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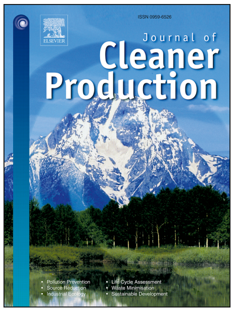

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PII: S0959-6526(21)01482-7

DOI: https://doi.org/10.1016/j.jclepro.2021.127263

Reference: JCLP 127263

To appear in: *Journal of Cleaner Production*

Received Date: 19 October 2020

Revised Date: 22 February 2021

Accepted Date: 21 April 2021

Please cite this article as: Marcello B, De Gennaro V, Ferrini S, Let the citizens speak: an empirical economic analysis of domestic organic waste for community composting in Tuscany, *Journal of Cleaner Production*, https://doi.org/10.1016/j.jclepro.2021.127263.

Credit Author Statement

Marcello Basili planned the project. All co-authors contributed to design the study. Valentina Di Gennaro collected the surveys and contributed to conduct the analysis under the supervision of Silvia Ferrini. Silvia Ferrini wrote the paper. All co-authors contributed to the writing.

Let the citizens speak: an empirical economic analysis of domestic organic waste for community composting in Tuscany

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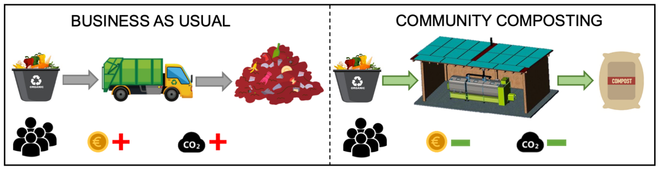
BUSINESS AS USUAL
COMMUNITY COMPOSTING
COMPOST

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Abstract

Organic waste represents an opportunity and a challenge for policy decision makers and lately the attention has been focusing on community composting practices identifying the environmental and/or economic aspects. Evidence of citizens' attitudes and preferences is scarce, and this paper aims to fill this gap. The results of a contingent valuation survey in three councils of the Province of Siena, Tuscany (Italy) are reported along with an extended cost-benefit analysis. Results echo previous findings that GHGs emissions and money-saving for all municipalities are positive and encouraging; moreover, our study proves that citizens are keen to switch to the community recycling composter system. Citizens present heterogeneous preferences and accordingly to the current waste management system they might need a small financial compensation to switch in favour of the local community system.

Keywords: community composting, domestic organic waste, recycling, sustainable development, citizens behaviour

JEL: Q53, Q56

1. Introduction

The waste management industry plays an increasing role in climate change mitigation (Ragoßnig and Hilger, 2008) and Circular Economy (CE) ambitions (Paes et al 2019). The Circular Economy (CE) is a circular system able to gradually decouple growth from the consumption of finite resources, in contrast to the current 'take-make-waste' linear model. Circular economy and waste management can also contribute to the wider goal of the Ecological Transition (ET) movement that aims to ensure the resilience of a community that, despite the economic crisis and global warming, can continue functioning at its full capacity.

The EU Waste Framework Directive (Directive 2008/98/EC, 2008) encourages re-use and material recycling solutions rather than energy recovery and disposal. In this context, composting is an intermediate solution and the separated collection of bio-waste is a measure promoted by the European Directive to encourage Member States to transition to circular economy management strategies.

A comprehensive European legislation on community composting is still missing but the literature has thrived in exploring the pros and cons of the system. Bio-waste and community composting have been studied from different perspectives and several studies focused on environmental issues using Life Cycle Analysis (LCA), Green House Gas (GHG) accounting and quality composition methods (Boldrin et al., 2009; Breitenmoser et al., 2018; Lundie and Peters, 2005; Møller et al., 2009; Oliveira et al., 2017; Zeller et al., 2020; Zorpas et al., 2018). Others investigate theoretical and economic aspects of waste recycling

(Adhikari et al., 2010; Bong et al., 2017; Pai et al., 2019; Zulkepli et al., 2017) but there's a lack of understanding the citizens' preferences and attitudes (Deus et al., 2019). Ultimately, the citizens need to actively contribute to the community composting system and their opinion is as important as the economic and environmental benefits.

In Italy, the Law Decree 266/2016 regulates the organization of community composting activities defining the operative criteria and authorization procedures for community composting up to 130 tons per year. Additionally, it introduces installation and equipment requirements, characteristics and use of the produced compost, control activity and input materials. The Italian normative promotes community composting as a form of organic waste to satisfy the EU recycling target (50% of urban waste recycled by 2020) and in 2017, the Tuscany waste management plan defines the objectives and actions to be pursued: (i) prevention and reduction of waste production and preparation for re-use through the promotion and dissemination of self-composting; (ii) increased recycling and recovery within the management of urban waste and special waste, by improving the quality of the compost product and the reduction of process waste; (iii) biological mechanical treatment plants and additional recovery of non-recyclable materials.

Community recycling composting (CRC) or decentralised composting is an alternative strategy for collecting and treating bio-waste (i.e., kitchen waste, yard waste) in a controlled operative environment (composter) located in specific neighbourhoods. In recent years, local communities have been showing an increasing amount of attention to decentralized composting because it can overcome limitations of centralized waste treatment facilities such as high transportation, operation and maintenance costs, high degree of specialized skills and advanced technology required, large facilities and low quality of compost.

The community-scale benefits have been currently analysed in previous studies with a focus on technical and economic features (e.g. Bruni et al., 2020; Zeller et al., 2020); however, from our research it emerges that the opinions and willingness to participate of citizens are commonly overlooked and this can cause a delay in gaining the support of decision-makers. In this research, we aim to contribute to the community scale composting literature considering the response of citizens of three small towns in Tuscany.

Our research considers the transition from the current organic waste system (separate waste collection) to community composting recycling and captures the environmental and economic benefits as well as preferences and attitudes of citizens through a direct survey. Although the case studies are in the province of Siena (Rapolano Terme, Cetona and Gracciano, a fraction of the municipality of Colle Val d'Elsa), we claim that the research findings can be relevant for other small municipalities which represent roughly 70% of Italian towns with less than 5,000 inhabitants (ISTAT, 2019).

The paper assesses the citizens' preferences and willingness to participate in a community composting system through a contingent valuation survey. These results are combined with current bio-waste management costs, investment costs and GHG emissions to value in a cost-benefit analysis (CBA) the pros and cons of community system. The economic feasibility is promising, and most importantly the citizens are supportive and prepared to participate. We conclude that the community composting systems should be encouraged as a practical action to recycling bio-waste and transition to circular economies.

The paper is organised as follows. The literature review is in Section 2. Section 3 defines methods. Section 4 shows the case study, the survey design and CBA. A discussion of evidence and results is in Section 5. Concluding remarks are in Section 6.

2. Background information

In the last decade, several papers focused on organic food waste and composting systems addressing the pros and cons. Table 1 summarizes the previous studies pointing out the aspect and methodology object of that analysis.

[Table 1 about HERE]

Environmental impact of bio-waste composting has been studied from different points of view. Zorpas et al. (2018) conduct a compositional analysis on household composting in Paralimni Municipality located in the Eastern Region of Cyprus in order to assess the percentage of composted waste. They verify that up to 40% of waste can be recycled with a significant contribution to reduce landfill use. Breitenmoser et al. (2018) analyse the biochemical methane potential of bio-waste from a sample constituted by household, fruit and vegetable markets and agricultural waste collection points. They monitored and collected data across seasons and community of different sizes (villages, towns and cities) in India to understand whether anaerobic digestion can provide bio-waste. They report that the mean biochemical methane potential at 37 °C was between 200–260, 175–240 and 101-286 NL_{CH4} kg $_{vs}^{-1}$ for household, market and agricultural bio-waste, respectively. Zeller et al. (2020) conduct a LCA of alternative circular management system from conventional treatment options to more circular management systems (co-composting and anaerobic digestion) to identify which have the best environmental performance. Their conclusions are that local systems and a combined treatment of food and green waste have environmental benefits if process emissions are properly managed, i.e. using bio-filters, and if the by-product are used as peat and fertilizer. Lundie and Peters (2005) quantitatively evaluate alternative food waste processors (co-disposal of food waste with municipal waste, home composting, centralized composting) using the LCA and they show that centralised composting has a relatively poor environmental performance due to the energy-intense waste collection activities required. Boldrin et al. provide the methodology of GHG accounting when specific information and data are available; in particular, their assessment considers the type of composting of organic waste and the use of compost in relation to the waste type and composition (kitchen organics, garden waste), the technology type (open systems, closed systems, home composting) and the use of the compost. Their conclusions are that the overall global warming factor for composting ranges between -900 and 300 kg CO_2-equivalents tonne^{-1} wet waste; moreover, they specify that major savings are obtained by use of compost as a substitute for peat.

Other studies focus more on the economic performance of bio-waste composting or on combined prospective that include either environmental or economic consideration. Zulkepli et al. (2017) provide a cost benefit analysis comparing landfill, community composting and anaerobic digestion for organic municipal solid waste in a community of 600 households located in Malaysia. Their results suggest that composting is the most economically profitable and environmentally feasible alternative compared with the others studied. Adhikari et al. (2010) compare the traditional landfilling practice and the on-site composting strategies (centralized composting facilities, community composting centres and home composting). They found that composting practices can lower management costs by 34-50% and reduce GHG emissions by 40%. Mu et al. (2017) analyse environmental and economic impacts of a scale project composting system at Kean University (KU) in New Jersey using the LCA and cost benefit analysis. Their results show that food waste composting systems reduce environmental impacts - especially in the categories of fossil fuel, GHG emissions, eutrophication, smog formation and respiratory effects – and it could generate a profit for the university campus of € 11,100-20,000 a year by selling vegetables grown with compost. Pai et al (2019) focus on an application of decentralized composting in Chicago using cost and GHG emissions impact analysis comparing the community composting to current food waste processing systems. They suggest that demographic and land use characteristics could influence community composting impacts and decentralized composting has also potential social benefits beyond environmental and economic ones. Their results provide the financial feasibility of city-wide decentralized composting strategy and the overall benefits is estimated $100/Mg of food waste composted. Bong et al. (2017) applied the GHG and cost analysis of community composting in a village in Malaysia. Their results show potential reduction of 71.64% on GHG emissions and significant revenue from the compost sale (roughly € 300-4,500 per year). Bruni et al. (2020) prove that the decentralized composting systems reduce transportation and maintenance costs, the need of specialized skilled workers, require simple technology with small facilities and produce high-quality compost that can be used as soil conditioner. It seems that the literature is supporting the idea that the decentralised composting system is promising. However, the studies reviewed are mainly focused on environmental and economic aspects disregarding the citizens' preference or taking for granted people's cooperation. Our study investigates citizens' preference towards community composting and use this information to run the overall assessment using GHG accounting and cost benefit analysis.

3. Methods

The citizens' attitudes and preferences are captured in a direct survey by contingent valuation method (Supplementary Information section C contains a brief description of the method). The contingent valuation is conducted through face-to-face interviews to collect information about: (i) environmental sensitivity of the respondents; (ii) satisfaction with the current separate waste collection service; (iii) knowledge of composting and the availability to carry it on with community composting; (iv) social and economic characteristics of respondents. The questionnaire describes the key characteristics of the community recycling composter for food waste with a picture and a brief text as suggested by the contingent valuation guidelines (Johnston et al., 2017). The chosen Community Recycling Composter is a steel automatic cycle machine with an annual capacity of 120 tonnes of waste. The mixed compost is obtained through fourteen working days; no special maintenance is required, and the absence of smell and leakage are guaranteed if it is used correctly. The price of the machinery is € 68,447 (20 year warranty), including the wooden shelter recovery equipped with energy system, mini photovoltaic or wind power plants to ensure full energy independence of the system (Table SI1 in supplementary information provides the technical details).

The citizens' preference for participating in the scheme was measured in two ways: (i) discount - the Willingness To Accept (WTA) – for joining the programme, (ii) and the distance that citizens are willing to walk to deposit the waste. The WTA is collected as open ended expressed as a percentage of the current waste fees. The willingness to walk is expressed as an interval card where different distances are available for the respondents to choose from.

The contingent valuation responses are modelled with linear, Tobit and interval regression techniques to determine the amount of money required as compensation and the ability to actively contribute to the waste composter by walking to the facilities. In order to explore the differences across respondents and municipalities, we regress the WTA and a set of control variables (e.g. age, education, income, household size, etc.) and compare two alternative modelling strategies (linear and Tobit model) to test the robustness of results. The selection of independent variables is driven by the economic theory and their statistical significance in the regression analysis.

The walking distance for conferring waste to the community recycling composter is the important factor in understanding the feasibility of this initiative. An interval regression model is used to investigate the relationship among willingness to walking and respondents' characteristics. The dependent variable is ordinal with *Short* = 0-200 meters, *Medium* = 200-400 m and *Long* = more than 400 m. A set of socio-economic variables are also included in the regression to control for heterogeneity of preferences (Table SI2 in supplementary information provides the description of variables).

The citizens' preferences and contribution measures (WTA and walking distance) are subsequently used in an extended Cost Benefit Analysis to assess the feasibility of the community composting system vs the traditional centralized system. The investment and operational costs are included as well as the GHG emissions estimates obtained with the Boldrin et al. (2009)'s approach.[1]

4. Results

4.1 Empirical case study

Rapolano Terme, Cetona and Gracciano are three towns in the province of Siena (Tuscany) with less than 5,000 inhabitants. The waste collection system varies according to different municipalities and includes door-to-door and street bins. The current food waste management system in Rapolano Terme consists of the door-to-door where the inhabitants put the bin outside the house depending on the scheduled weekly day for collection. In Cetona, the collection bins are positioned along the streets and citizens are responsible to

[1] They use global warming perspective and provide information about processes and data useful in accounting GHG emissions distinguishing between Upstream, Operation and Downstream (UOD) contributions.

deposit the rubbish in the dedicated area. In Colle Val d'Elsa the waste collection system is mixed. The door-to-door is adopted in the center, whereas in Gracciano bins are in streets. Table 2 reports the quantity and costs of food waste management in the three towns.

[Table 2 about HERE]

Cetona is the town with the most expensive waste collection system (€/t 502), Gracciano and Rapolano Terme exhibit similar expenses, €/t 336 and 355 respectively.

4.2 Survey design, socio-economic characteristics and models results

In total 192 participants took part in our survey and provided information about their attitudes and preferences. The three municipalities are equally represented, and the average age is 52 years old. The majority of the respondents are married (59%), 26% are single, 8% widowers and 7% cohabitant (partner not married). The average size of households is 3 people; the majority of the sample has a high school degree (48%), 29% have primary or professional education and 23% hold a university degree. Almost 60% of the population have an occupation, while the rest are students, retires, housewives and unemployed. The average income is €28,752 (st. dev. €28,028) per year. The average house size is 109 m^2, 63% of respondents own a garden and 19% of them buy fertilizer. Almost all respondents (96%) classify themselves as pro-environment and are particularly interested in maintaining and enhancing environmental quality.

The current waste management is acceptable for 36% of the sample; 30% are unsatisfied and 34% are neither satisfied nor dissatisfied. The average fee for the waste collection (called TARI) is €279 per year, but 79% of the sample believes that the amount is not proportionate to the quality of service ("Fee perception" in Table SI3). 94% of the sample is actively recycling and 78% of the respondents seems to be aware of how to do it correctly. 30% of the sample is composting at home and the same percentage of respondents knows the community recycling initiatives. The majority of respondents (92%) considers the community recycling composting an effective approach to recycling food waste and the same percentage of respondents are willing to participate in a municipal waste collection project.

The algebraic mean WTA to participate in the community organic waste recycling program is € 9.30 (st. dev. € 17.68) per year and it is obtained from the survey responses. However, Figure 1 portrays an interesting finding as the majority of respondents do not need any compensation to contribute to the community recycling initiative proposed. Indeed, the majority of respondents place on the left side of x-axis that represent an interval ranging between €0 and €150.

[Figure 1 about HERE]

In fact, 54% of the sample would be willing to participate in the community recycling composter without any monetary compensation. 24% will accept a 5% discount, 15% a 10% discount and a small proportion of them (3%) will require a compensation of 15% of the current waste fee. 4% of respondents will not contribute/accept discount as they cannot part-take in the community recycling composter for other reasons (e.g. disabilities). The descriptive analysis of sample is summarised in the supplementary information (Table SI3) All variables were initially included in all models testing multiple functional forms however we just report the statistical significant variables and the models specification that comply with economic theory and empirical regularities (Bateman et al 2011).

The linear and Tobit models suggest that the attitude of respondents towards the community recycling composter varies in the three municipalities.

[Table 3 about HERE]

Table 3 summarises the results. Inhabitants in Gracciano and Cetona are willing to accept lower compensation than Rapolano Terme. Respondents in Rapolano Terme are asking the highest compensation equivalent to more than €20 in the linear model and €13 in the Tobit model. Respondents who are keener to walk longer distances to dispose waste in street bins need a discount of €11. In general, age has a minor effect on WTA although younger people would like to receive a higher compensation than older people (about €4). Rich people require a higher level of compensation and this can be explained by the opportunity costs of time that needs to be dedicated to the community recycling initiative.[2] These socio-economic effects are not confirmed by the Tobit model which suggests modelling assumption influence results and the WTA is €9-13.

The walking distances is estimated by interval regression in relation to socio-economic characteristics like education and household size (base model) and then adding more variables concerning the practice of home composting by respondents and the belief of community composting as alternative for food waste management (extended model). Interval regressions show that Cetona's inhabitants are willing to walk 78-95 meters more than those of Rapolano Terme. Household with less than 3 people would walk less than 87 meters compared to large families. Respondents who already carry out home composting are willing to walk 78 meters more than those who do not do it. Inhabitants who believe that the community recycling composter is a good way to manage food waste are willing to walk 119 meters more than others. Table 4 reports the interval regression results.

[Table 4 about HERE]

4.3 CBA

[2] Other socio-economic variables have been tested but they were not statistically significant in the models.

A CBA is performed to consider the opportunity to invest in CRC. The performance indicator to measure the financial viability of the project is the Financial Net Present Values (FNPV) of the current centralized bio-waste management system that results negative at different discount rates (1%, 3%, 4%, 5%, 10%); in particular, they are between -1,569 (1%) and -740 (10%) thousand € in Gracciano, -4,626 (1%) and -2,182 (10%) thousand € in Cetona, -7,327 (1%) and -3,456 (10%) thousand € in Rapolano Terme. This means that the current situation is not financially sustainable.

Investment and operative costs of the community recycling composter system are considered. Investment costs (cash outflows) included in the CBA are the expenditures for the purchase of CRC, the cost of building the shed, the energy and personnel. Initial investment costs per town differ according to quantity of organic waste, composters and sheds needed. The energy considered include fix and variable costs: the first amount to 300 €/year and the latter amount to 0.5 €/kWh. The average energy consumed by the community recycling composter is 3 kWh per day (ENEA, 2016). The annual energy costs are €1,695 in Gracciano, €3,390 in Cetona and € 8,475in Rapolano Terme. Each community recycling composter needs one employee and the labor cost is set at € 24.000 per year. Moreover, the WTA estimates combined with the contingent valuation represent the cost that the council has to pay to encourage the inhabitants to devote time and effort to the community recycling composter. The mean WTA (€ 9.3) is applied to the three councils in the CBA. Table 5 reports the investment and operational costs and financial results of the CBA of the current food waste management system.

[Table 5 about HERE]

The extended CBA is conducted including the externalities (positive and negative) of the CRC. Several positive externalities can be considered: the saving of CO_2 emissions and costs due to transport and collection; decrease of food waste disposal in landfills and avoiding the consumption of fossil fuels to produce agrochemicals and the subsequent development of others greenhouse gases such as the N_2O as a result of their application; compost use contributes over time of carbon stock in soil (carbon sink), this contributes to reduction of CO_2 in the atmosphere; improving soil, positively influences soil workability, water retention and avoid erosion with consequent energy saving in soil tillage and irrigation (Amlinger et al., 2001); increase of soil biodiversity; safeguarding the fertility of soils with direct benefits on productivity.

The accounting of all externalities in monetary terms is challenging but we can claim that GHG emissions are surely the most relevant. We considered that in the current waste management system, organic waste needs to be collected and transported in the central treatment plant located in Asciano. This implies CO_2 emissions: in particular, Asciano is 80 km away from Gracciano, 39 km to Rapolano Terme and 64 km from Cetona. Considering 300 g/km of CO_2 emitted by a truck over 7.5 tonnes usually used for waste transport and multiplying the annual total of the kilometers travelled (8,320 km/year, 4,035 km/year and 6,656 km/year), the total annual CO_2 emission is 2.5 tonnes for Gracciano, 1.2 tonnes for Rapolano Terme and 2 tonnes CO_2 for Cetona. Moreover, Gentil et al. (2009) provide the balance of GHGs emissions in bio-waste composting initiatives which are the emissions directly linked to activities at the composting site and the degradation of the waste, in particular CH_4 and N_2O. In our study, the accounting of GHGs is based on the global warming contribution for enclosed composting technologies proposed by Boldrin et al. (2009). These authors measure the GHGs as tonne of wet waste (ww) composted. The CO2-equivalent tonne calculated are respectively -425 for Rapolano terme, -96 for Gracciano, and -190 for Cetona (table 6 reports the calculation of GHG emissions).

[Table 6 about HERE]

The international debate about the carbon price per tonnes is still ongoing. The literature proposes two main methodologies: the Social Cost of Carbon (SCC) and Marginal Abatement Costs (MAC). The SCC refers to the estimated monetary value of the damage produced by anthropogenic CO_2 emissions; it is defined as the marginal monetary value of the damage produced by the emission of 1 tonne of CO_2 in a given period of time (Pearce, 2003). More than 300 SCC estimates are currently available, and they derive from the variety of assumptions about climate impact categories, social discount rate, uncertainty and risk aversion. The CO_2 saved with the CRC is subsequently accounted for in monetary terms for the towns in the CBA considering as price of the CO_2 eq/t equals to €34 as in the European guide (European Commission, 2014).
The extended CBA reveals a huge saving in CO_2 equivalent emission and the monetary saving relating to it was estimated in 20 years: €85,738 in Gracciano, €166,726 in Cetona and €370,813 in Rapolano Terme. This represents an external benefit that the society is gaining by implementing the community recycling initiative.
The NPV of the extended CBA of the community composting scenario are positive: €167,094-29,750 in Gracciano, €2,142,983-1,291,117 in Cetona and €1,879,344-1,106,421 in Rapolano Terme. These results show that community composting is an economically sustainable practice.

[Table 7 about HERE]

Table 7 summarizes costs, benefits and Net Present Value (NPV) of the community recycling composter in the extended cost-benefit analysis[3].

5. Discussion

Research findings confirm common dissatisfaction for quality, effectiveness and costs of actual organic waste management system. Citizens reveal willingness and propensity to participate in municipal waste collection and recycling project, but few respondents were informed of the features of the community recycling composter. Only 36% of the respondents were satisfied by the current waste management system and a large majority of the sample considered waste fees (the average €279) to not be proportionate to the

[3] *The comparison of economic performance between industrial and community composting is a valid alternative to assess the efficacy of the organic waste system but it was not in the scope of the present paper.*

quality of the collecting service. On average, respondents presented an active and conscious behaviour toward recycled waste practises and about 30% of the sample is composting at home.

The average WTA required to implement the organic waste recycling by a community composer is €9.30, even if the majority of respondents claim to be willing to take part in this recycling project without any compensation (54%). More in details, experimental difference between respondents in municipalities were tested by linear and Tobit models to assess consistency and coherence of findings. Results highlighted citizens' significant attitude to actively implement the alternative recycling system with respect to the actual one without direct and indirect compensation for increased commitments. Nevertheless, model outputs reveal difference between respondents depending on municipality: compensation is small in Gracciano and Cetona, and large, €20 by linear model and €13 by Tobit model, in Rapolano Terme. According to Green et al. (1994), we found that young and rich people need higher compensation, probably because of higher intertemporal discount rate and greater opportunity cost of leisure time respectively.

Compensation for walking longer distance to disposals depends directly on the actual conferring system, age, income and town considered. The walking distance for conferring waste to the community recycling composter is not confirmed to be an insuperable limit for the feasibility of the project. Diverse collection waste systems already exist (the door-to-door collection for Rapolano Terme and street bins for Cetona and Gracciano) and citizens, used to the door-to door system, require a higher level of compensation. This suggests the need to accommodate and organize the community recycling composter system accordingly to the habits and attitudes of citizens as more financial incentives are required when time and effort of recycling are comparably higher than current waste system. Overall, citizens in favour of the new waste system are willing to walk on average 120 meter more than others and distance is not considered a barrier to implement the local community recycling system. This result echoes Leeabai et al., (2019) who found that distance of waste composers has a small effect on waste collection.

The CBA reveals a huge saving in CO_2 equivalent emissions and the potential opportunity cost considering only the current waste management costs in a long period (20 years). The negative FPNVs of current the bio-waste management system highlights the necessity to find an alternative. The positive EPNVs show that CRC is an economically and environmentally feasible way.

Unlike the GHG emissions and the cost-benefit analysis, the analysis of citizens' attitudes and behaviour in favour of CRC has been limited in previous studies and our findings shed light on their preferences. The survey reveals the importance of educational programs that could increase the interest of citizens regarding the economic, environmental and health benefits of CRC and enhance the participation and success rate of this sustainable waste system.

Our study aims to contribute to the literature of community recycling composting systems considering the economic and environmental benefits but also the citizens' preferences. Our findings reveal that switching from a central recycling system to municipal organic waste composers produces a positive economic net present value that means that community composting is an economic sustainable practice. CBA confirms that implementing CRC represents a societal improvement that county councils should accommodate to improve the organic waste collection systems, even if some unaddressed issues such as feedstock purity or market and economics influences need attention for the implementation of future bio-waste initiatives (Levis et al., 2010; Paes et al., 2019).

6. Conclusion

This paper contributes to the literature on the community recycling composting (CRC) system and estimates the economic and environmental benefits of this localized waste system in Cetona, Gracciano and Rapolano Terme, three municipalities with less than 5,000 inhabitants in the Province of Siena, Tuscany (Italy). A Contingent Valuation analysis was implemented for evaluating the willingness to accept the discomfort and inconvenience of switching from current centralized recycling organic waste system to municipal organic waste composers. Facing an unsatisfactory and expensive centralized recycling system, respondents required a very small direct compensation of €9.30. Crucially, the majority of the respondents will switch to the new recycling system without direct compensation and a negligible discount in comparison to the current annual waste fee. Considering the citizens' positive attitude towards the CRC, we also determine the maximum discount required to incentivize walking to the nearest organic waste facility. The average price was €9.30 (st. dev. is €17.68). Through an extended cost-benefit analysis of the CRC we reveal that the net present value is always positive and robust to sensitivity analysis tests. The positive balance of net saving emissions of GHGs in municipal bio-waste composting initiatives plays a crucial role in the positive results of the cost benefit analysis.

In conclusion, our research highlights that community composting is an economic and environmentally sustainable practice that should be sponsored, incentivized and implemented in small municipalities since the reduced management costs and the reduction of GHG emissions compensate the initial installation costs. We envision that these findings may be relevant for other small towns with characteristics similar to our case studies. Results can support policy makers who aim to implement community recycling initiatives and need to anticipate citizens' preferences and behaviour to prioritize the relevant actions (e.g. educational programs, funding, etc). Finally, CRC represents a response to a rapid response to circular economy initiatives that aim to foster resilience communities and an ecological transition in the post pandemic agenda.

List of abbreviations

ET **Ecological Transition**
CE **Circular Economy**
CBA Cost Benefit Analysis
CRC Community Recycling Composting
ENPV Economic Net Present Values
FNPV Financial Net Present Values
GHG Green-House Gases
MAC Marginal Abatement Costs

SCC	Social Cost of Carbon
WTA	Willingness To Accept

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Tables and figures

Table 1 - Studies of composting systems.

Literature	Description	Method	Location	Analysis	
				Environmental	Economic
Zorpas et al. (2018)	Quality household home composting assessment	Composition analysis	Paralimni, Cypros	✓	
Breitenmoser et. al. (2018)	Quality household, fruit and vegetable market and agricultural waste composition assessment	Composition analysis	Maharashtra, India	✓	
Zeller et al. (2020)	Analysis of alternative circular management system	LCA	Brussel, Belgium	✓	
Lundie and Peters (2005)	Comparative analysis among several food waste processor	LCA	Sydney, Australia	✓	
Boldrin et al. (2009)	Greenhouse gas (GHG) emissions related to composting of organic waste and use of compost assessment	GHG accounting	-	✓	
Oliveira et al. (2017)	LCA for organic waste treatment	LCA	Bauru, Brasile	✓	
Møller et al. (2009)	GHG accounting related to anaerobic digestion for organic waste materials	GHG accounting,	-	✓	
Zulkepli et al. (2017)	Landfill, community composting and anaerobic digestion comparison	CBA	Malaysia		✓
Adhikari et al. (2010)	Estimate of future GHG emissions and waste cost management in a macro view considering different scenarios	GHG accounting, cost analysis	Europe, Canada	✓	✓
Pai et al (2019)	Preliminary cost and greenhouse gas (GHG) emissions impact analysis	GHG accounting, cost analysis	Chicago, United State	✓	✓

Bong et al. (2017)	Cost and greenhouse gas (GHG) emissions impact analysis	LCA, cost analysis	Kulaijaya, Johor State, Malaysia	✓	✓
Mu et al. (2017)	Environmental and economic analysis of an in-vessel food waste composting system	CBA, LCA	New Jersey, United State	✓	✓
Deus et al. (2019)	Review of state-of-the-art municipal solid waste indicators	Bibliometrics	-	✓	✓
Paes et al. (2019)	Review of the main threats and weaknesses of organic waste management	Systematic literature review	-	✓	✓
Bruni et al. (2020)	Review of decentralized composting	Systematic literature review	-	✓	✓

Table 2 - Quantity and cost of food waste management in the period 2015-2018.

Town	**Inhabitants**	**Food waste produced**	**Cost of management**	**Cost/ Food waste produced**
		(t/year)	(€/y)	(€/t)
Gracciano	2,588	259	86,980	336
Rapolano Terme	5,249	1,145	406,035	355
Cetona	2,790	511	256,360	502

Table 3 – Linear regression and Tobit model.

Variable	Linear model			Tobit model		
	Coef.		SE	Coef.		SE
Rapolano	22.29	***	5.14	17.38	*	8.60

Cetona	-11.92	***	3.44	-10.64		6.42
Gracciano	-16.33	***	4.02	-30.45	***	2.44
Young Adult	-4.03		3.82	-7.81		8.15
Adult	-2.97		2.58	-9.87		5.48
High Income	7.21	*	3.25	12.15		6.80
m_walk						
• Medium	-4.91		3.21	-8.91		6.52
• Long	-11.23	***	3.02	-26.11	***	6.45
m_current	0.01	*	0.00	0.01		0.00
R-squared	0.2085					
Pseudo R-squared				0.0464		

Coef is the model coefficient which expresses the weight of the independent variable to explain the variability of the dependent variable, SE is the Standard Error which describe the precision of the estimates. Asterisks ***p<0.001; **p<0.01; *p<0.05 flag up the level of statistical significance.

Table 4 – Variables and interval regression results

Variables	**Base Model**		**Extended Model**	
	Coef.	**SE**	**Coef.**	**SE**

Cetona	95.76	**	40.97	78.20	*	40.27
Gracciano	42.62		45.89	0.75		45.32
Rapolano	393.53	***	93.33	267.77	***	75.65
Small HH	-87.80	**	33.58	-80.36	**	33.88
Edu						
2	-124.76		53.72	-101.92	*	52.04
3	-31.39		45.96	-19.15		44.35
4	-68.61		67.09	-50.29		64.80
5	-56.02		55.19	-32.48		53.67
HH_compost				78.54	**	32.27
P_solution				119.38	*	52.52
PseudoR2	0.08			0.12		

Coef is the model coefficient which expresses the weight of the independent variable to explain the variability of the dependent variable, SE is the Standard Error which describe the precision of the estimates. Asterisks ***p<0.001; **p<0.01; *p<0.05 flag up the level of statistical significance.

Table 5 – Investment and operational costs and Net present value of the current food waste management system

	Gracciano	Cetona	Rapolano Terme	UM
Bio-waste management costs	86,980	256,360	406,035	€/year
N. composting machinery	2	4	10	20 years
N. shed	2	4	10	20 years
Investment costs				
Composting machinery	136,894	273,788	684,470	€/20 years
Composting machinery without VAT	106,777	213,555	533,887	€/20 years
Building shed	20,000	40,000	100,000	€/20 years
Building shed without VAT	15,600	31,200	78,000	€/20 years
Operative costs				
Energy	1,695	3,390	8,475	€/year
Personnel	48,000	96,000	240,000	€/year
WTA	9.3	9.3	9.3	€ per inhabitant
Net present values				
1%	- 1,569,602	-4,626,175	-7,327,126	
3%	- 1,294,042	-3,814,004	-6,040,772	
4%	- 1,182,086	-3,484,029	-5,518,148	
5%	- 1,083,963	-3,194,824	-5,060,094	
10%	-740,510	-2,182,545	-3,456,805	

Table 6 – Assessment of CO_2–eq tonne^{-1} ww in the three towns.

	CO_2-eq. (kg tonne $^{-1}$ ww)*

	min	max	mean
Operation composting			
Electricity	0.9	6.5	3.7
CH_4	5	46	25.5
N_2O	0.3	35	17.65
Downstream			
Peat substitution	-44	-838	-441
N_2O emissions	-42	88	23
TOT			**-371.15**
	Food waste produced	**CO_2 -eq**	**CO_2 -eq**
	(t/year)	(kg/year)	(t/year)
Gacciano	259	-96053.62	**-96.05**
Rapolano Terme	1.145	-425011.29	**-425.01**
Cetona	511	-189642.80	**-189.64**

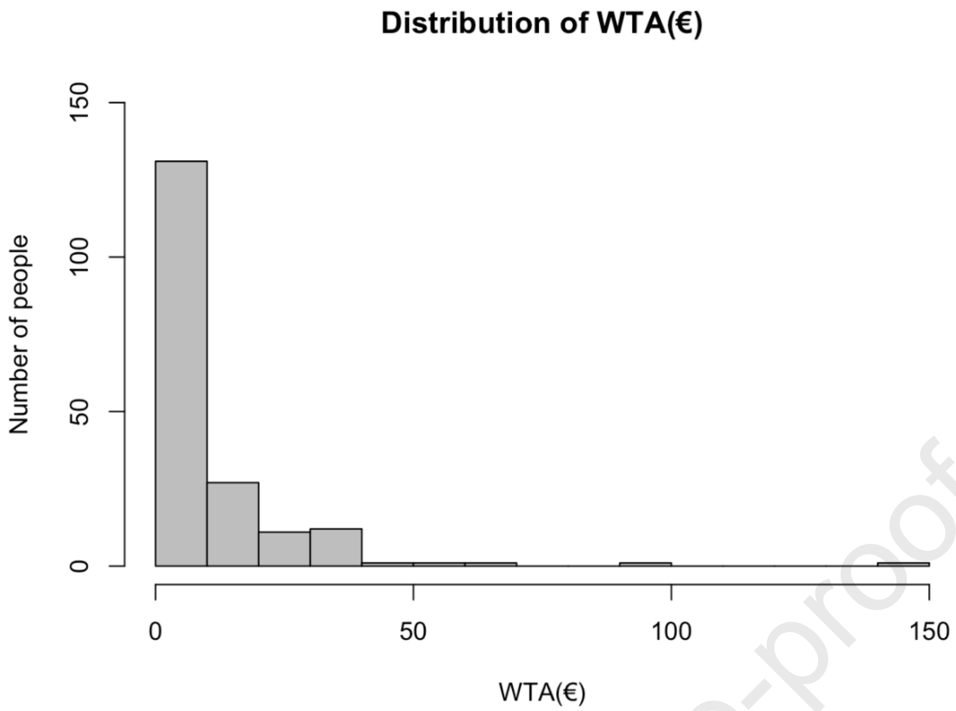
** CO_2-eq. (kg tonne $^{-1}$ ww) values from Boldrin et al. (2009)*

Table 7– Economic costs and benefits of community composting scenario and Net Present Values at different discount rates.

	Gracciano	Cetona	Rapolano Terme	UM
Benefits				
Management organic waste costs saved without CRC	86,980	256,360	406,035	€/year
CO_2 saved from transport	**2.171**	**1,737**	**1,053**	€/20 years
Net GHG accounting	**83,567**	166,726	370,813	€/20 years
Costs				
Incentive for WTA	24,068	25,947	48,816	€/year
Composting machinery	101,438	202,876	507,192	€/20 years
Building shed	14,820	29,640	71,400	€/20 years
Energy	1,610	3,390	8,475	€/year
Personnel	45,600	91,200	228,000	€/year
Net present values				
1%	167,094	2,142,983	1,879,344	
3%	120,012	1,731,319	1,505,284	
4%	101,177	1,564,651	1,354,100	
5%	84,852	1,418,940	1,222,085	
10%	29,750	1,291,117	1,106,421	

Figures

Figure 1 – Distribution of WTA (€)



Supplementary online materials

Table SI1 - Technical details of the Community Recycling Composter[1]

Overall dimensions	7m x 1.35m x h 3.05m
Electricity supply	230 V/50Hz --- 380 V/50Hz
Auger motor	1.5 kWh
Thermo-resistance	2 x 1 kWh
Cycle	Automatic continuation
Compost chamber volume	7.15 m^3
Time of stay in the composting chamber	14 days
Bio-waste capacity	330 kg/day (2310 kg/week) – 9.24 t/month – 120 t/year
Composted	99 kg/day – 36.15 t/year

[1] *Ecopipe composter is produced by the Comar Ecology LTD located in Sinalunga, Tuscany.*

Table SI2 - Description of the main variables used in the models

Variable	**Description**
Rapolano	Dummy = 1 for being Rapolano Terme municipality, 0 otherwise
Cetona	Dummy = 1 for being Cetona municipality, 0 otherwise
Gracciano	Dummy = 1 for being Gracciano municipality, 0 otherwise
Small HH	Dummy =1 if the Household size <=3
Edu	Ordinal variable (1-5) refers to the grade of education (1=elementary school, 2=middle school, 3= high school, 4= undergraduate degree, 5 = postgraduate)
Young Adult	Dummy =1 if age <=30, 0 otherwise
Adult	Dummy =1 if age=30-60, 0 otherwise
High Income	Dummy =1 if income >=10,000 €
m_walk	Ordinal variable refers to the willingness to walk in meters: Short = [0-200], Medium =]200-400], Long= >400
m_current	Continuous variable refers to meters currently walk by respondents to deposit the waste
HH_compost	Dummy = 1 if respondent makes home composting, 0 otherwise
P_solution	Dummy = 1 if the respondent believes that community composting can be a way to management food waste
Dist1	Lower bound of *m_walk*
Dist2	Upper bound of *m_walk*
Wta	Willingness to accept *as percentage of the current waste costs*

Table SI3 – Descriptive statistics of samples

Variables	**Obs**	**%**	**Variables**	**Obs**	**%**

Village			*Willingness to walking (m)*		
Cetona	49	26%	1=[0-200]	51	27%
Gracciano	84	44%	2=]200-400]	56	29%
Rapolano	59	31%	3=]>400	85	44%
Gender			*WTA as percentage of your current waste costs*		
F	96	50%	0%	104	54%
M	96	50%	5%	47	24%
Civil state			10%	29	15%
1=single	50	26%	15%	5	3%
2=cohabitant	14	7%	Refused	7	4%
3=married	113	59%	*Waste management satisfaction*		
4=widower	15	8%	1=completely unsatisfied	14	7%
Education			2=unsatisfied	44	23%
1=primary school	27	14%	3=neither satisfied nor dissatisfied	65	34%
2=secondary	29	15%	4=satisfied	59	31%
3=college	92	48%	5=completely satisfied	10	5%
4=undergraduate	13	7%	*Fee perception*		
5=postgraduate	31	16%	Fair	40	21%
Occupation			Unfair	152	79%
1=student	12	6%	*Recycling waste*		
2=retired	49	26%	Yes	181	94%
3=unemployed	13	7%	No	11	6%
4=income earner	115	60%	*Awareness recycling*		
5=not income earner	3	2%	Yes	150	78%
Garden			No	42	22%
Yes	120	63%	*Home composting*		
No	72	38%	Yes	58	30%
Use fertilizer			No	134	70%
Yes	37	19%	*Knowledge community composting*		
No	155	81%	Yes	57	30%
Environmental sensibility			No	135	70%
Yes	184	96%	*Community composting solution/Willing to participate*		
No	8	4%	Yes	176	92%
			No	14	7%
Tot	**192**	**100%**	**Tot**	**192**	**100%**

continuous variables

Variable	**Mean**	**(st.dev)**	**5%**	**95%**
Age	52	(18)	26.00	81.00
Household size	2.81	(1.12)	1.00	5.00

Income	28752.59	(28027.66)	1299.00	72320.00
TARI	278.63	(172.25)	100.00	500.00
House size	110.58	(70.36)	60.00	200.00
WTA (€)	9.30	(17.68)	0.00	37.10
Current metres walking	153.27	(418.34)	0.00	500.00
Dist1	235.42	(164.99)	0.00	400.00
Dist2	612.50	(354.26)	200.00	1000.00

Supplementary Information A

The comparison between the sample and the population is reported in Tab. SI4. Our sample represents well the population for the majority of the socio-economic data. Our sample follows the quota sample rules.

Table SI4 – Summary statistics of the sample and the population

Variable	**Rapolano Terme**		**Cetona**		**Gracciano**	
	Sample (N=59)	**Population* (N=5249)**	**Sample (N=49)**	**Population* (N=2790)**	**Sample (N=84)**	**Population* (N=2588)**
Gender						
Men	50%	50%	44.90%	48.1%	47.62%	48.5%
Women	50%	50%	55.10%	51.9%	52.38%	51.5%
Age	49.94 (19.13)	46.8	51.52 (16.69)	50.48	53.64 (18.39)	44.7
Household size	3.00 (1.15)	2.33	3.02 (1.24)	2.13	2.57 (0.98)	2.26
Civil state						
1=single	27.59%	38%	31.25%	38.78%	22.62%	41.58%
2= cohabitant	10.34%	-	4.17%	-	5.95%	-
3=married	51.72%	52.53%	58.33%	47.07%	64.29%	48.5%
4=widower	10.34%	8.98%	6.25%	11,77%	7.14%	7.16%
Mean Income (St.dev)	21,672 (17,368)	22,419	25,634 (26,223)		35,059 (33,052)	

* Italian Office of Statistic (ISTAT) data 1st January 2016

Supplementary Information B

Cost-Benefit Analysis (CBA) is a decision support tool for valuing the economic efficiency (advantages or disadvantages) of an investment by assessing its costs and benefits. The purpose of CBA is to prioritize investments considering their net present values in monetary term. Two monetary indicators summarize results of the CBA: Financial Net Present Value (FNPV) and Economic Net Present Value (ENPV). The FNPV is defined as:

$$FNPV = \sum_{t=0}^{n} a_t S_t = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \cdots + \frac{S_n}{(1+i)^n}$$

where S_t is the balance of cash flow which is the difference between revenues and costs in each time period t, a_t is the financial discount factor which is given by $1/(1+i)^t$ where i is the financial discount rate.

The project economic performance is measured by the ENPV that complement the financial costs and benefits with positive (benefits) and negative (costs) externalities and other welfare corrections. The ENPV is calculated as the FNVP but normally the social discount rate differs from the financial discount rate (i). In summary, FNPV uses accounting prices, which might be distorted by market failures and/or externalities, ENPV revised costs and benefits to reflect actual welfare values.

In our paper, investment and operative costs are based on information provided by the company of the Community Recycling Composter and their technical details are summarized in Table SI1. Costs are based on the bio-waste capacity of community recycling composter - that is the tons of processed organic waste (99 kg/day – 36.15 t/year) relative to the size of the three communities (Gracciano 259 t/year, Rapolano Terme 1,145 t/year, Cetona 511 t/year). This allows us to calculate the number of composters needed for each town. Then, we have considered the energy costs (fixed and variable), personnel costs (the average wage of an employee in the waste sector is € 24,000 per year) multiply for the number of composters needed (one employee per composter) and the WTA estimates with the contingent valuation that represent an additional cost for the council to switch from the current waste management to the community composting project.

Environmental externalities, saving in CO_2 equivalent emissions are calculated following the Boldrin et al. (2009)'s approach. The mean CO_2 equivalent savings result in 371,15 CO_2 -eq. (kg tonne -1 ww) considering operation and downstream contributions as showed in table 6. This value is multiplied for the quantity of organic waste produced by each town; converted in annual CO_2 equivalent, they equate to about 96, 435 and 190 respectively for Gracciano, Rapolano Terme and Cetona. Moreover, the saving in transport costs to the central treatment plant located in Asciano are are 2.5 tonnes for Gracciano, 1.2 tonnes for Rapolano Terme and 2 tonnes CO_2 for Cetona. The total CO_2 equivalent saved with the CRC is subsequently accounted for in monetary terms in the CBA considering as price of the CO_2 eq/t equals to €34 and then assuming an increase to €1 per year as in the European guide (European Commission, 2014). The total CO_2 equivalent monetary saving in 20 years is: €85,738 in Gracciano, €166,726 in Cetona and €370,813 in Rapolano Terme. This represents an external benefit that the society is gaining by implementing the community recycling initiative.

Supplementary Information C

The Contingent Valuation (CV) method is a survey-based stated preference technique that elicits people's intended future behaviour in constructed markets. Respondents are asked directly for their willingness to pay (or willingness to accept compensation) for a hypothetical change in the level of provision of the a specific service (or good). CV is applicable to a wide range of situations, including future changes and changes involving non-use values. Respondents are assumed to behave as in a real market one the design of the survey follow good survey design practices (Bateman et al. 2002, Johnston et al 2017).

In our paper, the WTA is calculated as double-bounded dichotomous choice question where the respondent was presented with a random value (0%, 5%, 10%, 15%) which represents the possible discount in the individual waste fee. The respondent received a higher/lower discount accordingly to the positive/negative response to the first bid. Table SI3 "WTA as percentage of your current waste costs" reports the discount value and the frequency of yes. Figure 1 reports the WTA express as actual discount fee that ranges from € 0 to € 150.

Supplementary Information D

This section summarizes the models included in the paper and all estimates are produced with the software R Studio.

The linear regression model studies the relationship between a dependent variable and one or more independent variables. The generic form of the linear regression model is

$$y = f(x_1, \dots, x_K) + \varepsilon = x_1\beta_1, \dots, x_K\beta_K + \varepsilon$$

or

$$y_{\mathrm{i}} = \boldsymbol{x}_{\mathbf{i}}'\boldsymbol{\beta} + \varepsilon_{\mathrm{i}}$$

where y is the dependent or *explained* variable and $x_1, \dots, x_K$ are the independent or *explanatory* variables. The function $f(x_1, \dots, x_K)$ can be specified following the economic theory and statistical regularities. The linear specification is the most common one. The term ε is a normal random *distributed component* that arises for several reasons, primarily because of omitted factors that we cannot capture in the model. The objective of regression is to determine the unknown parameters of the model (β_K) that represent the weight of each explanatory variable to explain the variability in the dependent variable. The estimator for the beta parameters is normally the Ordinary Least Square. Ultimately, estimates of betas can be used to test the validity of economic theories or to predict the variable y.

Once the dependent variable is not represented by a continue measure the regression analysis needs to employ censored regression strategies.

Tobit is a censored model usually described as follows

$$y_i^* = \boldsymbol{x}_{\mathbf{i}}'\boldsymbol{\beta} + \varepsilon_{\mathrm{i}}$$

$$y_i = 0 \qquad \text{if } y_i^* \leq 0$$

$$y_i = y_i^* \qquad \text{if } y_i^* > 0$$

This model is used when the dependent variable is censored and values in a certain range are all transformed to (or reported as) at a single value for example zero. The regression is conducted considering the *latent variable*, $E[y_i^{*a}|\mathbf{x}_i]$ is $\mathbf{x}_i'\beta$. The log-likelihood estimator is used to derive the parameters betas. In this paper, linear regression and Tobit models are used to regress the WTA provided by contingent valuation (CV) survey on a set of control variables (e.g. age, education, income, household size, etc.).

The interval regression is a generalization of censored regression. Generally, an interval regression is described as

$$\begin{aligned} Y(\boldsymbol{x}) &= A_0 + A_1 x_1 + \ \dots + \ A_n x_n \\ &= \mathbf{Ax} = \ [y^{-}(\boldsymbol{x}), y^{+}(\boldsymbol{x})] \end{aligned}$$

where $\mathrm{A}_0 = (A_0, A_1, \dots, A_n)$ is an interval coefficient vector, x = (1, $x_1, \dots, x_n$), and $y^{-}(\boldsymbol{x}), y^{+}(\boldsymbol{x})$ are bounds of the interval output $Y(\boldsymbol{x})$.

In our model, $y^{-}(\boldsymbol{x}), y^{+}(\boldsymbol{x})$ are lower and upper bound refer to the ordinal variable refers to the willingness to walk in meters with *Short* = 0-200 m, *Medium* = 200-400 m and *Long* = more than 400 m. A set of socio-economic variables are also included in the regression to control for heterogeneity of preferences such as education, household size and more variables concerning the practice of home composting by respondents and the belief of community composting as alternative for food waste management. The log-likelihood estimator is used to derive the parameters betas.

Highlights

- The paper evaluates environmental and economic sustainability of a community composting system by a Contingent Valuation Method.
- The majority of citizens are willing to participate in local community recycling of organic waste with minimal monetary compensation
- GHGs accounting and cost-benefit analysis results endorse the community recycling composter as a promising opportunity to reduce waste and recycle resources.
- Cost-Benefit Analysis shows a net positive revenue for the community compost system
- Results support a switch towards local recycling facilities

Declaration of interests

☒ 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: