



Efficiency evaluation of waste management: A systematic literature review of DEA applications

Damira Keček^{1*}, Katerina Fotova Čiković¹ and Davor Mikulić²

¹ University North, Trg dr. Žarka Dolinara 1, Koprivnica, Croatia

² The Institute of Economics, Trg J. F. Kennedyja 7, Zagreb, Croatia

Abstract

This paper aims to implement a systematic literature review to survey the Web of Science scientific database and review papers emphasizing the application of Data Envelopment Analysis (DEA) in the efficiency evaluation of waste management. This approach includes the identification, screening, eligibility, and inclusion phase of the relevant papers. The article also provides a theoretical overview of waste management and the DEA methodology. Researching the Web of Science scientific database according to the keywords "waste management", "waste disposal" and "data envelopment analysis" led to 12 full-text published papers written in English. Qualitative analysis of papers was carried out with an emphasis on the analyzed country, i.e. region, time frame, applied DEA model, and included input and output variables in the model. Research of this type complements the scientific literature on the importance of waste management. It provides key guidelines to scientists, policymakers, and authorities on efficient waste management as one of the key problems of today's society.

Keywords: data envelopment analysis, waste management, systematic literature review

1. Introduction

Even though there is no clear consensus on the definition of waste, according to the DIRECTIVE 2008/98/EC of the European Parliament, waste is "any substance or object which the holder discards or intends to discard or is required to discard". Gharfalkar et al. (2015) claim that waste is mostly perceived negatively by the public, but could be recognized as something that has value when it is reused. The idea that waste can be renewed, reused, recycled, or even a source of energy has been increasingly present in scholarly literature in recent years (Laurent et al., 2014).

Waste management represents the activities of collecting, transporting, sorting, and disposing of waste, and supervision over the performance of these activities, all by the relevant and valid legal regulations (Environmental Protection and Energy Efficiency Fund, 2024). In the context of sustainable development Izvercian & Ivascu (2015) define waste management as "an activity that shapes the environmental protection". Waste management has significance from ecological, social, and economic aspects. In addition to global concerns about climate

change and environmental pollution, waste management is also becoming a crucial issue that requires rapid action. Namely, on a global level, annually is produced 2.01 billion tons of municipal solid waste, of which 33% is not managed environmentally safely. The projection is that by 2050, global waste will increase to 3.40 billion tons, and in high-income countries, daily waste production per capita will increase by 19%, and in low- and middle-income countries by approximately 40% (Kaza et al., 2018). The European Union (EU) has invested significant effort in the continuous modernization and better implementation of waste management regulations that follow the specifics of the digital age and adapt to the circular economy (European Commission, 2020). Furthermore, the EU has included many practices such as prevention, reduction, reuse, recycling, and recovery through the adoption of the waste management hierarchy (Gharfalkar et al., 2015). Conducted studies indicate this approach to reducing the amount of produced waste has yielded positive results (Chioatto & Sospiro, 2023). Despite the vitality of the issue of efficient waste management throughout the globe, such empirical evaluations are scarce.

One of the most popular methodologies used to evaluate efficiency is the Data Envelopment Analysis (DEA) methodology. It is a non-parametric methodology of mathematical programming that enjoys many advantages since it can employ and analyze multiple input and output variables simultaneously and does not need to impose any functional form on data or make assumptions of efficiency/ inefficiency or certain relations in the sample (Fotova Čiković & Lozić, 2022). DEA is a frequently applied approach in the field of research involving the assessment of the economic and environmental efficiency of waste management (Halkos & Petrou, 2019; Gastaldi et al., 2020).

Therefore, the main objective of this paper is reflected in the identification, presentation, and analysis of relevant papers published in the Web of Science scientific database which include the application of DEA in the efficiency evaluation of waste management. The underlying goal was to investigate the state-of-the-art in this research area.

The structure of the paper is as follows: after the introduction, a theoretical overview of DEA and waste management is given. Section 3 presents the research approach and section 4 the research results. The last section provides a discussion and a conclusion and addresses the main contribution of the study, its main limitations as well as guidelines for future work.

2. Theoretical overview

2.1 Data Envelopment Analysis (DEA)

DEA is a non-parametric method based on linear programming, which is used to evaluate the relative efficiency of comparable entities based on empirical data on their inputs and outputs. It is suitable in cases where other approaches do not give satisfactory results (Rabar, 2010). Moreover, even though it is widely used in business to measure efficiency and performance (Vörösmarty & Dobos, 2023), DEA has a wide range of applications in various economic sectors because it was initially developed for analyzing the relative efficiency of non-profit DMUs with heterogeneous inputs and outputs (Jardas Antonić et al., 2020).

DEA methodology was first presented by Charnes et al. (1978) in their seminal paper in 1978 and was later modified by Banker et al. (1984). The most important difference between the two basic DEA models is the “possibility of treating scale economies” (De Carvalho et al., 2012). The Banker, Charnes, and Cooper model (BCC model) imply the calculation of a deterministic production frontier with variable returns to scale, whereas the Charnes, Cooper and Rhodes model (CCR model) follows constant returns to scale. Both CCR and BCC

models can be oriented either to inputs or outputs and both of them can be significant for the assessment of the efficiency in the library.

DEA determines the empirical efficiency frontier, and this is the reason why it is often referred to as the frontier technique. DEA is determined by the (best) existing Decision-Making Unit (DMU), and the efficiency frontier represents an achievable goal to which inefficient DMUs must strive. Thus, unlike typical statistical approaches that are based on average values, the DEA is based on extreme observations, comparing each DMU in the analyzed sample only to the best (and most efficient) ones (Rabar, 2010).

In this systematic literature review, the applications of DEA in the waste management process were considered. This study may represent a stepping stone for further exploration and empirical applications of DEA in waste management, as well as an inspiration to other academic members to employ the DEA methodology in the decision-making processes in any industry “due to its advantages, easy implementation, and insights it provides” (Fotova Čiković et al., 2022).

2.2 Waste management

Waste management includes the process in which “wastes are collected, transported and disposed of in the best possible way of limiting or eliminating the harmful effect of wastes” (Amasuomo & Baird, 2016). Jiyan (2021) defines it as “the techniques that will oversee and manage waste reasonably”. It is one of the biggest environmental problems in the world (Demirbas, 2011). To ensure a safe environment, sustainable waste management is important. Lifestyle, population growth, and increasing consumption lead to increasing waste generation. A systems-oriented approach is needed to address the root cause of the problem of linking waste generation with consumption (Singh et al., 2014).

According to Reno (2015), the lack of waste management infrastructure can “threaten human life and dignity” and usually its role is absent in the sense that “waste management makes things disappear by moving them elsewhere”, and “is considered most successful to the extent that its workings and flows remain invisible”. To improve such situations, it is necessary to raise awareness of the importance of waste management, reduce the amount of waste generated, and improve the infrastructure for waste management.

The synergy of the joint work of academia, organizations, and governments can contribute to the improvement of waste management (Anuardo et al. 2022). Government and organizations can financially assist the academy in equipping laboratories for waste processing and in financing research projects. Governments and organizations can cooperate with the academy on the development and implementation of technological solutions in the collection and final disposal of waste, while organizations and academics can collect information to support waste management plans proposed by the government.

At present, waste management is a vital and noticeable global issue (Khosravani et al., 2023). The main objectives of the current waste management policies are to “divert waste from lower positions on the waste hierarchy such as landfill and incineration to higher positions in the hierarchy such as energy recovery and recycling” (Malek et al., 2023) and they are “strongly influenced by the ‘waste hierarchy’, which recommends a priority order from the most preferred option of ‘prevention’ at the top to the least preferred option of ‘disposal’ at the bottom” (Gharfalkar et al., 2015). A current trend in waste management in developed economies is the “more holistic resource management”, as opposed to the “end-of-pipe waste management”, and there are two identified key drivers for this change, and these are the “institutional and responsibility issues, and public awareness” (Wilson, 2007).

The ever-increasing convergence to renewable and sustainable energy has become an imperative and there is a vast potential in the waste disposal economic sector to "generate income for any economy" since it provides hopes for a sustainable environment (Okedu et al., 2022). This was the main rationale behind this study, to provide a systematic literature review and gain insights into efficient waste management practices with the applications of the leading non-parametric DEA methodology. The research design and approach are elaborated in the following section.

3. Research approach

In this study, a systematic literature review (SLR) methodology was conducted with the main goal of identifying and presenting the applications of the DEA method in waste management-related studies. Systematic literature reviews, as assessments of published papers in a specific domain or research area, are by far the "most informative and scientific, provided that they are rigorously conducted and well justified" (Paul et al., 2021). Moreover, SLR represents a process of collecting relevant evidence on a certain topic "that fits the pre-specified eligibility criteria" and answers certain research questions (Mengist et al., 2020). Previously published studies and findings are essential to the dissemination of existing and the creation of new knowledge and the process of SLR invites scholars to identify existing patterns of prior findings, understand the depth and details of the existing knowledge, and explore and tackle gaps for further work and investigation (Mohamed Shaffril et al., 2021).

This SLR is conducted by surveying the Web of Science database, which is one of the globally most renowned multidisciplinary databases. The search was conducted in February 2024 and returned a total of 12 papers as results.

Table 1 elucidates the phases of the review. Namely, the first phase was the selection of keywords "waste management", "waste disposal" and "data envelopment analysis". A total of 27 papers were identified in the Web of Science scientific database. There were no restrictions on the publication year, i.e. all the available published papers since the introduction of the DEA methodology (in 1978) were included in the review. However, the scope of the studies needed to be in waste management with the application of DEA, and the publication language needed to be English. After the application of the eligibility criteria, the data extraction phase was initiated, which identified the final database for screening. In this phase, the abstracts of the returned papers were manually screened. In the fifth phase, a total of 12 full papers were included for exhaustive qualitative content analysis, which included region, time frame, applied DEA model, and input and output variables in the DEA model.

Table 1. Phases for the systematic literature review.

Phases	Description
(1) Research protocol	Web of Science database + Keywords selection: "WASTE MANAGEMENT", "WASTE DISPOSAL" and "DATA ENVELOPMENT ANALYSIS"
(2) Data Search	February 2024
(3) Eligibility criteria	Articles since 1978 (no restriction) Scope of the studies Publication language: English
(4) Data extraction	Final database creation + manual abstract and Full-text screening
(5) Exhaustive qualitative content analysis	Analysis of the findings and discussion of the results, state-of-the-art in the research area; guidelines for future work

Source: Authors' work.

4. Research results

In this section, the systematic literature review on the application of the DEA in the field of waste management is presented. Table 2 includes a tabular presentation of the 12 surveyed relevant papers according to authors and year of publication, the title of the paper, analyzed country or region, time frame, and applied DEA model. A detailed and qualitative analysis of the relevant papers follows Table 2.

Table 2. Systematic review of the application of DEA in waste management

Author/s and year of publication	Title of the paper	Analysed country/region	Time frame	Applied DEA model
das Mercês Costa et al. (2024)	Evaluation of the efficiency of urban solid waste management in Brazil by data envelopment analysis and possible variables of influence	Brazil	2019	output-oriented DEA
Halkos & Aslanidis (2023)	New circular economy perspectives on measuring sustainable waste management productivity	European Union	1995–2019	DEA, Malmquist productivity index, and the Malmquist–Luenberger productivity index
Agovino et al. (2023)	Environmental legislation and waste management efficiency in Italian regions in view of circular economy goals	Italy	2002–2019	Output-oriented DEA
Chioatto et al. (2023)	Sustainable solid waste management in the European Union: Four countries regional analysis	75 regions of Italy, France, Germany, and the Netherlands	2008–2013	DEA
Wang et al. (2022)	Measuring Profitable Efficiency, Technical Efficiency, Technological Innovation of Waste Management Companies Using Negative Super-SBM–Malmquist Model	America, France, and Canada	2019	a super-slacks measurement model and the Malmquist model integrated into the DEA
Llanquileo-Melgarejo et al. (2021)	Evaluation of the Impact of Separative Collection and Recycling of Municipal SolidWaste on Performance: An Empirical Application for Chile	Chile	2018	DEA and Mann–Whitney test
Gastaldi et al. (2020)	The Efficiency of Waste Sector in Italy: An Application by Data Envelopment Analysis	78 large cities in Italia	2015 and 2016	two output-oriented DEA models
Tüzüner & Alp (2018)	Comparison of Solid Waste Management Performances of Turkey and EU countries associated with Malmquist Index	Turkey and 24 EU countries	2006–2012	DEA, Malmquist Total Factor Productivity index
Sarra et al. (2017)	Evaluating joint environmental and cost performance in municipal waste management systems through data envelopment analysis: Scale effects and policy implications	Abruzzo, Italy	2011–2013	modified DEA model, Tobit, and Probit regression models

Author/s and year of publication	Title of the paper	Analysed country/region	Time frame	Applied DEA model
Ali et al. (2017)	Assessing knowledge, performance, and efficiency for hospital waste management—a comparison of government and private hospitals in Pakistan	Pakistan	2014-2015	DEA, questionnaire
Struk & Matulová (2016)	The application of two-stage data envelopment analysis on municipal solid waste management in the Czech Republic	Czech Republic	2010-2012	Two-stage Data Envelopment Analysis (BCC model and OLS and Tobit regressions
Sarkis (2000)	A comparative analysis of DEA as a discrete alternative multiple criteria decision tool	Oulu district of Finland	n.a.	multi-criteria decision-making methodologies and DEA ranking techniques

Source: Authors' work.

das Mercês Costa et al. (2024) analyzed the efficiency of urban solid waste management by using output-oriented DEA. The research covered 940 Brazilian municipalities, classified into groups according to the population range in 2019. Inputs in this research were: expenses on the collection of municipal solid waste/year, the number of workers involved with collection, and the number of vehicles used for collection. Outputs were: the volume of waste collected/year and the number of people served by the collection service. According to the results of the analysis, the higher efficiency was in municipalities with a population of more than 500,000 inhabitants, and only 12.34% of municipalities are considered efficient.

Halkos & Aslanidis (2023) analyze the relationship between sustainable and circular economy and sustainable waste management in the European Union using DEA for the period 1995–2019. The Malmquist and Malmquist–Luenberger productivity index were used to estimate the growth of total factor productivity. This research includes inputs: energy use, labor force, and gross investments in fixed capital, desirable output: gross domestic product, and undesirable output: municipal waste generation. The authors concluded that undesirable output variable represents a significant factor in the reduction of total factor productivity.

An assessment of regional efficiency in waste management in Italy was carried out by Agovino et al. (2023). Output-oriented DEA model was applied. Time series data in the period 2002 to 2019 were used. Input variables are GDP per capita, population density, and unemployment. Output variables are the ratio between separate waste and total waste and the ratio between landfilled waste and total waste. With this research, the authors tried to determine the effects of changes in the goals of separate waste collection and landfills on the efficiency of the waste management process. The authors concluded that these effects depend on socio-economic indicators, which vary greatly in Italian regions.

Chioatto et al. (2023) analyzed the performance of municipal solid waste management by using DEA for 75 regions of Italy, France, Germany, and the Netherlands in the period 2008 to 2013. The input variable was waste generation, and the output variables were waste treatment techniques: disposal, incineration and energy recovery, recycling material,

recycling composting, and digestion. The results show that Germany and the Netherlands have higher recycling rates, but that Italy and France are also showing gradual improvements.

An assessment of the profitable efficiency, position, and technical and technological innovation of nine large global waste management corporations from America, France, and Canada in 2019 was carried out by Wang et al. (2022). The super-slacks measurement model and the Malmquist model are integrated into DEA and applied in this study. The observed input variables were: Total Assets, Cost of Revenue, and Operating Costs, and the output variables were: Total Income and Net Income. The authors conclude that more efficient waste management requires better decision-making in the observed companies, both in terms of investments and strategies. The existence of deficiencies in technical and technological innovations entails the impossibility of achieving technical and technological improvements.

By using DEA, Llanquileo-Melgarejo et al. (2021) tried to examine the effects of selective collection and recycling of municipal solid waste on the performance of municipalities in providing municipal solid waste services. Analysis was conducted for 298 municipalities in Chile in 2018. To evaluate the efficiency of Chilean municipalities in municipal solid waste management DEA and Mann–Whitney test were applied. The input variable was defined as the total costs of municipal solid waste collection and disposal and the output variable as the quantity of municipal solid waste collected and disposed of. To evaluate the eco-efficiency of Chilean municipalities in municipal solid waste management, the input variable was the same as in the efficiency case, while output variables were defined as the quantity of paper collected and recycled, the quantity of glass collected and recycled, the quantity of plastic collected and recycled and quantity of organic matter collected and recycled. The results of the conducted analysis indicate the necessity of improving municipal solid waste management in Chile.

In the research by Gastaldi et al. (2020), two output-oriented DEA models were employed to analyze the ecological and economic performance of municipal waste systems. Input variables included were total cost per inhabitant and total cost per kg, total amount of waste collected, and average tariff applied in the municipality. The amount of separate waste collected per inhabitant and total separate waste collected were included as output variables. The analysis was carried out for 78 large cities in Italia in 2015 and 2016. Based on the conducted analysis, it was determined that the cities in the north and the centers of efficiency in terms of the observed problem are different from the cities in the south and the islands.

Tüzüner & Alp (2018) analyzed the efficiency of solid waste management in Turkey and 24 EU countries based on DEA. Data related to waste and the environment for the period 2006–2012 were used. Changes in countries' performance were examined by year using the Malmquist Total Factor Productivity index. Two models were built. The first model, related to the environment included three waste categories input variables and three output variables. The second model, related to economic performances, included two input variables and three output variables. Results indicate that from the environmental aspect, the analyzed countries increased production efficiency over time, and achieved more output with equal inputs. From the economic point of view, when public investments in the environment and expenditures for environmental protection remain the same, there is an increase in the municipal waste recycling ratio, the packaging waste recycling ratio, and the packaging waste recovery ratio.

In addition to the desired output, waste from a separate collection, Sarra et al. (2017) proposed in the modified DEA model the undesired output, unsorted waste, to be minimized. The input variable was waste costs. In addition to the DEA model, Tobit and probit regression models were also applied. Data for 289 municipalities in Abruzzo, Italy, for the period 2011–2013 were used. The results of this research indicate that the creation of multi-

municipal optimal territorial areas is useful to improve the environmental and cost efficiency of waste collection.

Ali et al. (2017) analyzed hospital waste management based on data from 12 hospitals in Gujranwala city in the period 2014 and 2015 in Pakistan. The research used data from the field, physical measurements, and data obtained using a questionnaire. Input variables for DEA were: the number of inpatients, number of outdoor patients, and number of sanitary workers. Outputs included general waste and biomedical waste. The DEA results showed that seven hospitals had major or pure technical inefficiencies in their waste management activities and that not a single hospital implements waste management in strict compliance with state regulations. Hospital staff have a low level of knowledge about safe hospital waste management practices. The authors conclude that the current situation in hospitals should be improved to avoid environmental and epidemiological risks.

A two-stage Data Envelopment Analysis (BCC model in combination with OLS and Tobit regressions) was applied to examine the efficiency of solid waste management of municipalities in the Czech Republic in the study of Struk & Matulová (2016). The research was conducted for the period 2010-2012. Input in their study is expenditures on solid waste management, while outputs are represented by population, number of dwellings, and serviced area. Results of the conducted analysis suggest that the efficiency of waste management in some Czech municipalities could be increased, for example, by incentives, the construction of a center for household waste recycling, or the installation of collectors. The aforementioned also requires additional costs, which should be paid attention to if these changes were to be introduced in the municipalities.

A comparison of multi-criteria decision-making methodologies and DEA ranking techniques is applied by Sarkis (2000) to the example of locating a municipal solid waste management system in the Oulu district of Finland. Inputs, i.e. minimizing criteria are cost, global effects, health effects, acidification releases, and surface water dispersed releases. Outputs, i.e. maximizing criteria are technical reliability, employees, and resource recovery. The results reveal that the inclusion of decision-maker judgments in DEA approaches gives better results comparable to those obtained by traditional multi-criteria decision-making approaches and that such an approach has an advantage for users because it requires less information from decision-makers and analysts. The authors concluded that "DEA seems to perform well as a discrete alternative multi-criteria decision-making tool".

5. Discussion and conclusion

Waste management is a vital issue and a sensitive area for many stakeholders, both privately owned organizations and local and national authorities, especially after becoming a part of the 17 Sustainable Development Goals (SDGs) and has also become a big challenge for city authorities, not only in developed, but also in developing countries, as a direct result of the increase of waste in general (Amri et al., 2020). The increase in waste in global terms could be attributed to the processes of increased global population, urbanization, industrialization, and economic growth, complimentary with the last century's evolutions (Khosravani et al., 2023).

In this paper, relevant scientific papers published as full-texts in the Web of Science database regarding the application of DEA in waste management are identified and presented. The identification of relevant papers was based on the keywords "WASTE MANAGEMENT", "WASTE DISPOSAL" and "DATA ENVELOPMENT ANALYSIS". The review of the Web of Science database was followed by a qualitative analysis of a total of 12 relevant full-text

papers. Following are the results of the whole procedure. Most of the analyzed papers were published in the last 8 years. The exception is the paper Sarkis (2000). This data indicates that the popularity of this type of research has increased in the last decade. Researches were mainly carried out in European countries (Halkos & Aslanidis (2023), Agovino et al. (2023), Chioatto et al. (2023), Gastaldi et al. (2020), Sarra et al. (2017), Struk & Matulová (2016), Sarkis (2000)). South American countries were analyzed in two papers (Ali et al. (2017), das Mercês Costa et al. (2024)), while several world countries approach was applied by Wang et al. (2022) and Tüzüner & Alp (2018). Most of the research covered at least two years, in three papers the data were annual. Mainly the output-oriented DEA model was used, but also a combination of the DEA approach with Tobit and Probit regression models, multi-criteria decision-making methodologies, Mann-Whitney test, Malmquist and Malmquist–Luenberger productivity index, etc. The input and output variables included in the studies differ from study to study. The number of input and output variables in the analyzed papers varies from 1 to 5, with 3 input and 2 output variables dominating in half of the articles.

This research contributes not only to the expansion of the scientific literature, but also guides policymakers and authorities in terms of waste management efficiency, which nowadays represents a significant problem at the regional level, but also globally. The selection of input and output variables can be useful in improving the environmental and economic efficiency of waste management.

The main limitation of this paper is reflected in the selection of only one scientific database, which excludes numerous works potentially relevant to this research topic. Also, in this research, the authors were based only on full-text papers to make the analysis as high-quality as possible. To overcome this limitation, the authors plan to conduct a more comprehensive bibliometric review and identify the existing trends in the literature regarding the application of the DEA method in waste management efficiency evaluation, as well as to predict future trends in this research area. Moreover, future research is expected to expand the research to other scientific databases as well as to include other research methodologies on this important issue of waste management. The authors plan to empirically assess the waste management efficiency in Croatia as well.

This study has significant scientific and practical contributions. Research of this type complements the existing scholarly literature on the importance of waste management and provides key guidelines to scientists, policymakers, and authorities on efficient waste management as one of the key problems of today's society.

References

- Agovino, M., Cerciello, M., Javed, A. and Rapposelli, A. (2023). "Environmental legislation and waste management efficiency in Italian regions in view of circular economy goals," *Utilities Policy*, vol. 85, 101675.
- Ali, M., Wang, W., Chaudhry, N., Geng, Y. and Ashraf, U. (2017). "Assessing knowledge, performance, and efficiency for hospital waste management—a comparison of government and private hospitals in Pakistan", *Environ Monit Assess*, vol. 189, 181.
- Amasuomo, E. and Baird, J. (2016). "The concept of waste and waste management," *Journal of Management and Sustainability*, vol. 6, pp. 88-96.
- Amri, S., Soesilo, T. B. and Martono, D. N. (2020). "Optimization of waste management in developing countries with spatial approaches (Study case: Depok City and Curitiba City)", In *IOP Conference Series: Earth and Environmental Science*, vol. 561, 012021.

- Anuardo, R.G., Espuny, M., Costa, A.C.F., Oliveira OJ. (2022). Toward a cleaner and more sustainable world: A framework to develop and improve waste management through organizations, governments, and academia. *Heliyon*. 8(4). doi: 10.1016/j.heliyon.2022.e09225.
- Banker, R. D., Charnes, A. and Cooper, W. W. (1984). "Some models for estimating technical and scale inefficiencies in data envelopment analysis", *Management science*, vol. 30, pp. 1078-1092.
- Charnes, A., Cooper, W. and Rhodes, E. (1978). "Measuring the efficiency of decision-making units," *Eur. J. Oper. Res*, vol. 2, pp. 429–444.
- Chioatto, E., Khan, M.A. and Sospiro, P. (2023). "Sustainable solid waste management in the European Union: Four countries regional analysis," *Sustainable Chemistry and Pharmacy*, vol. 33, 101037
- Chioatto, E. and Sospiro, P. (2023). "Transition from waste management to circular economy: the European Union roadmap," *Environ Dev Sustain*, vol. 25, pp. 249–276.
- das Mercês Costa, I., Dias, M. F. and Robaina, M. (2024). "Evaluation of the efficiency of urban solid waste management in Brazil by data envelopment analysis and possible variables of influence", *Waste Dispos. Sustain. Energy*.
- De Carvalho, F. A., José Jorge, M., Filgueiras Jorge, M., Russo, M., and Oliveira de Sá, N. (2012). "Library performance management in Rio de Janeiro, Brazil: Applying DEA to a sample of university libraries in 2006-2007", *Library Management*, vol. 33, pp. 297-306.
- Demirbas, A. (2011). "Waste management, waste resource facilities and waste conversion processes. Energy Conversion and Management," vol. 52, pp. 1280-1287.
- DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. (2008). Official Journal of the European Union, L 312/3.
- Environmental Protection and Energy Efficiency Fund. (2024). Waste management. <https://www.fzoeu.hr/en/waste-management/1345>
- European Commission. (2020). A new circular economy action plan, for a cleaner and more competitive Europe. Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions. COM(2020) 98 final, Brussels, March 11, 2020. https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF
- Fotova Čiković, K. and Lozić, J. (2022). "Application of data envelopment analysis (DEA) in information and communication technologies", *Tehnički glasnik*, vol. 16, pp. 129-134.
- Fotova Čiković, K., Martinčević, I. and Lozić, J. (2022). "Application of data envelopment analysis (DEA) in the selection of sustainable suppliers: A review and bibliometric analysis," *Sustainability*, vol. 14, 6672.
- Gastaldi, M., Lombardi, G.V., Rapposelli, A. and Romano, G. (2020). "The Efficiency of Waste Sector in Italy: An Application by Data Envelopment Analysis," *Environmental and Climate Technologies*, vol. 24, pp. 225–238.
- Gharfalkar, M., Court, R., Campbell, C., Ali, Z. and Hillier, G. (2015). "Analysis of waste hierarchy in the European waste directive 2008/98/EC," *Waste management*, vol. 39, pp. 305-313.

- Halkos, G. and Petrou, K. N. (2019). "Assessing 28 EU member states' environmental efficiency in national waste generation with DEA," *Journal of Cleaner Production*, vol. 208, pp. 509–521.
- Halkos, G.E. and Aslanidis, P.S.C. (2023). "New circular economy perspectives on measuring sustainable waste management productivity," *Economic Analysis and Policy*, vol. 77, pp. 764-779.
- Izvercian, M. and Ivascu, L. (2015). "Waste management in the context of sustainable development: Case study in Romania," *Procedia Economics and Finance*, vol. 26, pp. 717-721.
- Jardas Antičić, J., Kregar, K. and Vretenar, N. (2020). "Data Envelopment Analysis in measuring the efficiency of volleyball teams in Primorsko-Goranska county," *Zbornik Veleučilišta u Rijeci*, vol. 8, pp. 121-134.
- Jiyan, W. (2021). "Trash management and eco-friendly waste," *Adv Recycling Waste Manag*, vol. 6, 190.
- Kaza, S., Yao, L., Bhada-Tata, P., Van Woerden, F. (2018). "What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development Series. Washington, DC: World Bank. doi:10.1596/978-1-4648 -1329-0.
- Khosravani, F., Abbasi, E., Choobchian, S., & Jalili Ghazizade, M. (2023). "A comprehensive study on criteria of sustainable urban waste management system: using content analysis," *Scientific Reports*, vol. 13, 22526.
- Laurent, A., Clavreul, J., Bernstad, A., Bakas, I., Niero, M., Gentil, E., Christensen, T.H. and Hauschild, M.Z. (2014). "Review of LCA studies of solid waste management systems - Part II: methodological guidance for a better practice," *Waste Manag*, vol. 34, pp. 589–606.
- Llanquileo-Melgarejo, P., Molinos-Senante, M.; Romano, G. and Carosi, L. (2021). "Evaluation of the Impact of Separative Collection and Recycling of Municipal Solid Waste on Performance: An Empirical Application for Chile," *Sustainability*, 13.
- Malek, W., Mortazavi, R., Cialani, C. and Nordström, J. (2023). "How have waste management policies impacted the flow of municipal waste? An empirical analysis of 14 European countries," *Waste Management*, vol. 164, pp. 84-93.
- Mengist, W., Soromessa, T. and Legese, G. (2020). "Method for conducting systematic literature review and meta-analysis for environmental science research," *MethodsX*, 7, 100777.
- Mohamed Shaffril, H. A., Samsuddin, S. F. and Abu Samah, A. (2021). "The ABC of systematic literature review: the basic methodological guidance for beginners," *Quality & Quantity*, vol. 55, pp. 1319-1346.
- Okeku, K. E., Barghash, H. F. and Al Nadabi, H. A. (2022). "Sustainable waste management strategies for effective energy utilization in Oman: A review," *Frontiers in Bioengineering and Biotechnology*, vol. 10, 825728.
- Paul, J., Lim, W. M., O'Cass, A., Hao, A. W. and Bresciani, S. (2021). "Scientific procedures and rationales for systematic literature reviews (SPAR-4-SLR)," *International Journal of Consumer Studies*, vol. 45, pp. O1-O16.
- Rabar, D. (2010). "Ocjenjivanje efikasnosti poslovanja hrvatskih bolnica metodom analize omeđivanja podataka", *Ekonomski pregled*, vol. 61, pp. 511-533.

- Reno, J. (2015). "Waste and Waste Management," *Annu. Rev. Anthropol.* Vol. 44, pp. 557–72.
- Sarkis, J. (2000). "A comparative analysis of DEA as a discrete alternative multiple criteria decision tool," *European Journal of Operational Research*, vol. 123, pp. 543-557.
- Sarra, A., Mazzocchitti, M. and Rapposelli, A. (2017). "Evaluating joint environmental and cost performance in municipal waste management systems through data envelopment analysis: Scale effects and policy implications," *Ecological Indicators*, vol. 73, pp. 756-771.
- Singh, J., Laurenti, R., Sinha, R. and Frostell, B. (2014). "Progress and challenges to global waste management system," *Waste Management and Research*, vol. 32, pp. 800-812.
- Struk, M. and Matulová, M. (2016). "The application of two-stage data envelopment analysis on municipal solid waste management in the Czech Republic," *Proceedings of the international conference: quantitative methods in economics: multiple criteria decision making XVIII*, 349-355.
- Tüzüner, Z. and Alp, İ. (2018). "Comparison of Solid Waste Management Performances of Turkey and EU countries associated with Malmquist Index," *Politeknik Dergisi*, vol. 21, pp. 75-81.
- Vörösmarty, G. and Dobos, I. (2023). "Management applications and methodology developments in DEA-an overview of literature reviews," *International Journal of Management and Decision Making*, vol. 22, pp. 472-491.
- Wang, C.-N., Hoang, Q.-N., Nguyen, T.-K.-L., Hsu, H.-P. and Dang, T.-T. (2022). "Measuring Profitable Efficiency, Technical Efficiency, Technological Innovation of Waste Management Companies Using Negative Super-SBM–Malmquist Model", *Axioms*, 11, 315.
- Wilson, D. C. (2007). "Development drivers for waste management," *Waste Management & Research*, vol. 25, pp. 198-207.