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Ranking European countries on the basis of their environmental and circular economy performance: A DEA application in MSW

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ABSTRACT

The scope of this research is to present a more holistic approach on measuring countries' performance in managing and exploiting their Municipal Solid Waste (MSW). Specifically, we argue that relying solely on criteria like the recycling and/or the cyclical material use rate, can lead to an overestimation or underestimation of countries' true performance. That is because the level of waste generation is left unaccounted, despite the fact that low waste generation is an important environmental target, and so is the countries' true potential, as it is reflected by their economic and social progress.

Instead, we measure the environmental and circular economy performance of 26 European Union countries by implementing Data Envelopment Analysis and tackle the aforementioned problem by using the generated quantity of MSW per capita and the three dimensions of the Social Progress Index as inputs and the recycling and/or the cyclical material use rate as outputs. We do so, using a basic framework and a framework that imposes common weights to enforce a full ranking of the countries.

Our study shows large disparities among European countries, with respect to their performance. Interestingly though, the borders between Western and Eastern Europe have fallen, but not those between the north and the south: old EU members, such as Spain or France, perform significantly worst, both from an environmental and a circular economy perspective, than newer members, such as Slovenia or Poland. Finally, Belgium has been revealed as the best performer, both from an environmental and a cyclical economy perspective.

1. Introduction

Municipal Solid Waste (MSW) is not only an unavoidable product of our daily life, but also a complex and serious problem for our societies, due to the environmental impacts associated with its management. Industry's heavy dependence on the extraction and utilization of new materials and resources further exacerbates these environmental problems. Moreover, competition for scarce resources and high prices of raw materials put pressure on the competitiveness of European economies.

In view of these problems, the European Union (EU) faces two key challenges in the waste management sector. Firstly, to diminish the level of waste generation, "approaching production and consumption in a more thoughtful, effective, and responsible manner" (Corvellec et al., 2018), since the environmental benefits of avoiding waste clearly far exceed the environmental impacts of managing it. Secondly, to move waste management up the EU waste hierarchy (WH), by diverting waste towards treatments that allow re-using, recycling, composting and recovering energy from it (European Parliament and Council, 2008).

The transformation of the waste management sector will also be crucial in the transition towards a circular economy (CE), where products and materials are maintained and used for as long as possible, minimizing waste and resource use (European Commission (EC), 2015). Towards this end, the EC (2015b) introduced the Circular Economy package "Closing the loop – An EU action plan for the circular economy", with ambitious targets for waste management,

Abbreviations: CEP, Circular economy performance; CEP_b, Circular economy performance according the basic model; CEP_{wr}, Circular economy performance according the weight restricted model; CE, Circular Economy; CMU, Circular material use; CMUr, Circular material use rate; DEA, Data Envelopment Analysis; EP, Environmental performance; EP_b, Environmental performance according the basic model; EP_{wr}, Environmental performance according the weight restricted model; EC, European Commission; EU, European Union; MSW, Municipal Solid Waste; SPI, Social Progress Index; WH, Waste hierarchy.

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based on the EU WH. The package aims to promote a sustainable economy and alleviate the environmental pressures from waste, while providing European industries with high-quality secondary raw materials to be fed back into the production process.

Indeed, the concept of CE has gained significant prominence in today's politics, with its supporters emphasizing the economic opportunities it can create (World Economic Forum (WEF), 2014; EC, 2015c), as well as the expected environmental and societal benefits (MacArthur, 2015; Wijkman and Skånberg, 2015; Reike et al., 2018).

However, CE is also strongly criticized as being merely a concept in early stage (Kirchherr et al., 2017), that lacks sufficient conceptualization (Blomsma and Brennan, 2017) and a proper constructed framework (Lazarevic and Valve, 2017) and for failing to place enough weight on the social dimensions (Murray et al., 2017). Similarly, the EU WH has been criticized, as a concept, for many reasons, such as being inefficient to promote reduction of waste (Kijac and Moy, 2004; Barti, 2014; Ferrari et al., 2016), for not distinguishing different forms of recycling (Pires and Martinho, 2019) and even for its priority options with regards to their environmental impacts (Finnveden et al., 2005; Van Ewijk and Stegemann, 2016).

Despite these concerns, the examination of which is beyond the scope of this article, we believe that promoting efficient and environmentally friendly waste management and some form of circularity in today's resource strained global economy is important. Therefore, it is vital for policymakers and scientists to be able to measure waste management (hereafter environmental) performance and also to assess if EU countries are on the right track towards a more efficient exploitation of recycled materials (hereafter circular economy performance).

Nevertheless, assessing this progress is not a simple task. Although there are several intergovernmental, national and private initiatives aiming at measuring the progress in the implementation of the WH, in conjunction or not with the transitioning to a circular economy (EC, 2018; Mayer et al., 2019; Blomsma and Brennan, 2017; Pires and Martinho, 2019; Sassanelli et al., 2019), no commonly accepted framework exists (Bocken et al., 2016; Smol et al., 2017).

Making a step towards this direction, the European Commission (2018b) adopted a monitoring framework for circular economy that comprises ten indicators and serves as a tool for monitoring key trends in the transition and the success of taken measures, with respect to the related targets imposed by the EU legislation (EC, 2018). However, this set of indicators does not encompass the economic, social, and technical issues of CE in order to provide a holistic evaluation of waste management and economic circularity (see Iacovidou et al., 2017). In other words, although these indicators are useful for measuring the absolute performance of countries with respect to specific targets, they ignore the differences in the managerial abilities of these countries, which are driven by their economic and social status and thus, can lead to an underestimation or overestimation of their performance.

However, it is possible to combine some of these indices and construct a composite indicator (see e.g. Cylus et al., 2017), which can account for these economic and social differences. This is the approach we take in our study by implementing Data Envelopment Analysis (DEA) to measure the relative environmental performance (EP) and the CE performance (CEP) of EU countries. We do so by utilizing three out of the ten indicators adopted by the European Commission for the CE monitoring framework, namely the generation of MSW per capita, the MSW recycling rate (hereafter recycling rate) and CMUr, along with the Social Progress Index (SPI). We only use those three CE indicators, since the others are inappropriate for our analysis, either because they are related to other aspects of the CE like competitiveness and innovation or to a specific waste stream, while the indicator "Trade in recyclable raw materials" is already taken into evaluation in the computation of CMUr.

Summing up, two are the main contributions of our work. Firstly, to the best of our knowledge, this is one of the first attempts in the literature to measure relative EP and CEP, by incorporating in a DEA model, variables capturing social factors. Secondly, the performances calculated by the DEA models can be viewed as composite indicators that better reflect EP and CEP, compared to single indices. Therefore, the proposed framework can be used as a more objective tool for identifying best and worst performing countries and thus, can facilitate the development of relevant policies both at the EU and at a Member State level.

The remainder of the paper is organized as follows. Firstly, we provide a brief overview of MSW management in the EU and the transnational waste trade. In Section 3 we review the state of the existing DEA-literature on MSW. The methodology and the data used in the present study are incorporated in Section 4. Section 5 presents the results, along with some necessary discussion. Finally, Section 6 concludes.

2. MSW management and trade in EU

Naturally, the economic and social differences between the EU countries manifest themselves into differences in MSW generation and management, as evidenced by the Eurostat data used throughout this chapter (unless otherwise specified). In 2017, the average per capita MSW generation in the EU was 486 kg/year; a figure which is far higher for more developed countries and lower for poorer countries. Also, MSW generation is still increasing in around one-third of the Member States, despite governmental efforts to develop some type of policy prevention by raising public awareness (European Parliament, 2017) or by implementing Extended Producer Responsibility (EC, 2014).

In the waste management sector, more developed and technologically advanced countries are so far able to meet with greater ease the recycling targets for MSW imposed by the EU legislation, such as the 65% recycling rate for 2035 (European Parliament and Council, 2018). Germany has already reached the ambitious recycling target for 2035 with a rate of 66.19%, while Belgium, the Netherlands, Austria and Slovenia have achieved the 2020 recycling target of 50%.

However, many of these countries might face significant difficulties in reaching the 65% recycling target for 2035. For example, Denmark, Finland, the Netherlands incinerate more than 35% of their MSW. Therefore, in order to reach the 65% recycling target, they have to divert waste streams from incineration to recycling. This diversion does not constitute an easy task. On the one hand, countries have to respect the long-term commercial contracts signed with incinerator operators and on the other hand, find ways to transform their waste-to-energy policy. In addition, some countries, like Sweden and Denmark, are exhibiting incineration overcapacities that have led to an inter-EU trade of waste (European Parliament, 2017). These overcapacities must be taken into account by policy makers due to their potential impacts on the recycling market (Wilts and von Gries, 2015; EC, 2013).

On the other side, several countries, especially in the South and Eastern Europe, still present landfilling rates of more than 50%. These countries will also face a challenge to reach the recycling targets imposed by the EU. Not only do they have to raise and allocate sufficient funds to develop and implement costly waste recycling systems but they also need to promote citizens pro-environmental behaviour and attitudes.

Of particular interest, is also the world trade in waste that has emerged, particularly for glass, plastic, paper and board. The EU has risen as the top world exporter of non-hazardous waste for recovery, with a share of 34% in 2014 of global exports (EC, 2015d). Unfortunately, for many wealthy countries this trade is a way to "put their waste out of sight and out of mind" (Varkkey, 2019). Shipping their recyclables or their waste to be recovered overseas, is cheap, helps meet recycling targets and reduces domestic landfill. Under these circumstances, the environmental and economic potentials of the waste trade are often tarnished by cases of mismanagement, caused by laxer environmental standards and/or underdeveloped waste management capacities (OECD, 2018). Such an example is the disposal of recycled plastic waste in the ocean by the Asian importers (Chinadaily, 2018; Ritchie and Roser, 2018) due to their low quality as result of contamination, degradation and mixing different materials (see Iacovidou et al., 2019).

However, as emphasized by the EC, this trade can contribute to the promotion of industrial symbiosis, where the by-products or the waste of one industry are used as energy or raw materials for another and to economize on the use of natural resources on a global scale (EC, 2015e). Thus, it is obvious that the positive steps in reaching recycling targets are not sufficient. This is also corroborated from the fact that the EU's success in recycling does not go hand in hand with the exploitation of recyclables. In fact, the CMUr, the indicator developed by Eurostat (2018) to measure the contribution of secondary raw materials recovered from waste to overall material use, was only 11.7% for the EU(28) in 2016.

3. Literature review of MSW studies using DEA

DEA, developed by Charnes, Cooper and Rhodes (1978), has gained a prominent role in studies measuring the efficiency, productivity, or performance of a set of peer units. Its flexibility and adaptability to a variety of problems have permitted its application in a wide range of diversified fields, mainly in energy, agriculture, banking, industry, as well as, in public policy (Emrouznejad and Yang, 2017). However, its use is still limited in scientific publications on solid waste, although it is gaining more and more ground. Solid Waste researchers have started to use this methodology for various purposes such as to access the success in minimizing specific categories of industrial waste (Key et al., 2005; Lei, 2008), to measure the management efficiency for different SW categories, like healthcare waste (Ratkovic et al., 2012), packaging waste (De Jaeger and Rogge, 2014) or MSW produced by SMEs (Sarkis and Dijkshoorn, 2007; Cordeiro et al., 2012) etc.

In the MSW sector especially, DEA analysis has been performed to evaluate particular services provided by municipalities, like waste collection (García-Sánchez, 2008; Benito-López et al., 2011; Simões et al., 2013), to estimate the performance of different regions in recycling (Lozano et al., 2004; Chang et al., 2013; Yeh et al., 2016; Crociata and Mattoscio, 2016), to optimally select sites for locating SW facilities (Khadivi and Fatemi, 2012) etc. The majority of those studies aim to evaluate the cost efficiency (Simoes et al., 2012; 2013; Huang et al., 2011; Spallini et al., 2016; Rogge and De Jaeger, 2012; 2013) or the operational efficiency (Lozano et al., 2004; Ichinose et al., 2013; García-Sánchez, 2008) of MSW services. Consequently, the most commonly used variables are workforce, equipment and cost as input variables, while waste collected or treated are used as output variables. Although MSW generation has a vital role in driving MSW management performance, it is, in general, ignored by scholars using DEA analysis. To the best of our knowledge, only Chen (2010) evaluated the integrated cost efficiency of MSW management taking into account the generated quantities of MSW, as well as those collected and sorted, while Halkos and Papageorgiou (2016) estimate the environmental efficiency of different European regions considering waste generation only as an undesirable output.

In addition, a close look at the literature suggests that hardly any research has been carried out using DEA to evaluate the EP of countries on the basis of MSW recycling, while taking into account the level of MSW generation as well. However, the rising international and national focus towards waste reduction, reuse and recycling due to the recognized role of MSW management for sustainability, calls for a more complicated evaluation of EP on the basis of the WH.

The social influence on waste management performance is also rarely addressed. It is recognized by now, that the problem of MSW management is not only related to technological, institutional and financial issues, but is also a problem of "social mobilization" (Zurbrügg et al., 2012). Indeed, since 1990 there has been a growing research interest in investigating how various social dimensions impact the sustainable management of MSW (Ma and Hipel, 2016). So, it is surprising that in MSW DEA-literature only Crociata and Mattoscio (2016) use a social parameter, the cultural consumption, as an input to evaluate the performance of the twenty Italian regions in MSW recycling. We welcome this pioneering research considering that, although revealing the influence of social factors in MSW management is challenging, it is nonetheless important. In comparison to Crociata and Mattoscio (2016), we introduce more social parameters in the analysis and develop a broader indicator of environmental efficiency with respect to social factors.

Similarly, there do not seem to be any research articles that utilize DEA to measure the performance of the EU countries in moving towards a CE, much less to take into account how this effort is being shaped by social factors. As pointed out by the UN (2018), "future circular economy projects would benefit from a broad but well considered set of monitoring indicators that capture economic, environmental, social and governance impacts. Circular economy frameworks would benefit from having strategies and indicators measuring well-being and equity as much as they measure material flows". Such a framework is proposed in our study that emphasizes the importance of the "social element".

4. Methodology

The aim of this research is to measure the relative performance of the EU countries in managing and exploiting MSW, using DEA; a linear programming technique used for measuring the production efficiency or operational performance of similar activity units, commonly referred to as "decision making units" (or DMUs).

The key advantage of DEA and the main reason for its utilization is its non-parametric approach. Each DMU is treated as a "black box", in the sense that there is no exact knowledge of its internal operations (Li and Wang, 2015). Therefore, the researcher does not need to pre-specify a function format or a model capturing the way inputs are transformed into outputs, or how they achieve a specific level of performance. This flexibility facilitates the use of social factors/dimensions in MSW management studies and can provide a holistic measurement of performance. DEA technique maximizes the ratio of a weighted sum of outputs over a weighted sum of inputs, while the researcher does not have to enforce any judgment on their relative importance, thus avoiding subjectivity in the determination of weights (Tsai et al., 2016).

The following linear programming model (1) shows the basic modelling framework used in our study:

$$\mathrm{MaxP_d} = \sum\nolimits_{oc=1}^{n} \mathrm{u_{oc}y_{d,oc}} \tag{1}$$

$$\mathrm{st}\begin{cases} \sum_{oc=1}^{n} u_{oc}, y_{d,oc} - \sum_{ic=1}^{m} v_{ic} x_{d,ic} \leq 0 \\ \sum_{ic=1}^{m} v_{ic} x_{d,ic} = 1 \\ v_{ic}, u_{oc} \geq 0 \forall ic, oc \end{cases}$$

The performance measure is represented by P_d, where d = 1, 2,. . ..s is the country indicator. Each country uses m inputs, given by $x_{d,ic}, with ic = 1,2,\cdots,m,$ in order to generate $n$outputs, given by $y_{d,oc}, with oc = 1,2,\cdots,n$. Finally, v_{ic} and u_{oc} are the weight variables for input *ic* and output *oc* respectively.

The attribution of weights to each DMU and the resulting efficiency estimation, leads to a ranking of relative efficiency (Cooper et al., 2006; Cook and Zhu, 2014). However, within this framework, more than one country can be recognized as achieving the maximum performance, since the model allows each DMU to determine its own individual weights for inputs and outputs in order to maximize its efficiency. This property of the standard DEA model is recognized both as a strong and a weak point, since it allows DEA to evaluate the efficiency of any dataset, but does not bring a full ranking to all DMUs participating in the analysis.

To overcome this discriminatory problem, several methods have been proposed that result in a full ranking (see e.g. Lofti et al., 2013). In this study, in order to fully rank the EU countries on the basis of their performance, we use the weight restriction approach introduced by Yekta et al. (2018) and expressed by the following linear programming model (2).

$$\mathrm{Min} \sum_{d=1}^{s} a_d \tag{2}$$

$$\mathrm{st}\begin{cases} \sum_{oc=1}^{n} u_{oc}, y_{d,oc} - \sum_{ic=1}^{m} v_{ic} x_{d,ic} + a_d = 0 \forall d = 1,2,\cdots,s \\ \widehat{v}_{ic} \leq v_{ic} \leq 1 \\ \widehat{u}_{oc} \leq u_{oc} \leq 1 \\ \widehat{v}_{oc} \geq a \\ \widehat{u}_{oc} \geq a \\ a \geq 0 \end{cases}$$

Here, $\widehat{v}_{ic}$, $\widehat{u}_{oc}$ are used to represent the limit lower bound of input and output weights and a_d is the slack variable, that shows the deviation of each DMU with respect to the first constraint. With this approach, a positive common set of weights is constructed by restricting the individual input and output weights, preventing their dissimilarity or the possibility of ignoring any input or output.

4.1. Variables and data

In our study, the DMUs are the EU countries under evaluation, after we exclude two countries with missing data for the indicators used (Table 1). Their performance in the waste management sector will be assessed using both the basic (b) modelling framework, presented in model (1) and the weight restrictions (wr) approach, presented in model (2) above.

The first measure of performance to be evaluated is EP, which depicts the efficiency with which a country implements the EU requirements regarding MSW management. The associated output with this performance measure is the indicator MSW recycling rate. It is defined as the tonnage of MSW materials that are recycled, plus the quantities recovered to be composted and anaerobically digested, as a percentage of total MSW generation (Eurostat, 2019a). It is noted, that it is the most widespread indicator (Price and Joseph, 2000; Barti, 2014) used to demonstrate movement up (or down) the WH, since prevention and reuse, the top hierarchical priorities present a challenge to obtaining valid measurements.

Of course, the recycling rate alone is not sufficient to assess the waste sector's contribution to the CE (Di Maio and Rem, 2015).

For that reason, in order to construct the second performance measure, the CEP, we add as an output the indicator CMUr, which is defined as the ratio of the circular use of recycled materials to overall material use (Eurostat, 2019b). Higher values of CMUr imply that more secondary materials are used to substitute primary raw materials, reducing the environmental impact of primary material extraction (Eurostat, 2019b). Consequently, this performance measure depicts, not only the efficiency with which a country implements the EU requirements regarding MSW management, but also its ability in utilizing the recycling quantities into the production and thus, whether they succeed in transitioning towards a CE.

For the evaluation of both EP and CEP, we use as inputs the per capita generated quantity of MSW and the three broad dimensions of the SPI. The per capita generated quantity of MSW is a common environmental indicator (Joint Research Center, 2018) used in reporting, planning, clarifying policy objectives and priorities, budgeting, and assessing performance. According to a study commissioned by EC-DG Environment (2009), MSW generation per capita is among the three most used, best available indicators on household waste prevention. Also, it is recognized by OECD (2004) as a key indicator of the environmental pressure that waste exerts on the environment and is one of the ten CE indicators used by the EU.

The SPI, on the other hand, was developed as a complement to traditional economic measures of performance, like GDP. The basic blocks of the index reflect the degree, to which a society is able to cover the needs of its members, creates an environment in which citizens can improve their life quality and provides enough opportunities for individuals to advance to their full potential, respecting their choices and freedom. Therefore, "Basic Human Needs', "Foundations of Wellbeing" and "Opportunity" are the three broad dimensions upon which the index is constructed. Each of these dimensions is disaggregated into four thematic categories capturing the multifaceted concept of social progress (Fig. 1). The performance of each country is presented on a 0–100 scale, where a grade of 100 represents the best performance (Porter at al., 2017).

The use of these social dimensions as inputs is based on the results of previous studies (Wilson et al., 2012; Giannakitsidou et al., 2016; Kawai and Tasaki, 2016), which show that the management of MSW is highly correlated to composite indicators, like the Human Development Index and the SPI, which capture the prevailing social and economic conditions. Moreover, it has been well documented that economic and social development influence pro-environmental attitudes and behavior, in general. According to Inglehart (1995), citizens of wealthier nations display more pro-environmental attitudes, because of a general shift from materialistic to post-materialist values. Several other studies confirmed this process of value change and its relation to environmental behavior at the national level (Dalton, 2005; Oreg and Katz-Gerro, 2006; Franzen and Meyer, 2010). The given explanation is that as societies become more affluent, their members are less preoccupied with the economic struggle for survival and are free to pursue post-materialistic goals, such as environmental protection.

Table 1
List of European countries [EU(26)] included in the DEA-models.

Austria	France	Poland
Belgium	Germany	Portugal
Bulgaria	Greece	Romania
Croatia	Hungary	Slovakia
Cyprus	Italy	Slovenia
Czech Republic	Latvia	Spain
Denmark	Lithuania	Sweden
Estonia	Luxembourg	United Kingdom
Finland	Netherlands	

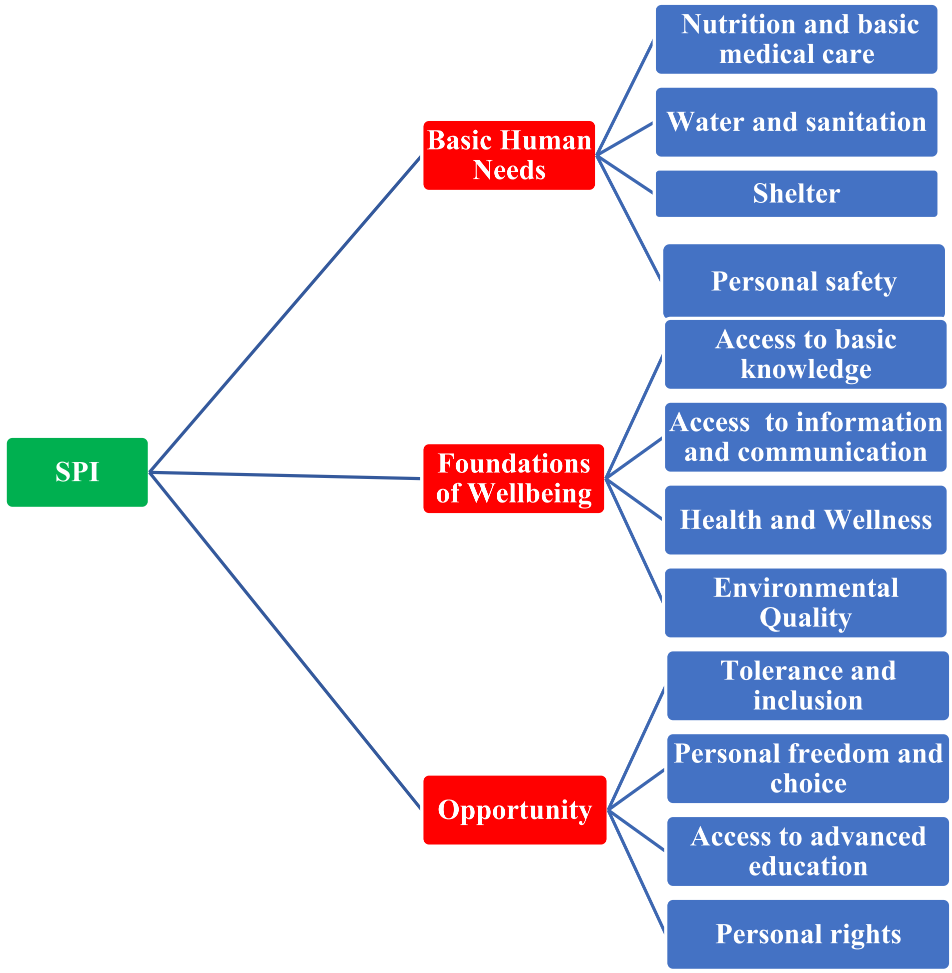

Fig. 1. Social Progress Index: Disaggregation into the basic dimensions and their respective thematic categories based on the SPI2017 Methodology Report (https://www.socialprogress.org/assets/downloads/resources/2017/2017-Social-Progress-Index-Methodology.pdf, accessed Dec. 3, 2018).

Pisano and Lubell (2017) showed that countries exhibit a stronger correlation between environmental attitudes and pro-environmental behavior, as the level of their social development increases. This was corroborated by Liu and Sibley (2012), who found that countries with a high HDI rating show a strong, positive correlation between the perceived importance of global warming and self-reported intentions to make sacrifices to protect the environment. The underlying reason being, that developed countries have fewer "external barriers" that hinder the transformation of people's intentions to real actions. Apart from the external barriers, "internal or psychological barriers" may also explain the cross-national variations in attitude–behavior correspondence. For instance, people who do not trust the institutions or the society, are more likely to think that environmental behavior will not pay off, even if they are concerned about current environmental conditions.

Based on such documentation, we argue that a holistic framework should incorporate a country's social characteristics. We do so in our analysis by using the SPI, which is the index used by the EC as a measurement tool to assess the social progress of European regions (EC, 2019) and also satisfies the criteria for efficient indicators, proposed by Stinglitz et al. (2009). It should be noted, that we chose not to use any economic index like GDP as an additional input for the DEA-models, considering that SPI is strongly and positively correlated to GDP (Ivanyos and Sandor-Kriszt, 2016; Qaisar et al., 2017). Table 2 summarizes the indicators used in our models as inputs and outputs.

Table 2
Input and output variables used in environmental and circular economy performance models.

Environmental performance models		Circular economy performance models	
Inputs	Output	Inputs	Outputs
MSW generated Basic human needs Foundations of wellbeing Opportunity	Recycling rate of MSW	MSW generated Basic human needs Foundations of wellbeing Opportunity	Recycling rate of MSW Circular material use rate

The data regarding the per capita generated quantities of MSW, as well as the recycling rate and CMUr, are retrieved from Eurostat (2019c, d, e) and the SPI data from the Social Progress Imperative website (SPI, 2019). Table 3 presents the descriptive statistics of all variables used. The EP measure is calculated for the years 2014 and 2017, since data on SPI exist from 2014 onwards, while data for MSW recycling are available until 2017. Accordingly, the CEP measure is calculated for the years 2014 and 2016. Finally, we remark that the number of countries and inputs-outputs included in our analysis fulfils the conditions suggested by various researchers that ensure that DEA analysis does not lose its discriminatory power (Golany and Roll, 1989; Cooper et al., 2007; Dyson et al., 2001).

Table 3
Descriptive statistics of input and output variables.

	Basic Human Needs			Foundations of Wellbeing			Opportunity			MSW generated			MSW Recycling rate			CMUr	
	2017	2016	2014	2017	2016	2014	2017	2016	2014	2017	2016	2014	2017	2016	2014	2016	2014
Min	85,81	85,03	84,95	76,41	72,68	72,36	61,02	61,11	60,35	272,00	261,00	249,00	13,90	13,30	10,30	1,30	1,40
Max	96,35	96,17	95,99	92,32	92,10	91,83	82,50	82,32	82,37	781,00	783,00	789,00	67,60	67,10	65,60	29,00	26,60
Average	92,90	92,65	92,65	87,14	85,49	85,29	73,47	73,41	72,24	474,46	464,36	454,48	38,80	37,59	33,39	8,88	8,75
Median	93,60	93,32	93,40	87,79	85,99	85,66	74,11	73,18	72,03	465,00	457,00	445,00	37,75	34,80	31,05	7,10	7,50
St. dev	2,85	2,95	2,93	4,65	5,03	5,00	6,59	6,64	6,59	109,03	114,64	119,10	13,91	13,77	13,73	6,78	6,21

5. Results and discussion

5.1. Results

The DEA model was implemented within the AIMMS modelling environment with CPLEX used as the standard solver. The results of the EP and the CEP models were obtained by solving the basic and the weight restricted linear programming problems with the respective inputs and outputs. The optimal value of the objective function for each DMU (country) is the EP and the CEP performance indicator respectively.

Starting with the results of the EP model (Table 4) for 2014, our calculations show that the worst relative performance with respect to this indicator is presented, in descending order, by Bulgaria, Romania, Croatia, Cyprus, Greece and Slovakia. Slovakia and Bulgaria, however, show a clear improvement in their performance over the four-year period 2014–2017, jumping from the 25th to the 16th position and from the 20th to the 13th position, respectively.

Looking at the data, it is clear that Slovakia's ranking improvement reflects the significant increase in its recycling rate, from 10.3% to 29.8% over this time interval, which offsets the increase in MSW generation (18.2%). For Bulgaria, the improvement in the relative EP and its upward trend in the ranking are justified by the observed increase in the recycling rate (from 23.1% to 34.6%), in conjunction with the small decrease (1.58%) in MSW generation over this four year period.

For Croatia and Greece, relative EP is also improved between 2014 and 2017, although they remain in the six last ranking positions. On the contrary, according to this indicator, Cyprus and Romania present deterioration in their performance. The two new countries that get, in 2017, into the group of the six countries with the lower environmental performance, replacing Slovakia and Bulgaria, are Portugal and Latvia. Latvia witnessed a significant MSW generation growth (20.34%) between 2014 and 2017, while the recycling rate decreased by 3.7%. Similarly, Portugal experienced an increase by 7.5% in MSW generation and a 2% decrease in the recycling rate. It is noted that, with respect to the countries that are identified as the six worst performers, the results of the two models (EP_b and EP_{wr}) do not differ, even if the second model enforces a full ranking of all countries.

The differences between the models become apparent with regards to the most efficient countries. According to the EP_b there were two efficient countries in 2014 (Belgium and Germany) and three most efficient countries in 2017 (Belgium, Germany and Slovenia). However, the EP_{wr} model recognizes Belgium as the only efficient country in both years. Germany, Sweden and Austria occupy the second, third and fourth position, for the year 2014. It

Table 4
Results of relative environmental performance (EP[1]).

	EP_b 2014		EP_b 2017		EP_{wr} 2014		EP_{wr} 2017	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Austria	0,9473	2	0,9451	2	0,8720	4	0,8684	4
Belgium	1	1	1	1	1	1	1	1
Bulgaria	0,4801	20	0,6837	13	0,4442	21	0,6525	15
Croatia	0,3610	22	0,4785	20	0,3379	23	0,4518	22
Cyprus	0,3159	23	0,2780	24	0,2506	25	0,2276	26
Czech Republic	0,6473	13	0,7568	9	0,5798	14	0,7116	11
Denmark	0,6897	11	0,6831	14	0,5447	20	0,5507	20
Estonia	0,6926	10	0,5668	18	0,6603	10	0,5549	19
Finland	0,5665	19	0,6705	15	0,5535	18	0,6496	16
France	0,6882	12	0,7142	11	0,6528	12	0,6894	14
Germany	1	1	1	1	0,9339	2	0,9393	3
Greece	0,2888	24	0,3337	23	0,2677	24	0,3149	25
Hungary	0,6444	14	0,7139	12	0,6238	13	0,7008	12
Italy	0,7516	8	0,8256	5	0,7152	7	0,7994	8
Latvia	0,6042	15	0,4438	21	0,5768	15	0,4314	23
Lithuania	0,5928	16	0,8737	4	0,5764	16	0,8590	6
Luxembourg	0,7854	5	0,7339	10	0,6879	8	0,6903	13
Netherlands	0,8524	4	0,8919	3	0,8176	5	0,8682	5
Poland	0,7696	6	0,8192	7	0,6568	11	0,7546	9
Portugal	0,5794	17	0,4878	19	0,5496	19	0,4780	21
Romania	0,4156	21	0,3902	22	0,3557	22	0,3504	24
Slovakia	0,2543	25	0,6260	16	0,2359	26	0,6029	17
Slovenia	0,7036	9	1	1	0,6721	9	0,9921	2
Spain	0,5748	18	0,5876	17	0,5562	17	0,5790	18
Sweden	0,9114	3	0,8226	6	0,9045	3	0,8135	7
United Kingdom	0,7637	7	0,7616	8	0,7425	6	0,7464	10
Average	0,6492		0,6957		0,6065		0,6645	

Columns EP_b and EP_{wr} show the results of the basic and the weight restricted model respectively.

is worth pointing out though, that Sweden would have been ahead of Germany in the ranking, if the three dimensions of the SPI were not taken into account, since Sweden surpasses Germany in two of the SPI's dimensions: Basic Human Needs and Foundations of Wellbeing.

In 2017, the second position was occupied by Slovenia, mainly because of its remarkable increase in the recycling rate, which jumped from 36% in 2014 to 57.8% by the end of that period. We emphasize that this 57.8% is the second best recycling rate, among all countries under examination. Likewise, Germany displays the best performance in MSW recycling with a rate of 67.6%. Still, despite its impressive achievements in recycling, Germany holds the second position behind Belgium in 2014 and the third place in 2017, behind Belgium and Slovenia. Germany's inferior performance, relative to the other two countries, is justified due to having significantly higher levels of MSW generation, but also due to its higher performance in all of the three dimensions of SPI, that is not reflected in more efficient waste management. As far as Sweden is concerned, it is downgrading from the third position in 2014 to the seventh position in 2017. It is a result driven by the improvement Sweden witnessed during this period in its social progress and by the combination of an increase in MSW generation by 3.19% with a fall in the recycling rate by 3.1%.

Turning next to the CEP_b (Table 5), our calculations show that the worst performing countries for 2014, again in descending order, are Portugal, Croatia, Latvia, Romania, Greece and Cyprus. In 2016, Latvia and Croatia interchange positions. The results are not surprising. Both the recycling rate and the CMUr of these countries, fall short of the EU(26) average. Moreover Cyprus, which is among the four countries with an MSW generation that exceeds 600 kg/year, while the EU(26) average was 459 kg/year and 468 kg/year in 2014 and 2016 respectively, surpasses all of the aforementioned countries in every SPI dimension. The inferior CE performance of Romania, Latvia and Croatia is also justified: They might produce less MSW and have a lower score in all the dimensions of the SPI than the EU(26) average, but also exhibit significantly lower recycling and CMU rates.

Portugal's place is taken by Slovakia by 2016. In this three year period, Slovakia witnessed a significant increase in the recycling rate (from 10.3% to 23%) and a marginal increase of 0.1% in the CMUr, that were not enough to compensate the effect of the simultaneous improvement in its social progress and the increased MSW generation.

Again, the results of our two models (CEP_b and CEP_{wr}) do not differ, with respect to the countries which are the six worst CE performers in 2016. However, because of the difference between the two models in assigning weights, there is a difference for year 2014, as the CEP_{wr} model excludes Latvia and Portugal from the six worst positions, replacing them by Slovakia and Bulgaria. Nevertheless, the changes in ranking are small for these countries and do not alter, in any significant way, the conclusions that can be derived for their performance.

The best performing countries for 2014, according to the CEP_b, are Belgium, Germany and Slovenia. The Netherlands are also considered among the most efficient countries, for 2016. However, the CEP_{wr} model, that forces a full rank, recognizes Belgium as the most efficient country, for both years under examination. Belgium, is among the countries that present an especially high score, above the EU(26) average, in all the SPI's dimensions, but has also achieved a MSW generation rate significantly below the EU(26) average. Therefore, with the second best CMUr and the third best recycling rate, Belgium ranks first with respect to the cyclical economy performance.

Belgium is followed by Germany, Sweden and Austria in 2014 and by Slovenia, Germany and Austria in 2016. Finally, it is worth mentioning that, according to the CEP_{wr}, the Netherlands is ranked fifth in both years, despite having the highest CMUr (26.6% in 2014 and 29% in 2016) and the third highest recycling rate (50.9% and 53.1% in 2014 and 2016, respectively), because it also presents especially high scores in all the SPI dimensions.

Table 5
Results of relative circular economy performance (CEP^1).

	CEP_b 2014		CEP_b 2016		CEP_{wr} 2014		CEP_{wr} 2016	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Austria	0,9451	2	0,9516	2	0,8599	4	0,8761	4
Belgium	1	1	1	1	1	1	1	1
Bulgaria	0,6837	13	0,6628	14	0,4365	21	0,6331	16
Croatia	0,4785	20	0,4387	20	0,3364	23	0,4132	23
Cyprus	0,2780	24	0,3011	23	0,2466	25	0,2423	26
Czech Republic	0,7568	9	0,7762	9	0,5767	14	0,7156	11
Denmark	0,6831	14	0,7024	13	0,5388	19	0,5587	19
Estonia	0,5668	18	0,6360	15	0,6610	11	0,5743	18
Finland	0,6705	15	0,7074	12	0,5486	18	0,6782	15
France	0,7142	11	0,7808	8	0,6584	12	0,6880	13
Germany	1	1	1	1	0,9211	2	0,9338	3
Greece	0,3337	23	0,3054	22	0,2625	24	0,2863	25
Hungary	0,7139	12	0,7242	11	0,6159	13	0,7019	12
Italy	0,8256	5	0,8568	6	0,7189	7	0,7765	9
Latvia	0,4438	21	0,5115	19	0,5667	16	0,4884	22
Lithuania	0,8737	4	0,9005	3	0,5668	15	0,8691	6
Luxembourg	0,7339	10	0,7350	10	0,6823	8	0,6868	14
Netherlands	0,8919	3	1	1	0,8294	5	0,8692	5
Poland	0,8192	7	0,8878	4	0,6636	10	0,7965	8
Portugal	0,4878	19	0,5488	17	0,5385	20	0,5268	20
Romania	0,3902	22	0,3991	21	0,3501	22	0,3429	24
Slovakia	0,6260	16	0,5198	18	0,2382	26	0,4915	21
Slovenia	1	1	1	1	0,6666	9	0,9774	2
Spain	0,5876	17	0,6075	16	0,5524	17	0,5899	17
Sweden	0,8226	6	0,8837	5	0,8901	3	0,8614	7
United Kingdom	0,7616	8	0,7996	7	0,7437	6	0,7486	10
Average	0,6957		0,7168		0,6027		0,6664	

Columns CEP_b and CEP_{wr} show the results of the basic and the weight restricted model respectively.

5.2. Discussion

Our study demonstrates how DEA can be used for the aggregation of individual single indicators used in the MSW sector, or indicators monitoring the transition to a more circular economy, with indices capturing social factors, in order to construct environmental and circular economy performance measures. These measures are not intended to substitute the traditional single indices, but to complement them, offering a deeper insight on the countries' performance.

It is noteworthy, that a major advantage of DEA is that it applies the "benefit of the doubt approach". This is manifested by the use of a maximization function and the attribution, endogenously, of weights to each variable, so as to reveal the maximum overall performance for each country. Moreover, DEA will not recognize an efficient unit as inefficient. In addition, the endogenous attribution of weights, for any country and any indicator, ensures that this method is not subject to specific normative preferences, which is a concern when constructing composite indicators by other techniques. Therefore, countries cannot claim that a poor relative performance is due to a harmful or unfair weighting scheme. The resulting ranking of the EU countries, with respect to these measures, can be a valuable tool for policymakers. By recognizing the most efficient countries, their best practices can be learnt and adopted by the inefficient ones, in order to improve not only MSW management, but also the cyclicality of their economy, both at a national level and for EU as a whole.

Our models for both years, showed that the vast majority of countries in the sample do not perform well, although, on average, EU(26) has shown improvement both in environmental and circular economy performance. The performance gaps between the efficient and less efficient countries are significant, suggesting that the latter countries have the potential for large improvements. Therefore, inefficient countries should learn from the waste policy and sustainable materials management, implemented by those identified as efficient, like Belgium. As an example, the waste policy of Belgium includes a mix of instruments, like subsidies, awareness raising campaigns, levies, recycling fees, landfilling and incineration bans etc. It is also worth noting that the "polluter pays" principle is firmly embedded in the Belgian waste management policy. Even households are charged, based on the volume or weight of their waste, while tariffs are differentiated, so that mixed household waste is more expensive to discard than selectively collected waste (inno4sd.net, 2019). In addition, Belgium has a dense network of reuse shops, while the state subsidizes those municipalities that launch waste prevention initiatives (UN, 2019).

It should be noted that a limitation of DEA is its inability to offer a prediction model of the country's maximum performance, since such a theoretical maximum cannot be determined (Othman et al., 2010). This happens because the performance scores are relative and based on the specific dataset. However, this means that even the countries that have been revealed as efficient, have plenty of room for improvement. This fact is recognized by the policymakers of Flanders, Belgium. Despite of their up-to date success, they are pushing forward an ambitious waste prevention program, aiming at a notable reduction in household waste to 116–258 kg, per inhabitant per year, by 2022, depending on each municipality's socio-economic factors (European Environmental Agency, 2016).

A final limitation of the DEA technique is its sensitivity to the presence of outliers, due to its inherent determinism. However, no outliers were observed in our particular data set, as evidenced by the descriptive statistics of the inputs and outputs. If such countries-outliers had been observed, they would have been excluded from the analysis.

Our input/output models are far from perfect. However, according to our opinion, they meet at least four of the five RACER requirements for indicators i.e. the criterion of relevance, acceptability, credibility, easiness and robustness (Srebotnjak et al., 2009). Also, we believe they meet the criterions suggested in the European Commission's Impact Assessment Guidelines (EC, 2009). According to these Guidelines, a scientific tool must be robust (not easily manipulated) and relevant (closely linked to the objectives to be reached). It is our view that our DEA based frameworks are robust, in the sense that all DMUs (countries) are assessed upon the same set of inputs and outputs, which are measured on a quantitative basis using data obtained from official sources. Moreover, since the overall objective is to measure relative environmental and circular economy performance, we feel that this framework is certainly relevant, since it provides an efficiency score for each country, expressing its performance in comparison to other countries. Results have a clear interpretation and are easy to comprehend even by non-experts. The proposed DEA models are easy to apply and provide the efficiency scores for all countries in negligible time. All these aspects make this evaluation framework a versatile tool for monitoring the performance of each country in comparison to others and for identifying policy objectives.

Finally, we should note that limitations of available data and indicators introduce an element of uncertainty when comparing across countries since the results of any model incorporating statistical data depend on their reliability and comparability. Although a fairly high degree of comparability between countries has been already achieved for the EC (2016), any improvement and harmonization in the statistical reporting by the EU countries (Eurostat, 2017) would be beneficial for any comparative analysis.

6. Conclusions

Summing up, the results of our study show that there are large disparities among EU countries, with respect to their environmental and circular economy performance. Interestingly though, the borders between Western and Eastern Europe, but not between the north and the south, have fallen: old EU members, such as Spain or France, perform significantly worse, both from an environmental and a circular economy perspective, than newer member states such as Slovenia or Poland, while southern countries like Cyprus and Greece remain among the worst performers, with respect to both performance measures.

At the same time, while countries like Denmark or Finland seem to be committed for the present to incineration, other countries like Slovenia have the potential to rise among the top environmental and circular economy performers, by exploiting the lack of such commitments, further reducing waste generation levels, increasing recycling and transforming their industrial methods in order to better exploit recyclable materials. Finally, with regards to the results of the present study, Belgium emerges as the best environmental and circular economy performer, surpassing Germany and the Netherlands, despite their achievements in MSW recycling.

Future achievements in environmental and circular economy performance can go hand in hand with the improvement of a country's social progress and create a kind of positive feedback loop. The shift towards a circular economy has the potential to boost economic growth by promoting innovation, creating more jobs and enhancing economic competitiveness. In turn, the positive economic and social advances, depicted by a higher social progress index, can be substantiated into more efficient waste management and can be used to strengthen the shift of the economy, since, as we discussed earlier, a higher Social Progress index is connected to stronger pro-environmental attitudes and stimulated social activity, factors that are necessary for achieving better results in environmental and cyclical economy performance.

For further research, there is a clear need to investigate why these national differences exist, by analyzing national circular economy strategies and their interaction with waste management practices. Furthermore, if input and output data are available over a longer time period, windows analysis may be performed to monitor changes in environmental and circular economy performance over time. In addition, if the weights of certain inputs or outputs are deemed too high or too low by policy makers, then appropriate weight restrictions that reflect experts' judgments may be incorporated in the form of additional constraints on the input and output weights. For details on DEA models with weight restrictions and the calculation of optimal weights see Podinovski (2016) and the references therein. Finally, additional analysis could also incorporate information on public expenditure for supporting national MSW and circular economy policies, e.g. public spending for promoting civil society awareness on MSW prevention and recycling, public funding for circular projects and programs, public funding on social enterprises operating in the MSW recycling sector etc. to obtain an even broader understanding.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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