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The Efficiency of Waste Sector in Italy: An Application by Data Envelopment Analysis

Massimo GASTALDI[1], Ginevra Virginia LOMBARDI[2], Agnese RAPPOSELLI[3]*, Giulia ROMANO[4]

[1]*Department of Industrial & Information Engineering & Economics, University of L'Aquila, Via Gronchi 18, L'Aquila, Italy*

[2]*Department of Economics and Management, University of Firenze, Via delle Pandette 9, Firenze, Italy*

[3]*Department of Management and Business Administration, University of Chieti-Pescara, Viale Pindaro 42, Pescara, Italy*

[4]*Department of Economics and Management, University of Pisa, Via Ridolfi 10, Pisa, Italy*

Abstract **– With growing environmental legislation and mounting popular concern for the need to pursuing a sustainable growth, there has been an increasing recognition in developed nations of the importance of waste reduction, recycling and reuse maximization. This empirical study investigates both ecological and economic performances of urban waste systems in 78 major Italian towns for the years 2015 and 2016. To this purpose the study employs the non-parametric approach to efficiency measurement, represented by Data Envelopment Analysis (DEA) technique. More specifically, in the context of environmental performance we implement two output-oriented DEA models in order to consider both constant and variable returns to scale. In addition, we include an undesirable output – the total amount of waste collected – in the two models considered. The results show that there is variability among the municipalities analysed: Northern and Central major towns show higher efficiency scores than Southern and Islands ones.**

Keywords **– Data Envelopment Analysis (DEA); ecological and economic efficiency; Solid Waste Management (SWM); undesirable output; urban waste management**

1. INTRODUCTION

According to the World Bank, in 2016 global generation of Municipal Solid Waste (MSW) was 2.01 billion tons, that is estimated to grow up to 3.40 billion tons by 2050 [1]. Municipal solid waste refers to household commercial and public services waste generation excluding waste generated by economic activities such as construction, energy supply, manufacturing, etc.

An average of 0.74 kg/day of waste are generated per person worldwide. This amount varies among region and countries and it increases as the population income increases [2]. The United States has a waste production of 2.58 kg/day per person; in Europe waste generation per day is 1.34 kg per person, while in Italy is 1.34 kg/day per person.

Waste generation is a growing concern at global level, given its positive correlation with urban growth and economic development. Without appropriate policy actions, waste generation will growth more and more and cities and urban settlements will have to deal with

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* Corresponding author.
E-mail address: agnese.rapposelli@unich.it

increasing demand of waste services, land scarcity and environmental problems. Waste treatment is commonly recognized as a significant source of environmental problems such as greenhouses gas emission (landfill emission) and water, soil and air contamination by heavy metal and chemical [3].

The 7th Environment Action Program (EAP) indicates waste reduction, recycling and re-use maximization as priorities for the waste policy in Europe, in a Circular Economy perspective aiming at reducing waste impact on public health and environment in the pursue of sustainable growth in Europe [4]. In this aim, EU countries are currently required to recycle at least 55 % of their MSW, to reach 60 % by 2030 and 65 % by 2035; landfill will be limited to 10 % of MSW by 2035. Recycling rate represents a key indicator to be considered in the evaluation of MSW services efficiency in attaining sustainability targets.

This paper illustrates an empirical analysis aimed at evaluating economic and environmental efficiency of waste systems at county level in Italy. In this aim, the study employs Data Envelopment Analysis (DEA) approach using publicly available data to assess ecological and economic performances of the SWM in 78 major Italian towns for the years 2015 and 2016. The sample has been selected to be representative of the national diversities and peculiarities providing data for the main county of each Italian regions. The selected years are the more recent ones for which all the needed data are available.

DEA has been widely applied to evaluate economic and technical efficiency of a wide range of public and private organization including waste services. In this context DEA assumption is based on the maximization of output at the smallest quantity of input, assuming that efficiency of the production process consists in desirable outputs generation from the amount of inputs used. However, DEA model application to ecological efficiency need to focus on the relationship between desirable (good) and undesirable (bad) outputs allowing to consider production process externalities as well as good outputs [5]. In this study we have carried out an analysis of both economic and ecological efficiency given that the ecological improvements are supposed to come jointly with costs saving and economic gains both for societies and companies [6]. Hence, the objective of this study is to verify the Italian waste service compliance with EU and national regulatory requirements in the pursuit of circular economy strategies. In this aim, this paper analyses the environmental performances of waste management in Italy to assess differences in waste management efficiency at regional level, considering the relationship between environmental and economic performances by considering, among others, economic variables such as the services costs and the tariff level as undesirable output. In order to asses ecological efficiency we include undesirable outputs by a specific selection and classification of inputs and outputs enabling us to consider environmentally focused decision making units (DMU). According to [7], in order to be able to evaluate SWM environmental-technical performances we consider undesirable outputs (environmental cost or bads) as desirable input in the DEA model, while we consider all desirable output (goods) as output in the model.

The paper is structured as follows: second section outlines literature review; third section illustrates data and fourth section describes methodology. Section 5 present DEA model results and finally Conclusion section discusses policy implications.

2. LITERATURE REVIEW

Efficiency of urban waste management has been the focus of an abundant stream of research, due to its relevance for community well-being, environmental sustainability, and service quality. However, further research is still needed [8] in consideration of the relevant economic, environmental and social impact of this public service and of the need to improve its performance to meet adequate quality and quantity standards.

As highlighted recently by [9], for efficiency estimation DEA has been widely employed in waste management research, resulting as the traditional and most applied methodology ([10], [11]).

Looking at researchers that have investigated efficiency of urban waste management service at municipal level using DEA (Table 1), data show that input and output selection has varied, even if total cost and quantity of total waste collected are the most frequently used input and output. However, an increasing number of research highlighted the need to focus on separate waste collected as a specific target defined by European and national legislation, by using only a separate collected waste fraction (reference [12] used as output organic waste collected), by including different amount of waste collected separately ([13]), or by considering the amount of separate waste collection as a desirable output along with unsorted waste collected considered as an undesirable output ([11], [14]).

Interestingly, no previous study used the amount of waste produced as an input (undesirable factor) or the tariff level applied in the municipality in the efficiency estimation. While the first variable has been usually included as an output, the latter has been neglected in previous research, notwithstanding its potential relevance for service quantity and quality, affordability, and with the citizens' request of higher service standards. Furthermore, it is a variable allowing to assess the tariff effectiveness in reflecting the polluter-pays principle of the EU Directive 2004/35/CE.

TABLE 1. LITERATURE REVIEW OF DEA PAPERS ABOUT MUNICIPAL EFFICIENCY IN URBAN WASTE MANAGEMENT: INPUT AND OUTPUT SELECTION

	N. DMU (municipalities)	**Years analysed**	**Input**	**Output**	**Country**
[15]	103	1993	Collection costs	Amount of waste collected; amount of recycled waste collected; recyclable rate (recyclable material as a proportion of total garbage collection)	Australia (South Wales)
[12]	75	1994	number of containers, total number of vehicles and total number of direct non-office workers expressed in terms of full working days	tons of collected organic material refuse	Spain (Catalonia)

[16]	113	2000	staff, vehicles and containers	Tonnage, collection points, collection point density and kilometres of surface area washing	Spain
[17]	1072	2005	Cost per capita	annual production of residues, index built from the survey on the suitability of the service	Spain
[18]	262	2015	Current expenditure for environmental management	Amount of waste collected	Italy
[19]	293	2008	Total cost	Amount of residual waste; amount of other municipal waste; amount of packaging waste; amount of other EPR waste; amount of green waste; amount of bulky waste	Belgium (Flanders)
[20]	196	2008	Trucks; workers; other OPEX	Amount of residential waste collected	Portugal
[13]	293	2008	Current expenditure	Amount of residual waste; amount of other municipal waste; amount of packaging waste; amount of other EPR waste; amount of green waste; amount of bulky waste	Belgium (Flanders)
[10]	771	2007–2010	Total cost	Annual production of waste, Annual production of waste, in tonnes/year, corrected by the index of service quality, Number of Containers	Spain

[11]	289	2011–2013	Total cost	waste from separate collection, unsorted waste	Italy (Abruzzo)
[21]	256	2002–2014	Total cost	annual waste production, annual production of waste corrected by the internal index of technical quality of the service, and the number of waste containers located on public roads	Spain
[22]	289	2011–2013	Total cost	waste from separate collection, unsorted waste	Italy (Abruzzo)
[14]	225	2016	total cost of unsorted waste; total cost of recyclables; other costs	recyclables collected; unsorted waste collected	Italy (Tuscany)

In order to derive policy implication, efficiency estimation obtained through efficiency analysis have been investigated in relationship with some relevant external and environmental variables (see for example the analysis of [11] or [23]), among which population density ([14]–[18]), population served ([14]–[16]), and geographical area ([23], [20]), highlighting contrasting results that call for further investigation.

3. DATA

The original dataset included data about urban waste management service in major town of each Italian province in 2015 and 2016.

Following previous studies on the efficiency of waste service management ([11], [13], [15], [18], [20]), total cost variables have been included as inputs, using both cost per inhabitant and cost per kg. Two further inputs have been included: total amount of waste collected and average tariff applied in the municipality.

As outputs, two variables have been used: amount of separate waste collected per inhabitant and total separate waste collected.

Data was retrieved from multiple sources. First of all, information about the average annual cost paid for the urban waste management service (“Tariff”, that in Italy is called TARI) was obtained from the annual reports called “Dossier Rifiuti” of Cittadinanzattiva, an Italian non-profit organization. Data was only available for the major town of each Italian province and is calculated considering a three-member household living in a house of 100 m^2 and with a gross annual income of 44 200 euro.

Further, data about total costs, amount of waste collected and rate of separate collection were retrieved from the publicly available Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) dataset. In accordance with ISPRA classification, total cost includes costs for collection and transport of unsorted waste, treatment and disposal of unsorted waste, collection and transport of sorted recyclable waste, for treatment and recycling of sorted recyclable waste, street sweeping and washing; shared costs (administrative, collection and litigation, general management, other); and costs of capital (amortization of the mechanical means for the collection, sweeping means and tools, containers for collection, financial depreciation for transferable assets and others, provisions and remuneration of capital).

The dataset also includes data about population (the number of residents) and population density retrieved from National Institute of Statistics (ISTAT) and the publicly available portal comuni-italiani.it. Main statistics of utilized dataset are presented in Table 2. Each major town has been classified with reference to its geographical location in accordance with ISTAT classification: North West, North East, Center, South and Islands (Fig. 1). 78 major Italian towns reported all relevant information and were considered in the empirical analysis. These towns cover all 20 Italian regions and have around 15.5 million of inhabitants, more than 25.5 % of the total Italian population.

TABLE 2. DESCRIPTIVE STATISTICS (2016)

	Average	**Maximum**	**Minimum**	**SD**
Tariff, €/year	299	579	149	82.10
Total cost per inhabitant, €	192	335	86	45.43
Total cost per kg, €	36	64	15	8.96
Total amount of waste collected, kg	110 691 333	1 689 206 114	8 425 439	214 816 832.45
Separate collected waste per inhabitant, kg	268	475	31	113.05
Separate collected waste, kg	49 303 106	709 436 934	1 948 069	92 971 050.92
Number of residents	198 340	2 873 494	21 632	376 374.93
Population density, habitants/km	1 365	8 153	147	1 538.47

4. METHODOLOGY

Data Envelopment Analysis, introduced by Charnes *et al.* ([24], [25]), is a powerful non-parametric technique for measuring and improving the relative efficiency of a set of independent and homogeneous z Decision Making Units (DMUs). In a process with a single input and a single output, efficiency is defined simply as:

$$\text{Efficiency} = \text{output} / \text{input} \tag{1}$$

Generally, in a process where there are several inputs and outputs, the efficiency can be defined as:

$$\text{Efficiency} = \text{weighted sum of outputs} / \text{weighted sum of inputs} \tag{2}$$

The problem of the above definition is in the choice of weights. DEA method solves this problem by introducing a particular weighting system for every single DMU. Reference [24], in fact, proposed that the maximum of efficiency for a DMU k0 can be calculated by solving the following problem:

$$\max_{w,v} h_0 = \frac{\sum_{j=1}^{n} w_j y_{jk_0}}{\sum_{j=1}^{m} v_i x_{ik_0}} \tag{3}$$

subject to:

$$\frac{\sum_{j=1}^{n} w_j y_{jk}}{\sum_{j=1}^{m} v_i x_{ik}} \leq 1 \qquad k = 1,\ldots,z \qquad w_j, v_i \geq \varepsilon \qquad \forall j,i, \tag{4}$$

where

z	Number of units;
m	Number of inputs;
n	Number of outputs;
w_j	Weight given to output j;
v_i	Weight given to input i;
ε	Small positive number.

This model maximises the ratio of weighted output to weighted input of the k_0th DMU, with the constraint that the same ratio for the other DMUs should not exceed unity, which is the maximal efficiency. The efficiency of the k_0th DMU will either equal to one, in which case it is efficient relative to the other DMUs, or will be less than one, in which case DMU k_0 is inefficient. The above equations are non-linear, but this problem was converted to an ordinary fractional linear programming problem [26].

DEA models can be divided into input-oriented models and output-oriented models: the former favour the potential improvement of resource utilisation and the latter analyse the potential improvement of produced outputs, by measuring the relative efficiency of a DMU in terms of maximal radial contraction to its input levels or expansion to its output levels feasible under efficient operation, respectively. DEA models also solve linear programming problems for each technology satisfying both constant returns to scale (CRS) and variable returns to scale (VRS). CRS reflects the fact that output will change by the same proportion as inputs whereas VRS reflects the fact that production technology may exhibit increasing, constant and decreasing return to scale [27]. DEA methodology is a well-known technique evaluating the systems' efficiency not only by calculating the relative efficiency of each DMU, but also helping policymakers in their decision processes suggesting measures and promoting policies able to reach efficiency in inefficient units. Hence, this approach can be useful for public and private policymakers to guide decisions towards more efficient systems.

5. RESULTS

In this study we have implemented both CRS and VRS specifications of the output-oriented DEA model in order to capture the impact of scale size on the performance of the unit analysed. The study compares only two years and more exactly 2015 and 2016. It should be noted that at this moment the data on waste costs relating to more recent years are not available.

TABLE 3. DEA SCORES BY MUNICIPALITIES

		2015			**2016**		
Municipality	**Zone**	**CRS**	**VRS**	**SCALE**	**CRS**	**VRS**	**SCALE**
L'Aquila	South	0.429	0.432	0.995	0.416	0.427	0.975
Teramo	South	0.787	0.791	0.995	0.762	0.763	0.999
Matera	South	0.299	0.301	0.993	0.319	0.325	0.980
Potenza	South	0.259	0.261	0.995	0.308	0.310	0.993
Catanzaro	South	0.132	0.132	0.996	0.488	0.491	0.992
Cosenza	South	0.659	0.697	0.946	0.644	0.683	0.943
Crotone	South	0.237	0.238	0.996	0.079	0.080	0.988
Reggio c.	South	0.226	0.231	0.978	0.359	0.367	0.978
Avellino	South	0.436	0.438	0.996	0.375	0.377	0.995
Napoli	South	0.453	0.453	1.000	0.533	0.534	0.999
Salerno	South	0.811	0.846	0.958	0.757	0.798	0.949
Bologna	Center	0.748	0.750	0.997	0.725	0.727	0.997
Forlì	Center	1.000	1.000	1.000	0.894	1.000	1.000
Ferrara	Center	0.800	0.868	0.923	0.778	0.888	0.876
Modena	Center	1.000	1.000	1.000	0.918	0.972	0.945
Rimini	Center	0.920	1.000	0.920	0.857	1.000	0.857
Ravenna	Center	1.000	1.000	1.000	0.907	0.996	0.910
Parma	Center	1.000	1.000	1.000	1.000	1.000	1.000
Piacenza	Center	0.830	0.938	0.885	0.757	0.868	0.873
Reggio E.	Center	0.930	0.943	0.987	0.847	0.917	0.924
Gorizia	North-East	0.819	0.869	0.942	0.784	0.794	0.988
Pordenone	North-East	1.000	1.000	1.000	1.000	1.000	1.000
Trieste	North-East	0.492	0.495	0.993	0.524	0.524	1.000
Udine	North-East	1.000	1.000	1.000	1.000	1.000	1.000
Frosinone	Center	0.207	0.217	0.954	0.186	0.208	0.895
Latina	Center	0.400	0.405	0.988	0.391	0.397	0.987
Roma	Center	1.000	1.000	1.000	1.000	1.000	1.000
Viterbo	Center	0.634	0.658	0.965	0.625	0.698	0.895
Genova	North-West	0.583	0.590	0.988	0.535	0.538	0.995
Imperia	North-West	0.490	0.519	0.943	0.445	0.462	0.963
Savona	North-West	0.388	0.397	0.976	0.512	0.523	0.980
Bergamo	North-West	0.935	0.943	0.992	0.939	0.940	0.998
Brescia	North-West	0.868	1.000	0.868	0.873	0.884	0.987
Como	North-West	0.864	0.873	0.990	0.885	0.890	0.995
Cremona	North-West	0.817	0.817	0.999	0.895	0.895	1.000
Lecco	North-West	0.731	0.732	0.999	0.788	0.798	0.988

Mantova	North-West	1.000	1.000	1.000	1.000	1.000	1.000
Milano	North-West	1.000	1.000	1.000	1.000	1.000	1.000
Pavia	North-West	0.514	0.546	0.942	0.658	0.680	0.966
Sondrio	North-West	0.936	1.000	0.936	1.000	1.000	1.000
Varese	North-West	0.759	0.786	0.966	0.843	0.854	0.987
Monza	North-West	0.744	0.748	0.994	0.837	0.843	0.992
Ascoli P.	Center	0.552	0.560	0.987	0.483	0.495	0.977
Isernia	South	1.000	1.000	1.000	1.000	1.000	1.000
Asti	North-West	0.798	0.809	0.987	0.778	0.802	0.971
Biella	North-West	0.814	0.846	0.962	0.869	0.932	0.932
Torino	North-West	0.793	0.798	0.993	0.717	0.721	0.995
Vercelli	North-West	0.891	0.907	0.982	0.810	0.813	0.996
Bari	South	0.541	0.548	0.987	0.556	0.557	0.998
Foggia	South	0.111	0.115	0.967	0.171	0.175	0.981
Taranto	South	0.255	0.259	0.986	0.224	0.226	0.991
Trani	South	0.347	0.358	0.970	0.244	0.247	0.990
Nuoro	Islands	0.783	0.800	0.979	0.695	0.739	0.939
Oristano	Islands	0.783	0.800	0.979	0.695	0.739	0.939
Sassari	Islands	0.579	0.592	0.979	0.619	0.628	0.986
Agrigento	Islands	0.193	0.204	0.946	0.112	0.115	0.976
Catania	Islands	0.150	0.151	0.994	0.165	0.174	0.951
Palermo	Islands	0.153	0.162	0.949	0.121	0.122	0.996
Trapani	Islands	0.331	0.370	0.896	0.256	0.284	0.903
Arezzo	Center	0.527	0.545	0.967	0.521	0.548	0.950
Carrara	Center	0.469	0.518	0.907	0.453	0.481	0.941
Firenze	Center	0.846	0.855	0.989	0.828	0.832	0.996
Grosseto	Center	0.457	0.506	0.902	0.448	0.471	0.951
Lucca	Center	0.877	0.979	0.895	0.970	1.000	0.970
Livorno	Center	0.532	0.550	0.966	0.551	0.560	0.984
Massa	Center	0.472	0.545	0.866	0.407	0.518	0.785
Pisa	Center	0.558	0.714	0.780	0.597	0.779	0.766
Pistoia	Center	0.556	0.592	0.940	0.513	0.553	0.927
Prato	Center	0.736	0.788	0.935	0.795	0.890	0.893
Bolzano	North-East	0.838	0.838	1.000	0.867	0.868	0.999
Trento	North-East	1.000	1.000	1.000	1.000	1.000	1.000
Perugia	Center	0.790	0.822	0.961	0.803	0.817	0.983
Terni	Center	0.501	0.516	0.971	0.610	0.620	0.984
Aosta	North-West	0.783	0.836	0.936	0.809	0.813	0.994
Belluno	North-East	1.000	1.000	1.000	1.000	1.000	1.000
Padova	North-East	0.840	0.841	0.999	0.845	0.846	0.999
Venezia	North-East	0.803	0.880	0.912	0.770	0.860	0.896
Vicenza	North-East	0.970	1.000	0.970	0.984	1.000	0.984

The DEA models results show significant differences among the considered towns and small differences for the considered years. As illustrated in Table 3, DEA scores of SWM ecological efficiency are high variable and they range in function of geographical localization, with South and Islands being less efficient than Centre and North.

The DEA scores are very similar in the years at regional level, even if Southern and Central towns show a slightly decline while North-West ones improve its scores (Table 4). The differences among national geographical areas are due both to differences waste services quality and management and to socio-economic characteristic of each specific area. Socio-economic characteristics of Northern Italy population, such as population density, education, age, employment, income, in fact, are positively correlated with higher consumer willingness to participate in waste reduction and recycling enhancement.

TABLE 4. MEAN EFFICIENCY SCORES BY GEOGRAPHICAL LOCALIZATION

		2015			**2016**		
Macrozone		**CRS**	**VRS**	**SCALE**	**CRS**	**VRS**	**SCALE**
North-West	19	0.774	0.797	0.971	0.800	0.810	0.986
North-East	10	0.876	0.892	0.982	0.877	0.889	0.987
Center	26	0.705	0.741	0.949	0.687	0.740	0.933
South	16	0.436	0.444	0.985	0.452	0.460	0.984
Islands	7	0.425	0.440	0.960	0.380	0.400	0.956
	78						

Furthermore, our results show that the ecological efficiency of MSW performs a small variation along the considered years. With regard to VRS model, the average efficiency score of the whole sample from 2015 to 2016 shows a slight increase (Table 5). This trend is positively affected by national and European regulatory policies aiming at enhancing waste reduction and recycling rate also incentivizing the waste management efficiency by applying sanctions for non-achievement of standards. Despite this effort the small increase in scores values underlines the slowness in the implementation of sustainable waste management practices due to the nature of the service which requires investments and long adaptation times. It must be noted, however, that the number of towns that reach the maximum efficiency score shows a slightly variation in the period not affecting the overall trend.

TABLE 5. DESCRIPTIVE STATISTICS OF DEA SCORES

	2015		**2016**	
	CRS	**VRS**	**CRS**	**VRS**
Average efficiency	0.664	0.686	0.663	0.688
Maximum efficiency	1.000	1.000	1.000	1.000
Minimum efficiency	0.111	0.115	0.079	0.080
Standard deviation	0.278	0.273	0.264	0.270
% Municipalities with the highest efficiency	12	16	10	14

As Table 6 shows, we have classified the DMUs in 4 groups based on the population density (habitants/km) to analyse DEA score in function of urban clusters. The average behaviour of scores is coherent with previous studies and it increases with population density up to 1500 habitants/km^2; for higher population density it decreases. Efficiency in SWM shows economy of scale of the waste service. Until a certain level of population density (1000–1500), in fact, the efficiency scores increase, then the average scores sink as the separate waste collection organization costs are influenced by urban density and morphology, posing limitation in the adoption of best practises for waste separate collection for space shortage that reflect in services and infrastructure additional costs.

TABLE 6. MEAN EFFICIENCY SCORES BY DENSITY

		2015			**2016**		
Cluster per habitants/km		**CRS**	**VRS**	**SCALE**	**CRS**	**VRS**	**SCALE**
>1500	24	0.700	0.717	0.978	0.703	0.713	0.986
1000–1500	9	0.850	0.876	0.970	0.883	0.911	0.970
500–1000	21	0.637	0.661	0.962	0.640	0.673	0.956
<500	24	0.581	0.606	0.960	0.561	0.593	0.952
	78						

We have classified the efficiency scores also on the basis of the tariff level (€/year) to assess if the DMU is efficient in term of relationship between tariff burden (TARI) and recycling rate in order to verify if the environmental effectiveness come with saving in term of household expenditure following the polluter-pays principle. The results show that the average DEA scores are higher with the lower tariff amounts (Table 7). This result confirms that the tariff follows the principle of polluter pays internalising the environmental costs both being increased by the amount of total waste generated and by the application of penalties for non-compliances and/or green taxes (landfill tax) to enforce the implementation of sustainable waste management systems.

TABLE 7. MEAN EFFICIENCY SCORES BY TARIFF TARI

Cluster per TARI (€/year)	**TARI 2015**	**TARI 2016**	**CRS**	**VRS**	**SCALE**	**CRS**	**VRS**	**SCALE**
<250	24	23	0.821	0.836	0.982	0.849	0.861	0.985
250–350	36	36	0.627	0.650	0.968	0.647	0.680	0.960
>350	18	19	0.527	0.559	0.945	0.468	0.494	0.952
	78	78						

6. CONCLUSION

In this paper we have investigated the economic and environmental efficiency [28]–[29] of 78 Italian provinces, by focusing on their waste systems during the 2-year observation period (2015–2016). To this purpose, we have implemented two output-oriented DEA models, which include also an undesirable output, and we have obtained measures of technical efficiency from CRS and VRS production frontiers.

The results provided by the CRS DEA model show that out of the 78 units analysed 12 and 10 are efficient in 2015 and 2016, respectively. The model suggests that the solid waste mismanagement have effect on consumer wellbeing with many policy implications, given that the household has not influences on waste services decisions nor he or she as any possibilities to select more environmentally focused waste services. This specific aspect indicates there is the need for policy action designed to address penalties and green taxes toward waste DMU, avoiding effect on consumer welfare and enhancing implementation and enforcement of environmental rules and circular economy strategies. When we implement the VRS DEA model, assuming that changing inputs will not result in a proportional change in outputs, the number of efficient units become 16 for 2015 and 14 for 2016.

Fig. 1. Italy and its aggregated macrozones.

By focusing on geographical localization, the results obtained show that there is high variability among the province analysed, with provinces located in Northern and Central Italy showing higher efficiency scores than the ones located in Southern Italy. Since the waste sector is administered by regional government, the gap in waste management efficiency among the considered regions asks for policy design set at national level aimed at addressing regional weakness in term of waste management. Indeed, there are no significant differences between the two years considered. Besides, DEA scores are higher in presence of low tariff amounts and population density up to 1500 habitants/km^2.

The study has some limitations. First, it focuses on 78 provinces. Future studies could compare a broader dataset of all Italian provinces as well as undertake international comparisons between countries to control for more geographical and regulatory characteristics. Moreover, it would be useful to extend the investigation period, adding more data as soon as they become available, to include other factors that affect provinces performance to obtain more robust results, and to introduce other performance indicators.

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