**An economic efficiency indicator FOR assessing income opportunities in sustainable waste management[[1]](#footnote-1)**

FRANCESCA BARTOLACCI (corresponding author)

University of Macerata, Department of Economics and Law

Via Armaroli, 43

62100 Macerata – Italy

[francesca.bartolacci@unimc.it](mailto:francesca.bartolacci@unimc.it)

ROY CERQUETI

University of Macerata, Department of Economics and Law

Via Crescimbeni, 14

62100 Macerata – Italy

[roy.cerqueti@unimc.it](mailto:roy.cerqueti@unimc.it)

ANTONELLA PAOLINI

University of Macerata, Department of Economics and Law

Via Armaroli, 43

62100 Macerata – Italy

[antonella.paolini@unimc.it](mailto:antonella.paolini@unimc.it)

MICHELA SOVERCHIA

University of Macerata, Department of Economics and Law

Via Armaroli, 43

62100 Macerata – Italy

[michela.soverchia@unimc.it](mailto:michela.soverchia@unimc.it)

**ABSTRACT**

This paper proposes a new economic efficiency indicator for measuring and analyzing the income opportunities for companies operating in the collection, transport and treatment of municipal solid waste, while also taking into account the environmental perspective. Specifically, the followed approach is based on a mixed economic and environmental perspective, with a focus on the income advantage stemming from the exploitation of secondary raw materials obtained from differentiated waste. To pursue this scope, an indicator at the company level is preliminarily identified; then, a systemic indicator is introduced by implementing an aggregation of the individual ones. The adopted methodological tool is of the rank-size type, which is particularly appropriate for inferring insights at the system level from empirical data at single company level. To validate the indicator and apply it to real data in the sector of interest, an empirical analysis is conducted on a group of Italian waste management companies. It is shown that the indicator can be a useful tool for generating valuable information for waste management companies and policy-makers, who are responsible for defining policies and programs that make the overall waste management system more sustainable, thus materializing environmental and social benefits.

*Keywords:* economic indicator; efficiency assessment; rank-size analysis; production costs; environmental protection; waste management.

1. INTRODUCTION

Waste, linked directly to the production and consumption models, is a growing issue for territories all over the world; it can pose a threat to public health and the environment if not dealt with properly. Waste management (WM) is one of the essential utility services underpinning citizens’ well-being, particularly in urban areas. In 2016 in the EU-28, the total waste generated by all economic activities and households amounted to about 2,500 million tons (Eurostat, 2018); this was the highest amount recorded during the last 10 years. Given the world’s increasing population and economic development, this amount could increase even more significantly in the future.

This paper focuses on municipal solid waste (MSW), paying particular attention to the level of economic efficiency that companies operating in waste collection, transport and treatment may achieve. These kinds of companies provide services that influence social well-being; thus, they should be sustainable in environmental and economic terms (Agovino et al., 2018; Bartolacci et al., 2018a). This condition may also be achieved by reintroducing materials recovered from waste into the economic system.

Recent EU waste strategies have been strongly based on the concepts of resource efficiency and promoting the exploitation of secondary raw materials. These principles have been confirmed by the circular economy approach (European Commission, 2011; 2015). Considering that EU countries are often characterized by natural resource scarcity, a more efficient use of waste that may feed-back into the economy as secondary raw materials has become an increasingly crucial issue. The Earth’s resources (e.g. water, clean air, metals, and minerals), which are the basis of the raw material production, should be used in a sustainable manner, allowing the economic system to generate higher-value output with less input. Acting on resource efficiency and income derived from recycling could create sustainable business and job opportunities from WM activities.

In general terms, WM companies’ incomes depend on the relationship between the costs incurred for the resource’ supply (input) and the revenues obtained by exploiting and selling those resources recovered from waste on the market (output), after waste treatment processes for obtaining valuable secondary raw materials are carried out. Thus, the analysis proposed here focuses on the income opportunity that may derive from recovery activities, especially concerning the recycling of differentiated waste collection (DWC). According to this approach, companies’ strategies should provide for waste recovery-based alternative treatment processes that lead to the closed-cycle management of resources and the substitution of raw materials (Bergeron, 2017; Massarutto, 2015). It follows that waste should not be seen as only an externality of production and consumption processes and should not be regarded solely as a problematic item that must be disposed of to minimize its negative impacts on the environment and public health. Rather, it can constitute a secondary resource to exploit in order to ensure sustainable production and consumption from an environmental and economic point of view (UNEP, 2015).

Within this context, it is necessary to clarify that WM companies’ incomes depend not only on the opportunity to realize the highest possible DWC rate, but also on the companies’ abilities to transform differentiated waste into resources that may be used to generate new products and, therefore, revenues. Otherwise, the environmental advantages deriving from DWC would not be economically sustainable and would, therefore, be difficult to achieve and maintain (Bartolacci et al., 2018b).

These critical economic and environmental issues should be properly evaluated for supporting WM decisions from collecting to recycling. It follows that the need to identify economic and environmental indicators is particularly relevant in this scenario.

The concept that waste can generate value has already been highlighted in the literature. Some authors state that recycling is a good example of this issue, not just because it might generate additional revenue, but also because it avoids disposal costs and negative externalities (Kinnaman, 2006; Marques et al., 2012).

The assessment of the economic impacts of WM has gained particular interest in the literature because it concerns the possibility of realizing the specific EU targets mentioned above for the life cycle of waste. However, the literature does not propose economic indicators to assess recycling income opportunities. In this respect, in fact, some studies focus on the cost analysis of waste collection processes (Benito-López et al., 2011; Dijkgraaf and Gradus, 2003; Elia et al., 2016; Passarini et al., 2011). Other papers deal with waste management and disposal (Albores et al., 2016; Beigl and Salhofer, 2004; Fricke et al., 2011; Lombrano, 2009; Okuda and Thomson, 2007). Some studies take into account the income benefits of waste recycling, but only a few of them specifically focus on MSW (da Cruz et al., 2012; De Feo et al., 2019; de Oliveira Neto et al., 2017; Hellweg et al., 2005). The scientific relevance of this latter issue is further increased by the critical conditions in which WM companies operate, since DWC activities are normally expensive (Greco et al., 2015; Koushki et al., 2004) and revenues deriving from DWC sales may not be sufficient to cover the relevant costs (Simões et al., 2012). This is because waste collection and treatment for recovery require an organized operating system that produces significant recurring operational costs (e.g., employees’ wages; amortization, maintenance and leasing of vehicles; fuel; services) and investments (e.g., buildings; plants; machinery; vehicles).

The literature focuses mainly on the building of indicators with the aim of measuring performance in terms of waste collected and costs incurred and thus, looking for methods and tools that can improve and optimize treatment activities (D’Alisa et al., 2012; Larsen et al., 2010; Rodrigues et al., 2016). Sometimes, the assessment of economic aspects is part of the cost-benefit analysis to take into account a diverse perspective beyond the environmental and social ones; different methods have been implemented to achieve such a target (Akhshik et al. 2017; Lo Storto, 2016; Soler et al., 2017). This kind of evaluation can be useful for setting strategies for sustainable WM monitoring and measuring the strategies’ performance during their realization (Hay and Noonan 2002; Kijak and Moy, 2004; Zurbrügg et al., 2014). In this specific field, some authors propose decision-making tools for WM companies whose priorities are the rationalization of costs and, at the same time, the achievement of specific environmental targets (Rigamonti et al., 2016; Sarra et al., 2017; Yuan, 2013).

Within the aforementioned context, this study tries to shed light on the opportunity to gain income from DWC recycling, paying particular attention to the measurement need of the WM companies’ capacity to cover their production costs by earning sufficient revenues. In so doing, the companies can become economically sustainable and can continue to ensure sustainable WM services to citizens over time.

The main purpose of this paper is to propose a new economic efficiency indicator to measure and analyze the income opportunities of companies operating in the collection, transport and treatment of MSW, while also taking into account the environmental perspective. To pursue this scope, an indicator at the company level is identified in order to define a systemic indicator by implementing an aggregation of the individual ones. Such indicators are based on a mixed economic and environmental perspective, with a focus on the income advantage stemming from the exploitation of secondary raw materials obtained through DWC. These indicators can be useful tools for understanding if and how companies are able to cover their total production costs[[2]](#footnote-2) with revenues deriving from an “economic use” of DWC.

The rest of the paper is structured as follows: Section 2 describes the methodology; Section 3 analyzes the economic efficiency indicators, their properties and limitations; Section 4 contains data and the results of the empirical analysis; and the conclusions and research perspectives are given in Section 5.

**2. METHODOLOGY**

A rank-size approach was implemented by ranking companies according to their production cost functions. In particular, the opportunity to cover such costs was verified by using a parameter that is a proxy of the economic efficiency that represents the income opportunity offered by the exploitation of revenue-generating DWC. In so doing, the WM companies’ net production costs – those costs not covered by the aforementioned revenues – were assessed. Such values significantly influence the economic sustainability of implementing EU policies through the realization of activities that should protect the environment and guarantee social well-being, i.e. by reducing waste and transforming the unavoidable waste into reusable and valuable resources. The systemic indicator was obtained by aggregating over the best-fit rank-size law obtained through the analysis of the individual companies.

Rank-size analysis has found applications in several applied sciences, given its versatility and remarkable properties (e.g., Ausloos and Cerqueti, 2016; Axtell, 2001; Bottazzi et al., 2015; Cerqueti and Ausloos, 2015a, 2015b; Cristelli et al., 2012; Gabaix, 1999; for a review, see Pinto et al., 2012). Adopting a rank-size approach is also in line with a more specialized strand of literature dealing with this procedure as a means of defining ecological indicators (e.g., Di Bari, 2004). Such a technique is particularly appropriate for the analyzed context, in that it allows one to properly create a rich synthetic system on the basis of reference empirical data. Indeed, the rank-size analysis is grounded in a best-fit procedure performed over a large family of decreasing parametric curves. The effectiveness of the calibration exercise leads to a representation curve that is able to widely describe the net production costs of the companies beyond the mere dataset. Essentially, it can be stated that the described procedure allows moving from a disaggregated individual analysis to a more informative one of a systemic type. In this respect, the considered group (leading to the individual indicators) can be viewed as the generator of the system described by the best-fit rank-size law (a systemic indicator).

3. DEFINITION OF THE ECONOMIC EFFICIENCY INDICATORS AND THEIR PROPERTIES AND LIMITATIONS

Considering a set of *N* companies operating in the context of MSW, the indicators are defined by employing the companies’ production costs. The economic efficiency in terms of income opportunities derived from DWC is introduced through an appropriate discounting procedure, where the discount term is based on an efficiency parameter. All the quantities are measured in a fixed reference period. Formally,

(1)

where represents the net production costs of the company , being and , respectively, the total production costs and the DWC rate of the company in the referenced period, and the economic efficiency parameter of the DWC. In particular, *α* depends on the ability of the company to obtain income from recycled materials. It is a parameter whose value is influenced by both micro and macroeconomic factors, such as the behavior of the company (i.e., the ability to prepare waste for recycling) and the level of development of the secondary raw materials markets. If *α* is zero, the net production cost is equal to the total production cost; this means that no revenues have been generated from the sale of differentiated waste. On the contrary, the value of *α* begins to rise (0.1, 0.2, 0.3, etc.) when the company is able to sell the aforementioned materials; the obtained revenues make it possible to cover part of the production costs. The maximum value of *α* (1) represents the maximum efficiency situation, given a certain level of DWC (*d* in rate); in this case, the company gets the maximum income from the secondary raw materials market. It is important to highlight that the net production cost does not depend only on *α*, but also on the level of *d*; if the latter is low, even with *α* equal to 1, the coverage of the total production cost would be limited. With a full *d* (100%) and *α* equal to 1, the net production cost would be zero; this means that the revenues derived from DWC are able to cover all the production costs.

The individual-level indicator is then obtained by implementing a rank-size procedure of the net production costs over the entire set of analyzed companies. For this aim, the 52 companies are sorted in terms of their ’s, from the highest value (rank ) to the lowest one (rank , on the basis of equation (1). Then, a best fit procedure according to a power law is implemented, so that size can be approximated by a function of the rank as follows:

(2)

where are the parameters to be calibrated. Of course, the best-fit parameters depend on the considered value of . Such a dependence is omitted in equation (2) for the sake of notation.

According to (2), the aggregated net production cost of the system generated by the companies through a systemic indicator is described as follows:

(3)

where are the calibrated parameters.

The term in equation (3) represents the economic efficiency indicator at the overall system level, and is obtained as an aggregation based on the economic efficiency indicator at the individual company level (see equation (2)).

An interpretation of the calibrated parameters and is in order.

The value of gives information on the maximum level of the net production costs in the overall sample. In particular, the highest ranked production costs are of high (low) value if the value of such a parameter is high (low).

The calibrated parameter captures the concavity of the best-fit curve, hence describing how the net production costs pass from high ranks to low ones. Substantially, a small (large) deviation among the costs ranked at high and medium levels would lead to a calibrated parameter of small (large) absolute value. Thus, the value of the systemic indicator in equation (3) might be viewed as an increasing function of and a decreasing function of .

Moreover, notice that the company-level indicator (defined in (1)) decreases with respect to the efficiency parameter , for each . Since the aggregation operator defining the systemic indicator increases with respect to its argument, equation (3) suggests that the systemic economic indicator is also a decreasing function of . This comment is based on the assumption that the economic efficiency derived from DWC is not a company-specific term, but is the same for the entire set of companies. This aspect is then crucial, in that it allows one to understand the impact of the technological improvements in the WM processes due to general policy implementation, and so it holds for the entire economic environment.

Along with the properties and the positive sides of the considered indicators, one must also give credit to the presence of some limitations of the approach. In this respect, we identify at least two critical aspects. The first one lies in the methodological approach employed for the definition of the indicators. Indeed, the analysis is based on a particular rank-size regression, hence being grounded in an approximation on the basis of an observed sample. Of course, approximation is only apparently a limitation in this context. In particular, as already mentioned above, the approximating curve obtained through the employed regression procedure allows the building of a generalized system from a set of data at individual company level. The second critical aspect is based on the considered dataset. Specifically, the obtained results are strongly dependent on the particular collection of data employed for the analysis; therefore, they cannot be adapted to different settings. Also, in this case, such an unavoidable limit does not affect the real target of the paper; indeed, the aim here is to provide a general procedure for measuring the income opportunities in WM by also including an environmental perspective. Reasonably, such a methodology does not depend on the special dataset being considered and can be employed in any country or regional context.

It is important to point out that the theoretical proposal has to be properly validated through a meaningful empirical exercise. Indeed, the defined indicators are based on a best-fit procedure, whose validity is then strongly related to acceptable performances in terms of goodness of fit.

**4. EMPIRICAL ANALYSIS**

**4.1 Data**

To validate the theoretical proposal and apply the indicator to real data related to the sector of interest, an empirical analysis was conducted on a group of Italian companies operating in the field of MSW collection and disposal in municipalities with a population greater than 50,000 inhabitants, over the period 2012-2015. These companies deliver WM services in one or more municipalities.

The basis of the empirical experiment is the computation of the individual indicators in equation (1). Concerning data sources, a high-quality data-set has been ensured, as only official sources were used: total production costs (the *PC*’s in equation (1), expressed in euros) were taken from official companies’ financial statements (in particular, the income statements) retrieved from companies’ websites. The DWC rates (the *d*’s in equation (1)) were calculated by dividing the DWC by the total waste collected (differentiated and undifferentiated). For the computation of the *d*’s, the DWC and the total waste collected data (expressed in tons) for each municipality served were retrieved from the Institute for Environmental Protection and Research (ISPRA) data base (Italian Ministry of Environment).

To ensure good data comparability, only mono-utility, predominantly medium–sized, no-listed companies having similar and comparable financial statements in form and content were considered, since they use the same accounting standards.

Thus, a total of 52 WM companies were investigated, all owned or controlled by municipalities. The public nature of the considered companies meets the evidence of the Italian WM sector (Utilitatis, 2016). Furthermore, the 52 analyzed companies represent the 37% and 42% of those operating in the WM sector, respectively, in terms of sales revenues and employee numbers, according to the Green Book survey for medium and medium-large size classes (Utilitatis, 2016). Such companies serve about 880 municipalities (with a very slight variation during the four-year period), spread over all the Italian territory (40% North, 27% Center, 33% South and islands). The analysis used data from four years, with a total of 3,497 observations.

4.2 Results and discussion

In order to explore the behavior of the indicator on the basis of the economic efficiency in terms of income managing the DWC, the set is discretized as and consider .

The values of the calibrated parameters and the goodness of fit as the value of changes are shown in Table 1. The goodness of fit is satisfactory in all the considered cases, with all the values greater than 0.93. Thus, according to rank-size theory, can be used in equation (2) to prove an economic efficiency indicator in a setting more general than the one described by the analyzed group.

|  |  |  |  |
| --- | --- | --- | --- |
| α |  |  |  |
| 0 | 180,000,000 | -0.6773 | 0.948 |
| 0.1 | 175,000,000 | -0.6838 | 0.953 |
| 0.2 | 169,000,000 | -0.6909 | 0.957 |
| 0.3 | 164,000,000 | -0.6988 | 0.961 |
| 0.4 | 159,000,000 | -0.7076 | 0.963 |
| 0.5 | 153,000,000 | -0.7174 | 0.964 |
| 0.6 | 148,000,000 | -0.7284 | 0.964 |
| 0.7 | 143,000,000 | -0.7410 | 0.960 |
| 0.8 | 138,000,000 | -0.7553 | 0.955 |
| 0.9 | 133,000,000 | -0.7719 | 0.945 |
| 1 | 128,000,000 | -0.7914 | 0.932 |

Table 1. Best-fit parameters and goodness of fit for the different efficiency scenarios .

Figure 1 contains the best-fit curves. The scatter plots of the data are not reported, for better readability.

Figure 1. Best-fit curves for the different efficiency scenarios .

Notice that there is a clear inverse relationship between the calibrated () and the efficiency parameter α. Specifically, the best fit curve flattens as α decreases (i.e., decreases), which means that there is a lower deviation of production costs across the ranks when the differentiated waste becomes less effective in covering them. In contrast, the parameter , which captures the value of the cost at rank 1, is higher when the percentage of differentiated waste does not provide relevant reductions of the production costs.

Table 2 shows the values of the net production cost indicators, as the economic efficiency parameter of the DWC changes.

|  |  |
| --- | --- |
|  |  |
| 0 | 2,000,000,000 |
| 0.1 | 1,930,000,000 |
| 0.2 | 1,850,000,000 |
| 0.3 | 1,790,000,000 |
| 0.4 | 1,730,000,000 |
| 0.5 | 1,650,000,000 |
| 0.6 | 1,590,000,000 |
| 0.7 | 1,540,000,000 |
| 0.8 | 1,480,000,000 |
| 0.9 | 1,440,000,000 |
| 1 | 1,400,000,000 |

Table 2. Values in euros of the net cost indicators for all the efficiency scenarios .

Notice that, as expected, the value of the aggregated net production costs decreases as the value of increases (see also Figure 2 for a quick look at the behavior of *α*)). The negative linear trend can be appreciated in Figure 3, where the scatter plot of *α*) with respect to *α* is juxtaposed with the linear trend. One can see the visual appeal of the linear fit.Figure 2. Interpolating plot of the function *α*).



Figure 3. Scatter plot of *α*) with respect to *α* juxtaposed with the linear trend.

The proposed indicator is particularly useful for the type of companies analyzed, since it gives information about the efficiency level assessed in terms of their capacity to cover the incurred total production costs, exploiting the revenue opportunities generated by the use of waste materials. This indicator tries to evaluate the income perspectives of the WM companies and thus, their capacity to guarantee the provision of extremely important services for the community. A greater knowledge of the achievable efficiency level by companies can facilitate and support their decision-making process related to all WM activities (from collection to disposal). Furthermore, inevitably, the observed efficiency level has an impact on the environment and society, which is related to the quality of the provided services and the fee level paid by the citizens.

An empirical analysis conducted to validate and apply the proposed systemic indicator showed that the net production cost decreases up to 30% when passing from the minimum level of economic efficiency ( to the maximum (). This confirms that the information that can be obtained from the proposed indicator can support the decision-making process of policy-makers, who must evaluate the opportunity to sustain WM companies with incentives and other proper tools in order to stimulate secondary raw materials’ markets. Specifically, in the analyzed system, even in the best–case scenario (maximum efficiency), the costs not covered by revenues (deriving from the “economic use” of DWC) are significant and prevalent. The other important share of exposed costs is normally covered by fees paid by citizens, who contribute more or less effectively, according to their environmental protection culture, to sorting and differentiating waste for separate collection. Moreover, the same municipalities are required to allocate funds to cover the costs (or the economic losses) of the companies. This means that if WM companies are not able to realize a satisfactory efficiency level, the relevant municipalities have to invest important financial resources that could have been more productively used to fund other environmental and social projects to improve citizens’ well-being.

The current context in which WM companies operate allows the efficiency and environmental targets to be widely conditioned by the implemented technologies. For instance, seldom does the design of the products go in the direction of reducing waste production and facilitating reuse and recovery, hence leading to the recycling of materials.

From a different perspective, it is important to consider the interconnections between the efficiency related to DWC and the market for secondary raw materials. Indeed, the development of the market might foster companies’ incomes through the sale of secondary raw materials coming from the circular economy phases. However, it is true that pushing DWC without taking into account several other aspects, such as material innovation and product design, is probably not sufficient to realize and implement the EU circular economy strategy in an environmentally and economically sustainable way.

In this respect, the characteristics of the indicators, along with the empirical results here presented, could guide policy-makers, governments and companies. The achievement of EU targets of sustainability and of circular economy principles is constrained by investment resources supporting innovative WM processes and fostering research and development in new materials and recycling activities.

5. CONCLUSIONS

WM companies must increasingly make decisions that, in addition to economic convenience, must consider environmental and social sustainability issues. In this paper, a new indicator was developed to evaluate the economic efficiency level that WM companies may achieve by exploiting DWC. Indeed, a general procedure for measuring the income opportunities that also includes an environmental perspective was proposed. To obtain the indicator, a rank-size analysis was used: a methodological tool that offers a complete description of the relationship between the economic and environmental dimensions of DWC.

The proposed methodology leads to a systemic indicator that is interesting because it allows the measurement of the economic efficiency level achieved by WM companies in carrying out their activities, while also considering the environmental impacts. Information that companies can obtain might be very useful for identifying the best strategies and actions to transform waste into resources, improve revenues and, thus, generate income opportunities. Such information is valuable for WM companies and for policy-makers, who are responsible for defining policies and programs that make WM systems more sustainable, thus realizing environmental and social benefits. On the one hand, policy-makers must push towards achieving the EU targets in terms of DWC and recycling; on the other hand, they must tackle the question of WM companies’ ongoing viability, which depends on their economic sustainability. Furthermore, policy-makers should facilitate the redesign of the entire waste cycle to reduce the quantity of waste produced and increase the quality of the secondary raw materials, with the aim of achieving essential environmental and social advantages. This is because the income opportunities are also related to external factors whose analysis and management should be a priority for policy–makers, from the quality of the materials obtained to the accessibility of secondary raw materials markets that can absorb and valorize those resources.

Another external factor that could influence income opportunities concerns the cultural traits of a country, which can play a role in explaining citizens’ behavior in differentiating waste. Indeed, such a culture is associated with the average level of education of the citizens, but it also exhibits a strong correlation with the corruption level of the country’s bureaucrats and politicians. This could be investigated in future research, to explore the reaction of the proposed economic efficiency indicator to variation in suitably identified cultural parameters.

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2. Total production costs are the amount of costs incurred by companies to realize operating activities concerning services’ provision to the users, from procurement of needed resources to service delivery. [↑](#footnote-ref-2)