Efficiency of materials management in the European Union

Aneta Masternak-Janus
*Department of Production Engineering,
Kielce University of Technology, Kielce, Poland*

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Abstract

Purpose – The purpose of this paper is to measure and evaluate the efficiency of materials management in the European Union countries (EU-28) during the period of 2008–2017.
Design/methodology/approach – The study was conducted using the method of data envelopment analysis (DEA) and variables applied to determine the resource productivity indicator. Therefore, the components of domestic material consumption constituted inputs in the DEA method, while gross domestic product (GDP) was applied as an output.
Findings – The results of the analysis showed that the Netherlands, Luxembourg, Latvia and the UK are the efficiency leaders among all the member states of the European Union. One of the least efficient countries is Poland, which uses too much natural resources in the process of generating goods and services. However, this consumption is growing at a slower rate than the value of GDP, which is beneficial from the point of view of sustainable development. Poland, like other inefficient countries, should reduce its consumption of natural resources in line with the best international practices.
Practical implications – The obtained research results can be a valuable source of information for decision-makers, and contribute to the adoption of more effective policies in order to improve the relationship between materials consumption and economic growth.
Originality/value – The application of the DEA method for calculating the efficiency of materials management represents a new approach, and it is the first attempt of its kind in the European Union countries.

Keywords Benchmarking, Technical efficiency

Paper type Research paper

Introduction

Materials management concerns all phenomena and processes related to the flow of material goods (i.e. natural resources, resources created as a result of processing and secondary resources, as well as semi-finished products) from the moment of their acquisition, through all stages of processing, to the final stages of production consumption (Skowronek, 1987; CSO, 2017). On the one hand, it is of particular importance for the creation of national income and constitutes the foundation of the proper functioning of the economy (CSO and SOB, 2017). An uninterrupted flow of materials allows for efficient operation of various sectors, which, through the production of useful goods, satisfy the growing material aspirations of the population and create jobs. On the other hand, the extraction, processing and transport of material resources have a negative impact on all the components of the natural environment, which means that it leads to their contamination with solid, liquid and gas waste. Moreover, the constantly changing lifestyles and the growing world population contribute to increasing the consumption of materials, which can lead to the depletion of natural resources (Wagner, 2002; Łuszczyk, 2010). As a result, environmental degradation and overexploitation of material resources deplete national wealth and may become an ecological barrier to social and economic development (Górka, 2014).

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In order to protect the environment and preserve natural resources for future generations, it is essential that a sustainable materials management be ensured, which consists in satisfying human needs through the use and reuse of materials in a more efficient way throughout their life cycle. In other words, using a smaller amount of materials in the manufacture of products, reducing the toxicity of materials and placing emphasis on their reuse are the primary objectives (EPA, 2009). The implementation of these measures will allow for achieving positive effects not only in the environmental, but also the economic (e.g. reduction of production costs) and social (e.g. higher quality of social life) dimensions.

Efficient management of material flows requires effective methods of monitoring and evaluation, at the micro-level (enterprise), the mezo-level (regional) as well as at the macro-level (national). In order to measure the efficiency of the inputs of materials to European economies, a resource productivity indicator is used, which is determined as a relation of gross domestic product (GDP) to domestic material consumption (DMC) (Eurostat, 2018). The higher the value of this indicator is, the lower quantity of materials has been used in the economy for the process of producing a unit of GDP (CSO and SOB, 2017). The resource productivity indicator provides an assessment of the absolute level of the use of natural resources (i.e. biomass, metal ores, non-metallic materials and fossil energy materials) in the process of economic development, and thus provides information on the efficiency of actions taken in order to reduce material consumption. It also allows comparison with the set baseline, including the analysis of domestic consumption of materials in a global context (Fischer-Kowalski *et al.*, 2011).

A new alternative approach to the measurement and evaluation of the efficiency of materials consumption in the economy is the application of the data envelopment analysis (DEA) method. This method employs a technique of linear programming to determine the relative technical efficiency, which denotes the transformation of physical inputs into results (Bhagavath, 2006). Due to its advantages, such as an effective system of assigning weights, the possibility of using multiple variables expressed in different units at the same time, as well as the fact that there is no necessity to possess the knowledge on the functional relationship between assumed inputs and outputs, it is widespread in many fields of economic sciences, e.g. agricultural economics, financial economics, development economics, ecological and environmental economics (Kortelainen and Kuosmanen, 2004; Sreedevi, 2016). Consequently, DEA is applied to assess the efficiency of both public and private organizations as well as regions and countries (Pan *et al.*, 2010; Mikušová, 2015; Masternak-Janus and Rybaczewska-Błażejowska, 2017; Zhao and Wei, 2019). So far, however, it has not been applied in the area of materials management.

The purpose of this paper is to analyse the efficiency of materials management in European Union countries (EU-28), including Poland, over the period of 2008–2017. The efficiency was calculated using the DEA method – the input-oriented CCR model and variables applied to determine the resource productivity indicators. The proposed approach allows decision-makers not only to carry out comparative research, but also to conduct the process of benchmarking of best practices in order to change the relationship between materials consumption and economic growth.

Research methodology

The DEA method measures the relative technical efficiency of homogeneous decision-making units, so-called DMUs, which are characterized by the same number and type of inputs and outputs (Zhu *et al.*, 2011). The procedure in the DEA method consists in maximizing the ratio of the weighted sum of outputs to the weighted sum of inputs for the evaluated DMU, while keeping efficiency scores (θ) not greater than 1 for the other DMUs from the examined set (Chu *et al.*, 2016). A DMU is considered to be efficient if its efficiency score equals 1, otherwise it is considered inefficient at a level of $1–\theta$. Efficient units form the so-called best practice frontier and constitute models (benchmarks) for inefficient units (Park and Sung, 2016). In order to be placed on the best practice frontier, units should carry out a benchmarking process, i.e. decrease their input values at the same output values or increase their output values at the same input values. The procedure depends on the orientation of the DEA model applied for the purpose of the study.

There are many DEA models in the literature, grouped by orientation (non-orientated or input- and output-oriented models) and returns to scale (constant returns to scale (CRS) or variable returns to scale (VRS)). Their application affects the values of the efficiency scores obtained (Jarzębowski, 2014). While the choice of model orientation depends on the purpose of the performed study, the choice of the returns to scale is not so unambiguous. Generally, if DMUs operate on a competitive market, it can be assumed that they operate in their most productive scale size and then the CRS model will be the most suitable (Lozano *et al.*, 2009).

The application of the DEA method for measurement and evaluation of the efficiency of materials management requires executing the following steps:

(1) design of the DEA model with a specific number and type of inputs and outputs, i.e. indicators of consumption of natural resources and economic indicators;

(2) inventory of data including collection of the values of indicators accepted at the first stage for each analysed DMU;

(3) selection of the DEA model with a specific orientation and type of the returns to scale, and then calculation of the efficiency score for each DMU under consideration; and

(4) conducting a benchmarking process for inefficient DMUs in order to improve the relation between consumption of materials and economic growth.

In order to calculate the efficiency scores in the EU-28 countries, the variables used by Eurostat to determine the resource productivity indicator were applied as inputs and outputs in DEA model. In view of the above, the following set of input variables has been defined:

- $x_1 =$ consumption of biomass per capita (Mg).
- $x_2 =$ consumption of metal ores per capita (Mg).
- $x_3 =$ consumption of non-metallic materials per capita (Mg).
- $x_4 =$ consumption of fossil energy materials per capita (Mg).

GDP per capita at current prices (euro) was applied in the DEA model as the output variable. In order to provide an analysis of material management efficiency over a longer period of time, the values of the assumed variables for all EU-28 countries were collected for a 10-years period of time (the years 2008–2017) (Eurostat Database, 2019).

Out of the many different kinds of DEA models, the input-oriented CCR model – first introduced by Charnes *et al.* (1978) – was selected in this study. This model assumes CRS, which denotes linear scaling of inputs and outputs without changing the efficiency. The input-oriented approach was chosen in this model, since reduction of the consumption of natural resources at a given level of economic performance should be the priority in the EU-28. The dual form of the input-oriented CCR model can be presented as follows:

$$\min \theta_o, \tag{1}$$

$$\sum_{j=1}^{J} x_{nj}\lambda_{oj} \leqslant x_{no}\theta_o, \tag{2}$$

$$\sum_{j=1}^{J} y_{rj}\lambda_{oj} \geqslant y_{ro}, \tag{3}$$

$$\lambda_{oj} \geqslant 0, \tag{4}$$

where θ_o is the efficiency score of the observed DMU; x_{nj} the amount of the nth input for the jth DMU; x_{no} the amount of the nth input for the observed DMU; y_{rj} the amount of the rth output for the jth DMU; y_{ro} the amount of the rth output for the observed DMU; λ_{oj} the weight coefficients related to inputs and outputs; $j = 1, \ldots, J$; $r = 1, \ldots, R$; $n = 1, \ldots, N$.

The CCR model allows for determining the optimal technologies and benchmarking formulas for ineffective units, the surplus of input values in relation to the optimal values and, consequently, the direction of productivity improvements. Besides, based on the sums of optimal weight coefficients λ obtained from the solution of the CCR model, the types of returns to scale can be determined for all EU-28 countries, and thus:

(1) If $\sum_{J=1}^{J} \lambda_{oj} = 1$, then the oth economy is characterized by CRS.

(2) If $\sum_{J=1}^{J} \lambda_{oj} > 1$, then the oth economy is characterized by decreasing returns to scale (DRS).

(3) If $\sum_{J=1}^{J} \lambda_{oj} < 1$, then the oth economy is characterized by increasing returns to scale (IRS).

Results

Efficiency analysis with the DEA model

In order to estimate the efficiency of 28 countries of the European Union, data from the period of 10 years were used, which required solving 280 linear programming tasks. Table I presents the values of technical efficiency scores for the years 2008–2017.

The results presented in Table I show that only the Netherlands, Luxembourg, Latvia and the UK were characterized by full technical efficiency during the period under consideration. Consequently, these countries achieved technical efficiency scores equalling to 1 in every year. In 2011, Sweden joined the technical efficiency leaders, also Estonia was a member of this group until 2013. In addition, France, Lithuania, Malta and Italy were mostly fully effective between 2008 and 2017. Of the 28 countries of the European Union, 36 per cent achieved an average technical efficiency greater than 0.9. The lowest level of average technical efficiency was 0.29 (Bulgaria).

The obtained results of the research show that Poland occupies the penultimate place in the ranking of average technical efficiency. This country consumes on average 67 per cent too much natural resources in the process of obtaining the GDP ($1–0.33 = 0.67$, where the average value of technical efficiency score $= 0.33$). The sums of optimal weight coefficients λ obtained in the CCR optimizing procedure indicate, however, that over the period of 2008–2017, Polish economy was characterized by IRS. This means that the consumption of natural resources, undoubtedly related to negative impact on the environment, grew at a slower pace than the value of goods and services. The situation therefore appears to be favourable from the point of view of sustainable development. Table II presents the types of returns to scale for all EU-28 countries. The occurrence of DRS is highlighted in grey.

As can be observed in Table II, the technical efficiency leaders in the years 2008–2017, i.e. the Netherlands, Luxembourg, Latvia and the UK, operated in the area of CRS during this period. Therefore, an n-fold increase in the consumption of natural resources in these

Table I.
Technical efficiency scores in the EU-28 countries for the years 2008–2017

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Average
Austria	0.58	0.62	0.55	0.81	0.76	0.84	0.83	0.84	0.75	0.74	0.73
Belgium	0.66	0.75	0.74	0.69	0.81	0.79	0.88	0.85	0.77	0.82	0.78
Bulgaria	0.26	0.36	0.31	0.28	0.33	0.27	0.25	0.24	0.29	0.27	0.29
Croatia	0.65	0.65	0.71	0.90	1	0.92	0.87	0.82	0.69	0.78	0.80
Cyprus	0.28	0.37	0.73	0.67	0.79	0.69	0.71	0.65	0.73	0.60	0.62
Czechia	0.64	0.78	0.69	0.58	0.79	0.76	0.70	0.72	0.70	0.88	0.72
Denmark	0.64	0.84	1	1	0.85	0.85	1	0.82	1	0.93	0.89
Estonia	1	1	1	1	1	1	0.89	1	0.64	0.85	0.94
Finland	0.31	0.41	0.32	0.44	0.56	0.45	0.46	0.56	0.57	0.55	0.46
France	1	1	0.85	1	1	1	1	1	1	1	0.99
Germany	0.66	0.72	0.72	0.65	0.67	0.73	0.70	0.73	0.72	0.76	0.71
Greece	0.61	0.71	0.65	0.60	0.63	0.63	0.60	0.60	0.58	0.60	0.62
Hungary	0.61	0.63	0.66	0.70	0.74	1	0.72	0.61	0.56	0.51	0.67
Ireland	0.39	0.48	0.59	0.68	0.83	0.63	0.70	1	0.94	0.87	0.71
Italy	0.79	1	0.82	0.89	1	1	1	1	1	1	0.95
Latvia	1	1	1	1	1	1	1	1	1	1	1
Lithuania	1	1	1	1	1	1	1	0.91	0.87	1	0.98
Luxembourg	1	1	1	1	1	1	1	1	1	1	1
Malta	1	1	1	1	1	1	1	0.82	1	1	0.98
The Netherlands	1	1	1	1	1	1	1	1	1	1	1
Poland	0.32	0.34	0.32	0.30	0.30	0.33	0.33	0.36	0.34	0.34	0.33
Portugal	0.52	0.61	0.46	0.95	0.84	0.98	0.88	0.83	0.83	0.73	0.76
Romania	0.49	1	0.48	0.46	0.50	0.57	0.52	0.49	0.50	0.51	0.55
Slovakia	0.51	0.51	0.50	0.54	0.54	0.58	0.58	0.60	0.58	0.59	0.55
Slovenia	0.68	0.99	0.75	0.64	0.79	0.84	0.77	0.80	0.73	0.68	0.77
Spain	0.69	0.81	0.64	0.87	0.93	1	0.93	0.97	1	0.96	0.88
Sweden	0.72	0.74	0.70	1	1	1	1	1	1	1	0.92
UK	1	1	1	1	1	1	1	1	1	1	1

countries resulted in an n-fold increase in GDP. Apart from Poland, the countries being in the area of IRS in the analysed period also include Bulgaria, the Czech Republic, Finland, Greece, Portugal, Slovakia, Slovenia, Croatia, Romania and Hungary, among which Croatia managed to operate at an optimal scale in 2012, while Romania in 2009 and Hungary in 2013. Countries such as Estonia, Lithuania, Malta and Italy operated within the area of either CRS or IRS.

Among the analysed countries in the area of DRS during the period of 2008–2017, Denmark and Austria occurred the most frequently. These countries should therefore pay particular attention to reducing the rate of consumption of natural resources, since it is growing faster than the value of GDP. During the period under consideration, France, Spain and Sweden were only once characterized by DRS. However, these countries succeeded in reducing the scale of activity to achieve more sustainable management of materials.

The calculated average scores of the technical efficiency of EU-28 countries was compared with the corresponding indicators of the average resource productivity for the years 2008–2017, as shown in Figure 1. Countries are marked with symbols in accordance with the international standard ISO 3166. The results led to the conclusion of the existence of a positive relation between overall efficiency of countries and their resource productivity. Thus, apart from Latvia, Lithuania and Estonia, the countries with the highest average scores for technical efficiency (above 0.90) generate also the highest average resource productivity (above 2.0 euro/kg), e.g. the Netherlands, UK, Luxembourg, Italy, France, Malta. However, some countries with high resource productivity indicators are also less efficient, e.g. Belgium and Germany.

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Austria	IRS	DRS	IRS	IRS	IRS	DRS	DRS	DRS	DRS	DRS
Belgium	IRS	IRS	IRS	IRS	IRS	DRS	DRS	IRS	DRS	DRS
Bulgaria	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS
Croatia	IRS	IRS	IRS	IRS	CRS	IRS	IRS	IRS	IRS	IRS
Cyprus	IRS	IRS	DRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS
Czechia	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS
Denmark	DRS	DRS	CRS	CRS	DRS	DRS	CRS	DRS	CRS	DRS
Estonia	CRS	CRS	CRS	CRS	CRS	CRS	IRS	CRS	IRS	IRS
Finland	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS
France	CRS	CRS	DRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS
Germany	IRS	IRS	IRS	DRS	IRS	DRS	DRS	IRS	DRS	IRS
Greece	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS
Hungary	IRS	IRS	IRS	IRS	IRS	CRS	IRS	IRS	IRS	IRS
Ireland	DRS	IRS	IRS	IRS	IRS	IRS	IRS	CRS	DRS	DRS
Italy	IRS	CRS	IRS	IRS	CRS	CRS	CRS	CRS	CRS	CRS
Latvia	CRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS
Lithuania	CRS	CRS	CRS	CRS	CRS	CRS	CRS	IRS	IRS	CRS
Luxembourg	CRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS
Malta	CRS	CRS	CRS	CRS	CRS	CRS	CRS	IRS	CRS	CRS
The Netherlands	CRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS
Poland	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS
Portugal	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS
Romania	IRS	CRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS
Slovakia	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS
Slovenia	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS	IRS
Spain	IRS	DRS	IRS	IRS	IRS	CRS	IRS	IRS	CRS	IRS
Sweden	DRS	IRS	IRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS
UK	CRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS	CRS

Table II. The types of returns to scale (DRS) in the EU-28 countries during the period of 2008–2017

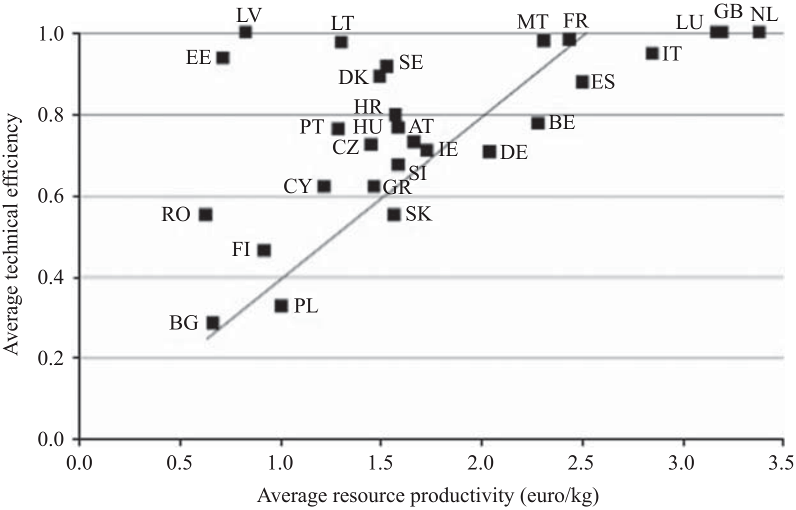

Figure 1. Technical efficiency of EU-28 countries in comparison to resource productivity

Application of the DEA model in the benchmarking process

The DEA method applied in order to assess the efficiency of materials management in EU-28 countries allows for determining a set of reference countries, the so-called benchmarks, the example of which should be followed by inefficient countries in order to obtain scores of technical efficiency equal to 1. The relations between ineffective countries and benchmarks can be presented using the so-called Hasse diagram. It is created on the basis of optimal weight coefficients λ obtained as a result of performing the DEA optimization procedure. Figure 2 shows the relations between EU-28 countries in 2017, however, the relations in other years can be similarly presented in a graphical form. Efficient countries avoiding wastefulness in the process of using natural resources in the production of goods and services were indicated using a darker colour.

On the basis of the weight coefficients shown in Figure 2, benchmarking formulas can be established for all inefficient EU-28 countries in order to achieve efficiency in 2017. For example, if the consumption of natural resources in Poland was modelled in 10 per cent on the consumption of natural resources in France, and also in 6 per cent on the consumption in Luxembourg, in 1 per cent on the consumption in Sweden and in 40 per cent on the consumption in the UK, then Poland would use no more than 34 per cent of the value of its current consumption to create GDP. In order to achieve efficiency in 2017,

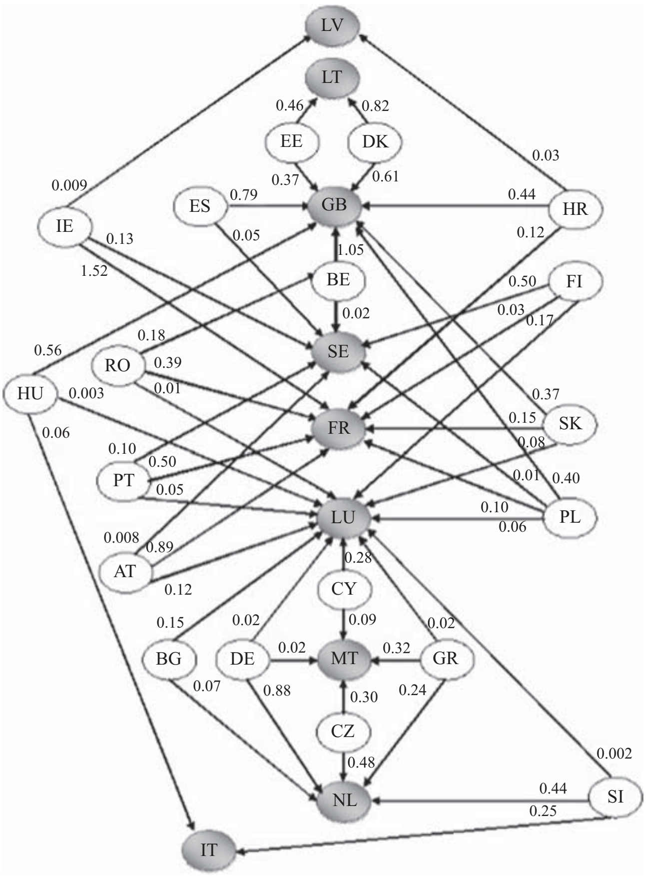

Figure 2.
Relations between the EU-28 countries in 2017

Poland should therefore reduce the consumption of both biomass, metal ores, non-metallic materials and fossil energy materials by 66 per cent. Figure 3 presents the average potential reductions (in percentage) in the consumption of natural resources for all inefficient EU-28 countries for the years 2008–2017.

The average potential reductions in the consumption of natural resources showed in Figure 3 depend on a given country and its inefficiency level over the years 2008–2017. The highest average reductions within the analysed period are required in the case of the consumption of metal ores in Bulgaria (93 per cent), which also exceeded the consumption of fossil energy materials by an average of 76 per cent and the consumption of biomass by an average of 71 per cent. The highest average reduction in the consumption of non-metallic materials is required in Romania (77 per cent). Poland, while maintaining unchanged GDP level, should reduce the consumption of natural resources by as much as 70 per cent on average.

In order to reduce the consumption of natural resources, inefficient countries should follow international best practices. On the basis of the information provided in Table III,

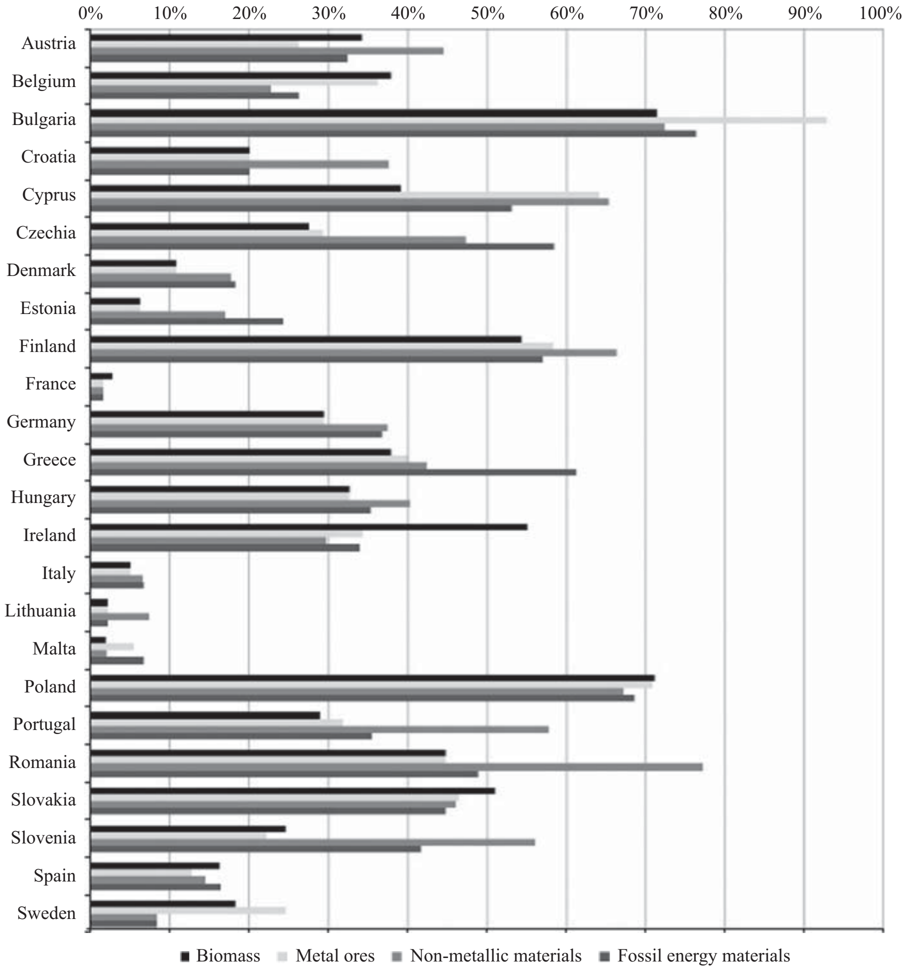

Figure 3. Average potential reductions in the consumption of natural resources in the EU-28 countries

Table III. Intensity of benchmarks establishment by effective EU-28 countries during the period of 2008–2017

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Croatia	–	–	–	–	3.6	–	–	–	–	–
Denmark	–	–	0	0	–	–	7.1	–	7.1	–
Estonia	0	3.6	0	0	3.6	3.6	–	7.1	–	–
France	28.6	14.3	–	17.9	21.4	21.4	25.0	28.8	35.7	28.6
Hungary	–	–	–	–	–	3.6	–	–	–	–
Ireland	–	–	–	–	–	–	–	14.3	–	–
Italy	–	21.4	–	–	3.6	7.1	28.6	10.7	17.9	7.1
Latvia	7.1	0	0	3.6	14.3	0	3.6	14.3	14.3	7.1
Lithuania	0	3.6	14.3	7.1	7.1	7.1	17.9	–	–	7.1
Luxembourg	64.3	50.0	46.4	53.6	50.0	28,6	39.3	50.0	28.6	42.9
Malta	35.7	32.1	67.9	18.4	17.9	14.3	14.3	–	17.9	14.3
The Netherlands	10.7	25.0	21.4	17.9	7.4	25.0	7.1	7.1	10.7	17.9
Romania	–	3.6	–	–	–	–	–	–	–	–
Spain	–	–	–	–	–	10.7	–	–	7.1	0
Sweden	–	–	–	10.2	14.3	14.3	17.9	14.3	10.7	25.0
UK	17.9	14.3	32.1	14.3	25.0	10.7	7.1	32.1	39.3	32.1

one may note that the dominant benchmark country is Luxembourg, which was an example of effective management of materials in the creation of goods and services in 2008–2017 for an average of 45 per cent of countries. The measures taken by inefficient countries should also be in line with the benchmarks established mainly by France, Malta and the UK.

Discussion

The presented research using the DEA method provided valuable insight into the effectiveness of materials management in the European Union, and thus provided data that can be used to inform both political decision-makers and the general audience about the efficiency of material flows in European economies. Studies have shown that, in the analysed period 2008–2017, only four EU-28 member states were relatively efficient every year, namely, the Netherlands, Luxembourg, the UK and Latvia. It should be noted that the first three countries have for years been leaders in terms of the resource productivity indicator. Thus, the Netherlands and the UK are characterized by a very low level of DMC (around 8–12 tonnes per capita) and, at the same time, they occupy high positions among EU-28 countries in terms of GDP per capita. The mentioned indicators are evidence of the fact that the economic activity in these countries is largely separated from the use of natural resources which translates into high efficiency. Although the DMC in Luxembourg (on average 22.67 tonnes per capita in 2008–2017) is at a much higher level than the EU-28 average (around 14.05 tonnes per capita in 2008–2017), this country has for years been the first in the GDP per capita ranking, leaving the economies of other European countries far behind. For example, in 2017, the GDP per capita in Luxembourg was over 30 per cent higher than in Ireland, ranked second, and almost 50 per cent higher than in the Netherlands, ranked third. According to the analysis, Latvia, which has a very low level of GDP per capita and is considered a less developed country, turned out to be effective in terms of materials management. Although the use of biomass in this country is high, at the same time, the use of metal ores and fossil energy materials is one of the lowest in EU-28. Ultimately, Latvia is 100 per cent effective, meaning that it does not waste natural resources when creating GDP.

Apart from the Netherlands, Luxembourg, Latvia and the UK, the remaining 24 EU-28 member states were inefficient in managing materials in the years 2008–2017, but to a varying degree. This means that they should reduce the consumption of natural resources in relation to their economic growth. Although as the conducted research revealed, in 15 inefficient countries (Bulgaria, Croatia, the Czech Republic, Estonia, Finland, Greece, Hungary, Italy, Lithuania, Malta, Poland, Portugal, Romania, Slovakia and Slovenia), the natural resources consumption never grows faster than the value of products and services, which seems beneficial from the point of view of sustainable development, target values have been designated for the consumption of biomass, metal ores, non-metallic materials and fossil energy materials based on benchmarking models. Despite the fact that these target values cannot be taken literally, they may provide governments and decision-makers with valuable data with respect to identifying areas which require improvements and determining the scope of work needed for achieving efficiency. The analysis of target values should be an impetus to explaining the causes of inefficiency, especially in those EU-28 countries which have for years been occupying the last positions in the efficiency ranking, such as, for instance, Poland.

In general, the level of using materials in an economy is very much dependent on the economic structure of a given country. Hence, in countries that specialize in livestock production (Ireland, Denmark) and timber production (Latvia, Finland), a high consumption of biomass is present, metal ore consumption is high in extracting countries (Bulgaria, Finland), whereas high consumption of fossil energy materials is observed in countries with an above-average activity in mining fossil fuels (Estonia, the Czech Republic). The consumption of non-metallic minerals is related to the level of investing in construction activity, the size of the infrastructure (e.g. road infrastructure), production of consumer goods (e.g. cars, household appliances, medicines) (Eurostat, 2018). Due to the fact that affecting a change in the economic structure is often impossible in practice, an effective measure resulting in sustainable materials management may be to change production methods into ones that are less material-intensive and introduce new organizational forms which contribute to saving natural resources. Taking this into account, inefficient countries should take advantage of benchmarking models and adopt the best available techniques for the processes implemented by them.

Conclusions

The presented research investigates the efficiency of materials management in the EU-28 countries based on the DEA method. This DEA approach allowed for a multi-criterion comparative analysis of all member states of the European Union and to gain knowledge on international best practices. Furthermore, it provided information on the types of returns to scale and identified the areas which require improvement. Consequently, the results of the study are intended to be of interest to governments and decision-makers in order to assist them in outlining the policy targets and actions towards sustainable materials management. They also demonstrate that the DEA method could be integrated into both national organizations and European institutions as a new powerful management tool to support the decision-making process.

The results yielded by applying DEA unequivocally showed that the Netherlands, Luxembourg, Latvia and the UK are the efficiency leaders among all the member states of the EU-28. Furthermore, for many years, Poland has remained one of the least effective countries. This means that the decision-makers in Poland face many challenges related to the promotion of innovations bringing benefits to both the economy and the environment.

Finally, it should be added that the implementation of activities which promote sustainable management of materials in the EU-28 countries determines the conduct of further research at a lower level of aggregation, which would have important implications for government and regional policies in terms of pro-environmental activities performed. In view of the above, future research is planned based on the DEA method concerning more detailed comparative analysis of regional effectiveness. It can provide an answer to the question of which regions in the EU-28 countries waste the most natural resources in the production of goods and services and, therefore, where more technical and financial support is needed to improve the situation.

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Corresponding author
Aneta Masternak-Janus can be contacted at: amasternak@tu.kielce.pl