Regional environmental efficiency in waste generation

Halkos, George and Petrou, Kleoniki Natalia

Department of Economics, University of Thessaly

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George Halkos and Kleoniki Natalia Petrou
Laboratory of Operations Research,
Department of Economics, University of Thessaly

Abstract
This paper employs Data Envelopment Analysis (DEA) to consider waste generation at a regional level in the European Union (EU). By doing so both good and bad outputs are taken into account and different frameworks are designed. Five parameters (waste generation, employment rate, capital formation, GDP and population density) are used for 172 EU regions and for the years 2009, 2011 and 2013. In doing so four frameworks have been designed with different inputs and outputs each time. The results show the more efficient EU regions according to each framework, but it should be noted that results from different frameworks should not be compared to each other. Overall results suggest that the highest performers are regions in Belgium, Italy, Portugal and the UK. Finally the efficiency results from DEA were reviewed against the treatment options employed in the relevant regions. Our findings show that although a country might be efficient according to DEA and by taking many factors into consideration, it is not necessary that regions within a country use sustainable waste treatment options as it is essential to account for trade and shipment of waste between regions and countries as well.

Keywords: Environmental efficiency; waste generation; EU regions; DEA.

JEL Codes: C6; O13; O52; Q50; Q53; Q56; R11.

1. Introduction

Waste disposals have been increasing over the past few years, hence their management has proved to be a rather challenging issue of the 21st century and a lot of research is being conducted in this field (Halkos and Petrou, 2016). Waste arisings and composition of waste differs not only across countries, but also by region according but not limited to the following factors (Eunomia, 2015): socioeconomic status, consumption habits, season, whether or not households have gardens and presence (or not) of tourists. These factors have been analyzed in various ways but most methods used in economic efficiency analysis are mainly quantitative, although qualitative approaches (such as brainstorming, SWOT analysis, the Delphi method) can be used too, usually to support quantitative findings attained through (Soukopová, 2011):

a) Either single-criterion techniques: integrating several indicators into one (e.g. multiple input-to-output ratios into a single efficiency score in the case of DEA)
b) Or multi-criteria analysis: keeping individual criteria separate to obtain a wider angle for assessment, often including non-economic perspectives.

Our paper deals with waste generation at a regional level in the European Union and employs Data Envelopment Analysis (DEA). By doing so both good and bad outputs are taken into account and different frameworks are designed. Data Envelopment Analysis (DEA) is a non-parametric approach that is used to measure the efficiency of certain Decision Making Units (DMUs) by employing linear programming techniques (Boussofiane et al., 1991). Then DEA assigns each DMU into an efficient frontier and produces an optimization model which in turn produces lower values for the inputs and higher values for the outputs (Lozano et al., 2009). DEA compares each DMU with all other and shows the ones that are operating inefficiently compared to the others by identifying best practice scenarios (Sherman and Zhu, 2006). One DMU is considered efficient, if there is no other operating point that is above this one; therefore if there is a point where less input is consumed or more output is produced then the DMU is considered inefficient (Lozano et al., 2009). The DEA frontier can act as the production frontier, but it must be noted that DEA is a method for performance evaluation and benchmarking against best-practice (Cook et al., 2014). DEA models treat bad outputs in various ways. Specifically, undesirable outputs are treated as inputs for processing (Berg et al., 1992; Hailu and Veeman, 2001), although this does not reflect the actual production process (Seiford and Zhu, 2002); data for undesirable outputs are transformed and those are used in evaluating environmental efficiency (Seiford and Zhu, 2002; Hua et al., 2007); The disposability of the production technology is considered, which is suggested by Fare et al. (1989; 1993; 2004; 2005) and further developed through other researchers too (Tyteca, 1996; Zhou et al., 2008; Tone, 2001; Tone, 2004; Halkos and Tseremes, 2007).

In DEA the DMUs that are efficient are defined by a rating of 1 (or 100%) and these ratings then form the efficiency frontier including the rest (not so efficient) DMUs; this rating provides a realistic and practical value of what a certain DMU has achieved and what can be further achieved by the other DMUs (Dostalova, 2014). Thus DEA disregards the ideal of efficiency according to the economic theory and focuses mostly on real and so far-from-ideal DMUs (Jablonský & Dlouhý, 2000). With time, extensions and additions have been done to DEA modeling techniques. One of those that shows a good potential is Network DEA which accounts for the relative efficiency of a system, by taking into account its whole structure thus providing more informative and useful results (Kao, 2014).

2. Background

Some recent studies have employed DEA to evaluate the efficiency of waste management (Bosch et al., 2000; Worthington and Dollery, 2001; Moore et al., 2005; Marques and Simões, 2009; Simões et al., 2010; Benito et al., 2010; Chen et al., 2010; De Jaeger et al., 2011; Chen and Chen, 2012;). Further modifications are being made to DEA so that it can better capture the full complexity of the process, for instance Rogge and De Jaeger (2012; 2013) suggested a way to differentiate performance efficiency by the main municipal solid waste components. Some regulating bodies and governments are using DEA also in their waste management policies, such as Spain and Australia (Simões et al., 2010).

Most waste-related studies which employ DEA simply focus on waste or pollution as an undesirable output within the standard DEA framework (Scheel, 2001; Seiford and Zhu, 2002). DEA has been also applied to measure the environmental performance at both micro and macro levels (Kortelainen and Kuosmanen, 2005; frameworks by Sarkis, 1999; Zaim, 2004; chemical and pharmaceutical firms in Sueyoshi and Goto, 2014):

- investment into waste treatment technologies (Sarkis & Weinrach, 2001),
- waste prevention vs. ecological treatment and recycling (Sarkis & Cordeiro, 2001),
- carbon dioxide emissions on a national level (Ramanathan, 2002, 2005; Kumar,2006; Wang et al., 2012).

In this paper regional EU data (NUTS level 2) was used for 172 regions from 17 countries and for the years 2009, 2011 and 2013.[1] According to the 1961 Brussels Conference on Regional Economies, NUTS 2 regional classification[2] is the most common framework used by Member States to apply their regional policies and therefore is the most appropriate level for analysing regional environmental problems (Eurostat, 2007). The parameters used, are counted as presented below:

- Regional waste arisings: waste generated (thousand tonnes)
- Regional employment rate: thousand number of people
- Regional gross fixed capital formation: current prices (million €)

[1] Regions (in parentheses) examined by country are Austria (7), Belgium (11), Bulgaria (6), Czech Republic (9), Estonia (1), Germany (36), Hungary (6), Italy (21), Latvia (1), Lithuania (1), Luxembourg (1), Malta (1), Netherlands (12), Poland (16), Portugal (7), Slovakia (4), UK (33).
[2] Further information on NUTS classification : http://ec.europa.eu/eurostat/web/nuts/overview

- Regional GDP (as proxy of economic development) [3]: current prices (million €)
- Regional population density: persons per km^2

2.1 Overall issues regarding missing variables in the current analysis

An issue that arose in the current analysis was that some data were missing in the regional statistics for DEA. This created some problems in analysing and contrasting data among different countries/regions.

In order to be able to handle missing data, it is vital to know why they are missing; there are three general 'missingness mechanisms' (Gelman and Hill, 2007; IDRE, 2016):

- Missing completely at random (MCAR): neither the unobserved values of the variable with missing nor the other variables in the dataset predict whether a value will be missing.
- Missing at random (MAR): other variables (but not the variable with missing itself) in the dataset can be used to predict missingness.
- Missing not at random (MNAR): the unobserved value of the variable with missing predicts missingness.

As far as this DEA analysis is concerned, the following assumptions had to be made to replace some missing values in the regional data:

1. Data on waste arising for the UK were missing for 2013 and as waste is the most important parameter in question for this project, it was assumed that waste arisings remained the same between 2011 and 2013.
2. Data on population density were missing for Leipzig and Thüringen for 2009, so 2011 data were used.
3. Also data for population density were missing for Nord-Est and Zuid-Nederland for all the examined years. To resolve this for Nord-Est the sum of Emilia-Romagna, Friuli-

[3] For the determinants of the environment and development relationship see among others Halkos (1992, 2003, 2011, 2013) and Halkos and Tsionas (2001).

Venezia Giulia and Trentino-Alto Adige e Veneto was used as Nord-Est consists of these regions. For Zuid-Nederland the relevant country's average was used.

3. DEA modeling results – Regional level (17 EU countries, 172 regions)

Table 1 presents the descriptive statistics of the inputs and outputs used in the different DEA model formulations and for all the years in question for the 172 regions.

Table 1: Descriptive statistics for all years and regions

	Regional GDP	Waste	Employment rate	Capital investment	Population density
2009					
Mean	44,368.44	847.95	81.13	8,937.98	387.05
St. dev	49,191.21	672.81	58.43	9,941.54	758.27
Min	2,816.00	79.37	3.00	455.06	11.40
Max	347,444.00	4,925.13	291.50	74,342.44	6,702.10
2011					
Mean	48,075.32	827.83	76.03	9,645.91	389.68
St. dev	52,355.63	662.81	55.53	10,506.05	778.63
Min	2,948.00	78.42	2.7	428.36	11.50
Max	367,536.00	4,824.17	266.70	74,588.87	7,131.10
2013					
Mean	49,583.85	801.78	72.58	9,405.29	393.90
St. dev	52,647.66	632.13	54.61	9,834.63	796.81
Min	2,951.00	72.59	2.5	501.18	11.50
Max	362,494.00	4,594.69	264.00	66,607.77	7,324.40

3.1 Presentation of four environmental production frameworks on regional analysis

The present analysis builds on the work by Halkos and Papageorgiou (2014, 2015) and furthers it by using more inputs and outputs and more recent EU data. The frameworks that have been designed are also based on their analysis with new additions in the inputs taken into account. More specifically in terms of methodology, first one of the pollutants in question, MSW generation is modelled as a regular output by applying the transformation introduced by Seiford and Zhu (2002, 2005). This is done in the first framework (M1). Then the pollutant is treated as a regular input following studies treating pollutants as costs which the main goal is its minimisation, which is performed in M2 and M3 each time with slightly different inputs. In Framework M4 the idea of eco-efficiency is used as introduced by Kuosmanen and Kortelainen (2005) and Kortelainen (2008). For all the regions in the DEA analysis a radial model was used, which is output oriented and with variable returns to scale.

3.2 Results of the DEA regional level study

Under the M1 framework the highest performers over the years 2009-2013 are: Région de Bruxelles-Capitale (Belgium), Yuzhen tsentralen (Bulgaria), Düsseldorf (Germany), Valle d'Aosta (Italy), Liguria (Italy), Lombardia (Italy), Nord-Est (Italy), Lazio (Italy), Sicilia (Italy), Luxembourg (Luxembourg), Algarve (Portugal), Greater Manchester (UK), Surrey, East and West Sussex (UK); whereas the areas with the lowest performers are: Flevoland (Netherlands), North Eastern Scotland (UK), Severozápad (Bulgaria), Zeeland (Netherlands), Trier (Germany), Jihozápad (Czech Republic), Strední Cechy (Czech Republic), Eesti (Estonia), Highlands and Islands (UK), Moravskoslezsko (Czech Republic), Prague (Czech Republic).

When using framework M2 and by treating the bad output as input, the highest performers are: Bremen (Germany), Greater Manchester (UK), Luxembourg (Luxembourg), Région de Bruxelles-Capitale (Belgium), Düsseldorf (Germany), Valle d'Aosta (Italy), Lombardia (Italy), Nord-Est (Italy), Lazio (Italy), Surrey, East and West Sussex (UK). The lowest performers are: Yugoiztochen (Bulgaria), Strední Cechy (Czech Republic), Severozápad (Czech Republic), Highlands and Islands (UK), Dél-Dunántúl (Hungary), Zeeland (Netherlands), North Eastern Scotland (UK), Észak-Alföld (Hungary), Yugozapadna i yuzhna tsentralna (Bulgaria) and Flevoland (Netherlands).

Framework M3 is similar to M2 but with the addition of an extra parameter, population density. In this one the highest performers are: Region de Bruxelles-Capitale (Belgium), Severozapaden (Bulgaria), Düsseldorf (Germany), Valle d'Aosta/Vallée d'Aoste (Italy), Lombardia (Italy), Nord-Est (Italy), Emilia-Romagna (Italy), Toscana (Italy), Lazio (Italy), Luxembourg (Luxembourg), Zuid-Nederland (Nerherlands), Região Autónoma dos Açores (Portugal), Surrey, East and West Sussex and Highlands and Islands (both UK). Under this framework the worse performers are: Flevoland (Netherlands), Severozápad (Czech Republic), Strední Cechy (Czech Republic), Zeeland (Netherlands), Moravskoslezsko (Czech Republic), Yugoiztochen (Bulgaria), Dél-Dunántúl (Hungary), Észak-Alföld (Hungary), Podkarpackie (Poland), Nyugat-Dunántúl (Hungary) and Praha (Czech Republic).

From framework M4, the highest performers are: Lombardia (Italy), Valle d'Aosta (Italy), Nord-Est (Italy), whereas the lowest ones are: Severozapaden (Bulgaria), Severen tsentralen (Bulgaria), Severoiztochen (Bulgaria), Yugoiztochen (Bulgaria), Yuzhen tsentralen (Bulgaria), Dél-Dunántúl (Hungary), Malta (Malta), Észak-Magyarország (Hungary), Algarve (Portugal), Opolskie (Poland).

As it is evident from this analysis, different frameworks return different results, namely the results from M1 are much different to M2, M3 and M4 which show a kind of similar picture overall. This difference can be explained by the fact that in M1 the bad output (waste generation) is actually considered as output, whereas in the other three frameworks it is considered as a normal input. Table 2 shows the average scores of each region for all the years divided by the framework option.[4]

The results of each framework cannot be compared to each other though as different assumptions are taken into account under each modelling framework. According to EEA (European Environment Agency, 2015) and other researchers, there are fluctuations in waste generation not only among the countries but also among regions within a country, which is due to the fact that there are separate waste management strategies among the regions themselves as well. This study's results are in agreement with this idea, as it was shown that certain regions from one country can be at the top environmental performers whereas other regions from the same one can be among the lowest ones.

[4] The Table presenting in detail the results of M1, M2, M3 and M4 frameworks for all regions for years 2009, 2011 and 2013 are not presented here but is available on request.

Furthermore table 3 presents the descriptive statistics per country of the different environmental frameworks over the examined period. The results show that on average terms the environmental efficiency scores regarding waste arising on a regional level are higher in framework M1 compared to the environmental efficiency scores from M2, M3 and M4. Overall the results obtained (on average terms) from M1 suggest that Belgium has higher environmental efficient regions followed by the regions in Italy, Portugal and the UK.

Table 2: Average scores of each region for all the years divided by framework

	M1	M2	M3	M4
Region	**Average**	**Average**	**Average**	**Average**
Région de Bruxelles-Capitale / Brussels Hoofdstedelijk Gewest	1.000	1.000	1.000	0.193
Prov. Antwerpen	0.694	0.723	0.775	0.196
Prov. Limburg (BE)	0.636	0.622	0.672	0.065
Prov. Oost-Vlaanderen	0.620	0.627	0.679	0.125
Prov. Vlaams-Brabant	0.729	0.729	0.806	0.110
Prov. West-Vlaanderen	0.602	0.604	0.658	0.105
Prov. Brabant Wallon	0.709	0.715	0.769	0.078
Prov. Hainaut	0.749	0.721	0.772	0.081
Prov. Liège	0.712	0.703	0.763	0.075
Prov. Luxembourg (BE)	0.722	0.687	0.779	0.032
Prov. Namur	0.682	0.682	0.754	0.044
Severozapaden	0.935	0.887	1.000	0.008
Severen tsentralen	0.991	0.887	0.948	0.009
Severoiztochen	0.872	0.587	0.656	0.012
Yugoiztochen	0.848	0.479	0.577	0.014
Yugozapadna i yuzhna tsentralna Bulgaria	0.729	0.533	0.658	0.069
Yuzhen tsentralen	1.000	0.606	0.687	0.016
Praha	0.570	0.605	0.634	0.109
Strední Cechy	0.550	0.488	0.563	0.047
Jihozápad	0.547	0.545	0.711	0.044
Severozápad	0.528	0.503	0.563	0.036
Severovýchod	0.638	0.620	0.722	0.051
Jihovýchod	0.576	0.562	0.666	0.064
Strední Morava	0.600	0.569	0.636	0.041
Moravskoslezsko	0.564	0.540	0.576	0.043
Stuttgart	0.740	0.771	0.822	0.454
Karlsruhe	0.752	0.794	0.833	0.279
Freiburg	0.676	0.727	0.810	0.191
Tübingen	0.630	0.698	0.772	0.173
Oberbayern	0.687	0.705	0.926	0.569
Niederbayern	0.694	0.748	0.896	0.104
Oberpfalz	0.637	0.701	0.829	0.099
Oberfranken	0.744	0.747	0.871	0.088
Mittelfranken	0.620	0.659	0.721	0.168

Unterfranken	0.752	0.787	0.916	0.119
Schwaben	0.643	0.688	0.782	0.162
Berlin	0.832	0.857	0.857	0.297
Brandenburg	0.664	0.689	0.862	0.160
Bremen	0.927	0.965	0.965	0.077
Hamburg	0.734	0.792	0.812	0.267
Darmstadt	0.864	0.902	0.925	0.462
Gießen	0.703	0.719	0.789	0.083
Kassel	0.720	0.744	0.862	0.103
Mecklenburg-Vorpommern	0.617	0.641	0.827	0.101
Braunschweig	0.661	0.686	0.767	0.149
Hannover	0.808	0.810	0.887	0.188
Lüneburg	0.633	0.627	0.767	0.108
Weser-Ems	0.629	0.649	0.753	0.199
Düsseldorf	1.000	1.000	1.000	0.510
Köln	0.889	0.900	0.932	0.426
Münster	0.788	0.795	0.839	0.207
Detmold	0.801	0.849	0.892	0.181
Arnsberg	0.895	0.905	0.944	0.297
Koblenz	0.706	0.716	0.815	0.116
Trier	0.538	0.570	0.662	0.037
Rheinhessen-Pfalz	0.697	0.705	0.758	0.175
Saarland	0.836	0.839	0.882	0.087
Dresden	0.579	0.640	0.695	0.109
Chemnitz	0.668	0.725	0.775	0.094
Leipzig	0.642	0.715	0.753	0.072
Thüringen	0.649	0.676	0.801	0.138
Eesti	0.553	0.547	0.873	0.046
Piemonte	0.778	0.795	0.936	0.345
Valle d'Aosta/Vallée d'Aoste	1.000	1.000	1.000	1.000
Liguria	1.000	0.884	0.933	0.130
Lombardia	1.000	1.000	1.000	0.958
Nord-Est	1.000	1.000	1.000	1.000
Provincia Autonoma di Bolzano/Bozen	0.616	0.629	0.763	0.055
Veneto	0.844	0.867	0.904	0.406
Friuli-Venezia Giulia	0.803	0.772	0.851	0.097
Emilia-Romagna	0.953	0.887	1.000	0.393
Toscana	0.988	0.941	1.000	0.297
Umbria	0.875	0.811	0.883	0.061
Marche	0.897	0.849	0.917	0.111
Lazio	1.000	1.000	1.000	0.513
Abruzzo	0.744	0.653	0.720	0.087
Molise	0.932	0.894	0.943	0.054
Campania	0.995	0.923	0.931	0.282
Puglia	0.922	0.828	0.869	0.196
Basilicata	0.877	0.819	0.887	0.036

Calabria	0.889	0.696	0.750	0.091
Sicilia	1.000	0.919	0.955	0.246
Sardegna	0.892	0.767	0.954	0.093
Latvija	0.674	0.562	0.889	0.057
Lietuva	0.962	0.702	0.979	0.086
Luxembourg	1.000	0.989	1.000	0.116
Közép-Magyarország	0.887	0.863	0.892	0.133
Nyugat-Dunántúl	0.784	0.551	0.626	0.027
Dél-Dunántúl	0.800	0.515	0.606	0.018
Észak-Magyarország	0.824	0.585	0.650	0.020
Észak-Alföld	0.845	0.528	0.610	0.026
Dél-Alföld	0.771	0.549	0.654	0.024
Malta	0.767	0.824	0.824	0.020
Groningen	0.868	0.922	0.961	0.082
Friesland (NL)	0.679	0.647	0.687	0.049
Drenthe	0.732	0.702	0.735	0.037
Overijssel	0.658	0.702	0.718	0.099
Gelderland	0.691	0.640	0.675	0.180
Flevoland	0.466	0.539	0.555	0.042
Utrecht	0.694	0.766	0.777	0.157
Noord-Holland	0.850	0.906	0.907	0.350
Zuid-Holland	0.741	0.766	0.767	0.380
Zeeland	0.532	0.525	0.569	0.031
Zuid-Nederland	0.745	0.808	1.000	0.360
Limburg (NL)	0.682	0.713	0.726	0.097
Wien	0.713	0.734	0.739	0.221
Kärnten	0.657	0.686	0.900	0.047
Steiermark	0.626	0.663	0.844	0.108
Oberösterreich	0.665	0.701	0.845	0.144
Salzburg	0.625	0.669	0.832	0.062
Tirol	0.583	0.615	0.819	0.075
Vorarlberg	0.693	0.894	0.909	0.087
Lódzkie	0.739	0.589	0.688	0.062
Mazowieckie	0.831	0.740	0.890	0.219
Malopolskie	0.800	0.663	0.713	0.078
Slaskie	0.932	0.688	0.713	0.129
Lubelskie	0.665	0.600	0.740	0.040
Podkarpackie	0.581	0.546	0.623	0.039
Swietokrzyskie	0.636	0.700	0.781	0.028
Podlaskie	0.634	+0.592	0.770	0.023
Wielkopolskie	0.838	0.694	0.851	0.096
Zachodniopomorskie	0.758	0.612	0.741	0.038
Lubuskie	0.673	0.624	0.724	0.022
Dolnoslaskie	0.791	0.649	0.761	0.085
Opolskie	0.687	0.687	0.753	0.022
Kujawsko-Pomorskie	0.736	0.601	0.706	0.045
Warminsko-Mazurskie	0.687	0.605	0.782	0.027
Pomorskie	0.708	0.563	0.666	0.058

Norte	0.888	0.706	0.818	0.138
Algarve	1.000	0.761	0.843	0.020
Centro (PT)	0.863	0.761	0.932	0.091
Área Metropolitana de Lisboa	0.969	0.926	0.932	0.181
Alentejo	0.729	0.623	0.976	0.031
Região Autónoma dos Açores (PT)	0.932	0.946	1.000	0.026
Região Autónoma da Madeira (PT)	0.927	0.9F08	0.908	0.038
Bratislavský kraj	0.603	0.599	0.670	0.054
Západné Slovensko	0.765	0.693	0.798	0.062
Stredné Slovensko	0.686	0.647	0.801	0.038
Východné Slovensko	0.705	0.676	0.796	0.039
Tees Valley and Durham	0.765	0.712	0.714	0.067
Northumberland and Tyne and Wear	0.798	0.772	0.798	0.090
Cumbria	0.803	0.828	0.983	0.034
Greater Manchester	1.000	0.986	0.986	0.186
Lancashire	0.937	0.910	0.917	0.091
East Yorkshire and Northern Lincolnshire	0.872	0.855	0.864	0.060
North Yorkshire	0.844	0.832	0.981	0.059
South Yorkshire	0.797	0.797	0.797	0.078
West Yorkshire	0.947	0.943	0.943	0.156
Derbyshire and Nottinghamshire	0.848	0.812	0.813	0.138
Leicestershire, Rutland and Northamptonshire	0.819	0.816	0.827	0.123
Lincolnshire	0.650	0.642	0.746	0.043
Herefordshire, Worcestershire and Warwickshire	0.790	0.786	0.826	0.092
Shropshire and Staffordshire	0.877	0.850	0.881	0.097
West Midlands	0.960	0.922	0.922	0.180
East Anglia	0.678	0.694	0.807	0.181
Bedfordshire and Hertfordshire	0.886	0.902	0.916	0.147
Essex	0.897	0.890	0.893	0.116
Berkshire, Buckinghamshire and Oxfordshire	0.839	0.885	0.915	0.253
Surrey, East and West Sussex	1.000	1.000	1.000	0.234
Hampshire and Isle of Wight	0.716	0.762	0.771	0.159
Kent	0.874	0.856	0.865	0.115
Gloucestershire, Wiltshire and Bristol/Bath area	0.817	0.840	0.910	0.200
Dorset and Somerset	0.837	0.835	0.885	0.086
Cornwall and Isles of Scilly	0.706	0.705	0.735	0.031
Devon	0.787	0.778	0.851	0.073
West Wales and The Valleys	0.853	0.752	0.893	0.100
East Wales	0.791	0.779	0.891	0.078
Eastern Scotland	0.778	0.732	0.917	0.153
South Western Scotland	0.757	0.687	0.822	0.159
North Eastern Scotland	0.479	0.526	0.691	0.057
Highlands and Islands	0.555	0.512	1.000	0.032
Northern Ireland (UK)	0.681	0.643	0.770	0.114

Table 3: Descriptive statistics of regions' environmental efficiency estimates grouped by country

Belgium (11 regions)		2009	2011	2013	Bulgaria (6 regions)		2009	2011	2013
Model 1-M1	*mean*	0.761	0.716	0.666	**Model 1-M1**	*mean*	0.894	0.886	0.907
	std	0.110	0.104	0.122		*std*	0.121	0.128	0.120
	min	0.628	0.611	0.567		*min*	0.749	0.700	0.720
	max	1.000	1.000	1.000		*max*	1.000	1.000	1.000
Model 2-M2	*mean*	0.754	0.686	0.691	**Model 2-M2**	*mean*	0.668	0.708	0.613
	std	0.107	0.112	0.115		*std*	0.260	0.181	0.137
	min	0.631	0.583	0.585		*min*	0.439	0.572	0.414
	max	1.000	1.000	1.000		*max*	1.000	1.000	0.817
Model 3-M3	*mean*	0.805	0.756	0.737	**Model 3-M3**	*mean*	0.709	0.779	0.774
	std	0.096	0.093	0.101		*std*	0.226	0.129	0.196
	min	0.682	0.662	0.631		*min*	0.508	0.661	0.517
	max	1.000	1.000	1.000		*max*	1.000	1.000	1.000
Model 4 -M4	*mean*	0.097	0.100	0.104	**Model 4 -M4**	*mean*	0.020	0.021	0.022
	std	0.052	0.053	0.057		*std*	0.022	0.024	0.024
	min	0.029	0.031	0.034		*min*	0.008	0.008	0.008
	max	0.188	0.195	0.206		*max*	0.066	0.070	0.071
Czech Republic (8 regions)		**2009**	**2011**	**2013**	**Germany (36 regions)**		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.581	0.588	0.546	**Model 1-M1**	*mean*	0.756	0.731	0.684
	std	0.025	0.042	0.056		*std*	0.109	0.113	0.104
	min	0.552	0.511	0.466		*min*	0.596	0.526	0.487
	max	0.632	0.651	0.633		*max*	1.000	1.000	1.000
Model 2-M2	*mean*	0.561	0.536	0.564	**Model 2-M2**	*mean*	0.791	0.740	0.732
	std	0.042	0.055	0.057		*std*	0.097	0.113	0.096
	min	0.514	0.452	0.476		*min*	0.618	0.531	0.561
	max	0.628	0.609	0.636		*max*	1.000	1.000	1.000
Model 3-M3	*mean*	0.641	0.633	0.627	**Model 3-M3**	*mean*	0.871	0.831	0.799
	std	0.040	0.084	0.078		*std*	0.077	0.092	0.081
	min	0.605	0.524	0.535		*min*	0.735	0.621	0.615
	max	0.717	0.759	0.726		*max*	1.000	1.000	1.000
Model 4 -M4	*mean*	0.053	0.056	0.054	**Model 4 -M4**	*mean*	0.187	0.195	0.206
	std	0.024	0.024	0.023		*std*	0.129	0.133	0.142
	min	0.037	0.037	0.035		*min*	0.036	0.037	0.040
	max	0.109	0.111	0.107		*max*	0.530	0.563	0.613
Italy (21 regions)		**2009**	**2011**	**2013**	**Hungary (6 regions)**		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.909	0.909	0.896	**Model 1-M1**	*mean*	0.928	0.853	0.674
	std	0.095	0.106	0.119		*std*	0.104	0.086	0.183
	min	0.682	0.591	0.573		*min*	0.787	0.753	0.480
	max	1.000	1.000	1.000		*max*	1.000	1.000	0.932
Model 2-M2	*mean*	0.839	0.834	0.889	**Model 2-M2**	*mean*	0.635	0.609	0.551
	std	0.113	0.123	0.116		*std*	0.098	0.171	0.141
	min	0.647	0.593	0.618		*min*	0.512	0.527	0.477
	max	1.000	1.000	1.000		*max*	0.793	0.958	0.836
Model 3-M3	*mean*	0.895	0.911	0.936	**Model 3-M3**	*mean*	0.689	0.686	0.644

	std	0.094	0.082	0.092
	min	0.692	0.732	0.696
	max	1.000	1.000	1.000
Model 4 -M4	*mean*	0.309	0.307	0.305
	std	0.314	0.315	0.315
	min	0.034	0.038	0.038
	max	1.000	1.000	1.000

Netherlands (12 regions)		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.665	0.714	0.705
	std	0.095	0.145	0.110
	min	0.478	0.437	0.484
	max	0.827	1.000	0.896
Model 2-M2	*mean*	0.695	0.713	0.751
	std	0.116	0.154	0.110
	min	0.504	0.490	0.575
	max	0.865	1.000	0.933
Model 3-M3	*mean*	0.753	0.738	0.778
	std	0.134	0.165	0.125
	min	0.585	0.490	0.590
	max	1.000	1.000	1.000
Model 4 -M4	*mean*	0.155	0.154	0.157
	std	0.135	0.131	0.135
	min	0.030	0.031	0.031
	max	0.389	0.371	0.380

Poland (16 regions)		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.753	0.730	0.710
	std	0.105	0.122	0.082
	min	0.619	0.532	0.560
	max	1.000	0.908	0.890
Model 2-M2	*mean*	0.675	0.589	0.641
	std	0.077	0.098	0.071
	min	0.468	0.435	0.525
	max	0.788	0.785	0.768
Model 3-M3	*mean*	0.749	0.726	0.757
	std	0.080	0.096	0.084
	min	0.544	0.560	0.606
	max	0.840	0.949	0.909
Model 4 -M4	*mean*	0.057	0.065	0.068
	std	0.046	0.053	0.056
	min	0.020	0.022	0.023
	max	0.192	0.225	0.241

Slovakia (4 regions)		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.683	0.657	0.729
	std	0.075	0.086	0.166
	min	0.586	0.562	0.484

	std	0.094	0.146	0.116
	min	0.562	0.596	0.548
	max	0.828	0.980	0.868
Model 4 -M4	*mean*	0.041	0.041	0.042
	std	0.045	0.045	0.045
	min	0.018	0.017	0.018
	max	0.133	0.132	0.135

Austria (7 regions)		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.689	0.667	0.599
	std	0.048	0.055	0.050
	min	0.630	0.583	0.535
	max	0.755	0.727	0.695
Model 2-M2	*mean*	0.748	0.701	0.677
	std	0.116	0.115	0.048
	min	0.641	0.592	0.614
	max	0.994	0.938	0.751
Model 3-M3	*mean*	0.887	0.855	0.782
	std	0.090	0.062	0.029
	min	0.749	0.738	0.732
	max	1.000	0.938	0.820
Model 4 -M4	*mean*	0.105	0.105	0.110
	std	0.059	0.059	0.062
	min	0.046	0.047	0.049
	max	0.218	0.218	0.229

Portugal (7 regions)		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.869	0.920	0.915
	std	0.094	0.110	0.092
	min	0.739	0.690	0.760
	max	1.000	1.000	1.000
Model 2-M2	*mean*	0.747	0.799	0.867
	std	0.145	0.156	0.109
	min	0.612	0.544	0.714
	max	1.000	1.000	1.000
Model 3-M3	*mean*	0.840	0.929	0.978
	std	0.098	0.075	0.059
	min	0.717	0.810	0.844
	max	1.000	1.000	1.000
Model 4 -M4	*mean*	0.076	0.074	0.076
	std	0.068	0.063	0.060
	min	0.021	0.020	0.020
	max	0.191	0.180	0.173

UK (33 regions)		**2009**	**2011**	**2013**
Model 1-M1	*mean*	0.838	0.829	0.754
	std	0.109	0.136	0.138
	min	0.586	0.359	0.315

	max	0.764	0.762	0.843		*max*	1.000	1.000	1.000
Model 2-M2	*mean*	0.674	0.575	0.713	**Model 2-M2**	*mean*	0.831	0.790	0.764
	std	0.061	0.048	0.144		*std*	0.116	0.136	0.133
	min	0.614	0.535	0.502		*min*	0.537	0.403	0.361
	max	0.759	0.634	0.820		*max*	1.000	1.000	1.000
Model 3-M3	*mean*	0.763	0.715	0.821	**Model 3-M3**	*mean*	0.885	0.870	0.839
	std	0.073	0.067	0.196		*std*	0.096	0.110	0.101
	min	0.685	0.618	0.530		*min*	0.628	0.510	0.565
	max	0.862	0.769	0.953		*max*	1.000	1.000	1.000
Model 4 -M4	*mean*	0.046	0.048	0.051	**Model 4 -M4**	*mean*	0.107	0.112	0.125
	std	0.011	0.012	0.012		*std*	0.054	0.057	0.064
	min	0.036	0.038	0.040		*min*	0.029	0.030	0.034
	max	0.059	0.062	0.065		*max*	0.229	0.249	0.280

4. Discussion

The efficiency scores obtained through DEA have been reviewed against the treatment options that have been employed in each region and which for this analysis are divided in landfill, incineration, material recycling and composting. Data for the treatment options have been obtained from Eurostat as well. First of all it is worth mentioning that overall in the EU a decrease in the use of landfill and an increase in the use of more sustainable treatment options has been noticed over the period 1995-2015.

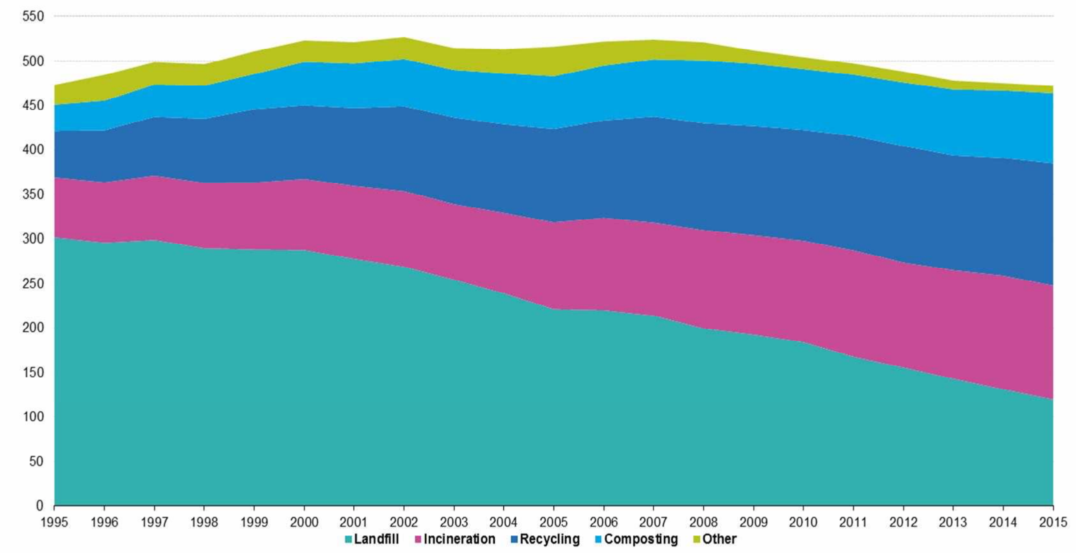

Figure 1: Municipal waste treatment per treatment option (1995-2015) (Eurostat, 2017)

The aim of the comparison in this analysis was to investigate whether regions with the use of more sustainable treatment options are the ones that are the highest performers regarding efficiency based on the DEA analysis. Table 4 presents the treatment options that have been used for the highest performing regions, whereas table 5 presents those options for the lowest performers.[5]

Table 4: Treatment options for highest performers overall (Y – yes, N – no)

Most frameworks – high performers	**Landfill**	**Incineration**	**Material Recycling**	**Composting**
Brussels	N	Y – most treated	Y	Y
Yuzhen tsentralen	Y	No data	No data	No data
Düsseldorf	No data	Y –most treated	Y	Y
Valle d'Aosta	Y – most treated	N	No data	Y
Liguria	Y	N	No data	Y
Lombardia	Y	Y	No data	Y
Lazio	Y	Y	No data	Y
Sicilia	Y	N	No data	Yes
Luxembourg	Y	Y – most treated	Y	Y
Algarve	Y	N	Y	Y
Manchester	Y	Y	Y	Y
Surrey etc.	Y	Y	Y	Y

Table 5: Treatment options for lowest performers overall (Y – yes, N – no)

Most frameworks – lowest performers	**Landfill**	**Incineration**	**Material Recycling**	**Composting**
Severozápaden	Y	No data	No data	No data
Zeeland	Y	Y – most treated	Y	Y
Flevoland	Y	Y – most treated	Y	y
Strední Cechy	No data	No data	No data	No data
Dél-Dunántúl	Y – most treated	N	Y	Y
North Eastern Scotland	Y – most treated	N	Y	Y
Észak-Alföld	Y – most treated	N	Y	Y

It was noticed that higher performing regions generally employ all four treatment options and for some landfill is still in extensive use for the majority of the waste treated. In Brussels and Luxembourg metropolitan regions incineration is mostly used instead. On the

[5] For the implementation of environmental management systems standards see Evangelinos and Halkos (2002) and Halkos and Evangelinos (2002).

other hand for the lowest performing regions generally landfill is used mostly in those ones with a small mix of other more sustainable options and with the exceptions of Flevoland and Zeeland, both regions of the Netherlands, which use mostly incineration.

These results are not unexpected because we need to account for the transport of waste between regions within a country and also the general trade of waste between countries. Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste aims at managing all the procedures around controlling waste shipments and to improve environmental protection in whole (Municipal Waste Europe, 2017). In those regards the principles of self-sufficiency, proximity of waste for disposal and prior informed consent need to be considered (Municipal Waste Europe, 2017). The growth in exports of waste in the EU can be attributed to a number of factors, mainly the recycling targets set in the waste directives, disparities in recycling infrastructure between EU Member States, increasing prices for secondary materials and increasing demand for materials, especially in Asian countries (European Environment Agency, 2012).

This means that despite the fact that a region uses mostly landfill for example, it can also be very efficient in DEA while taking many parameters into account (population density, GDP, labor, investment). This is due to the fact that it is possible that waste produced in that area is actually treated elsewhere. The Eurostat data for the treatment options refer only to a certain region and cannot reflect waste movement in that sense, therefore it is not possible to match these waste treated with the efficiency scores of DEA on the regional level. This would make more sense in a country level analysis.

5. Conclusions

As it has been mentioned before waste arisings have been increasing over the years and therefore their management and treatment have raised a lot of attention. This paper deals with the efficiency of 172 EU regions for the years 2009, 2011 and 2013 by employing DEA analysis and by using five parameters, namely waste generation, employment rate, capital formation, GDP and population density for the relevant regions. In doing so four frameworks have been designed with different inputs and outputs each time. The results present the more efficient EU regions according to each framework, but it should be noted that results from different frameworks should not be compared to each other.

Overall results show that the highest performers are regions in Belgium, Italy, Portugal and the UK. Finally the efficiency results from DEA were reviewed against the treatment options employed in the relevant regions. This review proved that although high performers generally employ a mix of all treatment options, landfill is still in extensive use in those regions. This can be attributed to the fact that although waste is produced in that region, it is actually treated elsewhere. Therefore although a country might be efficient according to DEA and by taking many factors into consideration, it is not necessary that this region uses sustainable waste treatment options as it is essential to account for trade of waste between regions and countries as well.

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