An Efficiency Analysis of Waste Management for the OECD Countries

Fazıl Gökgöz[1], Engin Yalçın[2]

[1] Ph.D., Professor, Faculty of Political Sciences, Ankara University, Ankara, Turkey

[2] Institute of Social Sciences, Ankara University, Ankara, Turkey

Abstract

Environmental protection is a highly important aim in industry-intensive countries. Efficient waste management is a highly remarkable contributor to the environment. Therefore, we aim to assess the waste management efficiency of the selected OECD countries, which constitute an important share in the world economy. To this end, we employ the Data Envelopment Analysis to analyze the waste management efficiency of the selected OECD countries. As per efficiency results, Belgium, Finland, Luxembourg, Norway, Slovenia, and Sweden are found efficient countries throughout the investigated period. Besides, Norway is found as the most efficient country among the efficient countries. We may conclude that circular economy-oriented countries perform better in terms of waste management.

Keywords: Waste management, data envelopment analysis, OECD

1. Introduction

Today, solid municipal waste is one of the most important difficulties developed countries strive to manage (Giannakitsidou et al., 2020). The depletion of fossil sources has led to an unpredictable future. Therefore, countries should maintain sustainable energy consumption and waste management (WM) by reducing waste circumvention and resource efficiency. Waste signifies an inefficiency in the developed economies. The formation of waste degrades the environment and harms sustainability (Zaman & Lehmann, 2013). One of the most efficient ways to deal with these problems is an efficient WM (Agovino et al., 2018). To develop this plan, various criteria should be considered to present a clear overview of countries (Torkayesh et al., 2021). In brief, decreasing the amount of generated waste, increasing the share of recycled materials are the main goals for WM (Romano et al., 2020). Governments continually seek ways to enhance their WM performance (Agovino et al., 2020). To this end, The Data Envelopment Analysis (DEA) is a mathematical efficiency technique employed to evaluate the comparative performance of alternatives (Ramalho et al., 2010). The WM efficiency can be observed via an empirical analysis of the DEA approach. In this respect, the performance trend of WM will be observed in the selected OECD countries over the investigated period. Thereby, governments can observe the WM trend of their countries and manage policies more efficiently.

The remainder of this study continues below. We briefly summarize the literature review about WM performance. Then, we introduce the research methodology used in our empirical analysis. Lastly, we terminate our study with conclusions.

2. Literature Review

To date, various papers have analyzed the WM performance of countries via different performance models. We summarize these studies performed to assess the WM efficiency of countries below.

Behzad et al., (2020) evaluated the WM performance of the Nordic countries via the EDAS method. They employ waste production, composite waste, landfilling waste, recycling waste, recycling rate, and Greenhouse Gas (GHG) emissions from waste as performance evaluation indicators. They conclude that Sweden demonstrated a dominant profile in terms of WM among the Nordic countries. Castillo-Giménez et al., (2019) evaluated the WM efficiency of the European countries via the DEA approach. They use the indicators of recycling, incineration, composting, and digestion as evaluation criteria. They conclude that the Northern countries performed better among the European Union (EU) countries. Llanquileo-Melgarejo and Molinos-Senante (2021) analyzed the WM efficiency of the Chilean municipalities by comprising an index of economic and environmental indicators via the DEA approach. They conclude that most municipalities are beyond being efficient, which indicates significant room for efficiency. Callao et al., (2019) assessed the WM of the European countries via the DEA approach. They employ total waste production, population density, and dangerous waste production as inputs while Gross Domestic Product (GDP), recycling rate, recycled dangerous waste, incineration, incineration with energy recovery, deposit into land treatment, and backfilling as outputs. Agovino et al., (2018) assessed the WM efficiency of the Italian cities from 2004 to 2011 via the DEA approach. They use the institutional quality index, added value per capita, population density as inputs while urban and unsorted collected waste as outputs. They conclude that northeastern and southern cities performed better in comparison to other areas. lo Storto (2021) evaluated the WM efficiency of the Italian municipalities via the output-oriented DEA approach. lo Storto (2021) employed solid waste cost as input while annual plastic, metal, paper, glass, the sorted and unsorted fraction of waste collection as outputs. lo Storto (2021) conducted the study from 2010 and to 2017 and concluded that most municipalities performed far from being efficient.

3. Research Method

3.1 The DEA Approach

The DEA method has been employed in various fields successfully. It is a non-parametric technique employed to analyze the comparative efficiency of alternatives. The efficiency is measured through the weighted outputs to inputs ratio. The DEA is a linear programming method to analyze the efficiency of alternatives based on various inputs and outputs. The best decision-making units constitute the production frontier. Then, other decision-making units can be compared as the distance to the best unit (Zhong et al., 2021). The basic superiority of the DEA is it does not need a prior assumption and its applicability to use multiple inputs and outputs (Matsumoto et al., 2020). The initial version of the DEA approach is based on the constant return to scale presumption (Yang & Chen, 2021). Presume that there exist N alternatives, M inputs, and S outputs. x_i and y_i denote the input and output of the alternative. We can acquire the ratio of outputs to inputs as $u'y_i/v'x_i$ for each unit (where u and v denote output and input weight respectively. As a result, the CCR model is converted into obtaining the best weight below (Zhong et al., 2021).

$$\max_{u,v} u'y_i/v'x_i \tag{1}$$

$$s.t. \frac{u'y_i}{v'x_i} \leq 1, j = 1,2, \ldots, N \tag{2}$$

$$u, v \geq 0 \tag{3}$$

The principal aim of the formulation is to maximize the efficiency score of the observed unit under the limitation that the efficiency score of other units is equal to or less than 1. Thereby, this formulation can be transformed into a linear problem. To this end, an efficiency frontier is constituted and other units can be categorized based on their distance to the efficiency frontier.

The DEA implementations can be input or output-oriented. In the input-oriented version, the principal aim is to generate a particular amount of output with minimum outputs. In the output-oriented model, the aim is to generate the maximum possible amount of output with a particular number of inputs (Fancello et al., 2020).

3.2 Super-Efficiency DEA Method

The conventional DEA method is not able to distinguish among efficient alternatives. To deal with this shortage, the super-efficiency DEA model was developed as an alternative approach. The formulation of the super-efficiency DEA model is given below (Yang et al., 2021).

$$\min \theta \tag{4}$$

$$s.t. \sum_{j=1, j\neq 0}^{n} x_{ij}\lambda_j \leq x_{ij0} \tag{5}$$

$$\sum_{j=1, j\neq 0}^{n} y_{rj}\lambda_j \geq \theta\, y_{rj0} \tag{6}$$

$$\sum_{j=1, j\neq 0}^{n} \lambda_j \quad (7)$$

$$\lambda_j \geq 0; i = 1,2,3 \ldots m; r = 1,2,3 \ \ldots, q; \text{j=1,2,3}\ldots, n \ (j \neq 0) \quad (8)$$

where "$m, q, and\ n$" are the number of inputs, outputs, and alternatives. "θ" denotes the efficiency assessment. "x_{ij}" signifies the ith input value for the jth alternative, "y_{rj}" denotes the "rth" value for jth alternative. "λ_j"denotes variable coefficient for the "jth" alternative.

4. Empirical Analysis

In this study, we aim to assess the WM efficiency of the selected OECD countries via the frequently used DEA approach. We retrieve our dataset from the Eurostat statistics website. We determine our inputs and outputs based on previous studies in WM efficiency. In this context, we use waste generation per capita, and population density are used as inputs while GDP per capita, the recycling rate of municipal waste are used as outputs in our empirical analysis. In our study, we determine the OECD countries in the European region as our dataset. In our analysis, we use the output-oriented version of the DEA as the main aim of the countries is to obtain the maximum possible GDP and recycling rate with a specific level of inputs. We present the unit and definitions of our indicators in Table 1.

Table 1. The Unit and Definitions of the Inputs and Outputs

Technical Criteria	Unit	The Definition of Criteria
Waste Generation	Kilograms Per Capita	This criterion gauges the waste collected by municipal authorities and disposed through the WM structure.
Population Density	People per Square km of Land Area	This criterion denotes the number of people living in each unit of area.
GDP Per capita	USD, Constant Prices	This criterion measures a country's economic output per person.
Recycling Rate of Municipal Waste	Percent	This criterion measures the rate of material recovered.

After presenting our inputs and outputs, we proceed with the empirical analysis to evaluate the efficiency of the selected OECD countries. The analysis results of the WM efficiency carried out via the CCR and super efficiency CCR models over the 2016-2018 period are included in Table 2.

Table 2. The Analysis Results of the WM Efficiency in the selected OECD Countries over the 2016-2018 Period.

Countries	2016 CCR Scores	2016 Super efficiency Scores	2017 CCR Scores	2017 Super Efficiency Scores	2018 CCR Scores	2018 Super Efficiency Scores
Austria	0,8900	0,8900	0,8965	0,8965	0,8806	0,8806
Belgium	1,0000	1,1245	1,0000	1,1784	1,0000	1,1912
Czechia	0,6098	0,6098	0,5501	0,5501	0,5511	0,5511
Denmark	0,5611	0,5611	0,5832	0,5832	0,5952	0,5952
Estonia	0,6774	0,6774	0,6854	0,6854	0,6352	0,6352
Finland	1,0000	1,0678	1,0000	1,0504	1,0000	1,0556
France	0,7077	0,7077	0,7307	0,7307	0,7402	0,7402
Germany	0,8790	0,8790	0,8851	0,8851	0,9108	0,9108
Greece	0,3133	0,3133	0,3433	0,3433	0,3510	0,3510
Hungary	0,7492	0,7492	0,7364	0,7364	0,8024	0,8024
Ireland	0,9081	0,9081	0,9931	0,9931	1,0000	1,0168
Italy	0,7655	0,7655	0,8035	0,8035	0,8162	0,8162
Latvia	0,5585	0,5585	0,5689	0,5689	0,5670	0,5670
Lithuania	0,9643	0,9643	0,9718	0,9718	1,0000	1,0336
Luxembourg	1,0000	1,1006	1,0000	1,1006	1,0000	1,0951
Netherlands	0,8434	0,8434	0,8581	0,8581	0,8703	0,8703
Norway	1,0000	2,0300	1,0000	2,0450	1,0000	2,0517
Poland	0,9195	0,9195	0,8595	0,8595	0,8412	0,8412
Portugal	0,5534	0,5534	0,5174	0,5174	0,4973	0,4973
Slovakia	0,5587	0,5587	0,6531	0,6531	0,7225	0,7225
Slovenia	1,0000	1,0842	1,0000	1,1216	1,0000	1,0455
Spain	0,6364	0,6364	0,6694	0,6694	0,6439	0,6439
Sweden	1,0000	1,3062	1,0000	1,2860	1,0000	1,3439
Switzerland	0,9295	0,9295	0,9221	0,9221	0,8998	0,8998
UK	0,7791	0,7791	0,7756	0,7756	0,7769	0,7769
Average Efficiency Level	0,7921		0,8001		0,8040	

Source: Authors' Calculations.

As per the CCR model results, six countries namely Belgium, Finland, Luxembourg, Norway, Slovenia, and Sweden are found efficient countries throughout the investigated period. A slight increase exists among the investigated period. As per super efficiency results, Norway is found as the most efficient country among the investigated period. The average efficiency level indicates that approximately 20% improvement room exists among the investigated period.

5. Conclusions

The WM is one of the most efficient ways to enhance environmental protection (Mir et al., 2016). Global waste generation is a serious threat to human health as well (Behzad et al., 2020). The increase in population and the necessity to enhance economic growth are combined to limit waste generation in developed countries (Alao et al., 2021). The WM should be conducted sustainably. Sustainable WM can be achieved by allocating resources properly and minimizing waste. The DEA approach is a suitable technique for this field as it can carry out an optimization procedure (Chen et al., 2010). In this study, we aim to evaluate one of the most important aspects of the environment namely WM. To this end, we employ the DEA technique to assess WM in the selected OECD countries. As per efficiency results, Belgium, Finland, Luxembourg, Norway, Slovenia, and Sweden are found efficient countries over the investigated period. Norway is found as the most efficient country among efficient countries. Our analysis results are compatible with preceding studies (Agovino et al., 2020; Giannakitsidou et al., 2020; Castillo-Giménez et al., 2019; Pires & Martinho, 2019).

In this part, we elaborate on the performance of well-performing countries. Norway is a pioneer country in terms of WM. Although Norway is not an EU member country, it adheres to WM standards put into effect by the European parliament. Significant waste policy tools encompass regulations, taxes, and economic impetus determined by the municipalities, businesses, and industries in Norway. Moreover, increasing the share of renewable energy sources is a significant contributor to WM performance (Malinauskaite et al., 2017). The Norwegian government put into effect an 80% recovery target in 1991 afterward waste taxes were introduced. A Landfill ban for waste was introduced. The circular economy (CE) is a beneficial regulation for WM as waste is regarded as a reused or recycled source (Jones, 2021). Sweden is another successful country in terms of WM. The Swedish government adopts a tariff-based WM via municipalities. The municipalities charge a fee for waste collection, recovery, and disposal (Andersson & Stage, 2018). Belgium is also a super-efficient country among the investigated OECD countries. The material recovery rate reaches 85% in Belgium. It has already exceeded its WM targets (Winternitz et al., 2019). The common feature of well-performing countries can be regarded as the transformation to the CE. The CE is a concept that strengthens the value chain from production to consumption (Luttenberger, 2020). All steps of the production and consumption encompass recycling and reuse of the resources on CE (Romero-Hernández & Romero, 2018). This action contributes to the WM performance of countries. We infer from the analysis results that the countries implementing the aforementioned incentives may become more efficient. We may also conclude that the DEA approach is a beneficial technique to assess WM performance.

References

Agovino, M., D'Uva, M., Garofalo, A., & Marchesano, K. (2018). Waste management performance in Italian provinces: Efficiency and spatial effects of local governments and citizen action. *Ecological indicators*, vol.*89*, pp.680-695.

Agovino, M., Matricano, D., & Garofalo, A. (2020). Waste management and competitiveness of firms in Europe: A stochastic frontier approach. *Waste Management*, vol.*102*, pp.528-540.

Alao, M. A., Popoola, O. M., & Ayodele, T. R. (2021). Selection of waste-to-energy technology for distributed generation using IDOCRIW-Weighted TOPSIS method: A case study of the City of Johannesburg, South Africa. *Renewable Energy*, vol.*178*, pp.162-183.

Andersson, C., & Stage, J. (2018). Direct and indirect effects of waste management policies on household waste behaviour: The case of Sweden. *Waste management*, vol.*76*, pp.19-27.

Behzad, M., Zolfani, S. H., Pamucar, D., & Behzad, M. (2020). A comparative assessment of solid waste management performance in the Nordic countries based on BWM-EDAS. *Journal of Cleaner Production*, vol.*266*, 122008.

Callao, C., Martinez-Nuñez, M., & Latorre, M. P. (2019). European Countries: Does common legislation guarantee better hazardous waste performance for European Union member states? *Waste Management*, vol.*84*, pp.147-157.

Castillo-Giménez, J., Montañés, A., & Picazo-Tadeo, A. J. (2019). Performance and convergence in municipal waste treatment in the European Union. *Waste Management*, vol.*85*, pp.222-231.

Chen, H. W., Chang, N. B., Chen, J. C., & Tsai, S. J. (2010). Environmental performance evaluation of large-scale municipal solid waste incinerators using data envelopment analysis. *Waste Management*, vol.*30*(7), pp.1371-1381.

Eurostat (EU Statistical Bureau). Access Date: 20 July 2021. Available: https://ec.europa.eu/eurostat/web/energy/data/database.

Fancello, G., Carta, M., & Serra, P. (2020). Data Envelopment Analysis for the assessment of road safety in urban road networks: A comparative study using CCR and BCC models. *Case studies on transport policy*, vol.*8*(3), pp.736-744.

Giannakitsidou, O., Giannikos, I., & Chondrou, A. (2020). Ranking European countries on the basis of their environmental and circular economy performance: A DEA application in MSW. *Waste Management*, vol.*109*, pp.181-191.

Jones, S. M. (2021). Waste Management in Norway. In *Advancing a Circular Economy* pp.111-139. Palgrave Pivot, Cham.

Llanquileo-Melgarejo, P., & Molinos-Senante, M. (2021). Evaluation of economies of scale in eco-efficiency of municipal waste management: an empirical approach for Chile. *Environmental Science and Pollution Research*, vol.*28*(22), pp.28337-28348.

lo Storto, C. (2021). Effectiveness-efficiency nexus in municipal solid waste management: A non-parametric evidence-based study. *Ecological Indicators*, vol.*131*, 108185.

Luttenberger, L. R. (2020). Waste management challenges in transition to circular economy–case of Croatia. *Journal of Cleaner production*, vol.*256*, 120495.

Malinauskaite, J., Jouhara, H., Czajczyńska, D., Stanchev, P., Katsou, E., Rostkowski, P., ... & Spencer, N. (2017). Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. *Energy*, vol.*141*, pp.2013-2044.

Matsumoto, K. I., Makridou, G., & Doumpos, M. (2020). Evaluating environmental performance using data envelopment analysis: The case of European countries. *Journal of cleaner production*, vol.*272*, 122637.

Mir, M. A., Ghazvinei, P. T., Sulaiman, N. M. N., Basri, N. E. A., Saheri, S., Mahmood, N. Z., & Aghamohammadi, N. (2016). Application of TOPSIS and VIKOR improved versions in a multi criteria decision analysis to develop an optimized municipal solid waste management model. *Journal of environmental management*, vol.*166*, pp.109-115.

Pires, A., & Martinho, G. (2019). Waste hierarchy index for circular economy in waste management. *Waste Management*, vol.*95*, pp.298-305.

Romero-Hernández, O., & Romero, S. (2018). Maximizing the value of waste: From waste management to the circular economy. *Thunderbird International Business Review*, vol.*60*(5), pp.757-764.

Torkayesh, A. E., Malmir, B., & Asadabadi, M. R. (2021). Sustainable waste disposal technology selection: The stratified best-worst multi-criteria decision-making method. *Waste Management*, vol.*122*, pp.100-112.

Winternitz, K., Heggie, M., & Baird, J. (2019). Extended producer responsibility for waste tyres in the EU: Lessons learnt from three case studies–Belgium, Italy and the Netherlands. *Waste Management*, vol.*89*, pp.386-396.

Yang, J., & Chen, B. (2021). Energy efficiency evaluation of wastewater treatment plants (WWTPs) based on data envelopment analysis. *Applied Energy*, vol.*289*, 116680.

Yang, Y., Guo, H., Wang, D., Ke, X., Li, S., & Huang, S. (2021). Flood vulnerability and resilience assessment in China based on super-efficiency DEA and SBM-DEA methods. *Journal of Hydrology*, vol.*600*, 126470.

Zaman, A. U., & Lehmann, S. (2013). The zero waste index: a performance measurement tool for waste management systems in a 'zero waste city'. *Journal of cleaner production*, vol.*50*, pp.123-132.

Zhong, K., Wang, Y., Pei, J., Tang, S., & Han, Z. (2021). Super efficiency SBM-DEA and neural network for performance evaluation. *Information Processing & Management*, vol.*58*(6), 102728.