Article

The Impact of Waste Management Facilities on Cost: A Comparative Analysis for Policy

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Abstract: An adequate number of waste management facilities is the key element to meet circular economy goals. Using empirical data taken from official sources the research framework bases on an econometric model to compare the elasticity of cost on quantity of different alternatives such as waste-to-energy facilities, mechanical biological facilities and landfills impact on waste management cost. Results suggest that both waste-to-energy facilities (-0.278%) and landfills (-0.38%) concur to lower the cost while the higher the percentage of waste sent to mechanical biological treatment facilities, the higher the cost (0.788%). This figure deserves to be examined in more details as such facilities represent an intermediary step in the chain which efficiency depends on the industrial organization of the chain.

Keywords: waste management; circular economy; sustainability, mechanical biological treatment, waste-to-energy; waste tax;

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1. Introduction

Fast-paced exploitation of natural resources has resulted in their limited availability while the growing need to safeguard the eco-system makes it necessary to move towards a circular economy [1–3]. In a circular economy perspective, the recoverable material is reused, repaired, shared, recycled, used for energy production: thus, limiting the use of landfills so that the circle closes with the transformation of waste into resources.

In recent years, the role of waste treatment facilities in moving towards a circular economy has become a universal theme in the policy debate worldwide [4–7]. This debate joins the more general context of the role of infrastructure for economic development [8]. Waste treatment facilities have gained importance for a variety of reasons. First, due to the increasing complexity of the waste management chain that skates from waste collection to disposal through a plethora of methods and technologies. Second, because of sustainable objectives that have prompted governments to commit to moving towards a cleaner economy. At the European level, Directive 2008/98/EC and Regulation 2014/955/EU define the strategy to achieve the objectives through the hierarchical principle of waste treatment: prevention, preparation for re-use, recycling, other recovery, and landfill as last option. Third, given the increasing concerns about the waste management cost as the sustainable development targets call for technologically advanced systems, which tend to increase the cost.

So, the selection of waste management approach and technology hinge on the local context in terms of capacity for investments and ongoing management [9] as well as the presence of existing facilities. In this regard, 2018 data show that Italian waste management facilities are unevenly scattered throughout the country despite it is essential to find the equilibrium between waste treatment facilities and social acceptability. For example, at the time of this writing, waste-to-energy facilities play a prominent role in progress towards a circular economy as they prevent landfilling and generate energy, such facilities nevertheless tend to face significant opposition from local communities and policymakers [10]. Like other local infrastructures [11], waste treatment facilities development projects should be sustainable with clearly defined long-term objectives [12,13].

Given that such benefits embed environment, social, and economic spheres [14,15], a consistent waste management policy shall integrate these three dimensions considering that benefits of the decision making occur in the feature [16]. Nevertheless, despite the implications for growth demonstrated by econometric studies, significant under-investment persists [17].

In this context, however, a prominent point is the so-called not in my backyard (NIMBY) effect that occurs when a work is undesirable because it is considered a threat to health or safety, or because it is associated with a worsening of a geographical area condition [18]. The NIMBY effect can lead to an inefficient allocation of resources given that regardless of distributed benefits, the environmental cost is concentrated in the area where the plant is located. There is evidence of NIMBY effects in recent political debate in Italy and data regarding the localization of waste treatment facilities across the country with area with no facilities, for example.

The objective of this paper is to test if and to what extent different waste treatment facilities affect the waste management cost. This is particularly important, because citizens typically fund waste management systems through the waste tax. The evidence stems from an empirical analysis based on data regarding 6616 Italian municipalities spread across the country, i.e., 82.9% of all the Italian municipalities or 91.5% of the Italian population.

Results confirm the positive contribution of waste treatment facilities available in a territory; specifically the higher the percentage of waste managed in local facilities, the lower the cost of waste management. This relation is confirmed in all typologies of facilities exception made for mechanical biological treatment. Such facilities indeed represent an intermediary step in the chain and by combining mechanical with biological treatment aim to separate materials predominantly from unsorted waste. It must be added though that mechanical biological treatment facilities are often identified as useful to meet circular economy objectives as the contribute to limit the waste sent to landfills. All this gives rise to a crucial reflection concerning the ecological and economic sustainability of these facilities. It is anticipated that at the time of this writing efficient waste management systems rely on mechanical biological treatment facilities given their role in reducing the fraction of waste sent to landfills, thus reducing the environmental impact.

The remainder of this paper is organized as follows. Section 2 refers to materials and methods, including the data and their source, the variables, and their calculation, as well as the econometric models used to analyze the data. Section 3 contains a synthesis of the results, followed by section 4 where the results are discussed; conclusions follow.

2. Materials and Methods

The paper bases on data regarding 6616 Italian municipalities spread across the country, i.e., 82.9% of all the Italian municipalities that reach 91.5% of the Italian population. The data refer to 2017 and 2018 in order to analyze the data net of financial adjustments that occur because of financial adjustments i.e., assessment and collection taxes. Economic data stem from official statements on waste tax revenues, indicated in the environmental declaration model, which is annually updated by municipalities and other delegated entities, typically in-house companies that manage the waste tax collection service. The computation of per capita costs refer to the resident population even if it should be noted that it refers to domestic, commercial, and tertiary as well as industrial users, besides non-resident people. The computation of per ton costs refer to quantitative data published by the Italian Institute for Environmental Protection and Research (ISPRA). Likewise, the Italian National Statistics Institute (ISTAT) provides other data such as the demographic and morphological ones. With regard to waste treatment facilities figure 1 shows that they are unevenly dispersed throughout the territory.

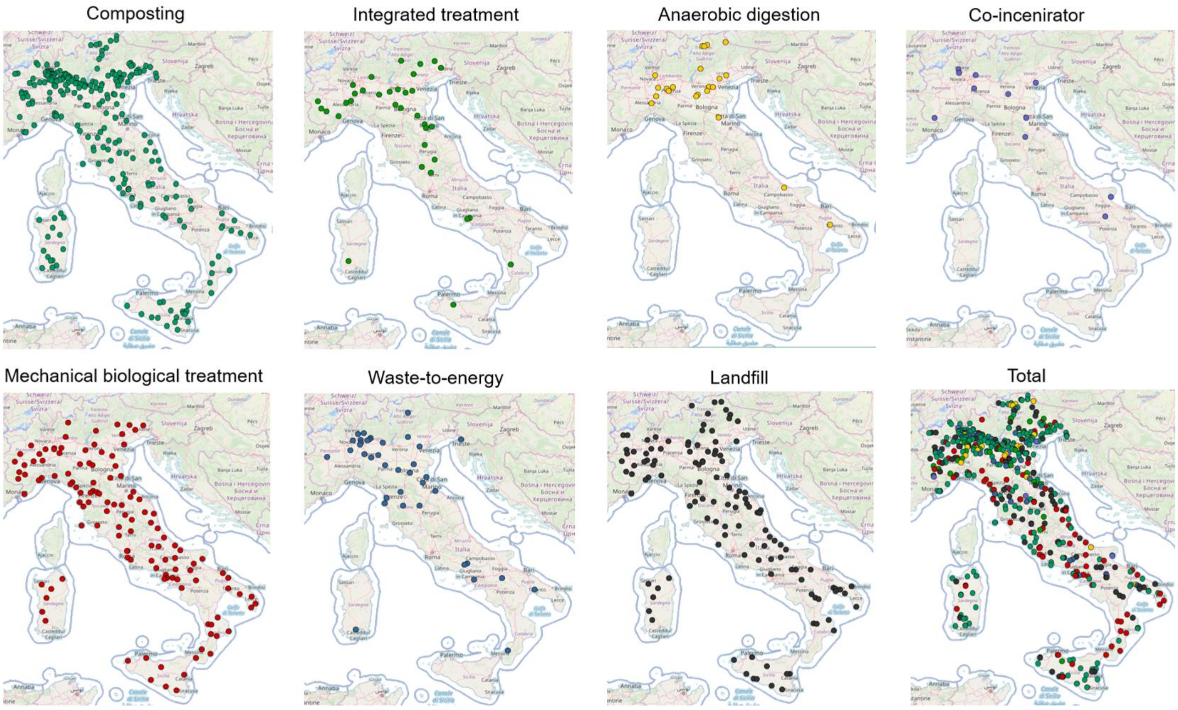

Figure 1. Distribution of waste treatment facilities across Italy. Source: ISPRA

Of the approximately thirty million tons of municipal waste produced in Italy annually, roughly 2 million tons are managed in regions other than those of production. The northern regions imports 12% of municipal waste and send to landfills roughly 10% of total waste managed. The central regions export around 16% of the municipal waste and the share sent to landfills makes up some 36% while southern regions export 7% of the waste produced with 29% sent to landfills. Figure 1 shows the distribution of waste treatment facilities across Italy. Table 1 shows a regional cross-section containing the number of waste treatment facilities by region and typology.

Table 1. Breakdown of waste treatment facilities by region

Region	Composting	Integrated treatment	Anaerobic digestion	Mechanical Biological Treatment	Landfill	Waste-To-Energy	Co-incinerator	Total
Piedmont	18	5	1	11	13	1	1	50
Aosta Valley	2	0	0	0	2	0	0	4
Lombardy	64	6	8	8	8	13	5	112
Trentino-Alto Adige	11	1	5	1	6	1	0	25
Veneto	44	5	5	6	12	2	1	75
Friuli-Venezia Giulia	13	2	0	3	1	1	0	20
Liguria	8	1	0	5	5	0	0	19
Emilia-Romagna	13	6	2	9	9	8	1	48
Tuscany	16	0	0	15	7	5	1	44
Umbria	4	4	0	5	4	0	0	17
Marche	6	0	0	6	9	0	0	21
Lazio	20	0	0	11	5	1	0	37
Abruzzo	6	0	0	5	6	0	0	17

Molise	2	0	1	3	3	1	0	10
Campania	4	2	0	7	2	1	0	16
Apulia	9	0	1	11	9	1	1	32
Basilicata	0	0	0	1	5	1	1	8
Calabria	6	1	0	9	4	1	0	21
Sicily	19	1	0	9	11	0	0	40
Sardinia	16	1	0	6	6	1	0	30
Italia	281	35	23	131	127	38	11	646

Source: own elaboration based on data published by ISPRA

Table 2 contains two kinds of information. The first four columns provide an overview of the Italian characteristics, by regions, as per population, municipal solid waste produced, share of sorted waste, and per capita waste production. Latest two columns present economic data, specifically the municipal solid waste management cost per capita and per ton of waste.

Table 2. key figures about waste production and costs

Region	Pop (m)	Waste produced (m ton)	Sorted waste (%)	Waste per capita (kg)	Cost per capita (€)	Cost per ton (€)
Piedmont	4.35	2.17	61.31	497.67	164.89	335.80
Aosta V	0.12	0.08	62.32	597.26	183.60	305.70
Lombardy	10.1	4.81	70.73	478.20	139.40	291.30
Trentino-A A	1.07	0.54	72.52	505.72	135.12	267.50
Veneto	4.90	2.36	73.83	481.72	144.20	381.60
Friuli-V G	1.21	0.60	66.61	494.76	127.85	257.70
Liguria	1.55	0.83	49.75	536.77	228.57	432.50
Emilia-R	4.45	2.95	67.36	660.46	175.32	265.90
Tuscany	3.73	2.28	56.17	612.43	206.44	338.80
Umbria	0.88	0.46	63.45	521.97	191.08	364.00
Marche	1.52	0.81	68.64	531.13	167.00	306.80
Lazio	5.87	3.03	47.33	514.92	222.21	419.20
Abruzzo	1.31	0.60	59.65	460.17	167.90	354.00
Molise	0.30	0.12	38.44	380.84	130.15	331.20
Campania	5.80	260	52.72	448.62	200.97	444.20
Apulia	4.02	1.89	45.48	470.93	191.92	394.30
Basilicata	.056	0.19	47.39	354.30	166.84	438.60
Calabria	1.94	0.79	45.27	403.37	156.31	382.10
Sicily	5.00	2.29	29.55	457.86	179.35	382.50
Sardinia	1.64	0.75	67.07	457.40	193.47	419.60
Italy	60.3	30.19	57.22	493.33	174.65	350.10

Source: own elaboration based on data published by ISPRA.

The information contained in table 2 deserves some preliminary considerations that underlie the research questions in this paper. The percentage of sorted waste differs significantly between different regions, ranging from about 29.55% to 73.95%, concerning the per capita production of waste; also, in this case, the differences are considerable. However, a more in-depth analysis of the types of waste that are assimilated to municipal waste would be necessary. Also noteworthy are the differences in cost, both per capita and per ton, for the users of the service, which shows maximum values to be almost double the minimum values. Hence the importance of understanding some of the determinants of these costs.

2.1. Variables

Based on previous literature findings and in order to the analyses to be performed, the following variables were identified:

- *ur*: the urbanization index is an ordinal variable that ranges from 1 to 3. Specifically, 3 stands for low urbanization, 2 medium urbanization, 1 high urbanization;
- *co*: a dichotomy variable where the value 0 corresponds to non-coastal municipalities, 1 otherwise;
- *alt*: this is the altitude of the municipalities (logarithm of meters a.s.l);
- *sw*: percentage of sorted waste;
- *wp*: waste produced (per capita);
- *sc*: this is a measure aimed at capturing the scale of the waste management service. It was computed as follows: logarithm of the product of km2, kilometers of roads, population and tons of waste;
- *wte*: percentage of waste sent to waste to energy;
- *mbt*: percentage of waste sent to mechanical biological treatment;
- *lan*: percentage of waste sent to landfill;
- *int*: percentage of waste treated using integrated treatment;
- *com*: percentage of waste treated using composting;
- *ad*: percentage of waste treated using anaerobic digestion;
- *sw*: percentage of sorted waste;
- *wmc*: municipal solid waste management cost (€).

Table 3 provides correlations between the variables mentioned above. From a reading of table 3, one can see that no heteroscedasticity issues emerge. This is important in the regression analysis given that in the case of heteroscedasticity, some of the classical hypotheses of the regression model fail.

Table 3. Correlation between variables used in the models

	wte	*wp*	*sc*	*ur*	*co*	*al*	*mbt*	*lan*	*int*	*com*	*ad*	*sw*
wte	1.00											
wp	0.07	1.00										
sc	-0.17	0.14	1.00									
ur	-0.15	-0.06	-0.42	1.00								
co	-0.22	0.24	0.28	-0.15	1.00							
al	0.01	-0.17	-0.35	0.33	-0.37	1.00						
mbt	-0.39	-0.19	0.16	0.11	0.25	0.10	1.00					
lan	-0.43	-0.14	0.10	0.19	0.21	0.17	0.65	1.00				
int	0.11	0.05	-0.06	-0.06	-0.17	-0.25	-0.50	-0.43	1.00			
com	0.11	0.03	-0.02	-0.03	-0.06	-0.03	-0.07	0.14	0.01	1.00		
ad	0.61	0.11	0.05	-0.05	-0.13	-0.12	-0.17	0.01	0.16	0.13	1.00	
sw	0.00	0.09	0.34	-0.25	0.13	-0.16	0.00	-0.04	0.00	0.00	0.02	1.00

Source: own elaboration

Some empirical evidence can be drawn from table 3. Especially the relationship between the three types of facilities that are particularly important in this paper. First of all, the complementarity that exists between waste-to-energy facilities and landfills (-0.43) and between waste-to-energy facilities and mechanical biological treatment facilities (-0.39) emerges. These two pieces of evidence are significant even if the first of the two relations appear more direct since the two technologies are complementary and are positioned at the base of the waste hierarchy. In addition to the graphic evidence provided by figure 1 from which one can see that where waste-to-energy facilities are concentrated there are few landfills and *vice versa*. On the other hand, the causality of the second correlation, which shows that as the percentage of waste treated in waste-to-energy facilities increases, the percentage of waste treated in mechanical biological treatment facilities decreases, is not apparent. Although this paper does not focus on the effects of one type of plant on the other, it is possible to see that where the use of waste-to-energy facilities is higher, the need to separate the undifferentiated fraction disappears. On the contrary, the relationship between landfills and mechanical biological treatment facilities is positive (0.69) and even in this case the relationship is not analyzed in this paper but it deserves attention

2.2. Econometric models

Besides typical cost drivers that influence waste management cost, this paper focuses on the implications of different plant typologies on such cost. Based on previous evidence, the hypothesis is that the availability of facilities instead of landfills not only reduces negative environmental externalities but also reduces the cost of waste management.

The research framework contains three types of variables: three variables that capture territorial features, namely the degree of urbanization *ur*, the proximity to the sea *co*, and the altitude *al*. In addition t the geographical features the models contain three variables that capture the characteristics of the service in terms of sorted waste share *sw,* waste produced per capita *wp* and scale of service *sc*.

Waste management cost *wmc* if a function of the independent variables listed.

$$wmc = f\begin{cases} territorial\ features: ur, co, al \\ service\ characteristics: sw, wp, sc \\ plants \end{cases} \tag{1}$$

Where:

$$plants = \begin{cases} mbt, la, wte \quad\quad if\ unsorted\ waste \\ mbt, int, com, ad \quad if\ sorted\ waste \end{cases} \tag{2}$$

In order to determine the influence of treatment and disposal facilities on waste management cost, it is appropriate to perform an econometric analysis using two regression models formalized in equation 3 and equation 4. Data were analyzed using different models. Specifically, equation 3 presents the model used for analyzing the impact of treatment and disposal facilities predominantly in use for unsorted waste: waste-to-energy facilities, mechanical biological facilities, and landfills. Similarly, equation 4 presents the model used for analyzing the impact of treatment and disposal facilities predominantly in use for sorted waste: mechanical biological facilities, integrated treatment facilities, composting facilities, and anaerobic digestion facilities. Both models were estimated using two unite of measure: cost per ton of waste and or per capita waste.

$$wmc = \propto + \beta_1 ur + \beta_2 co + \beta_3 al + \beta_4 sw + \beta_5 wp + \beta_6 sc + \beta_7 mbt + \beta_8 lan + \beta_9 wte + \varepsilon \tag{3}$$

In the same way, equation 4 formalizes the model related to sorted waste, i.e. it includes facilities typically used to manage sorted waste.

$$wmc = \propto + \beta_1 ur + \beta_2 co + \beta_3 al + \beta_4 sw + \beta_5 wp + \beta_6 sc + \beta_7 mbt + \beta_8 int + \beta_9 com + \beta_{10} ad + \varepsilon \tag{4}$$

Table 4 summarizes the results of equation 3 and equation 4 using both per capita and per ton of waste costs. Specifically, equation 3 presents per capita values in table 4.1 and per ton of waste 4.2, while equation 4 that refers to sorter waste, presents per capita values in table 4.3 and per ton of waste 4.4.

3. Results

The results of the first six contextual variables included in both models show the impact of widely analyzed drivers on waste management cost. The degree of urbanization that presents positive values i.e. in urbanized areas some economies of density can emerge because of population higher density. Moreover, being a coastal municipality is associated with a higher average cost. Then the altitude above sea level shows heterogeneous evidence. In addition, the lower the level of urbanization, the higher the cost, and the fact the more urbanized municipalities tend to have a higher population density that is associated with scale economy in operations can explain the evidence. The following two variables resemble information about the about the per capita production of waste *wp* and percentage of sorted waste *sw*. Consistently with previous literature findings inherent to the production per capita of waste show different results; so do results related to the percentage of sorted waste. The last variable before those related to facilities refer to the scale of the service *sc*, i.e., a measure that comprises municipalities' population, area, kilometers of road, and waste production, confirm previous literature indicating the role of scale economies in the waste management service, *ceteris paribus*.

Table 4. Econometric analysis

	Equation 3		Equation2	
Variables	wmc (1) per capita	wmc (2) per ton	wmc (3) per capita	wmc (4) per ton
ur	0.140	3.541	2.157*	5.645**
	(1.292)	(2.545)	(1.246)	(2.448)
co	61.56***	73.24***	52.92***	51.79***
	(2.983)	(5.878)	(2.959)	(5.812)
al	1.220**	7.964***	-1.639***	1.810
	(0.581)	(1.145)	(0.586)	(1.151)
sw	-0.0966**	0.0246	0.0506	0.413***
	(0.0380)	(0.0750)	(0.0375)	(0.0736)
wp	0.195***	-0.0846***	0.197***	-0.0765***
	(0.00420)	(0.00828)	(0.00413)	(0.00811)
sc	-0.989***	-2.351***	-0.853***	-2.296***
	(0.181)	(0.357)	(0.177)	(0.347)
wte	-0.496***	-0.972***		
	(0.0479)	(0.0944)		
lan	-0.425***	-1.240***		
	(0.0424)	(0.0835)		
mbt	0.780***	2.759***	0.513***	2.054***
	(0.0435)	(0.0856)	(0.0396)	(0.0779)
int			-0.691***	-1.376***
			(0.0596)	(0.117)
ad			-1.918***	-4.073***
			(0.169)	(0.332)
com			-0.830***	-2.807***
			(0.0918)	(0.180)
Constant	71.79***	338.9***	78.02***	366.7***
	(8.296)	(16.35)	(8.012)	(15.73)
Observations	6,321	6,321	6,321	6,321
R-squared	0.413	0.311	0.426	0.330

Source: own elaboration. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Equation 3 refers to facilities used for managing unsorted waste; equation 4 refers to facilities used for managing sorted waste.

Taking into account the models referring to the unsorted waste what emerges is worth noting. The waste management cost tends to decrease both as the use of waste-to-energy facilities increases and as the use of landfills increases. In the same way, co-incineration facilities also contribute to the reduction of the cost. Incidentally, mechanical biological treatment facilities imply an increase in costs. It should be noted that the impact of mechanical biological treatment facilities also persists in the models concerning sorted waste. Furthermore, it can be observed that the cost of the service tends to decrease as the use of integrated treatment, anaerobic digestion, and composting facilities increases regardless of the unit of measure, i.e., per capita or per ton of waste. These results are important for the definition of environmental policies aimed at planning plant capacity for waste treatment and disposal.

Table 5. Elasticity of cost on percentage of waste treated in different facilities

Variables	wmc (1) per capita	wmc (2) per ton	wmc (3) per capita	wmc (4) per ton
wte	-0,285%	-0,278%		
lan	-0,244%	-0,354%		
mbt	0,448%	0,788%	0,295%	0,587%
int			-0,397%	-0,393%
ad			-1,102%	-1,164%
com			-0,477%	-0,802%

Source: own elaboration.

Table 5 contains percent changes in waste management cost to waste treated or disposed of in different facilities. By considering the cost per ton of waste, at a 1% increase of waste treated corresponds a -0.278% decrease in cost, at a 1% increase of waste landfilled corresponds -0.354% cost. Finally, a 1% increase in waste treated in mechanical biological treatment leads to a 0.788% increase in cost.

4. Discussion

The results make it possible to formulate several considerations. First, the positive the role of both waste-to-energy facilities and landfills that tend to reduce the cost of waste management. Among the reasons that contribute to reduce cost, there is the fact that, as shown in figure 1, there are regions with serious facilities shortage culminating in need of export part of the waste produced to other regions or even to other countries; consequently the cost would also increase because of higher cost of transport. Returning to the mentioned waste disposal alternatives, although waste-to-energy facilities produce fewer negative environmental externalities than landfills, policymakers have often opposed such facilities.

Second, results suggest that the intermediate waste treatment phase, such as mechanical biological treatment facilities, concur to raise the cost of waste management. The potential critical role of this phase shall be better investigated, taking into consideration additional variables using general social cost as the dependent variable, e.g., considering landfill taxes, greenhouse gas emissions cost, and industrial organization, to name a few. Besides, another aspect worth noting is the relationship between the efficiency of mechanical biological treatment facilities and the quality of the sorted and unsorted waste. Moreover, by implementing mechanical biological treatment before landfilling, the environmental impact and waste mass are reduced up to 30% [19]. The mechanical phase allows the separation and classification of the various components of the waste using automated mechanical systems and other separators. Technologically advanced facilities also separate the combustible part of the waste that can be used to produce energy. The biological phase, on the other hand, involves the composting and anaerobic digestion processes of the organic part coming from the first mechanical phase, obtaining biogas. Consequently, the materials derived from the process output generate revenues in the form of secondary raw materials or energy.

Third, mechanical biological treatment facilities contribute to the consolidation of the circular economy in proportion to their technological efficiency; indeed, their effectiveness increases as the capacity to select the materials of unsorted waste increases. However, this prompts a potential efficiency paradox, i.e., as the quality of separate collection increases, the need of technologies aimed at separating its components decreases. Therefore, it is important that the facilities comply with the best available technology and that technologically obsolete facilities were upgraded through clean technology components and energy efficiency measures.

Fourth, to support the mentioned upgrading, policy-makers dispose of a set of policy tools [20] that can typically be tagged as market-based incentives and command and control where command and control tools can, for example, precede and complement market-based instruments [21]. The underlying paradigm of market-based instruments, one of achieving socially efficient use of environmental resources by shifting the cost of negative externalities associated with resource use to users or polluters [22].

It is clear the development and strengthening of waste treatment facilities within an industrial development path for the waste management sector is a *conditio sine qua non* for achieving circular economy objectives. Indeed, the shortage of waste treatment facilities generates inefficient brokerage mechanisms, which unjustifiably increases the cost for taxpayers and negatively impact on the economy.

Therefore, there is a policy implication too. The evidence described above paves the way to a general consideration, i.e., the need for policy-makers to find the equilibrium between the different types of facilities, and consequently, between the different technologies. So that the waste management systems were adequate, i.e., able to achieve the objectives of a circular economy and efficient, i.e., doing it at a sustainable cost to maximize social welfare [23].

5. Conclusions

There is a broad consensus on the desirability of the policy makers securing more resources to waste industry in order to assure an adequate number of waste management facilities to meet circular economy goals. Considering that this process should take place in the most cost-effectively way the paper has provided economic analysis and evaluation in support of policy makers and waste industry stakeholder in general by giving an account of how and to what extent the waste management cost depends on waste management facilities. Because waste management systems that use technologies that are more advanced cost more, the choice of waste management methodology and technology depends on the local context. Indeed the need to understand how intermediate waste management chain phases such as mechanical biological treatment impact on cost has justified the econometric analysis performed as it allowed to measure the elasticity of waste management cost on waste treated on different facilities. The analysis has prompted accurate results demonstrating that both waste-to-energy facilities (-0.278%) and landfills (-0.38%) concur to decrease cost. On the contrary, the higher the percentage of mechanical biological treatment facilities, the higher the cost. Indeed 1% increase of unsorted waste treated in mechanical-biological facilities, the cost of waste management increase by 2.78€ per ton, i.e., 0.79% on average. However, this evidence shall be read with caution and better investigated, taking into consideration additional variables, by discounting the avoided costs, or including fiscal measures like landfill taxes or internalizing greenhouse gas emissions cost to waste-to-energy, to name a few factors that may mitigate such figure. This research suggests that policymakers should encourage local administrators to move towards a circular economy by featuring the territory they administer with the required facilities to manage the waste that territories produce in order to make the waste management systems more effective in achieving circular economy objectives efficiently at a sustainable cost. It is necessary to design a waste management system, capable of meeting environmental, industrial, and economic growth needs. Developing such a path could boost the competitiveness of companies by making them less constrained by the dependence and volatility of raw material prices, guarantee new jobs, and make progress on environmental sustainability.

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