RESULTS AND DISCUSSION

3.1. Selected European decentralized composting case studies

3.1.1. The Austrian model for decentralized composting

In Austria, the separate collection of bio-waste at household level has been made mandatory by an ordinance issued in 1992, and the strategy for implementing the bio-waste management was "as much home composting as possible; brown bin offered wherever home composting is not possible; as much decentralized agricultural (on farm) composting as possible" (Amlinger, 2012, p. 10). The implementation of this strategy resulted in 50-60% of the municipal bio-waste generated at the national level being home composted, and almost a third of the collected bio-waste being recycled in agricultural composting facilities (Amlinger, 2012).

The decentralized agricultural composting of the municipal bio-waste based on the collaboration between waste management associations and farmers is an important part of the waste management system in Austria. It relies on on-farm composting in facilities with an average capacity of 1.100 tonnes/year, representing 64% of the facilities in the country (Amlinger, 2012). In this model, the municipal bio-waste is collected by waste-collecting companies or even by the farmers themselves (mainly door to door, but also by bring points for bulky green waste) and it is processed at farm level, usually using specific tools and machinery. This activity is strictly regulated - the composting process and the resulting material need to adhere to environmental norms and quality standards specified in a national technical guide (Amlinger et al., 2009), in order to ensure the lowest possible ecological impact, traceability, quality classification, and further use. Training and certifying organizations further support the farmers in the implementation of this process. The long-term implementation of this cooperation model between municipalities and farmers, and the importance given to the correct waste segregation (supported by both advising and fining) resulted in usually very low contamination rate of the collected bio-waste with non-compostable materials – in certain cases, less than 0.5% (Amlinger, 2020).

This collaborative, decentralized model has been successfully implemented not only in rural areas and small towns but also in the metropolitan area of Graz, which has over 300.000 inhabitants. In Graz, the municipal waste company is responsible for collecting the brown bins (used by households to separate bio-

waste) and for pre-treating the collected material. This pre-treatment includes removing impurities, mixing households bio-waste with garden and park waste, shredding bulky green waste, etc. The processed material is then transported to 18 farms and commercial composting facilities across the province of Styria for composting. The resulting compost at each farm is tested by an external laboratory and designated for either agricultural or non-agricultural use (Amlinger, 2012).

The correct segregation of the bio-waste at household level, home-composting and other small-scale community composting activities are supported by waste advisers and waste disposal fee reduction (e.g. a home composting bonus - Holding Graz, 2024). The waste advisers were established in Austria since 1986 as full-time employees of municipalities and/or waste management associations; in 2016, there was, on average, one waste adviser for 20.000 inhabitants (Dri et al., 2018). Their main role is awareness-raising and public education in sustainable waste management, but also advising local authorities, associations and companies in implementing collection schemes, communication campaigns, etc.

The regulation of the composting process, the existence of the quality assurance schemes and quality standards for compost have contributed to the development of a market for this product. However, in the decentralized agricultural model the largest share of the resulted compost (70-90%) is used in the farms that produced it, but municipalities may also request part of it for public space landscaping or for giving it for free to the residents (Amlinger, 2012).

3.1.2. The Pontevedra (Spain) case study

The "Revitaliza" Plan in Pontevedra province (Spain) is a notable example of implementing diverse decentralized composting solutions at the regional level. Launched in 2015 by regional authorities through the establishment of the Revitaliza consortium, the plan aimed to increase municipal recycling rates and manage bio-waste locally. At the time, Pontevedra had a low separate collection rate for recyclable waste - around 9% (Mato et al., 2019), while bio-waste accounted for 47% of municipal solid waste (Perez Losada and Martinez Abraldes, 2021). The province relies on incineration for waste disposal, but the incinerator is located outside its borders, requiring waste to be transported an average of 120 km (Mato et al., 2019).

After an in-depth analysis of local settlement patterns, waste quantities and composition, a decentralized composting system was designed as a mix of home-composting, community composting (in sites processing up to 30 tonnes of bio-waste/year), small composting facilities (1.000-3.000 tonnes/year), and a larger facility of 25.000 tonnes/year (Mato et al., 2019). Their spatial distribution was tailored to population density – home-composting was promoted in low-density areas; community composting sites (each equipped with three to ten composting modules) were established in communities of 100 to 1.000 inhabitants; small local composting facilities served more densely populated areas, and a large facility was designated for the city of Vigo, with approximately 300.000 inhabitants. Once fully implemented, the regional system will include 86.937 home-composting units, 2.912 community composting sites and six composting facilities, serving 61 municipalities and a total population of around 900.000 (Mato et al., 2019).

The implementation of the Revitaliza Plan was designed along three successive phases. As described by Perez Losada and Martinez Abraldes (2021), it starts with a learning and experimentation phase in the municipalities and households that voluntarily enlisted to the program. After that, the municipalities entering the second phase had to ascertain recycling objectives and a minimum level of implementation of the decentralized composting. In municipalities with a sequestration rate of bio-waste higher than 25%, the third phase may be implemented. This one is based on mandatory bio-waste segregation, full implementation of the decentralized composting, and firmly assumed separate collection targets. In 2021, after five years of Revitaliza Plan implementation, 47 municipalities had joined the program, with a total number of 10.349 home-composters and 162 community composting sites. Out of those municipalities, nine (including the Pontevedra city of around 80.000 inhabitants) were already in the second phase, and four of them were prepared for the transition to the third phase.

A key component of the Pontevedra case study is its community composting scheme, which serves 36.7% of the population (Mato et al., 2019). In this model, households separately collect their bio-waste and transport it nearby composting sites, located no more than 150m away. These sites are managed by "master composters", who are responsible for maintaining the composting process (e.g., watering, turning, sieving), monitoring operations (through regular inspections, data collection and sampling for quality analysis), and maintaining communication with participating households (Plana, 2020). The compost produced is either returned to the participating households or used for municipal landscaping. Local authorities support the installation and functioning of the composting sites by allocating public space for them, ensuring access to running water and bulking agents, and employing the "master composters". The Revitaliza consortium supplies composting modules, supports the monitoring of the community composting sites, the master composters' training (in special programs, in collaboration with local universities and NGOs), assists the municipalities with implementation,

and conduct awareness-rising and educational activities for the general population (Mato et al., 2019).

Because of their limited capacity, these composting sites do not require installation or environmental permits. Additionally, since the compost is used locally (it is not a market product), the composting sites are exempt from stricter quality standards applied to larger composting facilities under Spanish law (Mato et al. 2019). However, as meat and cooked food are accepted, proper sanitization of the compost is necessary (achieved by maintaining temperatures of at least 55°C for 14 consecutive days). Monitoring of 76 community composting sites revealed that these sanitization conditions were met in 92% of cases. Furthermore, in terms of the heavy metals content 75% of the compost samples qualified as at least Class B under Spanish compost quality regulations (Mato et al., 2019).

The implementation of the Revitaliza Plan led to a 5-20% increase in municipal waste recycling rates over five years in municipalities participating in its second phase (Perez Losada and Martinez Abraldes, 2021). Also, capturing up to 70% (ideally, 100%) of bio-waste through decentralized composting, could enable municipalities to cut waste management costs by half, primarily by reducing the frequency of residual waste collection (Zero Waste Europe, 2020).

3.1.3. The Besançon case-study (France)

Besançon metropolitan area is an illustrative successful case study for implementing a decentralized composting system in an urban area. Choosing not to rebuild a decommissioned oven of the local incinerator, the association in charge of waste management in the metropolitan area of Besançon and its neighbouring municipalities (163 municipalities with around 230.000 inhabitants in total) implemented several measures in order to increase the recycling rate of the municipal waste and reduce the quantity of the generated residual waste in the area (Zero Waste Europe, 2018). Increasing the efficiency of the separate collection of recyclable materials and implementing decentralized composting of bio-waste resulted in 85 kg/inhabitant/year reduction of the residual waste between 2008 and 2019 (Grand Besançon Métropole, 2020), while the quantity of bio-waste found in the residual waste dropped from 67 kg/inhabitant in 2009, to 36 kg/inhabitant in 2014 (Zero Waste Europe, 2018). The decentralized composting system in the area is based on voluntary participation of the population both to bio-waste segregation, and to the composting process. Its implementation started with the distribution of home-composters in 1999 and continued with the installation of small community composting sites near apartment buildings ("at the foot of the building") since 2008, and of larger community composting sites in the city-center since 2012 (AMORCE, 2019).

In 2022, with an infrastructure of more than 20.000 home-composers, 297 sites "at the foot of the building", and 23 collective composting sites in dense urban areas, the decentralized composting was accessible to 64.3% of the inhabitants in the area (SYBERT, 2022). The sites "at the foot of the building" provide a solution for bio-waste separate collection to around 10.000 households located in collective housing buildings (representing 20% of the collective housing in the city). The share of the participating households is 30-40% (AMORCE, 2019). The larger community composting sites provides this service for 5.300 households (10% of the collective housing) located in dense urban neighbourhoods, but the average participation is only 28% (AMORCE, 2019).

The composting sites "at the foot of the building" are managed by volunteers (usually residents of the building) with the support of the municipal waste management association and an NGO (AMORCE, 2019).

If the residents in a collective building want to start a composting site, first they need to make a request to the waste management association. For a fee, this one prepares the documentation, installs the composters, provides the mandatory initial training of the volunteers in charge of the site (in cooperation with a local NGO), and supplies bulking agents for a year. During a supervision period (one year), the new site and the households involved in separate collection and composting of the bio-waste receive inspections and guidance from a local NGO. The larger community composting sites are managed by the municipal waste association who install them, distribute buckets for the bio-waste segregation to the participating households, employ expert composters to perform the necessary tasks and find a use for the resulting product.

Training and supervising the volunteers has an important role in the success of the decentralized composting in this case-study. Moreover, training programs for various levels of expertise are available from the governmental agency "Agence de la transition écologique" (Ecological Transition Agency) and its partners (ADEME, 2024) - for instance, the initial training of the volunteers, the training program for "guide composteur" (aide composter), and the training program for "maître composteur" (expert composter). The expert composters are employed by green NGOs and waste management associations and are the ones that provide guidance to the volunteers and the general population interested in composting.

The low monitoring level of the process (the national regulations impose only a temperature monitoring – AMORCE, 2018) make the resulting "composted material" suited only for local, non-agricultural use – landscaping, flower-potting, etc.

3.2. Best practices for decentralized composting at the metropolitan area level

In Table 1 we summarize the main characteristics of the described case-studies in three domains: system design (in terms of the main features of the system and the minimum requirements for being reproduced elsewhere), circularity (in terms of the further use of the produced compost), and participation (in terms of the tools used for engaging and increasing households' and individuals' participation).

Table 1. Main characteristics of the selected case studies for decentralized composting of the municipal bio-waste in the EU.

Case study Characteristics	The management of bio-waste by agricultural decentralized composting in Austria	The regional management of bio-waste by decentralized composting in Pontevedra province (Spain)	The decentralized composting in Besançon metropolitan area (France)
SYSTEM DESIGN	- system based on the mandatory separate collection of bio-waste at household level and an entire ecosystem of organizations and companies around the agricultural composting of bio-waste – farms, companies producing specific equipment and tools, training organizations, inspecting organizations, quality standards for compost. The average composting capacity of an on-farm facility is around 1.100 tonnes/year; - the implementation of a similar system requires at least a legal framework for on-farm composting of the municipal bio-waste, existing standards for the agricultural use of the produced compost, mandatory bio-waste separate collection, and a very good level of bio-waste segregation at household level.	- system consisting of a locally adapted mix of composting options and of three stages of implementation at the municipal level, in accordance with the increasing local performance in segregating bio-waste. It is based mainly on a minimal level of regulation of the community composting sites, voluntary participation of the households in bio-waste segregation, and employed professionals for managing and monitoring the sites. The maximum capacity of a community composting site has to be less than 30 tonnes /year; - the implementation of a similar system requires at least a very good understanding of the bio-waste generation spatial patterns, available public space and municipal regulations for the installation of the community composting sites, training and employing professional composters, and finding ways of involving households in the bio-waste segregation and transport to the composting sites.	- system based on a local waste management organization supporting the voluntary participation of the urban households in bio-waste segregation and collective composting by providing composting options adapted to the density of the urban habitat and assistance in the management of the composting sites. The average capacity of a community composting site is up to 10 tonnes /year; - the implementation of a similar system requires at least the existence of volunteering citizens willing to get involved in collective composting, local regulations for the placement and functioning of the composting sites in urban areas, finding a use for the produced compost, and a support system for decentralized composting (e.g. training the volunteers taking care of the composting sites and providing bulking agents).
CIRCULARITY	- local use of the produced compost for agricultural purposes (based on mandatory quality standards), mainly on the farms that produced it.	- local use of the produced compost (based on its mandatory sanitization) for urban gardening and/or landscaping by the participant households and local municipalities.	- local use of the "composted materiel" (in French, matières compostées) in urban gardening, flower potting, landscaping, etc. (by participant households and the municipality).
PARTICIPATION	- the segregation of bio-waste at household level is mandatory - mainly door-to-door collection of bio-waste; - counselling (waste advisers) and finning; - financial incentives (e.g. the compost bonus, a waste fee reduction for the households that process their own bio-waste).	- counselling (master composters) to gradually increase the participation; - providing the population with composting solutions easy to access and use (proximity of the composting sites, process supervision and site management and monitoring by employed experts); - small rewards (bags of compost, restaurant meals, fruits and vegetables, etc.).	- supporting the pro-environmental attitudes and initiatives of the citizens (by installing collective composters on demand, supplying them with bulking agents, providing free instruction for the volunteers, and supervising the composting sites); - small rewards (compost); - PAYT scheme in place.

Source: own synthesis based on the described case studies in Amlinger (2012), Amlinger (2020), Mato et al. (2019), Perez Losada and Martinez Abraldes (2021), AMORCE (2019), and SYBERT (2022).

Based on Section 3.1 and Table 1, we identified several best practices that can be transferred to urban areas that need a fast and efficient implementation of a decentralized bio-waste management system. We present and discuss them in the following paragraphs.

Starting with an in-depth knowledge of the local circumstances. Successful implementation of a decentralized composting system means increased participation of the population in the segregation of bio-waste and producing good quality compost. As such, Plana (2020) highlights as the most important factors the excellent knowledge of both the biological processes involved in composting and of the local municipality where the decentralized composting will be implemented. Ideally (such in the Pontevedra case study we described, but also as illustrated by Pai et al., 2019, in the case of the city of Chicago, USA), the implementation will start with a study on the waste generation patterns and public attitudes toward waste in the area, followed by advancing locally adapted solutions for the collection and treatment of the generated bio-waste. Then, an implementation plan and the infrastructure will be put in place.

Planning a circular model. Regulations governing the composting process, end-of-waste criteria, and compost quality standards have been

established and implemented in many EU member states, primarily targeting commercial composting facilities (European Compost Network, 2022). In contrast, home and community composting are subject to less stringent requirements, or, in some cases, none at all (Plana et al., 2019). Nevertheless, ensuring the quality of the compost produced in these decentralized sites remains crucial, as the final product must be both usable and effectively used. This requirement presents two main challenges. The first is technical – the optimal size of a composting site must align with the local waste flow, while also meeting the requirements for an efficient composting process (namely adequate aeration, temperature control and moisture balance). When decentralized composting is used as an alternative to centralized bio-waste treatment at the urban and/or regional level, the system ideally needs to handle the full range of the bio-waste generated by the community including meat, fish, dairy and cooked food. In such cases proper sanitization becomes essential, typically achieved by maintaining temperatures above 55°C for at least 14 consecutive days (Plana et al., 2019). However, smaller composting sites may struggle to consistently reach these temperatures, compromising the sanitization process (Harrison, 2004). A review of decentralized composting in Italy concludes that "more focus should be given on the community composting rather than home composting, since it exhibits comparatively higher possibility of control mechanisms" (Bruni et al., 2020, p. 15).

The second challenge lies in finding suitable uses for the resulting compost. In this respect, the Austrian model is the best, with clear, strict composting procedures, established quality standards and on-site use of the processed material. In contrast, other decentralized composting models typically rely on distributing the compost to participating households, using it in public landscaping or applying it in urban gardens. However, in densely populated urban areas, identifying practical, local uses for the compost can be difficult. AMORCE (2019) highlighted this issue in its assessment of the Besançon case study.

Using small, modular units for quick implementation of community composting sites - in the context of high EU recycling targets that need to be reached soon, the speed of the implementation of a functional system is essential for urban areas in member states lacking bio-waste management systems. This speed depends, among others, on the level of regulation of the composting activity, which essentially relies on the site's capacity being above or under certain limits. For a fast implementation, small community composting sites (under the limit of the regulating capacity) would be of maximum interest (e.g. the Revitaliza Plan). Also, planning the system as a modular one allows for flexibility, while easily increasing the composting capacity if needed.

Training and using composting experts and/or waste advisers - in all the case studies presented, trained composting experts and/or waste advisers play an essential role in guiding citizens on waste management and composting practices. Their responsibilities vary depending on the model implemented and may include supervising composting at home or community sites, managing and monitoring the community composting sites (with varying degrees of hands-on involvement), and supporting local authorities and waste management associations in implementing customized systems. To perform effectively, these professionals need both technical expertise and strong communication skills. In the case studies analysed, they received training either through formal educational institutions (such as the local university in Pontevedra), or from NGOs (as seen in Besançon case study).

In terms of costs for the municipalities, the described case studies show two different situations – in some cases (e.g., Austria and Pontevedra) these experts are municipal or waste management company/association employees, while in others (e.g., Besançon) they serve as volunteers. However, one of the key challenges faced in Besançon has been the closure of "at the foot of the building" composting sites because of the absence of volunteers to oversee their operation – 32 composting sites were closed as a result of exhaustion/disengagement of volunteers or of volunteers managing the site moving away (AMORCE, 2019).

Using tools for behavioural change and practice persistence adapted to the local context - the success of a decentralized composting system as a primary method for managing municipal bio-waste depends on broad household participation and proper waste segregation. In areas where residents have limited experience with composting, changing waste disposal habits can be a significant challenge. In a compendium of cases, World Bank (2023, p. 18) lists 19 behavioural tools (grouped into three categories: social and motivational tools, financial tools, and system design tools) that have been used around the world for successful implementation of waste management systems. The social and motivational category include tools such as adequate framing (ways of presenting the information), using well-chosen messengers to deliver information (informal leaders, influential figures, etc.), making use of the social norms and social comparison, creating accountability, providing feedback, using gamification (e.g. a point-allotting system), and non-material (symbolic) rewards. The financial tools include various material rewards, negative incentives (fines and penalties) and appealing to loss aversion. Designing the system in ways that facilitate the desired behaviour (and/or make the undesirable behaviour more difficult to express) includes accessibility of the services, timely

messages (reminders about the desired behaviour), physical cues (system features that support the desired behaviour), simplifying behaviours and decisions, etc.

In the three case studies we presented in this paper one may identify several of the recommended tools above. The door-to-door collection of bio-waste (in Austria) and the location of the community composting sites "at the foot of the building" or in walking distance from the households (in Besançon and Pontevedra cases) increase the accessibility of the services. Supplying bulking agents for the community composting sites make easier for volunteers in Besançon to engage in composting. The "compost bonus" in Graz for the households that are home-composting is a financial incentive to start the practice or to continue with it, while small rewards (e.g. bags of compost, restaurant meals, agricultural products) for the volunteer participation in the bio-waste segregation in other case studies support the adherence to this practice.

Continuously monitoring the system – due to the specific nature of the composting process and the involvement of numerous stakeholders, decentralized composting needs continuous monitoring to enable system adjustments and evaluate performance. For instance, the Revitaliza Plan in Pontevedra uses a mobile app (Perez Losada and Martinez Abraldes, 2021) to register the task performed at every composting site, tracking temperature, module fill level, and issues reported by users (e.g., rodents, unpleasant odours). This monitoring system generates data on participation rates, the volume of bio-waste processed, and compost quality across different areas. Such information helps waste management organizations better understand system performance, respond quickly to problems and plan more effectively for future development.

3.3. Decentralized composting initiatives in Romania

3.3.1. National policies shaping bio-waste management in Romania

Formally, Romania's bio-waste management framework aligns with the EU directives on waste and with the EU's circular economy policy. The Landfill Directive (Directive 1999/31/EC) was transposed into national law through HG 349/2005, which set a target to reduce the amount of biodegradable municipal waste sent to landfills to 35% of the 1995 levels by July 2020. The Waste Framework Directive (Directive 2008/98/EC) and its 2018 amendment (Directive 2018/851/EC) were integrated into national legislation primarily in 2011 through a law on the waste regime (Legea 211/2011), then by the Government Emergency Ordinance No. 92/2021 (OUG 92/2021). These legislative measures introduced mandatory separate collection of municipal bio-waste and promoted home-composting and municipal composting systems. In 2020, Law No. 181 was enacted to regulate composting practices, compost quality and its usage (Legea 181/2020). Furthermore, Romania adopted a National Strategy for the Circular Economy in 2022, followed by an Action Plan in 2023. That plan emphasizes the expansion of infrastructure for separate collection of waste, the implementation of public information and awareness campaigns, and support for research in areas such as waste sorting technologies, anaerobic digestion, and composting, etc. (Planul de Acțiune pentru Strategia națională privind economia circulară, 2023). These measures complement the ones included in the National Waste Management Plan (PNGD, 2017), which include investments for extending separate bio-waste collection systems, and building anaerobic digestion and composting facilities.

However, the implementation of waste policy in Romania has encountered significant challenges. The delayed transposition of European waste policy into national law, coupled with weak enforcement mechanisms, have led to infringement procedures by the European Commission (Cugleșan, 2021). For instance, although Law no. 181/2020 mandates the separate collection and treatment of non-hazardous bio-waste as of January 1st, 2021, its enforcement has been hindered by the absence of technical regulations and the lack of adequate national waste treatment infrastructure. As of mid-2024, the technical norms for implementation have yet to be issued, and essential aspects such as end-of-waste status, compost quality standards, and acceptable uses for compost and digestate remained undefined.

Additionally, Romania's existing waste infrastructure is underdeveloped - the processing capacity of the existing composting facilities is insufficient for treating the estimated quantity of generated bio-waste (Feodorov, 2018), and there is no anaerobic digestion facility in use for the treatment of the municipal bio-waste (PNGD, 2017). Public awareness and participation in waste separation and recycling programs are also limited. According to the Special Eurobarometer 501 on environment, only 26% of the Romanians reported engaging in recycling behaviours, compared to the EU average of 66% (European Commission, 2020), resulting in persistently low recycling rates at local and national levels.

Within this context, Romanian municipalities (which are responsible for the municipal waste management), face substantial challenges. A 2022 report on county capital cities revealed that, by 2022, 41% had not initiated any actions for the separate collection of bio-waste, while another 24% were conducting pilot projects or occasional collection campaigns. In another 24% of the cities the collection was limited to residential areas with individual houses,

and only 11% had fully implemented separate bio-waste collection across both houses and apartment blocks (SAR, 2022). Moreover, only about 25% of the Integrated Municipal Waste Management Plans at the county level includes provisions for the separate collection of bio-waste in urban areas (Drăgan, 2021), while rural areas were expected to rely on home-composting (although not systematically implemented or supported).

Moreover, in urban municipalities that started to implement the bio-waste separate collection, the lack of incentives for households remains a key barrier. Pay-as-you-throw (PAYT) schemes are usually not implemented yet or implemented in a rudimentary form (mostly based on the container collection frequency). Furthermore, in several cases where the separate collection of bio-waste was implemented, a very high level of macro-contamination (up to 50%) was reported (Drăgan, 2021).

Given the inefficiency of the centralized bio-waste management systems in Romania, this study explores the decentralized composting as a complementary (or potentially alternative) approach.

3.3.2. Local composting efforts in the Cluj-Napoca Metropolitan Area

Cluj-Napoca is the second-largest city in Romania (of around 300.000 inhabitants), with a large and fast-growing suburban area. The share of the bio-waste in the generated waste in the city was found to be as high as 67% during summer months (Pop et al., 2015), but until 2021 the separate collection of household bio-waste was limited to the green waste from residential areas with detached houses. From 2021 onwards, the separate collection was extended (by placing brown bins at some of the municipal waste collection sites). However, there is no available data on its efficiency and households' compliance to it. In their survey on the municipal waste composition, Pop et al. (2015) also found a rather low level of compliance of the population to the separate collection of the waste – while found mostly in the residual waste bin, the organic waste also represented 31% of the content in the bins for plastic and metal and 22% of the content in the bins for paper. Nonetheless, despite this rather negative context, in the last five years several bottom-up initiatives for decentralized composting were noticed in the Cluj-Napoca Metropolitan Area.

The first decentralized composting initiative that we identified was *an entrepreneurial project based on vermicomposting ("Clujul compostează / Cluj is composting").* Upon request by interested households, the company that initiated the project distributed buckets for separate collection of kitchen waste in several blocks of flats – around twenty households registered for it. In exchange for a fee, the buckets were picked up once a week (Petean and Hruban, 2019; Sustenabil.cj). The composting process took place outside the city, in a rural area, 16 km away. The pilot project lasted one year (July 2018 - August 2019), then it was disconnected, lacking the funds for further investments to make the project profitable (Topai, 2020).

In June 2020 the Facebook group "*Compost în Cluj / Composting in Cluj*" was created, as both an educational platform for composting enthusiasts and a virtual market for exchanging compostable materials and compost. By February 2022, the group had grown to over a thousand members, with many users regularly collecting and giving away kitchen waste and green waste, as well as users that would take it and compost it (mostly in the peri-urban area). For these exchanges, besides direct contact among members, a web application (ShareWaste) was used in order to make this collaborative process more efficient. The same application listed 18 composting sites in the Cluj-Napoca Metropolitan Area, most of them located in neighbourhoods with detached houses and large green areas. One notable exception was a community composting project designed for a block of flats. Although it was quickly embraced by eco-conscious residents, it faced opposition from others, who viewed it as a nuisance and even reported it as an illegal waste site. As a result, the project was shut down after just four months, operating only from January to April 2021 (Clujul Sustenabil, 2021).

We also identified *bio-waste donation and collection practices within local producer-consumer communities and informal groups of permaculture enthusiasts* (e.g. "ROA Cluj – vânzare directă" Facebook group). Customers bring collected bio-waste to formal or informal farmers' markets, where they donate it to local producers for composting in rural area near the city (Ziarul Clujean, 2021).

Composting was also linked to the *urban community gardening* phenomenon. Besides the community garden projects that have recently appeared (and are mostly located on private land, in detached houses areas or even offered by large residential developers that picked up the recent eco-trend and present their future customers with urban gardens and community composting in their new complex buildings), in Cluj-Napoca, as in other Romanian cities, the urban gardening in dense neighbourhoods was an established practice since the Communist period. It started in the 1960s, when new residents moving from rural areas into the rapidly industrializing cities' blocks of flats appropriated small areas of undeveloped public space nearby and started to cultivate it with vegetables and flowers, or used for this purpose the small green areas near the buildings, a practice that has lasted until present times in some parts of the city (e.g. "La terenuri" area, described by Baibarac-Duignan and Medeșan, 2023).

These initiatives have not received financial support from local authorities or grant-making organizations. As a result, their expansion has been significantly limited. However, in other cities there were decentralized composting initiatives that have successfully attracted grant funding. For example, in 2021, the start-up Urban Cultor launched a community composting pilot project involving 30 households in Bucharest, as part of the "Food for the Earth – Composting Communities for Climate" project, funded by EIT Climate-KIC (Food for the Earth, 2021). Building on this initiative, community composting efforts expanded in 2023 through collaboration with several NGOs and other organizations under the "*Academia de compost / Compost Academy*" project, funded by the Bucharest Community Foundation (Academia de Compost, 2023). This new initiative includes the maintenance of 14 operational composting sites across the city, training programs, a free online course on composting, educational presentations in schools, etc. It also established a formal collaboration protocol with the municipality to secure public space for composting sites and to support the broader development of community composting. The "*Băimărenii compostează*" was a decentralized composting initiative in Baia Mare, financially supported for one year by the Oradea Community Foundation. The project engaged 70 families in collecting bio-waste at three composting sites. It involved over 250 participants in composting workshops and other environmental activities and successfully diverted approximately 400 kg of bio-waste per month (Fundația Comunitară Oradea, 2021).

Several authors have also documented examples of successful businesses incorporating decentralized composting into their operations: Mihai et al. (2023) describe the social enterprise "*Ateliere fără Frontiere*" located in Ciocănești (Dâmbovița County), approximately 30 km from Bucharest. The enterprise operates a business model centered on organic farming and the short-chain distribution of vegetables through subscription services to Bucharest residents. It also collects surplus food from major city retailers for redistribution to social canteens, collects and composts food waste from these retailers and several hotels, and provides employment for 20 vulnerable individuals. Feodorov et al. (2022) describe a food-waste composting initiative involving several restaurants operating within a shopping center in Bucharest, while Mihai et al. (2021) illustrate composting bio-waste as a part of a restaurant's journey towards Zero-Waste in the city of Iași.

3.3.3. Opportunities and obstacles in scaling decentralized composting in Romania

Although limited in scale, the decentralized composting initiatives presented in this paper offer noteworthy benefits. Firstly, they play an important role in raising public awareness and promoting a circular approach to managing household bio-waste. This, in turn, can help foster both public and institutional acceptance of decentralized composting (as illustrated by Urban Cultor projects). Secondly, these initiatives create opportunities for collaboration and the co-creation of locally adapted solutions among various stakeholders. For example, the "Compost Academy" demonstrates how public authorities can partner with NGOs to pilot decentralized composting solutions in urban contexts. Thirdly, informal community groups can provide a valuable niche for the emergence and development of green entrepreneurial initiatives, as they reduce the cost associated with outreach and marketing (Boussard, 2021).

However, these initiatives also face significant challenges. One of the main barriers to scaling decentralized composting is the lack of institutional support. For instance, in the Cluj-Napoca Metropolitan Area the composting sites are situated on private properties, and the related educational activities are largely carried out by informal Facebook groups and environmental NGOs. The growth of these bottom-up initiatives is further constrained by local regulations, which currently lack provisions for establishing composting sites in public spaces or densely populated areas. Moreover, financial sustainability remains a persistent issue. Most initiatives receive short-term funding, often limited to just one year, making it difficult to maintain momentum. Volunteer disengagement also poses a significant challenge, threatening both the continuity and long-term impact of these initiatives.

All the initiatives mentioned in subsection 3.3.2 show that there is a genuine interest in composting among residents of the Cluj-Napoca Metropolitan Area and other Romanian cities – whether through individual composting, separate collection and donation of bio-waste, or even paying for bio-waste pickup services. Yet, the overall extent of this interest remains uncertain, underscoring the need for more comprehensive data on public attitudes towards composting.

As outlined in the subsection 3.3.1 bio-waste management remains a persistent and complex challenge for local authorities in Romania. Difficulties in segregating bio-waste and ensuring its proper recycling stem largely from shortcomings in the design of waste-management systems, as well as from infrastructural, administrative and public engagement constraints. The case studies examined in this research paper demonstrate that a decentralized approach to bio-waste management represents a viable alternative (or a complement) to the existing centralized systems. The emergence of diverse bottom-up initiatives for decentralized composting in Romanian cities over the

past five years reflects growing public interest in composting and the accumulation of practical local knowledge. By combining European best practices with these local initiatives, a more effective and sustainable framework for bio-waste management can be developed. Beyond improving operational efficiency, this integrated approach encourages community participation and supports environmental education.

4. CONCLUSIONS

Due to its simple technological and natural processes, composting can be implemented in a decentralized and flexible manner across various spatial scales (from individual households to municipalities and regions), with multiple ecological and economic benefits compared with landfilling or incinerating the bio-waste. As illustrated by the case studies presented in this paper, decentralized composting is a viable alternative to centralized municipal bio-waste treatment in both rural and urban settings. This approach could be especially effective for urban areas in Romania and other European countries (both EU members and candidates) where waste management systems are still developing. In regions where the implementation of environmentally compliant waste-management systems was introduced later than in Western Europe, where facility construction is progressing slowly, and where environmental awareness of the general population remains limited, decentralized composting offers a practical and timely solution for aligning with European bio-waste management regulations.

However, to ensure efficiency and cost-effectiveness of decentralized composting, increased household participation is essential. Leveraging existing local composting initiatives can significantly facilitate the broader implementation of decentralized composting systems. This paper argues that recognizing and building upon established local practices while integrating proven best practices offers a more effective strategy for local authorities seeking to improve inefficient waste management systems than simply transferring solutions from other contexts.

This paper examines a range of bottom-up initiatives in the Cluj-Napoca Metropolitan Area and other Romanian cities, highlighting them as promising foundations for decentralized composting. These include green NGOs, informal networks of eco-conscious citizens engaged in bio-waste collection and composting, local food producer and consumer groups promoting circular practices, a tradition of urban gardening dating back to the Communist era, and entrepreneurial initiatives offering bio-waste pick-up services to urban households. The existence of these diverse local efforts indicates that a segment of the urban population is already receptive to bio-waste segregation and could be readily engaged in a decentralized composting system. With support from local authorities, these existing practices and attitudes could serve as a strong starting point for implementing mandatory bio-waste segregation in the future. Moreover, they offer valuable opportunities for experimentation allowing communities to identify effective practices and communication strategies while leveraging existing composting experience and social capital.

Drawing on best practices from three European case studies and insights from the compilation of bottom-up decentralized composting initiatives in Romanian cities, we advance the following recommendations for municipalities and policymakers.

Start with a local assessment. Before designing a decentralized composting system, carry out a detailed assessment of local conditions. This helps tailor the system to local patterns of bio-waste generation and ensures the design fits community needs. It also lays the groundwork for gaining stakeholder support from the beginning.

Promote compost use through the circular economy. Identify and support local uses for compost such as urban and periurban farming, landscaping or soil restoration. This does not only keep resources in use locally but also supports the environmental goals and encourages community participation.

Remove unnecessary regulatory barriers. Make it easier for communities to start and manage composting projects by simplifying rules and procedures. This encourages local innovation and helps decentralized composting become part of the broader waste management strategy.

Use flexible, modular infrastructure. Choose small-scale, modular composting units that can be deployed quickly and adapted to different neighbourhoods or conditions. This approach allows for easy scaling and local customization.

Invest in training and local expertise. Build a network of trained composting experts or waste advisers who can support residents, oversee composting sites and ensure quality control. Local expertise is key to long-term success.

Create strong monitoring and feedback systems. Set up systems to regularly track composting performance and environmental results. Use this data to make improvements over time and share it publicly to build trust and transparency.

Encourage lasting behaviour change. Run local campaigns with messages adapted to community values to encourage long-term participation in bio-waste segregation. Include composting education in schools.

Support the growth of bottom-up initiatives. Identify and assist bottom-up composting efforts. Offer them formal recognition, practical support, and small

grants to help them scale up and become part of broader waste strategies. Actively involve these initiatives in the co-creation of local solutions by including them in planning processes, facilitating dialogue with local authorities, and leveraging their on-the-ground knowledge to shape inclusive and sustainable waste management policies.

The findings of this study offer a framework to help policymakers develop context-specific solutions for decentralized composting in urban areas across Romania, as well as Central and Eastern Europe, particularly in cities with similar urban characteristics and public attitudes towards waste. A key limitation, however, is that an important part of the information is drawn from the Cluj-Napoca metropolitan area, which may not fully reflect conditions in other regions. Nonetheless, the presence of similar initiatives in other Romanian cities, and comparable policy and cultural contexts suggest that these strategies can be adapted elsewhere, even if they are not universally applicable. Another limitation is the lack of data on the effectiveness of local initiatives, especially regarding composting performance and public participation. This highlights the need for further research, including representative surveys to assess public attitudes towards composting, economic feasibility studies to evaluate decentralized composting as a primary bio-waste management strategy in Romanian cities, and pilot projects to test implementation before scaling up.

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