

The Development of a Performance Assessment Method for E-Waste Management in the European Union

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Abstract: *This study focuses on the performance of waste electrical and electronic equipment (WEEE, e-waste) management in countries from European Union. A detailed literature review is conducted, in order to reveal other trials of analysing the performance of waste management. At the same time, the study has a unique way of presenting aspects related to the concept of performance analysed for the WEEE management field. Issues related to performance are revealed by conducting a Data Envelopment Analysis. The output variable is set on the collection rate of e-waste, while the input variables are selected among factors which may influence the WEEE collection. The main advantage of such an analysis is that it not only provides an overview of the performance level for each country but also indicates the peers or reference countries. This way, comparisons among countries are easily realized. The paper ends with indicating the best and worst performers among Member States, along with limitations of the study and further developments.*

Keywords: DEA, collection rate, e-waste, performance.

I. Introduction

In the current context of an accelerated pace of global economic development and demographic and informational explosion, the issue of waste resulting from human activity is a constant that cannot be ignored anymore.

Among existing waste, a special place is held by waste of electrical and electronic equipment. Practically from the beginning of this millennium, because of intensive and extensive use of electronic devices (mobile phones, tablets, computers) but also of durable goods (refrigerators, dishwashers, washing machines, ovens, TVs and so on), the amount of waste in this field has grown exponentially. To gain a rough idea about this increase in the quantity of waste, it is sufficient to recall that in 1994 about 20 million computers were taken out of service, while 10 years later (in 2004) this figure grew to 100 million.¹

¹ Widmer, R., Oswald, H., Sinha, D., Schnellmann, M., & Boni, H., "Global perspectives on e-waste," *Environmental Impact Assessment Review* 25 (2005): 436-458, doi:10.1016/j.eiar.2005.04.001

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Moreover, the Global E-waste Monitor² estimated a generated amount of e-waste in 2014 of 41.8 million metric tonnes (Mt). It has also forecasted an increase up to 50 Mt of e-waste for 2018. The Global E-waste Monitor relates that categories comprising this amount of e-waste are: 1.0 Mt of lamps, 6.3 Mt of screens, 3.0 Mt of small IT, 12.8 Mt of small equipment, 11.8 Mt of large equipment and 7.0 Mt of cooling and freezing equipment.³

The issue of WEEE management performance evaluation is becoming increasingly important given that the ultimate goal of WEEE management is the exploitation (as various forms - reuse, recycling, disposal) this type of waste. In our opinion, an efficient system of WEEE management should primarily focus on limiting the maximum amount of equipment that can turn into WEEE by prevention; where this is not possible, emphasis must be on reuse / recycling and, ultimately, on the WEEE disposal. The discussed situation can be represented as a pyramid upside down, shown in the figure below:

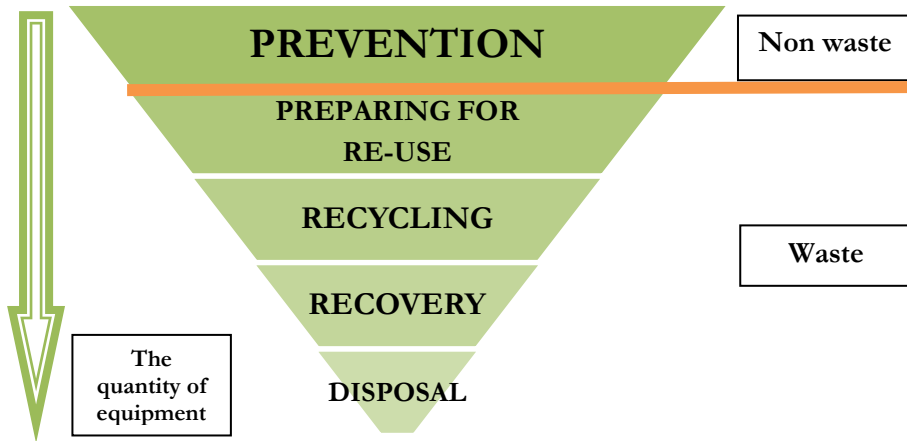


Fig. 1. The sequence of steps in an efficient WEEE management

Source: authors after European Commission (2008)

One can observe from the above figure that a good management of WEEE involves effective collection of WEEE. Indeed, all four stages of the management of WEEE (preparing for re-use, recycling, recovery and disposal) provide an efficient collection, able to reduce the maximum amount of waste. From this point of view, within European Union there is a significant discrepancy concerning the amount of collected WEEE per capita. There are countries (especially in Eastern Europe) where the amount of collected WEEE per capita does not exceed 4 kg (with Romania ranked last, with a collection rate of only 1.028 kg per capita in 2014); in contrast, countries such as Ireland, Austria and Belgium report in the same year a collection rate between 8 - 9 kg per capita, while the Nordic countries are the best collectors (Denmark – 5.82 kg per capita, Finland – 6.21 kg per capita, Sweden – 7.35 kg per capita, Norway – 9.61 kg per capita).⁴

² Baldé, C.P., Wang, F., Kuehr, R., & Huisman, J., *The global e-waste monitor – 2014*, United Nations University (IAS – SCYCLE, Bonn, 2015) on: <https://i.unu.edu/media/unu.edu/news/52624/UNU-1stGlobal-E-Waste-Monitor-2014-small.pdf> (last time accessed: 21 March, 2018).

³ Ibidem.

⁴ Eurostat. *Waste electrical and electronic equipment (WEEE)*, 2017, <http://ec.europa.eu/eurostat/web/waste/key-waste-streams/weee> (last time accessed: 21 March, 2018).

So, within this paper we are focusing on analysing the performance of the WEEE collection in European countries. The main reason is, as explained above, that an effective collection of WEEE contributes to an effective waste management. The second reason is that since each country has to establish its own target on collecting and recycling in relation to the quantity of electrical and electronic equipment put on market (European Commission, 2012) it becomes more important revealing the current status of performance and how it can be improved.

II. Literature review

In general, when talking about the concept of performance, there is no consensus among specialists on its contents. Actually, many terms are used to capture different facets of performance (for instance: efficiency, effectiveness, productivity, profitability, return, competitiveness, eco-efficiency). Many authors combine these terms in different ways to cover the concept of performance. Thus, Verboncu and Zalman⁵ consider that performance (in the context of organizational achievements) not only refers to the concepts of efficiency, effectiveness and competitiveness, but also to the company's procedural and structural behaviour. Other authors⁶ understand performance (as reported to an economic entity's activity) as a state of competitiveness. They argue that this state is achieved through a certain productivity and effectiveness level obtained within the developed activity.

In our view, we believe that this definition on performance can be considered only in the economic sphere, not in the social-cultural or in the environmental ones (where performance must capture other aspects too).

To define performance management within WEEE, we consider useful to take into account the implications WEEE management has on several levels:

- on the economic level, the performance may be translated as the quintessence of efficiency and cost-effectiveness;
- on the environmental level, the performance would be translated through eco-efficiency;
- in the social level, the performance may be understood as corporate social responsibility.

Therefore, performance in the management of WEEE occurs as a result of the performance in the three levels. A graphical representation of the situation is presented in figure 2.

According to Morris and Metternicht,⁷ performance in the management of WEEE can be influenced by many interrelated factors. Among the most important, we can mention:

- The economic factor that influences WEEE management performance through the funds allocated for this purpose;
- The political factor which influences the performance of WEEE management in particular through legislation promoted by central and local authorities involved in the management of WEEE;
- The technological factor that influences the performance through technology regarding treatment, recovery, recycling and / or disposal of WEEE;

⁵ Verboncu, I., & Zalman, M., *Management and performances* (Bucharest: Editura Universitară, 2005).

⁶ Niculescu, M., & Lavalette, G. *Growth strategies* (Bucharest: Editura Economica, 1999).

⁷ Morris A., & Metternicht, G., "Assessing effectiveness of WEEE management policy in Australia," *Journal of Environmental Management* 181 (2016): 218-230, doi:10.1016/j.jenvman.2016.06.013.

- The social factor which influences the performance of WEEE management through awareness among the population about the management of WEEE.

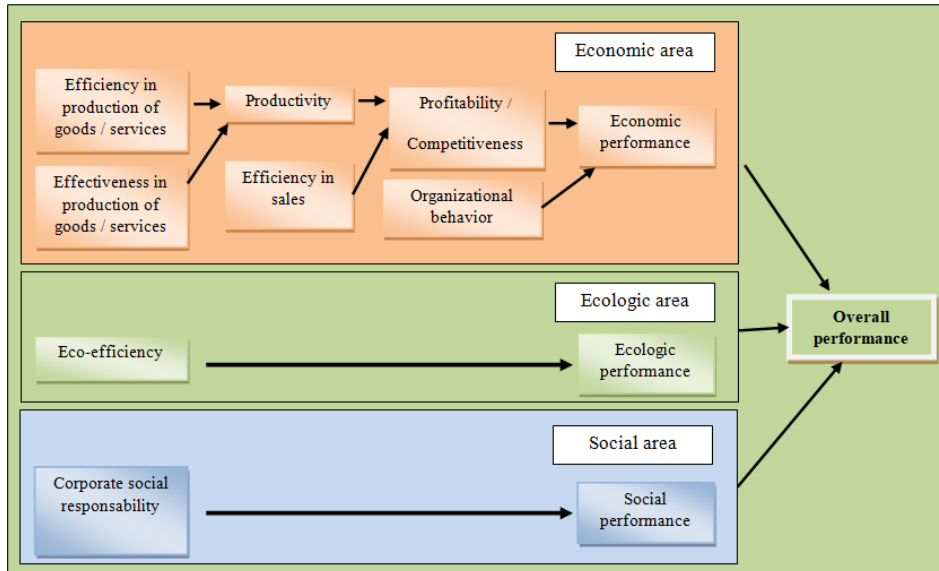


Fig. 2. The concept of performance in the field of WEEE management.

Source: the authors

There are various methods used by researchers when dealing with the subject of assessing the waste management performance. For instance, Mihai⁸ proposed a performance assessment method based on five specific waste indicators, for urban areas in a Romanian county, revealing poor performance of the system. Moving forward, Jingkuang and Yousong⁹ used a cause-and-effect diagram for improving waste management performance while applying a questionnaire based on 56 individual factors, considered by authors as waste management influence factors. Furthermore, Teixeira and Neves¹⁰ developed a framework out of 167 performance indicators and tested it by implementing it in a waste management system (WMS) in Portugal. The main idea of the framework was to integrate both context information (useful to identify system's characteristics) and performance indicators. As the authors argue, the framework turned out to be a helpful tool for stakeholders interested in information about the global performance of the WMS.¹¹

There are other authors using in their researches Data Envelopment Analysis (DEA), a popular performance measurement technique. Rogge and De Jaeger¹² propose an adjusted

⁸ Mihai, F.C., "Performance assessment method of urban waste management systems from Neamt county, Romania," *Present environment and sustainable development* 7, (2013): 160-167.

⁹ Jingkuang, L., & Yousong, W., "Establishment and application of performance assessment model of waste management in architectural engineering projects in China," *Systems Engineering Procedia* 1 (2011): 147-155.

¹⁰ Teixeira, C.A., & Neves, E. B., *Municipal Solid Waste Performance Indicators*, 2009, on http://www.iswa.org/uploads/tx_iswaknowledgebase/1-265.pdf (last time accessed: 21 March, 2018).

¹¹ Ibidem.

¹² Rogge, N., & De Jaeger, S., "Evaluating the efficiency of municipalities in collecting and processing municipal solid waste: A shared input DEA-model," *Waste Management* 32 (2012): 1968-1978.

shared-input version of DEA with the aim to identify the activities where the municipality can perform better and with a higher efficiency regarding costs. Cristobal et al.¹³ combine DEA with Life cycle assessment method and a retrofit process (guide actions that can have an influence in the inefficient options in order to improve them), so as to develop a three stage methodology. These authors also explain in detail the advantages of using DEA, and among them we selected the one stating that DEA as a decision support tool in multicriteria analyses, has no need for prior assumptions regarding the relationship between inputs and outputs and that it helps identifying optimal and suboptimal alternatives and ways to improve the latter ones.¹⁴

Chen, Chang, Chen & Tsai¹⁵ also used the DEA to evaluate performance-based efficiencies of municipal incinerators in Taiwan. These large-scale incinerators have different operational conditions and treat only municipal solid waste. The authors conclude that their analysis is usefully not only for Taiwan, but also for other countries interested in finding optimal management strategies for promoting the quality of solid waste incineration.¹⁶

Also concerned about solid waste and interested in studying the performance of Portuguese solid waste services, Simões, De Witte & Cunha Marques¹⁷ apply DEA in a traditional approach but also in a new approach consisting in the bootstrap methodology application to the DEA estimators.

The reason for choosing DEA to conduct the analysis within this paper lies in its useful purpose in assessing the performance of WEEE collection and revealing best practices and reference countries.

III. Data and methods

As explained in theory, DEA is “based on mathematical programming to measure the relative efficiency of Decision Making Units (DMU) which present a homogeneous set of inputs and outputs.”¹⁸ It was developed in 1978 by Charnes et al. and improved in 1984 by Banker et al.¹⁹ DEA combines all inputs and outputs into a single efficiency score with a scale between 0 and 1. Efficient DMU receive a score equal to 1, while inefficient DMU receive a score less than 1. So, as explained by Galán-Martín et al.²⁰ not only that DEA reveals the values for the efficiency scores, but also offers specific guidelines in order to improve the efficiency level of a DMU.

¹³ Cristobal, J., Limleamthong, P., Manfredi, S., & Guillen-Gosalbez, G., “Methodology for combined use of data envelopment analysis and life cycle assessment applied to food waste management,” *Journal of Cleaner Production* 135 (2016): 158–168.

¹⁴ Ibidem.

¹⁵ Chen, H.W., Chang, N.B., Chen, J.C., & Tsai, S.J., “Environmental performance evaluation of large-scale municipal solid waste incinerators using data envelopment analysis,” *Waste Management* 30 (2010): 1371–1381, doi:10.1016/j.wasman.2010.02.002

¹⁶ Ibidem.

¹⁷ Simões, P., De Witte, K., & Cunha Marques, R., “Regulatory structures and operational environment in the Portuguese waste sector,” *Waste Management* 30 (2010): 1130–1137, doi:10.1016/j.wasman.2009.12.015

¹⁸ Ibidem.

¹⁹ Vaninsky, A., “Efficiency of electric power generation in the United States: Analysis and forecast based on data envelopment analysis,” *Energy Economics* 28 (2006): 326–338.

²⁰ Galán-Martín, A., Guillén-Gosálbez, G., Stamford, L., & Azapagic, A., “Enhanced data envelopment analysis for sustainability assessment: A novel methodology and application to electricity technologies,” *Computers and Chemical Engineering* 90 (2016): 188–200.

Within this paper, the DMU's are the countries, the Collection rate of WEEE²¹ will represent the output, while the other three indicators will be part of the inputs: the Population which attained Tertiary studies,²² the Minimum Wage (Eurostat, 2016c), the Unemployment rate.²³ They are all available for 2013 for 20 countries in the European Union. The figures 3-6 show the levels registered by each country (listed alphabetically) in 2013, for each indicator.

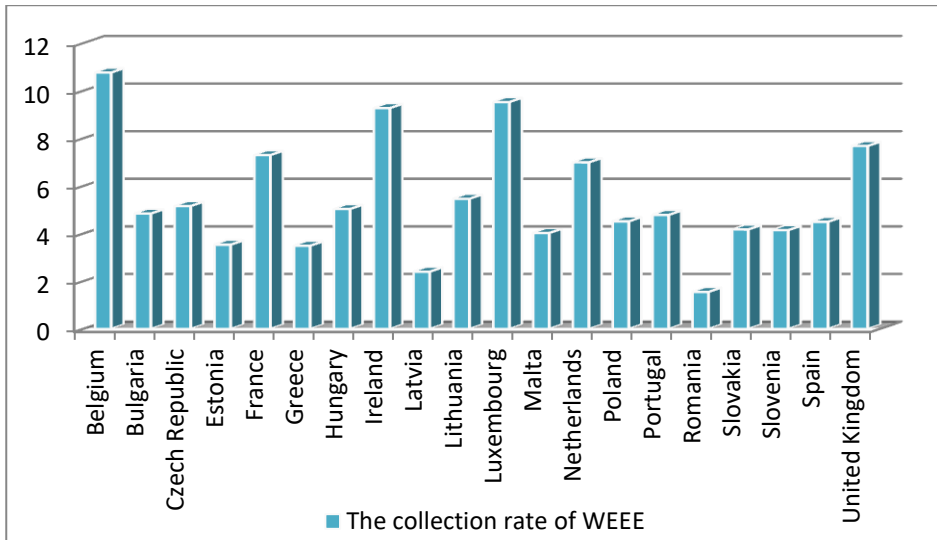


Fig. 3. The collection rate of WEEE (kilograms per capita) in the European Union in 2013²⁴

One can observe within Figure 3, that the major WEEE collectors in 2013 are Belgium, Luxembourg, Ireland and United Kingdom, followed by France and Netherlands. Moving further to figure 4, it seems that the highest values for the minimum wage indicator are registered also in these countries. The importance of the minimum wage is to signal that when a person benefits of a higher income, will eventually have a greater inclination to participate in the collection of WEEE for recycling.²⁵ However, the minimum wage has the

²¹ Eurostat, *Waste collected from households (kilograms per capita)* (2016) on: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waselec&lang=en (last time accessed: 21 March, 2018).

²² Eurostat, *Minimum wages (eur/month)* (2016) on: <http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&pcode=tps00155&language=en> (last time accessed: 21 March, 2018).

²³ Eurostat, *Population by sex, age and educational attainment level, in 1000, Tertiary education (levels 5-8)*, (2016) on: <http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do> (last time accessed: 21 March, 2018).

²⁴ Eurostat, *Waste collected from households (kilograms per capita)*, (2016) http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_waselec&lang=en (last time accessed: 21 March, 2018).

²⁵ Marinescu, C., Ciocoiu, N., & Cicea, C., "Socioeconomic factors affecting e-waste collection rate in countries from European Union," in Proceedings of the 10th International Management Conference "Challenges of Modern Management", November 3rd-4th, 2016, Bucharest, Romania, on http://conferinta.management.ase.ro/archives/2016/PDF/2_6.pdf (accessed: 21 March, 2018).

lowest influence on the collection rate of WEEE (as compared to the other two variables: the unemployment rate and the population which attained Tertiary studies) as revealed in a previous work.²⁶

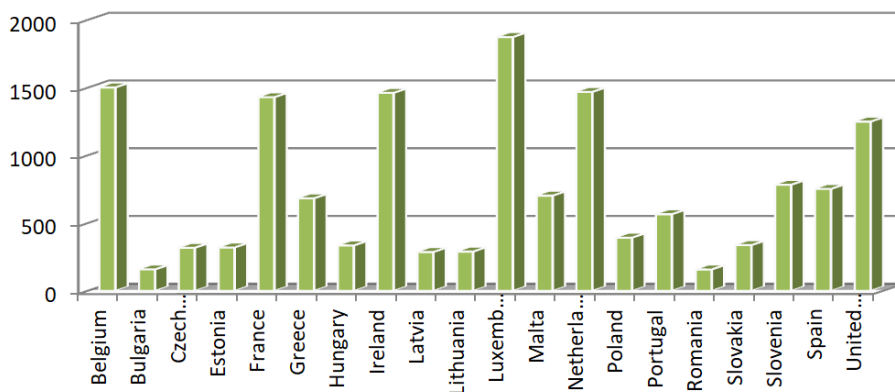


Fig. 4. The minimum wage in European Union in 2013²⁷

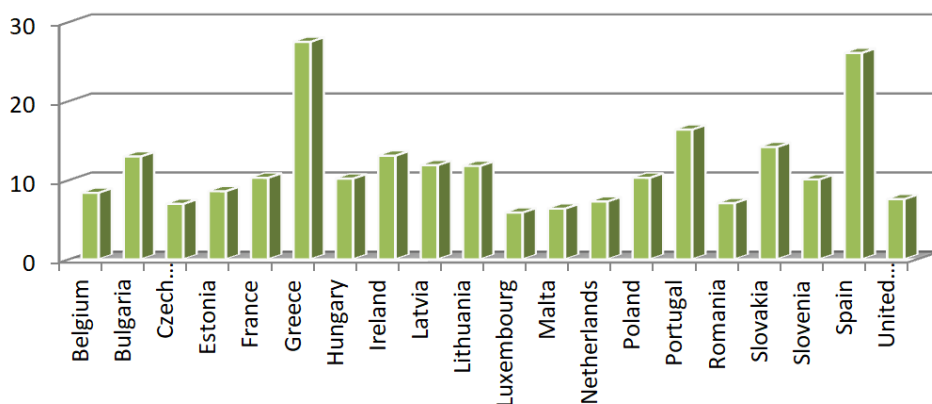


Fig. 5. The unemployment rate in European Union in 2013²⁸

Moving forward to figure 5, one can observe that high unemployment rates are associated with low collection rates of WEEE (as reported in figure 1). This happens because people looking for a job and preoccupied in this sense, having little interest towards waste sorting and hindering collection and recycling. Lastly, figure 6 presents a more dramatic situation regarding a social indicator. It seems that the concern for bachelor study is extremely low in

²⁶ Ibidem.

²⁷ Eurostat. (2016b). *Minimum wages (eur/month)*, (2016). On: <http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&pcode=tps00155&language=en> (last time accessed: 21 March, 2018).

²⁸ Eurostat. *Unemployment by sex and age - annual average- Percentage of active population* (2016). On http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=une_rt_a&lang=en (last time accessed: 21 March, 2018).

many member states of EU. Only United Kingdom, France, Spain and Poland report over 5000 thousands persons with tertiary education in 2013. Surprisingly, even if Spain prides itself with more than 30% of population having superior studies Eurostat,²⁹ it also registers a high unemployment rate. Choosing the level of education in our analysis was supported by the assumption that population with a high level of education will positively influence waste collection rate, by being more aware on its importance.

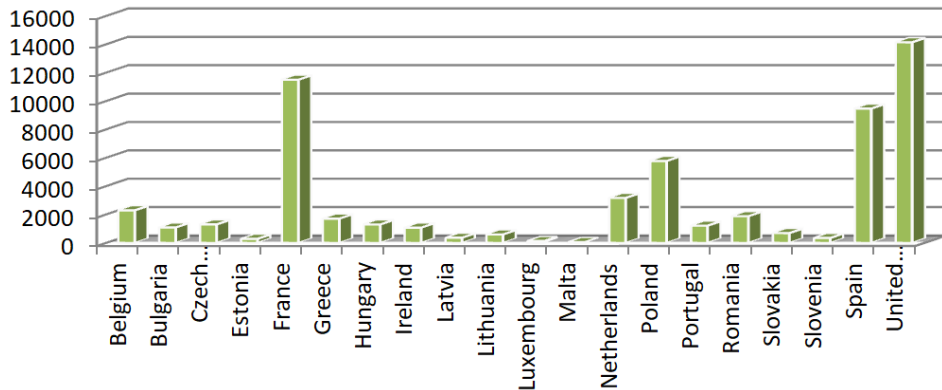


Fig. 6. The population with tertiary education in European Union in 2013³⁰

Figure 7 summarizes the steps in applying DEA. Firstly it reveals what inputs are subject to DEA in order to maximize the output. This option is called Output orientated DEA.

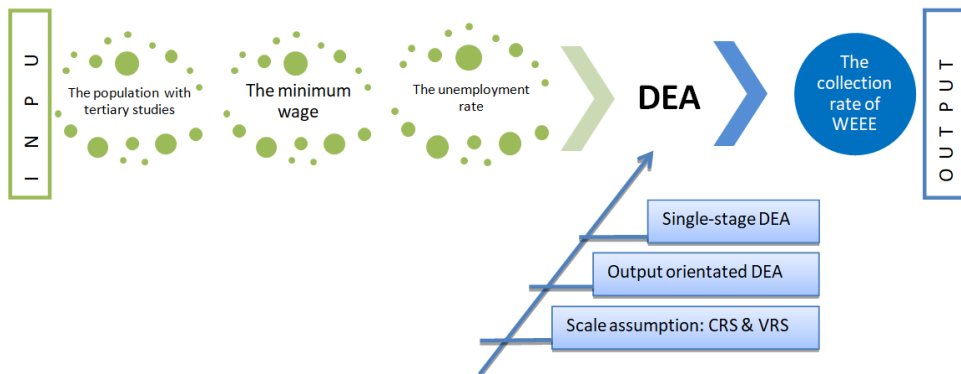


Fig. 7. DEA with inputs, output and instructions. Source: the authors

²⁹ Eurostat, *Population by sex, age and educational attainment level, in 1000, Tertiary education (levels 5-8)*, (2016), on <http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do> (last time accessed: 21 March, 2018).

³⁰ Eurostat, *Population by sex, age and educational attainment level, in 1000, Tertiary education (levels 5-8)* (2016). On: <http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do> (last time accessed: 21 March, 2018).

In conducting DEA, there are two types of orientation:³¹

- Input orientation (the analysis is oriented to minimize the inputs while maintaining the current levels of the outputs);
- Output orientation (the analysis is oriented to maximize the outputs while maintaining the current levels of the inputs).

The scale assumptions that can be used in DEA analysis are:

- CRS – meaning constant return to scale;
- VRS – variable return to scale (either increasing or decreasing).

As explained by Popovic and Martić,³² constant returns to scale “implies that a change in the amounts of the inputs leads to a similar change in the amounts of the outputs”. So, this means that variable return to scale implies that a certain change in the value of the inputs does not lead to a similar change in the outputs. Jarzębowski³³ also explains three situations for returns to scale. The first one reports an increasing return to scale which appear when outputs increase faster in relation to growth of used inputs. The second situation reports decreasing returns to scale which appear when outputs increase slower as compared to the increase in used inputs. The third situation reports constant returns to scale which appear when outputs have a growth proportionally to the one of used inputs.

In our analysis, we will be using both types of return to scale to describe two types of technical efficiency and calculate the scale efficiency. As explained by Popovic and Martić,³⁴ the technical efficiency represents a measure of how well the DMU uses its inputs to obtain outputs. According to Debreu and Farrell cited in Jarzębowski,³⁵ “the measurement of technical efficiency is the difference between one and the maximal possible reduction of inputs, while production of a certain volume of inputs is technologically possible”. In our case, instead of production we have the collection rate of WEEE.

The scale efficiency will be calculated by dividing the obtained technical efficiency from CRS to the technical efficiency from VRS.

Choosing as a method One stage DEA, will create a mathematical programming problem which will find those values for the output and inputs capable to maximize the efficiency for a country.

IV. Results and discussion

According to table 1, the best performers or the most efficient countries in collecting WEEE are the ones with scale efficiency of 1. When less than 1, the scale efficiency indicates less efficient countries. The increasing return to scale indicate that if a country will experience a change in its inputs, then the collection rate will experience a major change;

³¹ Yang, Z., “A two-stage DEA model to evaluate the overall performance of Canadian life and health insurance companies,” *Mathematical and Computer Modelling* 43 (2006): 910–919; Zhu, J., “Quantitative Models for Performance Evaluation and Benchmarking,” *International Series in Operations Research & Management Science* 213 (2014), DOI 10.1007/978-3-319-06647-9_2, Springer International Publishing Switzerland.

³² Popovic, G., & Martić, M., “Two-stage DEA use for assessing efficiency and effectiveness of micro-loan programme,” in *The 7th Balkan Conference on Operational Research BACOR 05 Constanta*, May 2005, Romania, on http://fmi.unibuc.ro/balkan-conf/CD/Section6/popovic_martic.pdf (last time accessed: March 21, 2018).

³³ Jarzębowski, S., “Efficiency and returns to scale – a concept of using deterministic approach,” *Quantitative methods in economics* 15 (2014): 102–111.

³⁴ Popovic, G., & Martić, M., *Two-stage DEA use for assessing efficiency and effectiveness of micro-loan programme* (2005).

³⁵ Jarzębowski, S., *Efficiency and returns to scale* (2014).

decreasing return to scale indicate that if a country will experience a change in its inputs, it will be experienced as a slight change in the output. We also created table 2, to offer the performance ranking for analysed countries. The worst performers as Latvia, Greece, Spain and Romania have little technical efficiency from CRS-DEA, as reported in table 1. This fact appoints that they do not use properly the inputs to create the output, or that they do not act as needed in order to influence the collection rate of WEEE.

Table 1. Efficiency summary. Source: authors' calculation in DEAP software

No	Country	Technical efficiency from CRS DEA	Technical efficiency from VRS DEA	Scale efficiency	Type of return to scale
1	Belgium	1	1	1	-
2	Bulgaria	1	1	1	-
3	Czech Republic	1	1	1	-
4	Estonia	0.993	1	0.993	increasing
5	France	0.633	0.698	0.907	decreasing
6	Greece	0.268	0.486	0.552	decreasing
7	Hungary	0.841	0.910	0.924	decreasing
8	Ireland	0.822	0.992	0.829	decreasing
9	Latvia	0.614	1	0.614	increasing
10	Lithuania	1	1	1	-
11	Luxembourg	1	1	1	-
12	Malta	1	1	1	-
13	Netherlands	0.717	0.734	0.977	increasing
14	Poland	0.668	0.778	0.858	decreasing
15	Portugal	0.544	0.718	0.758	decreasing
16	Romania	0.453	1	0.453	increasing
17	Slovakia	0.656	0.736	0.892	decreasing
18	Slovenia	0.665	0.678	0.982	decreasing
19	Spain	0.310	0.600	0.517	decreasing
20	UK	0.826	0.848	0.975	increasing
21	MEAN	0.751	0.859	0.862	

Table 2. Performance ranking. Source: authors' calculation in DEAP software

No.	Country	Performance
1	Belgium	1
2	Bulgaria	1
3	Czech Republic	1
4	Lithuania	1
5	Luxembourg	1
6	Malta	1
7	Estonia	0.993
8	Slovenia	0.982
9	Netherlands	0.977
10	United Kingdom	0.975
11	Hungary	0.924
12	France	0.907
13	Slovakia	0.892
14	Poland	0.858
15	Ireland	0.829

No.	Country	Performance
16	Portugal	0.758
17	Latvia	0.614
18	Greece	0.552
19	Spain	0.517
20	Romania	0.453

As shown by Vincova,³⁶ DEA aims both to determine the efficiency rate of the units in discussion, and find target values for inputs and outputs of the inefficient units. So, within table 3, we can find the projection summary, with radial and slack movements. The slack movements correspond to the input slacks (or excesses), while the radial movement corresponds to the output improvements. The results are important to stimulate those inefficient countries in input slacks.

For instance, for France, there are reported two slacks, one on Input 2 (the unemployment rate) and one on Input 3 (population with tertiary education level). This means that France could reduce the values of those two inputs with the reported slacks and remain with the same output. This information is relevant if talking about the unemployment rate, which should be lower. If considering Input 3, it seems that current level of education (which is relatively high as compared to other European countries) acts like a negative force and is considered in excess. So, more educated people are not in the same time the most aware persons in regard to environmental issues. This is signalling that more educational actions should be conducted to promote and raise awareness on WEEE collection and recycling.

The output improvement for France is reported at 3.154 kg per capita of collected WEEE. So, at the actual level of inputs, France is capable of collecting more WEEE. The analysis does not report any slack movements on Input 1, which is the minimum wage. So, current level of wages is supporting current level of collection activities. Input 2 represents the unemployment rate and Input 3 represents population with tertiary education level.

Table 3. Projection summary. Source: authors' calculation in DEAP software

No	Country	Variable	Original value	Radial movement	Slack movement	Projected value
1	Belgium	Output	10.763	0	0	10.763
		Input 1	1501.82	0	0	1501.82
		Input 2	8.4	0	0	8.4
		Input 3	2287.6	0	0	2287.6
2	Bulgaria	Output	4.84	0	0	4.84
		Input 1	158.5	0	0	158.5
		Input 2	13	0	0	13
		Input 3	1078.5	0	0	1078.5
3	Czech Republic	Output	5.156	0	0	5.156
		Input 1	318.08	0	0	318.08
		Input 2	7	0	0	7
		Input 3	1298	0	0	1298
4	Estonia	Output	3.534	0	0	3.534
		Input 1	320	0	0	320

³⁶ Vincova, K., "Using DEA models to measure efficiency," in *BLATEC*, Vol. XIII, 8, on http://www.nbs.sk/_img/Documents/BIATEC/BIA08_05/24_28.pdf (last time accessed: March 21, 2018).

		Input 2	8.6	0	0	8.6
		Input 3	281	0	0	281
5	France	Output	7.296	3.154	0	10.450
		Input 1	1430.22	0	0	1430.22
		Input 2	10.3	0	-1.699	8.601
		Input 3	11499.6	0	-9312.235	2187.365
6	Greece	Output	3.49	3.696	0	7.186
		Input 1	683.76	0	0	683.76
		Input 2	27.5	0	-16.805	10.695
		Input 3	1705.2	0	-562.830	1142.370
7	Hungary	Output	5.032	0.495	0	5.527
		Input 1	335.27	0	0	335.27
		Input 2	10.2	0	0	10.2
		Input 3	1294.5	0	-431.819	862.681
8	Ireland	Output	9.271	0.076	0	9.347
		Input 1	1461.85	0	0	1461.85
		Input 2	13.1	0	-5.218	7.882
		Input 3	1069.2	0	0	1069.2
9	Latvia	Output	2.398	0	0	2.398
		Input 1	286.66	0	0	286.66
		Input 2	11.9	0	0	11.9
		Input 3	359.4	0	0	359.4
10	Lithuania	Output	5.462	0	0	5.462
		Input 1	289.62	0	0	289.62
		Input 2	11.8	0	0	11.8
		Input 3	590.6	0	0	590.6
11	Luxem- bourg	Output	9.526	0	0	9.526
		Input 1	1874.19	0	0	1874.19
		Input 2	5.9	0	0	5.9
		Input 3	124.8	0	0	124.8
12	Malta	Output	4.025	0	0	4.025
		Input 1	702.82	0	0	702.82
		Input 2	6.4	0	0	6.4
		Input 3	49.1	0	0	49.1
13	Nether- lands	Output	6.992	2.534	0	9.526
		Input 1	1469.4	0	0	1469.4
		Input 2	7.3	0	0	7.3
		Input 3	3166.3	0	-1799.098	1367.202
14	Poland	Output	4.514	1.288	0	5.802
		Input 1	392.73	0	0	392.73
		Input 2	10.3	0	0	10.3
		Input 3	5769.6	0	-4863.414	906.186
15	Portugal	Output	4.786	1.884	0	6.670
		Input 1	565.83	0	0	565.83
		Input 2	16.4	0	-5.375	11.025
		Input 3	1208.5	0	-231.224	977.276
16	Romania	Output	1.548	0	0	1.548
		Input 1	157.5	0	0	157.5
		Input 2	7.1	0	0	7.1
		Input 3	1878.2	0	0	1878.2
17	Slovakia	Output	4.172	1.500	0	5.672

		Input 1	337.7	0	0	337.7
		Input 2	14.2	0	-2.535	11.665
		Input 3	686.7	0	-28.791	657.909
18	Slovenia	Output	4.145	1.972	0	6.117
		Input 1	783.66	0	0	783.66
		Input 2	10.1	0	-1.086	9.014
		Input 3	342.4	0	0	342.4
19	Spain	Output	4.494	2.994	0	7.488
		Input 1	752.85	0	0	752.85
		Input 2	26.1	0	-15.599	10.501
		Input 3	9463.4	0		1239.091
20	UK	Output	7.68	1.377	0	9.057
		Input 1	1249.85	0	0	1249.85
		Input 2	7.6	0	0	7.6
		Input 3	14139.6	0	-12485.03	1654.566

Table 4. Summary of peers and peers weights. Source: authors' calculation in DEAP software

No.	Country	Peer / Peer weight	Peer / Peer weight	Peer / Peer weight
1	Belgium	Belgium / 1.0		
2	Bulgaria	Bulgaria / 1.0		
3	Czech Republic	Czech Republic / 1.0		
4	Estonia	Estonia / 1.0		
5	France	Lithuania / 0.059	Belgium / 0.941	
6	Greece	Belgium / 0.325	Lithuania / 0.675	
7	Hungary	Czech Republic / 0.312	Belgium / 0.030	Lithuania / 0.658
8	Ireland	Belgium / 0.401	Luxembourg / 0.433	Lithuania / 0.166
9	Latvia	Latvia / 1.0		
10	Lithuania	Lithuania / 1.0		
11	Luxembourg	Luxembourg / 1.0		
12	Malta	Malta / 1.0		
13	Netherlands	Luxembourg / 0.361	Belgium / 0.498	Czech Republic / 0.141
14	Poland	Belgium / 0.079	Lithuania / 0.664	Czech Republic / 0.257
15	Portugal	Belgium / 0.228	Lithuania / 0.772	
16	Romania	Romania / 1.0		
17	Slovakia	Belgium / 0.040	Lithuania / 0.960	
18	Slovenia	Luxembourg / 0.248	Malta / 0.245	Lithuania / 0.507
19	Spain	Belgium / 0.382	Lithuania / 0.618	
20	United Kingdom	Belgium / 0.563	Czech Republic / 0.267	Netherlands / 0.171

Table 4 summarizes peers and their weights, which mean the reference countries that are efficient and whose examples should be studied by the country under discussion in an effort to use good practices and increase their level of efficiency³⁷ or performance. Note that out of the best performers, Belgium and Lithuania are the ones that appear more often as peers.

³⁷ Barba-Gutiérrez, Y., Adenso-Díaz, B., & Lozano, S., "Eco-Efficiency of Electric and Electronic Appliances: A Data Envelopment Analysis (DEA)," *Environmental Modeling & Assessment* 14 (2009): 439–447.

V. Conclusions

Using the DEA method, we managed to measure a relative performance of WEEE collection in several countries from European Union. In the same time, DEA pointed out the benchmarks for those countries that did not performed so well, according to the scale efficiency score. It has also projected some values, possible to achieve by each country if making the necessary changes in inputs. By revealing the best performers in terms of e-waste collection, one can deepen the knowledge in order to understand and reveal the best practices that contributed to obtaining the reported efficiency. In the same time, by revealing best practices, the countries with a lower performance, can follow up and improve those activities in order to increase collection performance. This claims a further analysis and the development of certain measures to be implemented according to each country's legislative and policy environment.

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