Assessment of national waste generation in EU Member States' efficiency

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Abstract

Waste generation and management may be considered as either a by-product of economic actions or even used as input to economic activity like energy recovery. Every country produces different amounts of municipal solid waste (MSW) and with different composition. This paper deals with the efficiency of 28 EU Member States for the years 2008, 2010 and 2012 by employing Data Envelopment Analysis (DEA) and by using eight parameters, namely waste generation, employment rate, capital formation, GDP, population density and for the first time SOx, NOx and GHG emissions for the relevant countries. With these parameters six environmental production frameworks have been designed each with different inputs and outputs. The empirical analysis shows that overall the more efficient countries according to all frameworks include Belgium, Germany, Austria, the Netherlands, Sweden and Norway. These results were then reviewed against the recycling rate of each country for the examined time periods. The recycling rate actually depicts the DEA results, namely more efficient countries seem to have a higher recycling rate too. Moreover the DEA efficiency results were contrasted to the overall treatment options used in the countries under consideration. Overall it is noticed that countries employing all four treatment options with high use of more sustainable ones and decrease in the use of landfill are the ones that also proved to be efficient according to DEA.

Keywords: Environmental efficiency; waste generation; EU Member States; Data Envelopment Analysis; sustainability; environmental policy.

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

1. Introduction

Waste is a vital part of any economy, being a by-product of economic activity and originating from businesses, the government and households, but it can also act as an input to economic activity for instance through material or energy recovery (Defra, 2011a). This is because waste generated is influenced by the degree of urbanisation, patterns of consumption, household income and lifestyles in each country (Eurostat, 2014a). For instance there is a strong link between affluence and waste generation, despite improvements in efficiency (World Bank, 1999). The amount of Municipal Solid Waste (hereafter MSW) generated per inhabitant (waste per capita) can be a valuable tool in capturing the potential environmental and health impacts, through for instance soil and water contamination or poor air quality (Eurostat, 2014b).

The treatment options of MSW can be classified generally as landfill, incineration, recycling and composting. Sustainable Waste Management (SWM) is one of the most challenging issues faced by both developed and developing countries which are now trying to cope with pressure by national and international communities to reduce their environmental impacts overall. An important driver is the *Waste Hierarchy*. According to the Waste Hierarchy top priority is given in preventing waste in the first place, if waste is created, priority is then given in preparing it for re-use, then recycling, then recovery and as last resort disposal, i.e. landfill (Defra, 2011b).

Environmental efficiency has been gaining a lot of attention and has both theoretical value and practical meaning (Song et al., 2012). With the help of Data Envelopment Analysis (hereafter DEA) one can measure the efficiency performances of comparable Decision Making Units (DMUs) which have multiple (usually) inputs and likewise outputs in conditions where there is accurate information on their values and no knowledge about the production or cost function (Rogge and De Jaeger, 2012). DEA compares each DMU with all other and shows the ones that operate inefficiently compared with the others by identifying best practice scenarios (Sherman and Zhu, 2006). Charnes et al. (1978) were the first to propose the measurement of DMUs' efficiency under constant returns to scale (CRS), provided that all DMUs operate at their optimal level. Then Banker et al. (1984) employed variable returns to scale (VRS) in their model, thus accounting for the use of technical and scale efficiencies in DEA. One important benefit of DEA is that one does not need to make any assumptions regarding the relationship between inputs and outputs (Seiford and Thrall, 1990).

In the present study, with the help of DEA, environmental efficiency indicators in national waste generation will be explored. A number of parameters are used including: waste, GDP, labour, capital, population density, air pollution emissions in the form of NOx, SOx and GHG for 28 EU Member States and for the years 2008, 2010 and 2012.[1]

The structure of the paper is as follows. Section 2 reviews the relevant existing DEA waste management studies while section 3 presents the proposed methodology together with the data used and the environmental production frameworks applied in the analysis. Section 4 presents the empirical findings with section 5 discussing the results and their implications. The last section concludes the paper.

2. DEA applications in waste management studies

As mentioned, environmental efficiency has gained research attention both theoretically and practically. According to Rovere et al. (2010) an approach is needed that considers technical, socioeconomic, environmental and technological factors of the various alternatives and they also suggested that multi-criteria analysis could be employed. Although there is a practical value in this approach, it only drew a few researchers' attention (Angelis-

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[1] For details on air pollutants see among others Halkos (1992, 1996, 2011, 2015).

Dimakis et al., 2011). In evaluating environmental efficiency, life-cycle approaches have been used. In these regards, life-cycle thinking comes handy in examining all stages of a product's lifecycle and determining where there is room for improvement, for instance in reducing environmental impacts and in using resources and generally avoiding situations that create negative consequences (European Commission, 2010).

With Life Cycle Assessment (LCA) one can estimate the environmental impacts of a process or product, based on the efficiency of the operations; if data is available for comparable settings, then performances can be benchmarked and relevant links can be established (Lozano et al., 2009). Inventory data are converted to a reduced number of environmental indicators which help identify hotspots and the relevant environmental improvement actions (Baumann and Tillman, 2004). LCA has also been employed to assess eco-efficiency of processes and products (Kuosmanen and Kortelainen, 2005; Kortelainen and Kuosmanen, 2007; Barba-Gutiérrez et al., 2008).

In addition to LCA, the majority of the parametric studies was aiming to analyse background variables such as the costs rather than the cost efficiency of waste collection and management (Rogge and De Jaeger, 2012). An exception to these studies is the one conducted by Simões and Marques (2011) who used the parametric approach of Stochastic Frontier Analysis (SFA) to assess how the operational environment affects cost efficiency of waste management.

Other recent studies used 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). Of course modifications are being conducted to DEA so that it can assess the full complexity of a 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 also use DEA in their waste management policies, like in Spain and Australia (Simões et al., 2010).

Generally, DEA can be used in waste management studies to assess efficiency of waste collection programs that are inefficient and need to be improved for instance through studying the collection methods, transportation ways, collection vehicles and collection times of the waste collection programs of the efficient DMUs (Yüksel, 2012). One study conducted in the Flemish municipalities aimed at those activities where the municipality under-performed and therefore cost efficiency gains are possible; results prove that the average cost efficiency score is quite low for these waste fractions which have lower cost share, hence it is obvious that the municipalities focus on those activities that have the biggest cost share such as residual MSW collection and processing services (Rogge and De Jaeger, 2012). In another study conducted in large cities of Turkey, efficiency of waste collection programs in those cities was benchmarked and it was found that apart from two cities the rest could improve their outputs (Yüksel, 2012).

In these regards, the concept of technical efficiency, for instance one basic application is the amount of waste that can be reduced without worsening any input or output (Cooper et al., 2011), as it requires only minimal information and assumptions, but also because other types assume that technical efficiency has been achieved (Førsund & Sarafoglou, 2005). Most waste-related studies which employ DEA focus on waste or pollution as an undesirable output (Scheel, 2001; Seiford and Zhu, 2002).

In more detail regarding previous DEA works, Bosch et al. (2000) assessed MSW collection services in Spain by using as inputs containers, vehicles and workers and as output waste collected. The same output was used by Benito et al. (2010) and MSWM costs as input again in Spain. Similarly waste treated and waste recycled were used as outputs and MSWM costs as inputs for Czech Republic (Fiala, 2007) and Portugal (Marques and Simoes, 2009).

Worthington and Dollery (2001) studied solid waste management by local governments, including municipalities taking into account as input collection and expenditures and as output garbage and recyclables collected. MSWM costs were used as inputs in further studies as well, for instance De Jaeger et al. (2011) with a focus on Belgium and Simoes et al. (2010) on Portugal. Moore et al. (2005) examined municipal waste management using as inputs staff and MSWM budget and as output citizens served in the 46 US largest cities. Finally Huang et al. (2011) studied local MSW collection services in Taiwan using a dummy input and five key performance indicators (KPIs) as outputs.

3. Research method, data and production frameworks for the analysis

3.1 The proposed methodology

DEA is a non-parametric approach applied to assess the efficiency of the DMUs into consideration with the use of linear programming techniques (Boussofiane et al., 1991). Generally the number of DMUs should be at least twice the number of inputs and outputs together (Golany and Roll, 1989). On the other hand, other researchers argue that the number of DMUs should be at least three times this number (Banker et al., 1989). But this kind of rules are not overbearing, meaning that in certain conditions there might be a significant number of DMUs and the model could still be efficient (Cook et al., 2014).

DEA models are either input-oriented minimizing inputs while at least achieving the given output levels or output-oriented models maximizing outputs without requiring more inputs.

At this point it is essential to define efficiency, which is the ratio of output to input; a state of absolute efficiency is achieved if the greatest possible output per unit of input is accomplished and it is not possible to create any better conditions without altering technology or anything else in the production process (Sherman and Zhu, 2006).

As introduced by the linear programming estimators by Charnes et al. (1978), Farrell’s (1957) input measure operationalization of efficiency for multiple inputs /outputs assuming free disposability and convexity of the production set, supports for a given DMU operating at a point it can be defined as:

$$\hat{\Psi}_{DEA} = \Big\{ (x,y) \in R_{+}^{p,q} \,\Big|\, y \le \sum_{i=1}^{n} \gamma_i Y_i ; x \ge \sum_{i=1}^{n} \gamma_i X_i , \text{for } (\gamma_1, ..., \gamma_n) \\ \text{s.t.} \sum_{i=1}^{n} \gamma_i = 1; \gamma_i \ge 0, i = 1, ..., n \Big\}.$$

To estimate the frontier under the assumption of variable returns to scale (VRS, Banker et al., 1984) input efficiency score of a DMU operating at a point under the assumption of VRS can be calculated as:

$$\hat{\theta}_{DEA}(x_0, y_0) = \inf \Big\{ \theta \,\Big|\, (\theta x_0, y_0) \in \hat{\Psi}_{DEA,VRS} \Big\}$$

$$\hat{\theta}_{DEA}(x_0, y_0) = \min \Big\{ \theta \,\Big|\, y_0 \le \sum_{i=1}^{n} \gamma_i Y_i ; \theta x_0 \ge \sum_{i=1}^{n} \gamma_i X_i , \theta > 0; \\ \sum_{i=1}^{n} \gamma_i = 1; \gamma_i \ge 0, i = 1, ..., n \Big\}.$$

Similarly the output efficiency score of a DMU operating at a point under the assumption of VRS can be calculated as:

$$\hat{\lambda}_{DEA}(x_0, y_0) = \sup \Big\{ \lambda \,\Big|\, (x_0, \lambda y_0) \in \hat{\Psi}_{DEA,VRS} \Big\}$$

$$\hat{\lambda}_{DEA}(x_0, y_0) = \max \Big\{ \lambda \,\Big|\, \lambda y_0 \le \sum_{i=1}^{n} \gamma_i Y_i ; x_0 \ge \sum_{i=1}^{n} \gamma_i X_i , \lambda > 0; \\ \sum_{i=1}^{n} \gamma_i = 1; \gamma_i \ge 0, i = 1, ..., n \Big\}.$$

3.2. Data used

In this DEA application the following variables are used: waste, GDP, labour, capital, population density, NOx emissions, SOx emissions and GHG emissions with data obtained from Eurostat. In total 28 EU Member States are studied for the years 2008, 2010 and 2012. The parameters are counted in the following units for this analysis:

- Waste: waste generated by households (tonnes)
- GDP: current prices (million €)
- Labour: number of people (in thousand)
- Gross fixed capital formation: current prices (million €)
- Population density: persons per km^2
- SOx emissions: tonnes from waste sector
- NOx emissions: tonnes from waste sector
- GHG emissions: million tonnes of CO_2 equivalent.

Following the collection of all the relevant data from Eurostat, 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.

Table 1: Descriptive statistics for all years

	Waste (MSW)	**GDP**	**Labour**	**Investment**	**Population density**	**SOx emissions from waste**	**NOx emissions from waste**	**GHG emissions from waste**
2008								
Mean	7,921,692.5	433,181.5	7,986.4	106,864.2	167.5	143.5	403.9	6.6
St. dev	11,152,434.5	660,359.2	10,180.0	147,510.1	244.3	312.1	717.1	9.3
Min	145,817.0	5,468.5	158.6	1,203.1	15.6	0.0	0.0	0.0
Max	35,754,996.0	2,407,913.0	38,541.5	520,809.0	1,295.5	1,362.0	2,707.0	41.1
2010								
Mean	7,950,260.5	422,196.1	7,774.2	94,052.4	169.2	92.3	385.7	6.0
St. dev	10,880,325.9	645,277.5	10,076.9	136,172.4	247.5	201.1	673.4	7.7
Min	149,564.0	5,541.5	162.6	1,411.6	16.0	0.0	0.0	0.0
Max	36,311,611.0	2,375,659.2	38,737.8	501,449.0	1,311.7	890.0	2,433.0	29.9
2012								
Mean	7,666,294.2	427,893.0	7,743.8	97,806.3	170.5	91.9	399.3	5.6
St. dev	10,571,666.9	658,959.0	10,134.9	144,453.6	250.7	191.3	675.2	7.0
Min	155,147.0	5,680.2	170.3	1,306.0	16.5	0.0	0.0	0.0
Max	36,471,810.0	2,471,753.3	39,126.5	555,866.0	1,327.4	825.0	2,355.0	24.8

3.3 Environmental production frameworks for the country level analysis

The present analysis relies on and extends the work by Halkos and Papageorgiou (2014, 2015) as a basis and further develops this by using different inputs and outputs on a country level. The frameworks that have been designed are also based on their analysis with new additions in inputs taken into account. 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 two frameworks (M1 and M2), in which different inputs are taken into account. Then the pollutant is treated as regular input following studies treating pollutants as damage costs with the main goal being its minimization, which is performed in M3 and M4 again with different inputs in each framework. In Framework M5 waste is treated as a regular input again but this time aerial gases are also taken into account as bad outputs (NOx, SOx and GHGs). Finally in framework M6 the idea of eco-efficiency is used as introduced by Kuosmanen and Kortelainen (2005) and Kortelainen (2008). For all 28 countries in the DEA analysis a radial model was used, which is output oriented with variable returns to scale.

4. Empirical findings of DEA modelling

Several studies propose that MSW is affected by population's income as economic activities are very much related to waste generation and there is no strong evidence of decoupling waste generation from GDP and subsequently consumption (Mazzanti 2008; Mazzanti and Zoboli 2005, 2008; Sjöström and Östblom 2010; Halkos and Papageorgiou, 2014, 2015). This justifies the variables used in our proposed model formulations (waste generation, GDP, labour force, capital investment, population density and aerial gases in the form of NOx, SOx, GHGs emissions).

Under the M1 framework the highest performers are Bulgaria, Germany, France, Italy, Luxembourg, Malta, the UK and Norway over the years 2008-2012, whereas the areas with the lowest performers are Czech Republic, Estonia, Slovenia and Slovakia. Over the years Belgium, Greece, Spain, Cyprus, Latvia and Poland show some improvement though.

When using framework M2 and adding population density as well, the highest performers are Bulgaria, Germany, Estonia, Spain, France, Italy, Cyprus, Lithuania, Luxembourg, Malta, Finland, Sweden, UK and Norway. The lowest performers are Hungary, Austria, Poland, Slovenia and Slovakia.

From framework M3 and by treating the bad output as input, the highest performers are Germany, France, Luxembourg, Malta, the UK and Norway; whereas the lowest ones are Bulgaria, Czech Republic, Estonia, Cyprus, Latvia, Lithuania, Poland, Hungary, Slovenia and Slovakia.

For framework M4 with the same model as M3 and the addition of population density, the highest performers are Germany, Estonia, Ireland, France, Cyprus, Luxembourg, Malta, Finland, the UK and Norway; whereas the least performing are Bulgaria, Czech Republic, Latvia, Hungary, Portugal, Romania and Slovakia.

Moreover according to framework M5 the highest performing countries are Belgium, Bulgaria, Denmark, Germany, Estonia, Ireland, France, Italy, Cyprus, Luxembourg, Malta, Poland, Portugal, Finland, the UK and Norway. The least performing ones are Slovakia and Romania.

Finally for framework M6, Germany, Malta and Norway are the ones being the most efficient. In this instance, the least performing ones are Bulgaria, Czech Republic, Estonia, Cyprus, Latvia, Lithuania, Hungary, Romania and Slovakia.

As it is evident these different frameworks extract different results. This difference can be explained by the fact that in M1 and M2 the bad output (waste generation) is considered as output, whereas in frameworks M3 and M4 it is considered as a regular input. M5 deals with different inputs and outputs so it cannot be compared. Finally in M6 only the relationship between waste and GDP is accounted for, therefore the results cannot be *compared to the other frameworks either.

Table 2 presents the efficiency scores over the years for the six different frameworks. Also table 3 presents the average scores (year-wise) per country per modelling framework. As it can be seen under frameworks M1-M5 the efficiency scores are on average higher than in M6. This suggests that different modelling techniques are not comparable among them since they take into account diverse assumptions. It can be clearly observed that the lack of a uniform environmental policy among the European countries is reflected upon their environmental efficiency levels. Regarding changes over the years in all models, there is not much difference over these years showing that probably not many changes have been implemented in these countries and possibly also a lack of coherent EU environmental policy in place.

5. Discussion

The most commonly used treatment options of MSW include: landfill, incineration, recycling and composting. Developed countries are looking into avoiding waste going to landfill and increasing the recycling and recovery of materials. As mentioned an important driver is the Waste Hierarchy (Figure 1).

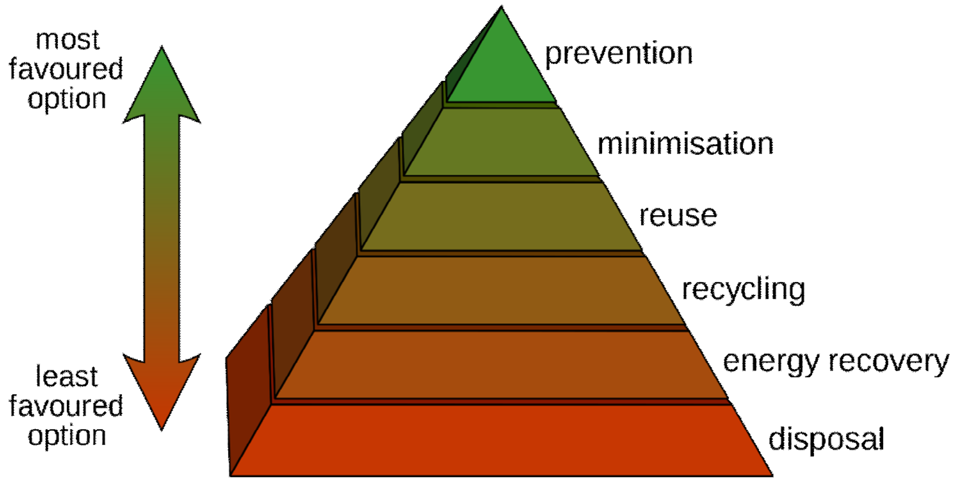

Figure 1: Waste hierarchy (Defra, 2011b)

The DEA results regarding the efficiency of EU countries with the parameters taken into account were contrasted to both the recycling rate of those countries and the treatment options used overall. At the moment only around 40% of the waste produced by EU households is recycled (European Commission, 2015). Table 4 presents the recycling rate of municipal waste (as %) for the countries in our analysis. As can be noticed from this table the countries that have the highest recycling rates overall are Belgium, Germany, Austria, the Netherlands, Sweden and Norway. Moreover Bulgaria, Czech Republic, Ireland, Greece, France, Italy, Lithuania, Hungary, Malta, Poland, Portugal, Romania and Slovenia show an increase in their recycling rates over the years with very big increases of this share in most of these countries. These recycling rates are in agreement with the efficiency results from the DEA analysis, namely the countries that are more efficient according to DEA generally present a higher recycling rate than those inefficient ones. Overall to raise levels of high-quality recycling, waste collection and sorting methods need to be improved, for instance by financing extended producer responsibility schemes, where manufacturers contribute to product collection and treatment costs (European Commission, 2015).

Furthermore the DEA efficiency results were contrasted to the overall treatment options (as shown in Table 5) used in the countries into consideration. Landfill, a method commonly used in the past, is being recognized now as inappropriate as it can create many health and environmental problems. It's still not certain though to which effect landfilling affects human health; for instance research in the UK points out the possibility of landfills being responsible for birth defects in the vicinity (Elliott et al, 2000). An important part of landfilling is its aftercare management, which usually covers the monitoring of emissions (e.g. leachate and gas) and receiving systems (e.g. groundwater, surface water, soil, and air) and maintenance of the cover and leachate and gas collection systems (Laner et al., 2012). A minimum period of aftercare is specified by certain regulations; for example, the Euro3pean Landfill Directive (European Commission, 1999) specifies a period of at least 30 years of aftercare as a basis.

Incineration refers to the combustion of waste for recovering energy nder conditions of high temperature (WMR, 2009). This method reduces the form of the waste from 95 to 96% depending on the recovery degree and composition of materials. That way incineration manages to reduce the amount of waste going to landfill (WMR, 2009).

The biodegredation of organic matter through an aerobic process which converts organic matter is called composting (Eunomia, 2015). Composting facilities need to function at or near maximum design capacity, in order to make sense financially (Environment Agency, 2002).

Finally recycling refers to the systematic collection, processing and reuse of materials, which include the following categories: paper, glass, plastic, wood, aluminium products and iron (Halkos, 2013). Research has shown that the increasing recycling rates (as well as composting and thermal treatment) are highly correlated to the declining rates of landfill (European Environment Agency, 2015).

Germany is efficient under all DEA frameworks and is actually the country in EU with the most incineration, material recycling and composting of waste and treats only a small amount of waste at landfills. Spain, Italy, France, the Netherlands and Sweden generally employ all treatment options with Sweden and the Netherlands almost without any landfill treated waste.

The surprising result is the UK which is efficient under all frameworks but still highly relies on landfill for the year 2008, but this decreases with the passing of time, with almost 60% decrease of waste sent to landfill. Overall though it is noticed that countries which employ all four treatment options with high use of more sustainable ones and decrease in the use of landfill are the ones that also proved to be efficient according to DEA. Therefore it is possible to infer that when a country uses sustainable treatment options, it is also efficient under DEA by means of the parameters taken into account in this analysis.

Waste management has a critical role in the circular economy: it determines how the EU waste hierarchy will be enforced giving priority to prevention, preparation for reuse, recycling and energy recovery through to disposal, such as landfilling (European Commission, 2015). Therefore the treatment options employed by each country are very much related to the European Commission’s Circular Economy Package, with aims to accelerate Europe's transition towards a circular economy by certain legislative proposals, along with the waste reduction targets across EU member states (European Commission, 2016). To achieve the transition to a circular economy, the value of products, materials and resources needs to be maintained in the economy for as long as possible and the generation of waste minimised (European Commission, 2017).

Table 2: Results of M1, M2, M3, M4, M5 and M6 frameworks for the EU countries for 2008, 2010 and 2012

	M1			M2			M3			M4			M5			M6		
Country	**2008**	**2010**	**2012**	**2008**	**2010**	**2012**	**2008**	**2010**	**2012**	**2008**	**2010**	**2012**	**2008**	**2010**	**2012**	**2008**	**2010**	**2012**
Belgium	0.909	0.913	0.937	0.909	0.913	0.937	0.879	0.868	0.897	0.879	0.868	0.897	1.000	1.000	1.000	0.808	0.792	0.752
Bulgaria	1.000	1.000	1.000	1.000	1.000	1.000	0.406	0.512	0.457	0.504	0.567	0.523	1.000	1.000	1.000	0.093	0.079	0.095
Czech Republic	0.582	0.571	0.503	0.584	0.572	0.503	0.527	0.470	0.511	0.533	0.470	0.516	0.905	1.000	1.000	0.384	0.370	0.379
Denmark	0.895	1.000	1.000	0.895	1.000	1.000	0.943	0.911	0.918	0.943	0.911	0.918	1.000	1.000	1.000	0.784	0.614	0.594
Germany	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Estonia	0.647	0.754	0.561	1.000	1.000	1.000	0.477	0.672	0.498	1.000	1.000	1.000	1.000	1.000	1.000	0.242	0.213	0.241
Ireland	0.917	1.000	1.000	0.955	1.000	1.000	0.995	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.909	0.825	0.918
Greece	0.726	0.984	1.000	0.742	0.988	1.000	0.736	0.756	1.000	0.753	0.770	1.000	0.923	0.943	1.000	0.572	0.441	0.394
Spain	0.849	0.895	0.978	1.000	1.000	1.000	0.695	0.742	0.795	0.749	0.841	0.982	0.834	1.000	1.000	0.588	0.608	0.618
France	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.902	0.913	0.871
Italy	1.000	1.000	1.000	1.000	1.000	1.000	0.930	0.927	0.920	0.930	0.927	0.920	1.000	1.000	1.000	0.671	0.663	0.677
Cyprus	0.925	0.976	1.000	1.000	1.000	1.000	0.600	0.673	0.902	1.000	1.000	1.000	1.000	1.000	1.000	0.299	0.272	0.275
Latvia	0.559	0.811	1.000	0.717	1.000	1.000	0.383	0.661	0.383	0.591	0.929	0.714	1.000	1.000	1.000	0.215	0.151	0.102
Lithuania	0.989	1.000	0.869	1.000	1.000	1.000	0.539	0.811	0.649	0.774	1.000	0.993	0.934	1.000	1.000	0.161	0.152	0.185
Luxembourg	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hungary	0.928	0.781	0.680	0.931	0.781	0.681	0.656	0.689	0.728	0.715	0.715	0.735	0.960	1.000	1.000	0.277	0.299	0.312
Malta	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Netherlands	0.907	0.924	0.949	0.907	0.924	0.949	0.869	0.885	0.913	0.869	0.885	0.913	0.869	0.885	0.913	0.780	0.806	0.793
Austria	0.867	0.890	0.867	0.877	0.893	0.867	0.871	0.813	0.836	0.872	0.813	0.836	0.872	0.817	0.836	0.744	0.649	0.735
Poland	0.761	0.913	0.964	0.762	0.913	0.964	0.648	0.645	0.697	0.658	0.650	0.697	1.000	1.000	1.000	0.525	0.460	0.455
Portugal	1.000	0.919	0.930	1.000	0.919	0.930	0.688	0.665	0.848	0.723	0.678	0.849	1.000	1.000	1.000	0.345	0.349	0.364
Romania	0.972	1.000	0.777	0.976	1.000	0.778	0.315	0.428	0.412	0.327	0.438	0.417	0.629	0.827	0.898	0.185	0.183	0.227
Slovenia	0.627	0.724	0.710	0.676	0.775	0.734	0.611	0.682	0.796	0.724	0.778	0.867	0.740	0.778	0.904	0.401	0.364	0.411
Slovakia	0.730	0.654	0.536	0.740	0.658	0.536	0.512	0.515	0.556	0.585	0.543	0.567	0.674	0.643	0.667	0.237	0.246	0.278
Finland	0.821	0.784	0.786	1.000	1.000	1.000	0.970	0.921	0.928	1.000	1.000	1.000	1.000	1.000	1.000	0.895	0.852	0.878
Sweden	0.875	0.876	0.893	1.000	1.000	1.000	0.864	0.882	0.903	0.977	0.981	1.000	0.992	0.991	1.000	0.807	0.882	0.881
United Kingdom	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.921	1.000	1.000
Norway	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Average	**0.874**	**0.906**	**0.891**	**0.917**	**0.941**	**0.924**	**0.754**	**0.790**	**0.805**	**0.825**	**0.849**	**0.869**	**0.940**	**0.960**	**0.972**	**0.598**	**0.578**	**0.587**

Table 3: Average scores per country and per modelling frameworks

	M1	**M2**	**M3**	**M4**	**M5**	**M6**
Country	**Average**	**Average**	**Average**	**Average**	**Average**	**Average**
Belgium	0.919	0.919	0.881	0.881	1.000	0.784
Bulgaria	1.000	1.000	0.458	0.531	1.000	0.089
Czech Republic	0.552	0.553	0.503	0.506	0.968	0.378
Denmark	0.965	0.965	0.924	0.924	1.000	0.664
Germany	1.000	1.000	1.000	1.000	1.000	1.000
Estonia	0.654	1.000	0.549	1.000	1.000	0.232
Ireland	0.972	0.985	0.998	1.000	1.000	0.884
Greece	0.903	0.910	0.831	0.841	0.955	0.469
Spain	0.907	1.000	0.744	0.857	0.945	0.605
France	1.000	1.000	1.000	1.000	1.000	0.895
Italy	1.000	1.000	0.926	0.926	1.000	0.671
Cyprus	0.967	1.000	0.725	1.000	1.000	0.282
Latvia	0.790	0.906	0.476	0.744	1.000	0.156
Lithuania	0.953	1.000	0.666	0.922	0.978	0.166
Luxembourg	1.000	1.000	1.000	1.000	1.000	1.000
Hungary	0.796	0.798	0.691	0.722	0.987	0.296
Malta	1.000	1.000	1.000	1.000	1.000	1.000
Netherlands	0.926	0.926	0.889	0.889	0.889	0.793
Austria	0.874	0.879	0.840	0.840	0.842	0.709
Poland	0.879	0.879	0.663	0.668	1.000	0.480
Portugal	0.950	0.950	0.734	0.750	1.000	0.352
Romania	0.916	0.918	0.385	0.394	0.784	0.198
Slovenia	0.687	0.728	0.697	0.790	0.807	0.392
Slovakia	0.640	0.645	0.527	0.565	0.661	0.254
Finland	0.797	1.000	0.939	1.000	1.000	0.875
Sweden	0.881	1.000	0.883	0.986	0.994	0.857
United Kingdom	1.000	1.000	1.000	1.000	1.000	0.974
Norway	1.000	1.000	1.000	1.000	1.000	1.000

Table 4: Recycling rate of municipal waste (%) (higher performers in green color) (Eurostat data)

	2008	**2010**	**2012**
Belgium	56.2	57.7	55.7
Bulgaria	19.4	24.5	25
Czech Republic	10.4	15.8	23.2
Denmark	42	42.3	41
Germany	63.8	62.5	65.2
Estonia	20.2	18.2	19.1
Ireland	33.6	35.7	36.6
Greece	17.7	17.1	19.3
Spain	39.7	29.2	29.8
France	33.3	34.9	36.8
Italy	23.8	31	38.4
Cyprus	7.3	10.7	13.6
Latvia	6.4	9.4	15.8
Lithuania	8.5	4.9	23.5
Luxembourg	46	46.5	47.4
Hungary	15.2	19.6	25.5
Malta	2.9	5.2	12.1
Netherlands	48.4	49.2	49.4
Austria	63.2	59.4	57.7
Poland	10.5	21.4	19.6
Portugal	17.3	18.7	26.1
Romania	0.9	12.8	14.8
Slovenia	18.9	22.4	41.9
Slovakia	7.4	9.1	13.3
Finland	34.3	32.8	33.3
Sweden	45.8	48.1	47.2
United Kingdom	36.4	40.2	42.6
Norway	43.6	42.1	39.8

6. Conclusions

As highlighted in the previous section waste arisings have been getting a lot of attention recently as has their management and treatment. This paper deals with the efficiency of 28 EU Member States for the years 2008, 2010 and 2012. For this task it employs DEA and uses eight parameters, namely waste generation, employment rate, capital formation, GDP, population density and for the first time SOx, NOx and GHG emissions for the relevant countries. The obtained results present the more efficient EU countries according to each framework, but it should be stressed that results from different frameworks should not be compared to each other due to the different inputs/outputs used. Some of the overall more efficient countries according to all frameworks include Belgium, Germany, Austria, the Netherlands, Sweden and Norway.

These results were then reviewed against the recycling rate of each country for the examined period. The recycling rate actually depicts the DEA results, namely more efficient countries seem to have higher recycling rates too. Moreover the DEA efficiency results were compared to overall treatment options used in the countries in question. Germany is efficient under all DEA frameworks and is actually the country in EU with the most incineration, material recycling and composting of waste and treats only a small amount of waste at landfills. Spain, Italy, France, the Netherlands and Sweden generally employ all treatment options with Sweden and Netherlands almost without any landfill treated waste. The only surprise is the UK which is efficient under all frameworks but still highly relies on landfill for the year 2008, but this decreases with the passing of time, with almost 60% decrease of waste sent to landfill.

Overall it is noticed that countries that employ all four treatment options with high use of more sustainable ones and decrease in the use of landfill are the ones that also proved to be efficient according to DEA.

Table 5: Municipal waste by waste operations (Eurostat data, http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasmun&lang=en)

Landfill

GEO/TIME	2008	2010	2012
Luxembourg	60	62	61
Sweden	140	38	27
Netherlands	154	145	138
Denmark	175	130	89
Malta	266	226	203
Germany	286	206	107
Estonia	333	267	129
Belgium	371	84	51
Austria	373	153	207
Norway	415	137	44
Cyprus	531	490	451
Slovenia	685	571	316
Latvia	705	617	516
Lithuania	1.237	1.079	971
Slovakia	1.276	1.325	1.211
Finland	1.406	1.136	901
Ireland	1.939	1.496	1.028
Czech Rep	2.057	2.162	1.828
Hungary	3.341	2.838	2.609
Bulgaria	3.359	3.041	2.323
Portugal	3.530	3.381	2.593
Greece	4.181	4.903	4.507
Romania	6.486	4.813	3.427
Poland	8.716	7.428	7.158
France	10.995	10.745	9.120
Spain	13.091	14.789	13.263
Italy	16.069	15.015	11.720
UK	17.590	14.686	11.277

Incineration

GEO/TIME	2008	2010	2012
Bulgaria	0	0	0
Cyprus	0	0	0
Greece	0	0	0
Lithuania	0	1	0
Malta	0	0	1
Romania	0	21	89
Estonia	1	0	47
Latvia	3	0	0
Slovenia	13	9	10
Poland	40	39	51
Ireland	82	109	427
Luxembourg	124	123	121
Slovakia	157	183	168
Czech Rep	369	497	654
Hungary	393	406	364
Finland	478	556	925
Norway	873	1.154	1.346
Portugal	993	1.058	930
Austria	1.357	1.636	1.693
Belgium	1.956	2.028	2.108
Spain	2.170	2.044	2.112
Denmark	2.186	2.025	2.387
Sweden	2.272	2.099	2.233
UK	3.448	4.124	5.698
Italy	4.372	5.440	5.529
Netherlands	4.936	4.675	4.515
France	12.166	11.730	12.141
Germany	17.247	18.256	17.192

Material recycling

GEO/TIME	2008	2010	2012
Malta	8	13	20
Cyprus	42	61	70
Latvia	43	60	84
Slovakia	60	98	140
Romania	72	162	165
Estonia	78	41	52
Luxembourg	89	93	96
Lithuania	101	43	261
Slovenia	190	203	270
Czech Rep	280	452	665
Portugal	567	619	549
Hungary	607	641	832
Norway	670	609	620
Finland	715	495	589
Greece	797	872	869
Bulgaria	871	1.003	749
Poland	895	1.783	1.244
Ireland	977	910	829
Denmark	1.106	857	1.081
Austria	1.476	1.272	1.168
Sweden	1.520	1.414	1.403
Belgium	1.784	1.807	1.736
Netherlands	2.450	2.354	2.196
Spain	3.898	4.175	4.277
Italy	4.631	6.107	7.177
France	5.972	6.143	7.217
UK	7.775	8.069	8.173
Germany	22.752	22.476	23.596

Composting

GEO/TIME	2008	2010	2012
Bulgaria	0	0	92
Cyprus	0	0	7
Malta	0	0	10
Romania	3	650	580
Latvia	5	4	13
Lithuania	15	19	51
Slovenia	17	22	42
Estonia	28	33	19
Czech Rep	50	76	85
Slovakia	64	59	81
Luxembourg	68	67	68
Hungary	85	148	183
Greece	100	142	209
Ireland	107	107	156
Finland	234	332	323
Norway	343	358	333
Portugal	382	399	694
Poland	386	790	1.128
Sweden	522	564	621
Denmark	606	720	639
Belgium	1.103	1.060	1.033
Austria	1.683	1.520	1.650
Netherlands	2.330	2.310	2.353
Italy	3.106	3.943	4.339
UK	4.402	4.786	4.788
France	5.581	5.917	5.720
Spain	6.158	2.767	2.245
Germany	8.082	8.298	8.864

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