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Community composting: A multidisciplinary evaluation of an inclusive, participative, and eco-friendly approach to biowaste management

Annalisa De Boni [a], Francesca Maria Melucci [a,*], Claudio Acciani [a], Rocco Roma [a]

[a] Department of Agricultural and Environmental Sciences (DISAAT), University of Bari Aldo Moro, 70126, Bari, Italy

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ABSTRACT

The problem of waste management continues to grow as landfilling and incineration face both environmental, social, and economic concerns. In this study, the implementation of community composting plant in a municipality is presented evaluating the effectiveness of participatory processes and practices of community composting to solve a common demand of bio-waste management. In a multidisciplinary approach, different methodologies to analyse the environmental and economic impacts, institutional feasibility and social acceptability of the process are applied. As in this municipal composting plant local communities and citizens are directly involved in generating socio-economic and ecological benefits for themselves, these benefits are quantified and made comprehensible to the local stakeholders and citizenship through Life Cycle Assessment and Cost Benefit Analysis. The Delphi method was applied for exploring the institutional feasibility of the community composting plant and a direct inquiry to citizens was performed to evaluate their social acceptability. Results showed that the proposed model reduces the environmental impact, expressed as carbon footprint, respect to alternative landfill or incinerator scenarios, ensures the economic sustainability, also taking into account the possibility to obtain a compost appreciated by the market, meanwhile the social acceptability resulted strongly influenced by the level of information and knowledge of community.

1. Introduction

Worldwide, the development of urban areas, as well as the rapid growth of the population, has resulted in production of waste at an alarming rate and the problem of waste management (WM) and disposal continues to grow. According to the Urban Waste Report (ISPRA, 2020), in 2018, the total production of municipal waste in EU28 was about 250.6 million tonnes per year, 31% of which was recycled, 27% was directed to energy recovery, 17% to composting and anaerobic digestion, 1% was incinerated and 25% disposed of in a landfill.

Organic waste (OW), in particular from kitchens and canteens, garden, and parks waste, may be treated in composting plants to produce, through a controlled aerobic stabilization process, high-quality compost, valuable as a soil conditioner, since it adds organic matter to soil, sequesters carbon in soil, improves plant growth, preserves water, reduces reliance on chemical pesticides and fertilizers, and helps to prevent nutrient runoff and soil erosion (Askarany and Franklin-Smith, 2014). Applications of compost can replace fertilisers and peat, operating as plant growth media and soil conditioners (López et al., 2021), can be used in hobby gardening, land rehabilitation, mulching in agriculture and landscaping (Inckel et al., 2005), avoiding the impacts of the industrial production of fertilisers and the extraction of peat. By avoiding landfilling, composting helps to reduce global emissions of greenhouse gases (GHG), and it can benefit local economies (Paul et al., 2017; Blazy et al., 2021).

In recent years, sustainability concerns drew attention and encouraged the policy debate on the role of WM in reducing waste impact and moving toward a circular economy and sustainable urban development (Tisserant et al., 2017a; Makarichi et al., 2018; Mia et al., 2018; de Gennaro and Forleo, 2019; Zeller et al., 2019, 2020). A systemic approach involving the whole community is acknowledged as crucial to face many technical and social aspects of municipal solid waste management (MSWM) (Blengini et al., 2012, Golebiewski et al., 2020). Many scholars (Liu et al. 2019; Achillas et al., 2011) underlined that public acceptance and community involvement are associated with a lot of different factors: perceived health and environmental risk/benefits, land degradation and energy recovery, WM cost, aesthetic nuisance, fairness/justice. To achieve a consensus by the local society and above all,

* Corresponding author.
E-mail addresses: annalisa.deboni@uniba.it (A. De Boni), francesca.melucci@uniba.it (F.M. Melucci), claudio.acciani@uniba.it (C. Acciani), rocco.roma@uniba.it (R. Roma).

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its involvement and active participation, it is essential to implement a participatory process that is more likely to be achieved by a consultative decision-making approach of community engagement, transparency, and co-design (Wolsink, 2010; Achillas et al., 2011).

Composting can take place in urban, suburban, and rural areas (Pai et al., 2019). In this paper, a case study of community composting (CC) is analysed. Composting at the community scale is a participatory, bottom-up process in which citizens are actively involved. The process involved citizens and local stakeholders, from the earliest design stages, in a range of activities, for example, OW collection and composting services within certain neighbourhoods by entrepreneurs and farmers; community drop-off networks; demonstration and training activities, presentation of system performance and discussion of the obtained results. All these activities engaged community leaders and citizens and improved their awareness of the opportunities represented by community composting (Platt and Seldman, 2000). Community composting yields many other benefits like social inclusion and empowerment, local soils improvement, enhancement of food security, local job creation, new know-how and skills within the local workforce and communities are the key to tackle sustainability and climate change issues: local initiatives, as campaigns, social movements, and community projects, can build a sense of community and can improve a local knowledge and experience (Flowers and Chodkiewicz, 2009; Flachs, 2010; Smith and Sobel, 2010). CC may solve a collective problem: the disposal and management of the organic fraction of municipal waste, in a circular economy perspective, as the organic fraction is easily recyclable and reusable as a soil improver. Moreover, through collaborative and motivated engagement of the community a connection with the nature and the environmental themes has been developed (Christie and Waller, 2019), inspiring local action and a movement toward global solution (Falk and Dierking, 2000; Schlesinger, 2016). So, because of different stakeholders' objectives (Salhofer et al., 2007; Pérez et al., 2020) it is important to define, since the beginning, clear rules, and to share common objectives (Marchi et al., 2000). Local initiatives develop a collaborative and direct learning and a greater connection with nature, which inspires communities to engage in solving global problems through local projects (Christie and Waller, 2019).

Supporting and expanding the implementation and efficiency of decentralized and participated WM programs requires the evaluation and communication of the financial, social, environmental, and overall planning impact of new systems as part of the integrated MSWM (Pai et al., 2019). Economic, environmental, and social impacts evaluation of the waste processing systems is considered as part of an efficient integrated WM planning approach (Ibáñez-Forés et al., 2019a; Pai et al., 2019).

This study aims to underline the potential of community-led initiatives, where community actors play a key role in managing their own resources. In line with the principle of "commoning" (Bollier, 2016), local communities and citizens are directly involved in generating socio-economic and ecological benefits for themselves. These benefits are quantified and made comprehensible to the citizenship through environmental (Life Cycle Assessment) and economic (Cost Benefit Analysis) analyses. The CCP provide a new socially innovative and inclusive approach to solving a common problem: OW management. Bock et al. (2012) highlighted the importance of the social aspect to promote a sense of local development.

This study hence proposes a comprehensive inter-disciplinary framework to guide policy makers, planners, and other stakeholders in estimating the potential of decentralized WM especially regarding composting, with the aim to:

- analyse the environmental impact of the CCP, through the Life Cycle Assessment (LCA);
- evaluate the economic feasibility and the cost-effectiveness of CCP, through the Cost-Benefit Analysis (CBA);
- underline and validate the effectiveness of the participative process by analysing its institutional feasibility and its social acceptability. In light of the results of the economic and environmental analyses, the institutional feasibility has been investigated considering stakeholders' opinions, through the application of the Delphi Method, and the social acceptance of the local community, through a direct survey among the citizens.

2. Materials and methods

In relation to its multidisciplinary approach, three different and well-established methodologies to assess the environmental and economic impacts, and social acceptability of the CCP were applied. In particular, the environmental performances were analysed according to LCA (Cherubini F. et al., 2009; Mondello G. et al., 2017), the economic sustainability was evaluated through a CBA (Martinez-Sanchez et al., 2015). The results of the two previous analyses were shared with local stakeholders and citizens. The social sustainability was investigated through the application of the Delphi method (Hill and Fowles, 1975a; Linstone et al., 2002) involving local stakeholders to evaluate the institutional feasibility and through a direct survey among citizens aimed to explore the social acceptability.

2.1. System description

The study was carried out in a municipal CCP collecting OW from same municipality and vicinities located in southern Italy. All the data for the environmental and the economic analysis, were collected directly by interviewing the owner of the CCP.

OW is collected three times a week, through a door-to-door collection system; 894 households give OW to the composting mill. For the collection and the transport of 1 tonne of OW to the CCP, a distance of 15 km is covered with a truck. A complete composting cycle takes 90 days: for 45 days, OW remains inside the electromechanical composting machine, where it is shredded and mixed to allow access to air, water, and microbes; later the compost is manually removed into the earthworm's compost tanks for another 45 days. Thanks to the earthworm breeding, the residence time of compost in the electromechanical composting machine is reduced, thus increasing the load of the compost bin. In addition, the earthworm breeding needs only manual work for its handling and, overall, earthworm manure is a high-value soil improver in agriculture. Twigs and pruning residues are taken from the conveyor belt and treated separately, directly or after a period of drying. Leachate leaked out from the drain of the electromechanical composting machine and derived from the washing water for cleaning up the yards, is reused to moisten the earthworm's compost tanks.

Energy consumption during composting is required by the gas cleaning systems to remove odour emissions and in aerating the materials; moreover, photovoltaic panels were installed on the roof of the office to light the yard. From 1 tonne of OW, 0.15 tonnes of compost is produced.

2.2. Life Cycle Assessment

LCA is a holistic and objective procedure for evaluating energy and environmental loads related to a process or activity, throughout its life cycle according to the ISO standards (International Standard Organization, ISO 14040:14043). The life cycle approach and methodologies, like Life Cycle Assessment (LCA), are well developed and widely applied (Forleo et al., 2018; Ibáñez-Forés et al., 2019a; Alberto López Ruiz et al., 2022) to define environmental and economic impacts. Currently a social analysis of composting is the least developed methodology (Aziz et al., 2016).

Thanks to a LCA study an overview of different WM strategies can be provided, by assessing the environmental impacts of the systems studied (Finnveden, 1999; Cherubini et al., 2009; Gruber et al., 2016; Xocaira

Paes et al., 2018; Paes et al., 2020). According to Notarnicola et al. (2017), the multi-criteria approach of LCA can be able to support decision makers to improve WM (Andersen et al., 2010). LCA has been used also to compare different composting systems as shown in the study by Bong et al. (2017), Abeliotis et al. (2016) and Martínez-Blanco et al. (2010).

LCA has been extensively used to analyse urban Municipal Solid Waste (MSW) collection and transportation strategies (Taşkın and Demir, 2020), to evaluate the efficiency of food waste bioconversion (Salomone et al., 2017), to study the relationship between MSWM and GHG emissions (Bartolozzi et al., 2018; Magazzino et al., 2020; Mandpe et al., 2022), to evaluate the carbon footprint of the solid waste collection in a municipality (Zabeo et al., 2017), to provide an overview of the environmental impact of MSW landfills (Sauve and Acker, 2020), to compare the environmental performance of different municipal waste pre-collection and transport systems (Pérez et al., 2020) and different scenarios of MSWM (Behrooznia et al., 2020) and MSWM strategies (Edwards et al., 2018; Wang et al., 2020).

In this study the SimaPro 7.1 software was used to model the systems and the Ecoinvent Data v2.1 (2011) and SimaPro databases were used for data implementation. The impact characterization was developed through the CML baseline 2000 method (Guinee, 2002), and EPD (2008). Avoided production of similar conventional products, for example chemical and organic fertilizers, were not considered. No allocation or system expansion was performed.

2.2.1. *Scope definition*

The objectives of the first step of the study are to:

- evaluate the environmental impacts related to the CCP;
- improve the production phases to identify the processes which produce the most significant environmental problems;
- compare emissions from different bio-waste disposal scenarios, including landfill and incineration.

In the LCA assessment, a one-year production of 3.7 tonnes of compost was considered; while in the economic assessment, the maximum load of the CCP (i.e., 240 tonnes of OW, equivalent to 72 tonnes of compost) was considered.

The functional unit (FU) in LCA provides a reference to which the inputs and outputs of the inventory are related (ISO, 2006); a production of 3.7 tonnes of compost was obtained in one year and all the results are referred to 1 tonne of compost produced.

System boundaries (Fig. 1) were defined starting from the door-to-door collection of the OW, the filled recycled paper bags, until the production of compost, including the transport of the harvested bio-waste to the compost bin, and the vermicomposting.

2.2.2. *Life cycle inventory analysis*

The Life Cycle Inventory Analysis (LCI) is an inventory of the input/output data with respect to the system studied. LCI included data from two different categories:

1. Primary data were directly collected from the pilot plant and include monthly waste collected in the year, the electric power consumption, the cubic capacity of the van used to transport OW and the kilometres travelled for collection, the amount of process water used, the number and weight of recycled paper bags for the collection of waste.
2. Secondary data collection includes different sources: international literature and database, official websites (e.g.: truck fuel consumption was evaluated using the technical data sheets on the web) and technical references and estimates.

The quantity of input of each process applied during CCP life cycle and data sources are specified in Table 1.

2.3. *Cost-benefit analysis*

The concept of sustainable development has heightened underlining the importance of cost accounting in assessing the economic sustainability of processes affecting the environment (Kuosmanen and Kortelainen, 2007). The cost-effectiveness is an important information for the decision-making and the policymaking of government. The CBA is an analytical tool to evaluate the economic advantages or disadvantages of an investment decision by assessing its costs and benefits to assess the welfare change attributable to it and has been used to evaluate the economic feasibility of CCP. Other authors (Jamasb and Nepal, 2010; Dobraja et al., 2016) have applied the CBA in order to make an assessment of different waste management options (composting, landfilling, recycling, anaerobic digestion, etc.). The first part of CBA concerned the financial sustainability (the cash inflows, properly discounted, must be able to cover all investment costs) (Fig. 2), and the internal rate of return

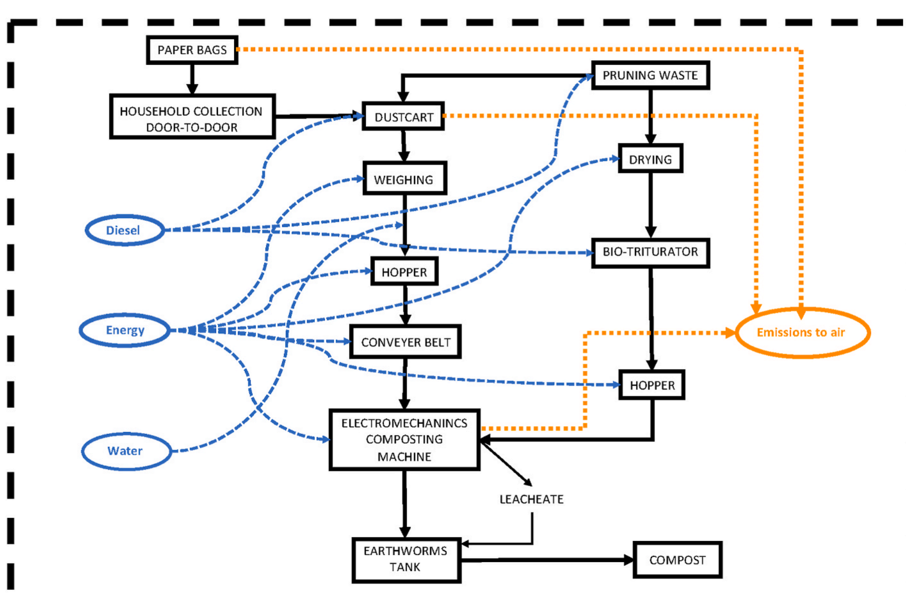

Fig. 1. I/O flow chart and system boundaries of the.

Table 1
Processes, input quantities and data sources.

Processes	Input	Unit	Quantity/ year	Data sources and other info
Transport	Diesel	Kg	474.36	Ecoinvent (Diesel, IT) Dustcart: cc 2000 m^3; 8 km/L Tot. distance travelled 3619,2 km/year Bio-triturator: 96 L/ year
Waste collection	Bags	Kg	2,231.40	Ecoinvent (Paper, recycling) 156 bags/family/year 0.016 kg/bag
Composting process	Electricity	KWh	1,461.00	Ecoinvent (Electricity, medium voltage, production IT)
Washing	Water	L	30,000.00	Ecoinvent (Tap water, at users) 5 m^3/two-months

Source: data collection at composting plant

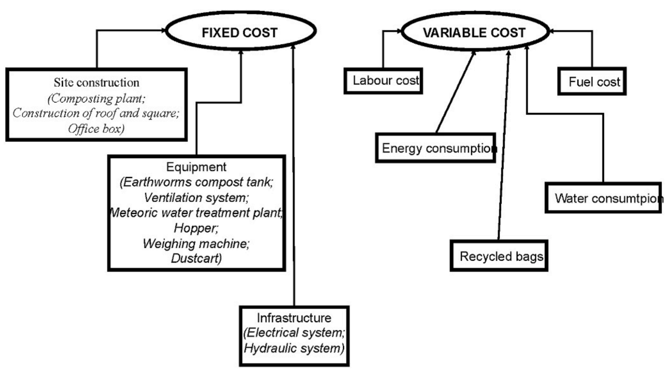

Fig. 2. Key data to compute the cost of the community composting plant.

(IRR) was analysed to assess the economic efficiency based upon CBA (Ali et al., 2013). The economic sustainability was evaluated through the economic analysis (Aye and Widjaya, 2006; Ikhlayel, 2018), considering the externalities involved in the process affecting public goods as the cost-opportunity of the avoided GHG emissions (Hunkeler et al., 2008).

The CBA provides information on the set-up cost and on the revenue generation (Bong et al., 2017); it may consider both the costs and benefits associated with the product and the externalities (e.g., avoided emission of GHG, effect on land use; etc).

The analysis considers the following assumptions:

- discount rate (r) equal to 1.5%;
- maintenance fee equal to 1% the replacement value of plant;
- insurance fee equal to 3% the replacement value of plant;
- selling price of the compost was set equal to 1€ per kilo, obtained by calculating an average of market prices;
- maximum load of the CCP is 240 tonnes of OW, producing 72 tonnes of compost in a year.

2.4. Delphi method

The Delphi method is a survey technique that uses the answers to a standardized questionnaire provided by a group (said "panel") of experts or social actors to reach a convergence of opinions or, in the face of a problem, facilitate the achievement of a common opinion shared as much as possible (Chaney, 1987; De Boni and Forleo, 2019).

It is developed in several rounds, during which the administrator who manages the process provides participants with a statistical summary of the responses given by all the panel members and their motivations (Needham and Loë, 1990; Linstone et al., 2002).

The analysis of social sustainability of the proposed model was carried out following two phases. In the first phase, the process of managing the organic fraction of household waste was evaluated considering stakeholders and experts opinions, with the aim of highlighting variables that could act as drivers or obstacles to its implementation. The second phase assessed the perception and acceptability of the proposed innovation by citizens end-users.

2.4.1. Stakeholders' analysis

The panel of experts was selected depending on the Expertise criterion, according to which, given the subject of research, participants must have a high knowledge of the object under study but must have diversified skills among themselves. The participant stakeholders were identified considering that the main purpose of the study was to provide information about opportunities and development of CCP in a forecasting situation in which mathematical analysis may be inappropriate. In this case, data are insufficient, changes in a previous trend are expected, and new elements, especially linked to local social factors, are likely to interfere (Austin et al., 2015; Rowe and Wright, 2001).

The panel of stakeholders involved in this phase of the evaluation were mainly cooperatives, associations and administrators of the municipalities served by the composting plant (V. Ibáñez-Forés et al., 2019a).

Three groups of stakeholders were defined:

1. the first group, consisting of eight service cooperatives, represented the needs and views of those who offer services to citizens,
2. the second group, composed of eleven associations acting in the territory represented the needs of consumers; these associations, particularly interested in the model of living lab, actively took part in the public service, such as the recovery of the organic fraction of municipal solid waste;
3. the third group, consisted of five mayors or representative persons of municipalities, interested in the environmental effects and benefits of the CCP and in the participation of citizens in public life that may result from the involvement in the composting project.

During the exploratory phase the research theme is set to define with accuracy the items and concepts that will set up the basis of the next steps (Glenn, 2009). Consultation activities (living lab) were conducted with the stakeholders, that were a key part of the participatory design process.

All the stakeholders involved in the analysis, took part both in the implementation of the participatory planning process and in the management of the innovative process of valorisation of the organic fraction of waste. The stakeholders' panel was asked in a two round Delphi-like approach. The forecasting task of this investigation was to elicit and combine judgments and evaluate the consensus. Two iterations were considered sufficient by many qualitative forecasting studies (Lloyd, 2011).

During the consultation activities of the participatory process, an open structured interview format was chosen to collect information (Gill et al., 2013) from stakeholders, through a set of questions and relevant issues starting from the evidence from literature review. The questions, focused on drivers and obstacles influencing CC adoption and management, required narrative responses.

The selected obstacles and drivers were grouped in the "First round"; by analysing the answers of which a new set of questions were defined to be submitted to the same experts during the Delphi's "Second round".

2.4.2. Consumers' analysis

The social sustainability analysis was completed through a survey made amongst the citizens and aimed to evaluate the social acceptability for the proposed community composting process. A structured questionnaire, disseminated through internet platforms and social networks, was addressed to citizens of the community actively involved in the project and to citizens who did not directly take part in the project. The purpose of this part of the study was to evaluate the citizens' awareness, involvement, participation to the proposed innovation process. The questionnaire included mainly closed-ended questions aimed to profile citizens according to their socio-economic features and to detect the main issue affecting their appreciation and willingness to engage in the composting process. Finally, citizen willingness to pay for the compost resulting from the CC was also investigated.

3. Results and discussion

3.1. LCA: impact assessment and interpretation

The environmental assessment is done using the CML 2 baseline 2000 V2.05 and EPD (2008) V1.03 methodologies. The impact assessment methodology CML was chosen because it considers a 100-year time horizon, as the IPCC recommends observing the quantity of CO_2 with the same radiative force 100 years after zero (Pacheco and Silva, 2019) and it is also the most applied in research (Zaman, 2010). Considering the Global Warming Potential in the time horizon of 100 years (GWP_{100}), according to CML 2 baseline 2000 methodology, the total GHG emissions are 83.99 kg CO_2/t of compost. Particularly, results highlight that the environmental impact is caused for 59.76% by the paper bags used for waste collection, followed by the electricity consumption of the system (30.74%) and the fuel used for the transport of waste (9.47%) (Fig. 3).

Compost acts as a carbon sink, increasing the store of soil organic matter (Biala et al., 2021) and should be considered as a negative contribution to the total GHG emissions; the compost uses in gardening and horticulture, displacing the use of peat and fertilizers, can reduce CO_2 emissions (Smith et al., 2001; Andersen et al., 2010; Bong et al., 2017).

GWP, as way of comparing different studies, needs to be expressed in tons of food waste to be treated; it follows that the CCP's GWP_{100} is equal to 12.59 kg CO_2/tonne of FW. GWP shows a much lower potential environmental impact compared to that of the other authors (Martínez-Blanco et al., 2010; Mondello et al., 2017). The actual difference lies in that a CCP collecting biowaste from neighbouring municipalities allows to reduce the path and fuel consumption for biowaste collection and transfer to the CCP (15 km/t).

Comparing the environmental sustainability of CCP, in terms of GHG emissions, to other WM strategies highlights that landfilling shows the highest impact indeed, according to Bong et al. (2017) and Mondello et al. (2017), the GWP related to landfill is 1710.4 kg CO_2 eq./t of waste

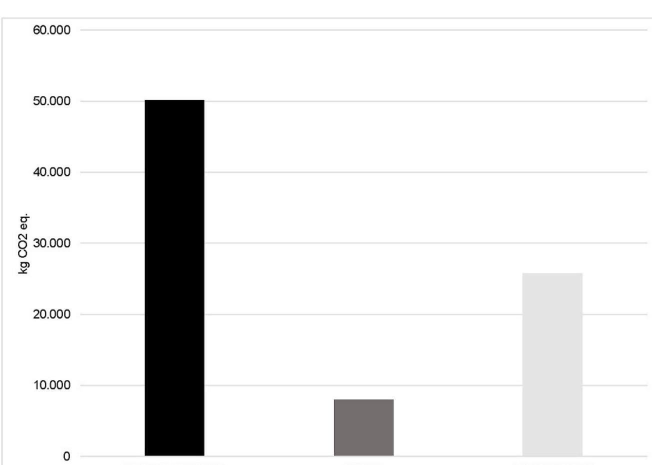

Fig. 3. GHG emissions as kg CO_2 eq./t of compost.

and 1243.98 kg CO_2 eq./t of waste, respectively, followed by the incineration scenario according to Cherubini et al. (2009) and Mondello et al. (2017), the GWP related to incineration is 948 kt CO_2 eq./t of waste and 822.67 kg CO_2 eq./t of waste, respectively.

To specify the energy aspect, the EPD method was used, by analysing the category "Non-renewable, fossil", expressed in MJ eq.: the process of the recycled paper bags represents the main energy consumption (1810.29 MJ eq./t of compost).

3.2. Economic sustainability

3.2.1. Cash flow composition and financial analysis

An assessment period of 20 years at constant prices was considered; in each year, 3 entire composting cycles performed were assumed; only in the first year two cycles were considered, due to plant construction time. The cash flow represents the flow of revenues and expenditure for the acquisition and management of all items, assumed as at the end-of-year, up to duration of the project of an enterprise (Ayyub, 2014).

The first step of the analysis is to determine the initial investment (I_0) covering all the fixed costs of the composting plant. The I_0 (Table 2) includes the cost of CCP, the purchase of two earthworms compost tanks, the forced ventilation system, the meteoric water treatment plant, the hopper, the shredder, the truck for the transport of OW, the weighing machine, the electrical and hydraulic systems, the construction of the yard, roof, and fence, etc.

The second step of the analysis is to determine the total variable costs (VC) of the CCP, incurred in one year (Table 3). The component "Labour work" includes compost quality controls, routine CCP maintenance, management of the CCP by three workers, their wage (considering an hourly tariff of 12 euros) and the salary of the administrative staff, equal to 5% of Gross Profitable Production (GPP).

The selling price of 1 kg of compost was assumed at € 1, based on the medium retail price, resulting from a survey among local retailers and specialized web sites. Considering a production of 72 tonnes of compost and the savings from the expenditure for the landfill of the corresponding amount of waste, that is of 26,880 € the GPP (data obtained from municipal accounting and related to the avoided cost of landfilling), is € 98,880.00, including the compost sale and the avoided cost of landfilling.

The financial analysis was carried out considering as indicator the Internal Rate of Return (IRR), that is the rate of return on investment, and it is used to estimate the profitability of a potential investments. The IRR [eq. (1)] considers the net present value (NPV) of all cash flows to be equal to zero. The NPV is the difference between the present value of

Table 2
Total initial investment (I_0) for the CCP.

Component of I_0	Initial value (€)	Lasting years	Depreciation charge (€)
Composting plant	91,000	25	3,640
Earthworms compost tank (2)	7,000	10	700
Forced ventilation system	500	10	50
Meteoric water treatment plant	5,000	20	250
Hopper	15,000	25	600
Shredder	9,000	25	360
Office box	7,000	20	350
Weighing machine	2,500	10	250
Electrical system	4,000	15	267
Hydraulic system	2,500	15	167
Roof	30,000	25	1,200
Construction of the square	40,000	25	1,600
Fence	3,000	15	200
Truck	20,000	10	2,000
Earthworms	400	16	25
Total I_0	**236,900**		
Total depreciation quotas		**11,658.33**	

Table 3
Total variable costs of the CCP, for one year.

Component of Variable Cost	Value (€)
Labour cost	34,852.00
Energy consumption	1,150.00
Fuel consumption	4,704.96
Bags	6,275.88
Water	300.00
Total Variable Cost	**42,282.84**

cash inflows (expected revenue from selling the produced compost) and the present value of cash outflows (expected expenditure) over a given period.

$$IRR = \sum_{t=1}^{t} \frac{CF_t}{(1+k)^t} = 0 \quad [1]$$

CF_t = cash flows at a discount rate (k) during the period t.

t = time expressed in period.

The IRR shows how many years it needs to cover all the investment costs; as the graph (Fig. 4) shows, the minimal return year for investing in a CCP is between the 6 and the 7 years, in line with literature references on this item (Bong et al., 2017).

The financial analysis shows that the realization of such business model is self-sustaining, thanks to the avoided costs for the landfilling and to the revenues from the sale of the compost. Indeed, in six and a half years the total initial investment (with the total earnings from the sale of produced compost per year and the cost of the avoided landfilling) will be recovered.

3.2.2. *Economic analysis*

In the economic analysis the externalities of embedded CO_2 emissions in OW is encompassed by the CBA. Carbon emission pricing is an economic measure to mitigate climate change and to trigger a behavioural change in reducing emissions of GHG (OECD, 2021). Considering the economic value of the avoided CO_2 in one year (Table 4), the CCP would have greatest benefits on the GPP.

CCP business could offer a win-win strategy by considering the savings in terms of carbon sequestration; indeed, composting can allow a reduction of maximum 65% in GHG emissions, compared to landfilling (Seng et al., 2013). This can be an important value-added with the aim and the perspective of reducing carbon emissions.

So, this demonstrated that CCP could be a good business model provided the scale of the plant is the correct one (or big enough), the produced compost is a high-quality one and the GHG savings are always improved (by using electric trucks for the waste collection and photovoltaic panels).

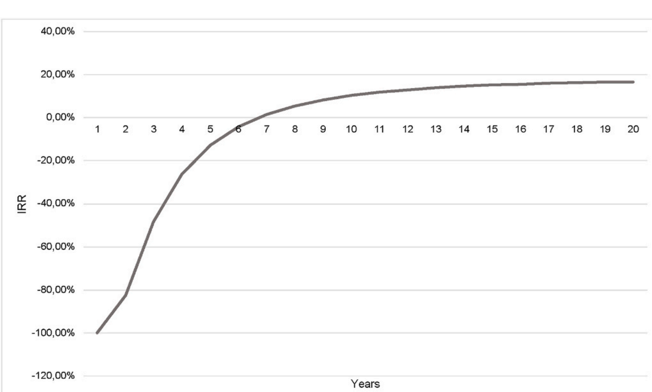

Fig. 4. IRR values by year.

Table 4
Value of the avoided CO_2 per year.

Waste and emission	Amount and values
Amount of organic waste composted (t/year)	240.00
Avoided CO_2 (t/year)	103.15
CO_2 market price (€/t)	23.50
Total value of avoided CO_2 (€/year)	**2,423.98**
Total GPP, incl. external cost of CO_2 (€/year)	**101,303.98**

3.3. *Social sustainability*

In the first Delphi round, stakeholders' opinion about the set of drivers and obstacles, defined in the preliminary phase were expressed through the attribution of a score from 1 (unimportant) to 5 (very important). The analysis of the results allowed to highlight not only the most relevant drivers and obstacles, but also the level of concordance of the opinions expressed by the different stakeholders on the proposed aspects.

Tables 5 and 6 show:

- the averages scores expressed for aspects considered as incentives and hindrances to the adherence to CC process;
- the standard deviation from the general average for each score, representing the level of agreement among stakeholders.

Table 5
Drivers favouring the adherence to the community composting process.

	DRIVERS	I ROUND		II ROUND	
		Score	Standard Deviation	Score	Standard Deviation
D1	Municipal waste management efficiency	4.92*	0.39*	4.00	0.30*
D2	Compost usefulness for municipal areas	4.52*	0.75*	**4.50***	**0.60***
D3	Citizens' environmental awareness	4.52*	0.51*	**4.75***	**0.60***
D4	Compost certification	4.41*	0.93*	**4.50***	**0.69***
D5	Involvement of local community	4.41*	0.80*	**4.50***	**0.69***
D6	Info about use and value of compost	4.37*	0.74*	**4.50***	**0.61***
D7	Community composting info	4.26*	0.45*	4.25	0.63*
D8	Availability of compost for citizens	4.26*	1.26		
D9	Door to door collection efficiency	4.22*	0.80*	4.00	0.61*
D10	Awareness/information campaigns	4.19*	0.83*	4.25	0.66*
D11	Local market for compost	4.19*	1.14		
D12	Composting processing info	4.15*	0.78*	4.25	0.60*
D13	Institutional support	4.15*	0.73*	4.25	0.67*
D14	Economic incentives to citizens	4.15*	1.06*	4.00	0.67*
D15	Economic sustainability of private plant	4.11*	0.85*	**4.75***	**0.68***
D16	Economic sustainability of door-to-door collection	4.09	1.00*	4.00	0.68*
D17	High availability of organic waste	3.89	1.50		
D18	Citizens' education	3.81	1.33		
D19	Use of compost for private citizens' gardens	3.70	0.87*		
D20	Low availability of organic waste	3.15	1.26		
D21	Citizen age	2.96	1.53		
D22	Number of household members	2.81	1.11		
	Average values	**4.09**	**1.09**	**4.27**	**0.73**

Table 6
Obstacles to the adherence to the community composting process.

	OBSTACLES	I ROUND		II ROUND	
		Score	Standard deviation	Score	Standard deviation
O1	Scarce institutional support	4.69*	0.74*	**4.50***	**0.58***
O2	Scarce information on Community composting	4.44*	1.01*	**4.50***	**0.58***
O3	Underestimation of composting quality respect to fertilizers	4.26*	1.13*	**4.50***	**0.58***
O4	Low involvement of local authorities	4.07*	0.78*	3.75	0.50*
O5	Difficulties to locate composting plant	4.07*	1.11*	4.00	1.15
O6	Citizens' lack of interest	3.96*	1.02*	**4.50***	**0.58***
O7	Lack of home space for separate collection	3.89	1.69		
O8	Difficulties in communicating composting advantages for the citizen	3.70	1.20		
O9	High costs of door-to-door collection	3.38	1.60		
O10	Lack of organic waste to be composted	3.31	1.35		
O11	Local market for compost	3.22	1.28		
O12	Preference for individual compost bins	3.00	1.88		
O13	Lack of gardens or gardens terraces to use compost	3.00	1.39		
	Average values	**3.90**	**1.39**	**4.22**	**0.71**

The items receiving a score higher than the average and a standard deviation (SD) lower than the average, were considered of higher importance and able to gather a good level of consensus among respondents. These items, marked with asterisks in the second and third columns of the tables, were included in the second-round questionnaire.

The analysis of the aggregated results has allowed to highlight the level of concordance of the opinions expressed by the different stakeholders on the proposed aspects and the drivers and the most relevant obstacles.

3.3.1. Drivers

The statistical analysis of the First-round responses lead to a Delphi "Second-round", whose questionnaire was administered to the same experts. The time between rounds was less than one month and the comments gathered from the experts give abundant and high-quality qualitative information. In general, the quality and stability of the panel of experts may be considered satisfactory: only two of selected experts did not take part until the end.

Looking at the second round's score (Table 5), the most relevant items boosting the participation to the CCP were related to the social acceptance of process: truly, public sensitivity to environmental issues (D3: 4.75) and the involvement of local community in the process (D5: 4.50) achieved the highest values in terms of importance and showed a high convergence of views from stakeholders (SD 0.60, 0.69). Economic feasibility of CCP is also a relevant (D15: 4.75) and widely shared (SD 0.68) aspect, as availability to initial capital cost has been identified as a critical point for CCP. These results are consistent with results of economic analysis developed inside this study and with other authors insights (Pai et al., 2019). The opportunity of employment of compost in municipal areas (parks, gardens, green areas) has been identified as an opportunity (D2: 4.50, SD 0.60) by most of stakeholders; composting may reduce the collection and treatment costs of food waste associated with landfills and convert OW into a useable product. Consistently with the former aspects, the information about use and value of compost (D6: 4.50, SD 0.61) were recognized as valuable incentives for the community to join the process, especially if the compost can boast of a quality certification (D4: 4.50, SD 0.69). Results of other studies (Vázquez and Soto, 2017; Cerda et al., 2018) showed that home composting of OW may supply compost of high quality for gardens or farming and that the more correct the collection and separation of waste and the lower the percentage of inappropriate materials, the higher is the compost quality.

3.3.2. Obstacles

The obstacles (Table 6) considered important for the adoption of CCP, are numerically less relevant than the drivers and interviewed stakeholders showed an even greater unity in their judgments. The highlighted obstacles were mainly related to the difficulty of communicating the benefits of CCP. The underestimation of usefulness and quality of the compost and the poor awareness of its properties as a soil improver (O3: 4.50; SD 0.58) prompt to consider the compost comparable to any other fertilizer. Scarce information on CCP (O2: 4.50, SD 0.58) and on its benefits from an environmental and economic aspect, induce to not perceive CCP as a profitable business opportunity that can positively affect social development too (Aziz et al., 2016*)*. This confirms the fundamental role played by information and the sharing of objectives with the reference community. The citizens' lack of interest was also scored (O6: 4.50, SD 0,58) as an important obstacle to the process's implementation and adhesion. These results are not surprising as several other authors (Soltani et al., 2015) highlight the need to develop strategies engaging all categories of stakeholders and final users (citizens) from the very first phases of the composting process planning.

Finally, the scarce institutional support revealed itself as a further obstacle to the CCP (O1: 4.50, SD 0.58). Currently, CC actions are rarely integrated in the Regions' solid waste strategies, and Regional Planning Authorities usually do not activate subsiding mechanisms supporting the initial setup investment or technical assistance of composting plants, nor do they provide compensation arrangements, information and training actions, boosting citizen participation (Pai et al., 2019).

3.3.3. Consumer's analysis

The main features of the 419 citizens involved in the consumer analysis are summarized in Table 7. Almost 70% of respondents live in urban area and less than one third of them declared to use the compost for a garden, a flowered balcony, or indoor plants. More than 90% of the sample declared to give the waste separately in the municipality of residence.

In line with this result, it was observed that more than half of the sample was not able to give a correct definition of compost (Table 7), recognizing only partially its agronomic qualities. In addition, most respondents show that they do not know the process of CC (Table 7), not appreciating the environmental benefits.

Looking at Table 8, 40% of the sample declared a willingness to join CCP initiatives regardless of any incentive, while a similar percentage (38%) declared its willingness to join the CCP in exchange for a reduction on municipal taxes on waste or a voucher (7%). The possibility of withdrawing the compost produced free of charge was positively evaluated by 10% of respondents, consistently with the results of the Delphi analysis. The location of the CCP does not seem to be of particular concern to the respondents who declare themselves willing (more than 50%) to have a community plant at less than 5 km from their home. Finally, the willingness to pay for community compost was assessed.

The results highlight the lack of appreciation for compost by citizens: only one third of respondents would be willing to pay for community compost a price higher than the market price, a fifth would buy it only at a lower price and most consumers would not buy it at all. The higher WTP is not related to the possibility of making use of the compost for gardening and/or flowered balcony or indoor plants, neither to the residence in rural or urban area with garden, but rather to the citizens' income. Insights showed that more than 43% of citizens willing to pay more than the market price have the highest income (>40,000 €/yr.).

Table 7
Sample's description.

CRITERION	SCALE OF MEASUREMENT	FREQUENCY (%)
Age (years)	20–29	9.2
	30–39	13.3
	40–49	27.5
	50–59	26.7
	60–69	20.0
	>70	2.5
Gender	Male	42.9
	Female	57.1
Education	Compulsory school	12.4
	High school	19.3
	University degree or postgraduate	68.3
Income	Up to 20.000 €/year	10.1
	From 20.100 to 40.000 €/year	47.1
	More than 40.000 €	42.9
Profession	Housewife	4.2
	Freelancer	35.0
	Worker	0.8
	Employee	54.2
	Student	5.0
Place of residence	Urban area	69.2
	Urban area with garden	18.3
	Rural area	12.5
Separate collection in the town hall	Mandatory	83.3
	Voluntary	16.7
Attitude towards separate collection	Regularly and scrupulously	90.0
	Occasionally	3.3
	No attention	2.5
	Home composting	4.2
Knowledge about compost	Fertilizer	50.0
	Soil improver	48.3
	Plant protection product	1.7
Uses of compost	Unused	70.8
	Farm	2.5
	Ornamental plants	13.3
	Garden	10.8
	Backyard	17.5
Knowledge of community composting	Know it	37.5
	Unknown	62.5

Table 8
Consumers' opinion about participation, location, and Willingness to pay compost.

PREFERENCES	CHOICE	FREQUENCY (%)
Incentive to participation	No incentive	40.0
	Vouchers	7.0
	Free quantity of compost	10.0
	Reduction of taxes	38.0
	No participation	6.0
Minimum distance from houses	No idea	16.0
	<1 km	33.0
	1.1–5 km	19.0
	5.1–10 km	24.0
	>10 km	8.0
Willingness to pay 5 L of compost	No idea	30.0
	No purchase	19.0
	Less than market price	21.0
	Market price (about 5 €)	22.0
	More than market price	8.0

Moreover 82% of citizens in this group declared to be graduated. Finally, 30% of consumers did not express an opinion, confirming that the acceptability of the compost and composting process must be supported by adequate information and educational programs, emphasizing its economic, environmental, and social value.

4. Conclusion

The present study is a contribution to the literature in terms of assessing social, economic, and environmental sustainability of CC; a holistic approach was carried out to evaluate the performance of CCP. The need to re-design a more efficient bio-waste management, protect and improve the quality of the environment, protect human health, ensure efficient and rational use of natural resources, promoting the circular economy, according to Directive EU 2018/851, justifies our research purposes.

The results of this study showed how the proposed model of OW management could meet the needs of managing OW while ensuring the economic and environmental sustainability of the process. In particular, the environmental impact proved to be lower than the alternative landfill or incinerator scenarios. Regarding the economic sustainability, CC could limit and discourage the use of other OW disposal methods, especially pursuant to the possibility of obtaining a product that can be rewarded by the market. In this sense, the role of compost quality certification is crucial to enhance on the market a particularly effective product with high content in organic matter and high soil improver power. Social acceptability resulted strongly influenced by the level of information and knowledge of the community: further efforts should be aimed at informing and involving citizens in the process, considering CC as a downstream and upstream activity particularly valuable because at the same time it attempts to reduce the large amount of OW going to landfills and produces compost as a high value product to be used in many activities (Boldrin et al., 2011; MacLeod and Moller, 2006).

This study highlighted how CC may represent a valid and efficient OW management strategy in a small community. The strength of the proposed approach lies in the sensitivity of the local citizens and in their active involvement; the citizens, acting themselves as main players of a small-scale circular economy, become gradually more careful about the process and the methods of waste delivery. The economic, environmental, and social advantage in cases of small communities and limited territories lies in the possibility of treating small quantities of bio-waste in a decentralized system, smaller than in industrial ones. The case study demonstrated that improving locally driven methods of addressing social, ecological, and environmental sustainability, as the CCP, may significantly affect the bio-waste management strategy.

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.

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