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Designing circular economy-compliant municipal solid waste management charging schemes

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ABSTRACT

We simulate the performance of a gain-sharing charging scheme aimed at boosting the circularity of municipal solid waste management; its effectiveness is empirically tested by comparing it with the performances of unit pricing and standard schemes. When unit pricing charging schemes are in place, environmental performance significantly improves while the per capita cost slightly decreases. However, by narrowing the analysis to more comparable municipalities, there are circumstances in which the unit pricing and standard charging schemes are equivalent. Instead, under specific conditions, a rewarding charging scheme can outperform, thus making it a first-best option according to socioeconomic and geographical characteristics.

1. Introduction

The role of optimal charging schemes in boosting the transition to a circular economy has become a prominent topic among environmental economists. Indeed, despite the many existing tools and technologies that can be used to improve municipal solid waste management (MSW) circularity, a critical bottleneck lies in engaging citizens to contribute to improving the system performance while guaranteeing the cost reflectivity of the charging scheme.

Citizens, institutions, and businesses typically fund MSW management through fees and taxes, subsidies from the municipality's budget, revenues from sales of materials and energy, and income from extended producer responsibility schemes (World Bank, 2018). Such revenue streams need to ensure full cost recovery and guarantee the financial equilibrium of the industry.

Although it is widely recognized that fixed or quasi-fixed waste fee schemes fail to provide citizens with price signals, these schemes are widely used. In contrast, under unit pricing charging schemes (UCSs), citizens pay for MSW management services per unit of waste, volume, or other new drivers (Elia et al., 2015). Designing rewarding charging schemes has become a vital prerequisite for the healthy functioning of an MSW management system. In general, incentivizing users is of utmost importance (Alzamora and Barros, 2020; Elia et al., 2015), as renewed interest in MSW management charging schemes demonstrates (Di Foggia and Beccarello, 2018). For example, a recent study indicated that UCSs could lead to a more balanced payment system (Weber et al., 2019), while another study evaluated its effects on the disposal of MSW and found a decrease in the priced waste flow (Bueno and Valente, 2019). In contrast, a recent paper suggested that such schemes can support waste sorting and reduce residual waste generation (Ukkonen and Sahimaa, 2021).

This article extends the literature by identifying a twofold research gap. Scholars have often measured the impact of UPC on pricing levels, highlighting the changes before and after their introduction, but more insights are needed to compare different territories. Arguably, scholars should give more attention to the fact that UCSs can underperform because of exogenous factors such as insufficient waste treatment capacity, market structure, governance, or geographic and socioeconomic variables that impact both the cost and the performance of the service. It is anticipated, for example, that where waste treatment capacity is insufficient, UCSs may not increase the system's environmental performance, differently from territories with sufficient capacity. So, there needs to be more clarity in identifying the optimal conditions under which a specific charging scheme performs the best.

Alternative MSW management charging system performances are compared by measuring the per capita cost for users, and, in particular,

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the role of sorted materials is analyzed according to the charging model. The Standard Charging Scheme (SCS) resumes the charging model applied by 87.3% of Italian municipalities (i.e., the normalized scheme), whereas the UCS refers to 12.7% of Italian municipalities. In addition, we simulate the per capita cost using a gain-sharing charging scheme (GCS) aimed at incentivizing user involvement in the MSW management process by increasing the percentage of separated waste collection.

Widely speaking, results confirm that UCSs are associated with higher environmental performance in both percentage of sorted waste and per capita waste generation and with a positive impact on per capita cost. Nevertheless, this relationship is affected by external factors. GCSs could also improve environmental performance and incentivize users to improve their rate of separated collection in underperforming territories.

The remainder of this article is organized as follows. Section two reviews the relevant literature and provides background information. Section three describes the methods used to run the analyses, the samples' definition, and the model specification. Section four reports the results that are discussed in section 5. The Conclusion section follows.

2. Background

Efficient waste management services are vital to citizens' well-being and the environment's conservation. Many factors concur in its organization and performance. Given that this paper focuses on charging schemes, it is worth introducing previous works on economies of scale and regulation that intertwine with the cost of MSW management service and its alternative charging schemes. The reason is straightforward; this is a public service with multilevel governance: The central State, which sets the targets; Regions, which define regional plans; Authorities, which are aimed at regulating both environmental, technical, and economic issues; Municipalities, which are typically responsible for the local organization of the collection phase.

As a public service, waste management charging schemes should recover all the costs associated with rendering the service, including capital, operating, maintenance, depreciation, debt service (interest), and administration, to facilitate the financial sustainability of the service. In addition to the well-known economic targets mentioned above, environmental targets have recently taken momentum. Indeed, economic efficiency is not the only criterion for charging scheme design (Brown et al., 2015). A thought-provoking topic is how to design charging schemes that encourage efficient and effective use of spaces, reduce waste to landfills, and comply with the polluter pay principle. With respect to recycling, efficient charging mechanisms can boost recovery and technology investment decisions given the need to support and improve the circular economy, in particular, the capacity of the recycling and reuse industries (Bohm et al., 2010; Gullì and Zazzi, 2011; Pérez-López et al., 2016; Sarra et al., 2017), which are at the heart of the circular economy transition.

Considering the role that users may play in the development of the recycling industry, we can argue that the evolution toward advanced charging mechanisms helps meet circular economic goals (D'Onza et al., 2016; Debnath and Bose, 2014), especially when well-designed charging schemes incentivize citizens to become involved in the circular process and increase their awareness of the importance of separating waste as well as encourage technological innovation to optimize recycling capacities (Di Foggia and Beccarello, 2021; Nelles et al., 2016).

In this respect, many waste management charging schemes exist wherein fixed, and quantity-based pricing schemes are the two most common models. The first is frequently employed because it is simple to use and guarantees a steady flow of revenues, which is advantageous given that revenue management is essential for business sustainability. The second approach assumes that consumers are billed based on the amount and type of waste they produce (Chu et al., 2019; Elia et al., 2015; Morlok et al., 2017).

Modern approaches to charging users based on the quantity and quality of waste assume that users are charged according to the quality and quantity of waste provided to the MSW management system. Implementing such schemes can lead to remarkable outcomes in MSW management performance by increasing the amount of individually sorted waste, which represents an application of the polluter pays principle (Morlok et al., 2017). Many scholars consider UCSs to be positively correlated with environmental sustainability (Chamizo-González et al., 2018). According to the European Environmental Agency (EEA), there is a positive correlation between implementing these mechanisms and recycling rates. However, it may be argued that although these schemes promote economic, social, and environmental sustainability, they may increase the complexity of MSW management and thus require sound regulation, user involvement, and economic and other resource inputs (Morlok et al., 2017).

If the role of users is a service demand-side efficiency driver, from the production side, previous literature has identified many drivers; among others, economies of scale and regulations deserve special attention. Taken for granted that economies of scale play a remarkable role in waste management, it should be noted that they have been broadly investigated in the collection phase and, to a lesser extent, in the treatment phase; regardless of the scope of the analyses, scholars have reached heterogeneous conclusions (Bel and Fageda, 2010; Llanquileo-Melgarejo and Molinos-Senante, 2021; loStorto, 2021) because, for example, unlike in other network industries, MSW management is heavily affected by contextual factors.

That said, economies of scale in the recycling industry have received little attention, even if their role is expected to increase in the circular economy transition (Di Foggia and Beccarello, 2022; Lavee and Khatib, 2010; Swart and Groot, 2015). It is clear that regulations impact service efficiency, given that effective regulation might improve business performance by contributing to the creation of market opportunities (Kitching et al., 2015).

Nonetheless, realizing new regulations can also be harmful because of such factors as market structure rigidities, asymmetric information among regulators and market participants, deficits in waste capacity treatment, and political concerns, even if doing so can resolve allocative distortions (Guerriero, 2013) that have recently emerged in countries struggling to cope with the volatility of international raw materials and energy prices.

It is of primary importance to implement efficient regulations to stimulate investment and resolve concerns related to information asymmetries (van Beukering et al., 2014) that typically exist in highly concentrated industries or the presence of monopolies (Basso et al., 2017). Economic theory typically sees competition as the first-best option for maximizing social well-being (Gouri, 2020; Gundlach et al., 2019); thus, legal monopolies should demonstrate the same economic efficiency as competitive markets. Some scholars suggest that decision-makers should make additional improvements in terms of economic regulation (Asquer et al., 2017; Simões and Marques, 2012). Robust economic regulation in MSW management is necessary because the sector can be subject to inefficient conditions due to market failures and a lack of incentives (Marques et al., 2018).

It is argued that GCSs with behavior-incentivizing parameters induce positive user responses and thus lead to economic, environmental, and technical efficiency. Economic efficiency is boosted by users who are expected to respond to charging schemes by behaving in such a way as to reduce the cost for them, which can be considered a gain in terms of social well-being. Environmental efficiency follows economic efficiency because the higher the environmental performance is, the lower the cost.

Technical efficiency is facilitated by efficient charging schemes to facilitate investments in the circular economy (Tisserant et al., 2017). This concept, which is gaining momentum, intends to extend the useful life of materials, increase the share of recycled goods, promote green technologies (Kirchherr et al., 2017), and reduce landfill waste. Since users and businesses shall be incentivized to improve their role in improving MSW environmental performances (Lakhan, 2016), charging schemes should improve well-being by distributing efficiency benefits across society. All the mentioned studies provide background information and outline the call for more empirical evidence on the impact of alternative mechanisms on the cost of MSW management. We contribute to the literature by providing relevant information in three scenarios.

3. Methods

We aimed to provide evidence of the potential role of modern charging schemes in improving the efficiency of MSW management services by considering that charging schemes produce price signals that incentivize users to improve their environmental performance.

3.1. Sample and variables

We conducted an empirical analysis that modeled MSW management costs according to alternative charging scheme scenarios. We gathered data and defined the samples and groups of municipalities for comparison, as shown in Fig. 1, which resumes the research approach.

Data referred to 2020, i.e., the latest available year on the national municipality waste management cadaster. Data were collected for a single year, given that the information related to municipalities with a UCS in place was limited to 2020. Table 1 puts this study in context by comparing our sample to the national data, as it contains relevant information regarding the study variables. Table 1 contains information regarding the distribution of charging schemes nationally and in our sample. Two groups were defined: Group 1 contains municipalities that apply SCS, whereas Group 2 contains municipalities that apply UCS.

Table 2 contains information regarding the variables at the national level and in our sample that is representative of the population given that it contains 61% of municipalities. Nevertheless, as expected, there are some differences, specifically in the population density and the cost per capita.

Table 3 contains variables that reflect the materials from MSW since the higher the environmental performance of citizens is in terms of the rate of sorted waste, the higher the quantities of materials available for sale to the recycling industry, and the higher, in turn, the potential reward to citizens in terms of savings. Therefore, understanding the impact of materials according to alternative charging schemes is relevant to this study.

The national MSW management cadaster MWM report contained revenues from energy and material sales. We allocated the data to the municipalities using a waste production factor based on the amount of waste produced. Table 4 reports the correlations among the study variables to evaluate the degree of collinearity that, in this case, does not cause problems in estimating the regression coefficients. The variables contained in Table 4 were used in the regression models, as shown in Table 5 and Table 6. Such variables were selected following previous studies. The area of municipalities, the urbanization level, and the altitude are deemed to impact costs, especially collection routes, whereas being a coastal municipality may impact tourism activities. Population density is also a well-known, widely used variable in the analysis of waste management. Municipality revenues are a proxy for the complexity of service being intertwined with waste generation activities.

Similarly, Fig. 2 presents information regarding the relation between MSW per capita generation and cost per capita, controlling for the environmental performance in terms of the percentage of sorted waste.

Table 1
Charging schemes and group at a glance.

	Italy		Sample	
Groups	Municipalities	Population	Municipalities	Population
1 (SCS)	6903	53.3 M	3784	39.5 M
2 (UCS)	1001	6.3 M	557	4.7 M

Table 2
Sample and national data.

Label	Unit	Italy	Sample
Number of municipalities*	N	7094	4341
Total population*	Million	59.6	44.2
Per capita MSW production+	kg	488.46	458.87
Sorted waste+	Percentage	63.04	66.23
Altitude*	Meters	355.31	310.05
Area*	Km^2	38.16	40.99
Population per municipality*	Average	7536	10,203
Coastal zone*	Percentage	14.71	16.84
Population density*	People per Km^2	300.55	405.04
Urbanization index*	Ordinal 1–3	2.6	2.48
Municipal budget^	Log of Euros	7.23	7.44
C+	Euros per capita	175.6	154.23
UCS+	N	1001	557

Source: *Italian Institute of Statistics,+Institute of Environmental Protection, ^ Ministry of Intern. Average values except for the total number of municipalities and total population.

Table 3
Descriptive statistics of waste variables.

Description	variables	Mean	SD
Organic waste (org)	org	22.28	12.75
Paper and cardboard (paper)	paper	10.96	3.88
Waste glass (glass)	glass	9.41	3.71
Furniture, other durable goods, wood packaging, and other	wood	4.11	2.72
Metal from MSW	metal	1.76	1.35
Plastic and assimilated	plastic	6.11	3.26
Waste electrical and electronic equipment	weee	1.23	0.82
Municipal textile waste	textile	0.76	0.69

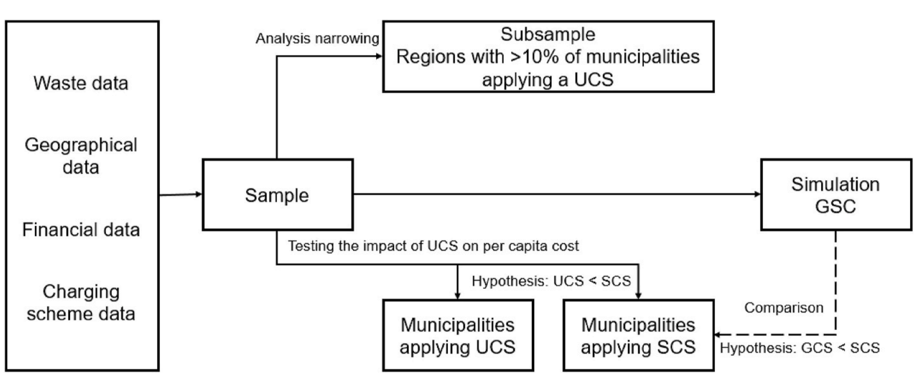

Fig. 1. Research framework.
Source: own elaboration. Hypotheses are elaborated in Fig. 3.

Table 4
Correlations among geo-economic variables.

	Area	Altitude	Coastal zone	Pop. Density	Finance	Urbanization index
Area	1					
Altitude	0.2	1				
Coastal zone	0.08	−0.2	1			
Pop. Density	−0.3	−0.2	0.11	1		
Finance	0.28	0.45	0.17	−0.2	1	
Urbanization index	0.11	0.31	−0.1	−0.57	0.3	1

Table 5
Impact of the UCS on per capita cost.

	Model 1 sample	Model 2 Subsample[d]
(Intercept)	4.003[a]	3.881[a]
	(0.143)	(0.207)
Log (Pop. density)	−0.048[a]	−0.049[a]
	(0.009)	(0.012)
Urbanization index	−0.058[a]	−0.059[b]
	(0.015)	(0.019)
Coastal zone	0.212[a]	0.191[a]
	(0.018)	(0.039)
Log (area)	0.003	0.015
	(0.007)	(0.010)
Log(altitude)	−0.038[a]	−0.017[b]
	(0.005)	(0.007)
Log (finance)	0.254[a]	0.254[a]
	(0.012)	(0.019)
Metal	−0.035[a]	−0.050[a]
	(0.005)	(0.006)
plastic	0.002	0.009[c]
	(0.002)	(0.003)
paper	−0.006[a]	−0.009[a]
	(0.002)	(0.002)
organic	−0.005[a]	−0.005[a]
	(0.000)	(0.001)
weee	−0.005	0.005
	(0.007)	(0.009)
glass	−0.017[a]	−0.019[a]
	(0.002)	(0.003)
UCS	−0.103[a]	−0.090[a]
	(0.016)	(0.017)
N	3099	1895
R2	0.386	0.359

[a] $p < 0.001$.
[b] $p < 0.01$.
[c] $p < 0.05$.
[d] Regions with >10% of municipalities with UCS in place.

Table 6
Scenario analysis.

	Model 3	Model 4	Model 5
(Intercept)	*Group 1 | SCS*	*Group 1 | GCS*	*Group 2 | UCS*
	3.591[a]	3.289[a]	4.015[a]
Log (Pop. density)	(0.150)	(0.157)	(0.506)
	−0.041[a]	−0.039[a]	−0.062
Urbanization index	(0.009)	(0.010)	(0.033)
	−0.038[c]	−0.036[c]	−0.147[b]
Coastal zone	(0.016)	(0.016)	(0.046)
	0.223[a]	0.245[a]	0.134
Log (area)	(0.018)	(0.019)	(0.083)
	0.003	0.011	−0.001
Log (altitude)	(0.007)	(0.008)	(0.026)
	−0.028[a]	−0.025[a]	−0.038[c]
Log (finance)	(0.005)	(0.006)	(0.016)
	0.294[a]	0.324[a]	0.228[a]
metal	(0.013)	(0.014)	(0.043)
	−0.018[a]	−0.023[a]	−0.104[a]
plastic	(0.005)	(0.005)	(0.016)
	−0.005[c]	−0.003	0.033[a]
paper	(0.002)	(0.002)	(0.008)
	−0.005[b]	−0.006[a]	−0.000
organic	(0.002)	(0.002)	(0.006)
	−0.006[a]	−0.006[a]	−0.002
weee	(0.000)	(0.001)	(0.002)
	−0.011	−0.014	0.030
glass	(0.007)	(0.007)	(0.030)
	−0.018[a]	−0.019[a]	−0.001
N	(0.002)	(0.002)	(0.007)
	2645	2645	454
R2	0.424	0.444	0.218

[a] $p < 0.001$.
[b] $p < 0.01$.
[c] $p < 0.05$.

Such information is useful for better contextualizing the impact of alternative charging schemes.

Some insights emerge from Fig. 2; among others, the higher rates of separate collection correspond, on average, to lower per capita costs and the fact that the per capita cost of municipalities in regions with a higher percentage of municipalities applying a UCS is relatively low: Lombardy, Trentino A.A., Veneto, and Emilia Romagna.

3.2. Charging schemes

After defining the groups, we report the structure of the following charging models to run our comparative analyses on the performance of alternative MSW management charging systems. Given that our purpose is to define a GCS, we emphasize that the total cost per capita (C) of MSW management is achieved by adding fixed costs per capita (FC) and per capita variable costs (VC), as in Equation (1).

$$C = FC + VC \tag{1}$$

Note that per capita costs refer to the resident population, but it should be noted that the service covers both households and non-households, as well as costs arising from nonresidents in the municipality. However, fixed costs stay the same according to the scenarios, whereas variable costs depend on the different schemes. Equation (2) formalizes the fixed costs, which remain unchanged in our model: these costs include sweeping costs (*swc*), administrative costs (*adc*), general waste treatment costs (*grc*), other typical costs (*occ*), and capital costs (*ck*).

$$FC = swc + adc + grc + occ + ck \tag{2}$$

Equation (3) formalizes the total costs according to the SCS scheme, which resumes the charging model applied by 87.3% of Italian municipalities (i.e., the normalized scheme), according to which the variable costs are collection and transportation (*ctc*), treatment, and disposal (*tdc*), recycling (*trc*), and separated collection (*scc*).

$$TC = FC + \mathrm{ctc} + \mathrm{tdc} + \mathrm{trc} + \mathrm{scc} + \mathrm{trc} \tag{3}$$

The UCS scheme formalized in Equation (4) refers to the 12.7% of Italian municipalities. Here, the costs are those in Equation (3), less the value of factors related to quantity (δkg) and quality (δq).

$$C = FC + \mathrm{ctc} + \mathrm{tdc} + \mathrm{scc} + \mathrm{trc} - (\delta\mathrm{kg} + \delta\mathrm{q}) \tag{4}$$

In addition, we simulated the per capita cost via a GCS aimed at incentivizing user involvement as a percentage of separated waste collection, as in Equation (5).

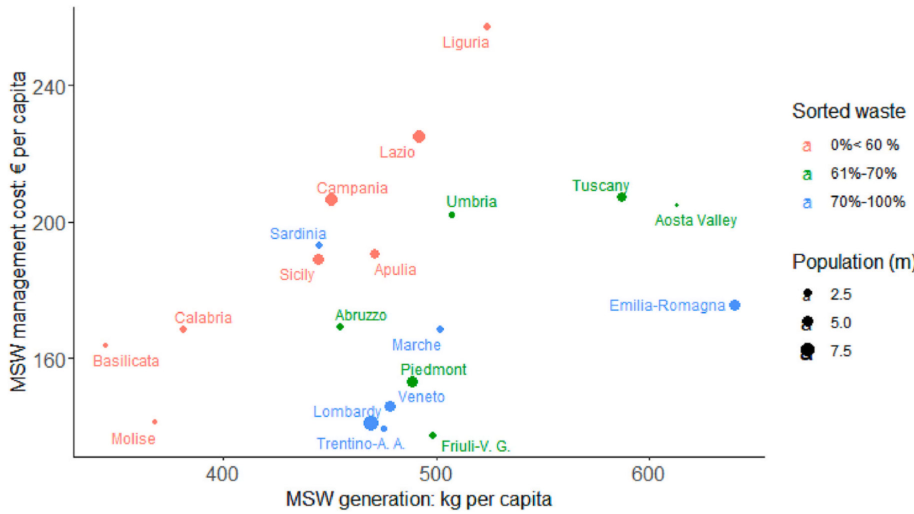

Fig. 2. Cost and MSW generation according to the rate of sorted waste.
Source: own elaboration

$$C = FC + ctc + tdc + trc + scc - \theta(R) \quad (5)$$

In Equation (5), $\theta(R)$ reflects revenues from materials and energy from waste. Such factors can be considered incentivizing since the higher the rate of separated waste collection, the higher the material sale revenues.

4. Results

Fig. 3 shows the relevant information related to the average cost of MSW management, which helps refine our analysis. Fig. 3 also shows the hypotheses proposed in this article, based on a sharing factor of revenues derived from material sales obtained from separated waste collection.

Table 5 presents the results of the first part of the econometric analysis. We tested the hypothesis that a UCS would reduce average MSW management costs. We reiterated the model using two groups as samples to make this analysis more robust. The results obtained from Model 1 are primarily compatible with those obtained from the previous literature. As population density increases, the average management cost tends to decrease, which is confirmed by the variable representing urbanization.

These results confirm the existence of density economies during the waste collection phase. Regarding the results of the main morphological and orographic variables, the coefficients assume different values but are primarily concordant with some exceptions. In coastal municipalities, the average cost of MSW management tends to increase, probably due to the seasonality of waste production associated with tourist activity. A variable that appears to be statistically insignificant is the municipal area, probably because productive and urban structures affect waste collection companies' management models and efficiency.

The orographic variable that tends to have a reducing effect on the average cost of MSW management is altitude, which can be determined using different factors related to the type of waste produced in mountainous territories as opposed to the composition of municipal waste produced in urban areas. This view is confirmed by the economic

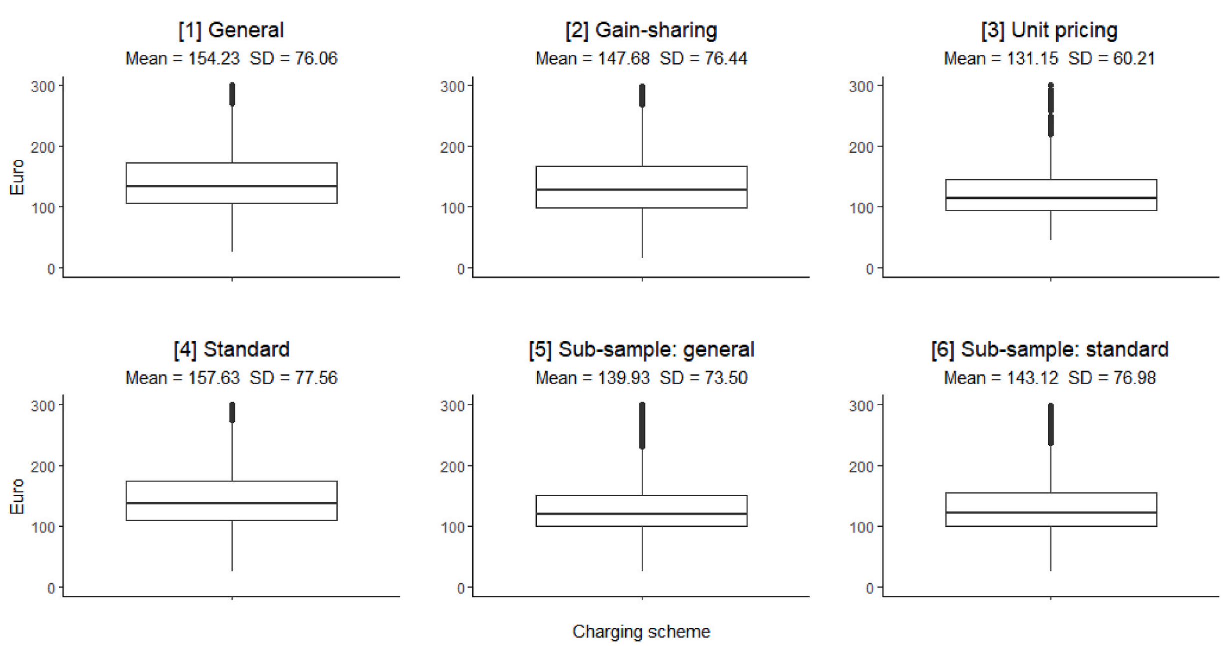

Fig. 3. Per capita costs of alternative charging schemes.
Source: own elaboration

variable, which is correlated with the presence of productive activities proportionally higher in urban areas than in mountainous territories. Heterogeneous results emerged from analyzing the materials comprising the separated waste collection. Metals, plastics, paper, organic matter, and glass reduce the average MSW management cost; however, this result has not been confirmed for plastics and waste of electric and electronic equipment.

These results can also be explained in light of the economic considerations that can be made in the two reference markets. The market for recycled plastics has experienced extreme volatility in the last five years due to demand shocks, and these price changes have led to economic and financial imbalances in the plastics recycling industry. In the case of weakness, we can assume that this sector has economies of scale and scope that require significant resources to cover the management costs.

There is evidence that within Group 2, USC and SCS are similar, confirming the hypothesis that different charging systems led to similar costs if applied by municipalities of most advanced regions in terms of waste treatment capacity. Another implication emerges from the analysis of groups; in those regions with a treatment capacity gap, a GCS may outperform UCS due to lower administrative, implementation, and transaction costs.

Table 5 contains the results of the two regression models. Model 1 refers to the sample, whereas Model 2 refers to the subsample (i.e., the analysis is limited to the regions where at least 10% of the municipalities applied a UCS). Two prominent pieces of information emerge from Table 5. The first is the impact of UCSs on total costs, from which it can be speculated that there is indeed a small but statistically significant average decrease in the total cost of MSW management attributable to UCSs. The second is that the impact of UCSs on the total cost of MSW management is less when the analysis is narrowed to the subsample.

The results of the overall scenario analysis are reported in Table 6. We comment on how the same independent variables used in previous models affect the average operating costs under different assumptions. We then empirically compared alternative MSW management charging systems by considering the typical full-cost recovery SCS, a scenario in which we simulated a GCS aimed at rewarding users' contribution to the functioning of the system and a scenario in which a UCS is in place. Model 3 contains the regression performed on Group 1 and SCS. Model 4 contains the regression performed on Group 1 using the GCS. Model 5 contains the regression performed on Group 2 and the observed total cost.

Table 6 reports some primary considerations. First, the transition from Group 1 to Group 2 determines the loss of significance of the variable related to population density. This finding is notable, as it is necessary to analyze the role of this factor in the optimal organization of the collection of MSW. The sign of the coefficients remains the same; however, they lose their significance. Similar considerations can be drawn from the variable that indicates a coastal municipality. The variable related to the separate collection of plastics is also notable −0.005* in Model 3 and -0.003 in Model 4, whereas the impact becomes positive 0.033*** in Model 5. Although statistically nonsignificant, the role of waste of electric and electronic equipment moving from Group 1, namely −0.011 in Model 3 and -0.014 in Model 4, to Group 2, i.e., 0.030 in Model 5.

Finally, it is essential to highlight the relationship between the environmental and economic variables, as shown in Fig. 4, from which specific evidence emerges. It can be seen from the UCS diagram of Fig. 4 that MSW management costs tend to decrease until a 60% rate of separated collection is reached and that an increase in costs follows this trend until a maximum of approximately 75% of the separated collection rate is reached. Subsequently, the costs resume their decline. Instead, the standard diagram of Fig. 4 shows that costs tend to increase as long as the rate of separated collection increases until it reaches 45%; on average, costs decrease afterward.

Fig. 4 is consistent with previous literature, in which UCSs are associated with higher environmental performance (+4%) and lower per capita generation of MSW (−12 kg). Considering the cost of MSW management, however, the SCS and UPS are similar (Beccarello and Di Foggia, 2022). Regarding the circumstances in which UCSs may fail to achieve the desired targets, it is possible to speculate that there is an impact of UCSs on total costs; however, the impact is less when the analysis is narrowed to the subsample of more comparable territories.

5. Discussion

Municipal solid waste management costs are generally borne by users, who should contribute to increasing the system's overall efficiency by increasing the sorted waste rate and reducing the MSW produced. Such behavior can be incentivized using proper cost-reflective charging schemes. Our purpose was to quantify the positive externalities for society in response to calls for the expanded use of market-based instruments in MSW management (Farley et al., 2015). Given that

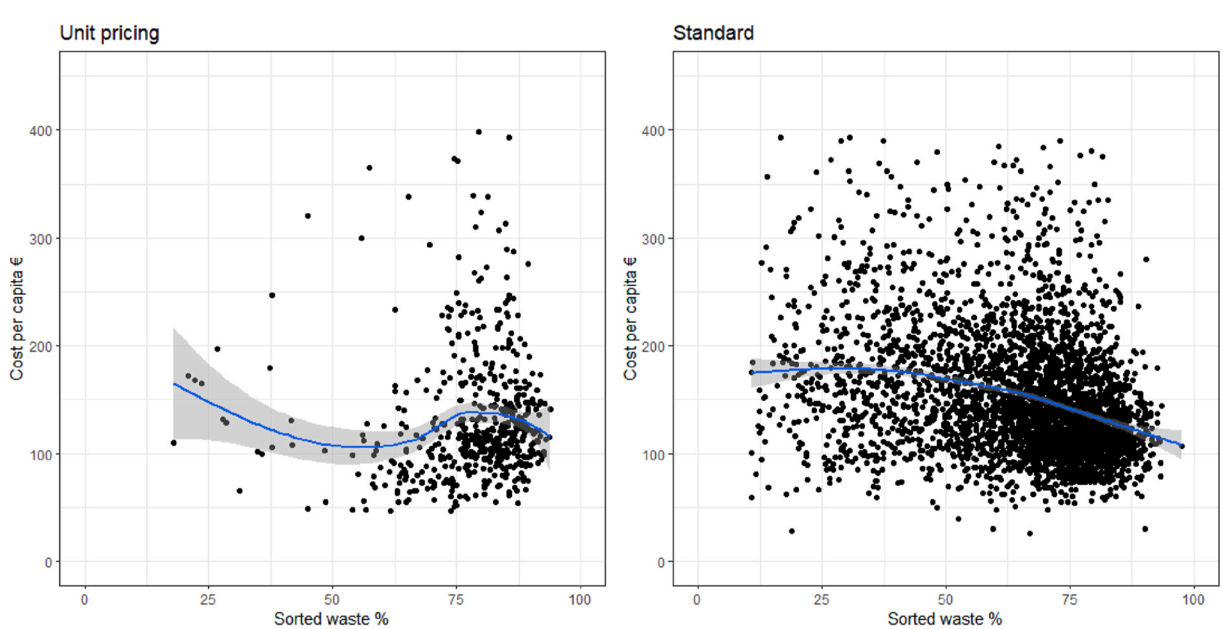

Fig. 4. Environmental performance, UCS and SCS.

economic efficiency and environmental performance go hand in hand, our analysis was based on a simulation that appraises alternative MSW charging schemes to understand the circumstances in which a specific scheme might best apply. Widely speaking, the results confirm the positive role of UCS on the environmental performance of MSW management and, to a lesser extent, the impact on cost. The impact on cost seems significant at the national level; however, per capita cost slightly differs between alternative charging schemes when municipalities or regions with similar treatment capacities are compared. A possible reason for this finding is that exogenous factors significantly impact costs, particularly those associated with local waste treatment and disposal, consistent with previous insights.

The implementation of GSCs in regions characterized by insufficient waste treatment capacity might outperform other charging schemes, and it would be a way to increase the cost reflectiveness of charging schemes. Consistent with previous insights (Di Foggia and Beccarello, 2020). Considering the Italian landscape, even a recent study emphasized that the Italian MSW tariff system already in use is a suboptimal pricing method and thus proposed an alternative implementation of the UCS (Drosi et al., 2020). However, according to another study conducted in Italy, the UCS may reduce the amount of waste generated by 9.6%, albeit with a limited impact on the share of sorted waste (Compagnoni, 2020). Implementing advanced charging schemes in areas characterized by insufficient waste treatment capacity may be costly in terms of compliance because companies need to upgrade their data tracking and gathering systems, reporting functions, and, in some cases, their organizational structures. In this regard, the GCS scheme outperforms the UCS scheme because effectively establishing the latter may increase administrative and management costs due to the increased need for more advanced waste accounting, customer relations systems, and operational sophistication. Implementing a GCS can have several advantages, such as disseminating information to users, improving the overall system performance, and increasing the rate of separated waste collection, which, in turn, positively impact the secondary materials markets. Such a virtuous circle lowers the risks associated with resource shortages and import reliance, which have become severe problems in several economies.

Although our results share similarities with previous literature, comparing countries with different characteristics is tricky because of different contexts (Alzamora and Barros, 2020). For example, in Belgium, researchers found that a UCS increases the recycling rate significantly and reduces the quantity of residual waste and concluded that such a scheme could contribute to the development of material reuse and recycling economies (Morlok et al., 2017). Similarly, a recent study underlined the role of UCS in reducing free-rider behaviors (Weber et al., 2019) and improving environmental performance. Therefore, it is necessary to devise reward mechanisms. Indeed, in Estonia, it was found that people are not economically motivated to sort their waste if differences in fees between separately collected and unsorted waste are negligible, while implementing a UCS would increase the cost of MSW management (Voronova et al., 2013). Focusing on Japan, another study indicated that consumers respond to economic incentives for recycling, which, as expected, differs by income group (Usui and Takeuchi, 2014). It has also been suggested that UCSs may curb the quantities of unsorted waste but not significantly increase recycling (Huang et al., 2021). A similar figure was found in a previous study conducted in Sweden, where pay-by-weight schemes were associated with a 20% reduction in waste per capita (Dahlén and Lagerkvist, 2010); in Slovenia, it was reduced by 22%. Interestingly, the size of the effect depends on the pricing mechanism (Slučiaková, 2021).

This study is also aimed at supporting decision-makers. Indeed, our results are useful for comparing alternative charging structures. On the one hand, there is a broad consensus on the role of UCS in moving toward more sustainable MSW management, which is confirmed by our analysis. However, the implementation cost of UCSs is relevant, considering the increasingly stringent targets and deadlines to meet those targets. As argued in the results section, a GCS may lead to remarkable improvements from economic and environmental standpoints while lowering implementation and administrative costs. Scholars, utility managers, and policymakers benefit from this paper since, at the time of this writing, no previous articles with the same research scope have been published, and besides providing insights into UCS, the performance of a complementary, easily implementable GSC is provided.

Nevertheless, this paper has some limitations. Among others, it is worth emphasizing that municipalities were aggregated into two groups whose size and geographical scope differ. The analysis was cross-sectional due to data availability. The reward factor of a GSC is heavily affected by the prices of material markets, which may weaken the results, and the impact of the waste treatment capacity on MSW management costs is exogenous to the charging schemes.

Future research should address the link between charging schemes and circularity given that, in a context where substantial investments will have to be made to achieve predefined objectives, policies aimed at supporting the MSW management industry have struggled despite the global commitment to meeting circular economy targets (Sharma et al., 2021), due in part to the hurdles faced by this industry (Salmenperä et al., 2021), such as developing economies of scale and secondary raw materials markets, which have prevented this sector from increasing its economic value. Conversely, the circularity of the MSW management industry can be increased by optimizing the quality and quantity of inputs (Drosi et al., 2020; Jang et al., 2020), which can be boosted by incentivizing the implementation of proper charging schemes in MSW management.

6. Conclusion

This study aimed to understand how modern charging schemes can boost the circularity transition of the MSW management industry and engage users to proactively contribute to such a transition. Provided that new regulatory and charging scheme implementation often implies greater management complexity and more resources needed to manage services, we have added information about the potential benefits to society of a GSC scheme by comparing its performance with alternative models. We have argued that per capita costs can be reduced by rewarding users according to their proactivity in reducing waste production and increasing their performance in separating diverse types of waste. Thus, a stimulus for reducing waste and improving the quality of the separated collection is generated by ensuring that a specific share of revenues accrues to users. Therefore, such a factor aims to incentivize users to engage in virtuous behaviors that, in turn, result in lower costs and contribute to funding the system. Our results show that at the national level, where UCSs have been implemented, the average cost tends to decrease by up to 10.3%; however, this effect is reduced when the analysis is narrowed to more geographically comparable territories. Indeed, exogenous factors such as market structure, historical environmental performance, and waste treatment capacity significantly impact costs.

Interestingly, a GCS would reduce per capita costs by 4.2%. Given its low implementation costs and minimal organizational complexity, it can be a viable tool in territories where the cost of implementing UCSs exceeds the benefits. There are circumstances in which UCS may underperform, providing evidence that within municipalities belonging to regions with proper waste treatment capacity, USC and SCS are similar, confirming the hypothesis that different charging systems led to similar costs if applied by municipalities of most advanced regions in terms of waste treatment capacity.

Another implication emerges from the analysis of groups; in those regions with a treatment capacity gap, a GCS may outperform due to lower administrative, implementation, and transaction costs. GCSs also impact the recycling industry because the development of secondary materials markets depends on the quality and quantity of differentiated waste. Given the rising demand for sustainable products, the recycling industry is currently encouraged to develop and increase the role of secondary raw materials and develop related marketplaces so that the circular economy may become a viable growth strategy. Our results contribute to the field of MSW management, provide insights based on empirical analysis, and shed light on the potential impact of a gain-sharing model.

Declaration of competing interest

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

Data availability

Data will be made available on request.

Municipal waste management cost and fee schemes (Reference data) (BOARD)

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