Research article

Waste treatments in the European Union: A comparative analysis across its member states☆

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GRAPHICAL ABSTRACT

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ABSTRACT

Waste treatments, which add value to the production system, may contribute to achieving a more circular economy. These recovery treatments are material recycling, composting and digestion, and energy recovery. This paper analyses recycling activity and other waste treatments in the European Union (EU), using a comparative approach among its Member States. In order to do this, some factors that may influence these treatments are studied, such as economic development, R&D expenditure, resource productivity and the period of each country's permanence in the EU. Although waste treatment rates have converged between countries from 2010 to 2018, there are still differences. In order to explain these differences, the countries have been grouped into three clusters through a K-means non-hierarchical cluster statistical analysis. Subsequently, a non-parametric Kruskal-Wallis test has been applied to examine whether these observed differences are significant in the last year of the period analysed. The results corroborate the main hypothesis of this research: there are various behaviour patterns in waste treatments according to the country clusters and based on their real GDP per capita, R&D expenditure, resource productivity and number of years as an EU member.

1. Introduction

The management of the waste selective collection and its diverse treatments, especially recycling, contribute to achieving a circular economy. This implies a more efficient use of resources, in addition to respecting and caring for the environment to a greater extent than the traditional linear economy.

This paper aims to shed light on Member States' compliance with European Union (EU) waste treatment targets. To this end, firstly, the evolution of the different waste treatment rates in EU countries and their degree of convergence is analysed from 2010 to 2018. Secondly, the possible causes of the observed differences among Member States in 2018, the last year of the period analysed, are examined.

In the context of the circular economy, the EU is making a great effort to ensure that all Member States meet minimum standards in waste management and treatment. In this regard, it is worth highlighting the legislation approved by the EU in the area of waste.

Waste management is regulated by various EU directives, which are modified as new needs arise, such as, for example, the increase in waste generated, the urgency to eliminate them and the opportunity to turn their management into an activity with positive effects, both economic and social. This last need has been included in the 2018 Directive that modifies the 2008 Waste Management Directive, within the regulatory framework of the EU circular economy. Therefore, it would be interesting to review what has been achieved so far and examine the level of successfully achieving the objectives set by the EU regulations.

As early as the 1970s, environmental policy arrived at the core of the EU's agenda and is nowadays one of its fundamental policies. Moreover, the EU's environmental policy has always taken its economical dimension into consideration. At first, European institutions based their action on environmental matters given the need to avoid possible distortions to the common market provoked by national environmental law (Jans and Vedder, 2011, pp. 3–6). Later, Europe considered that economic transformation through a more environmentally friendly development approach could be a source of economic opportunities. From this point of view and as a growth strategy, the Commission has highlighted the "European Green Deal", which aims to make the economy of the EU Member States sustainable through measures that transform climate and environmental challenges into opportunities (European Commission, 2019). Thus, the EU has opted for the transformation of the current production-consumption system, with the aim of achieving sustainable development in its three dimensions: economic, social and environmental, all in line with the concept of sustainability proposed by Korhonen et al. (2018).

The transition into a circular economy is clearly at the core of this transformation. There is no doubt about the change of paradigm it represents, in contrast to the linear system, wherein the life cycle of products is limited to extraction, production, consumption and finally deposit of waste. The circular economy focuses on a more efficient and sustainable use of resources, based on reusing and maintaining them in the productive system as long as possible. At the same time, it reduces the production of waste to a bare minimum.

The EU has opted for this model and has currently proposed a new action plan for the circular economy, which aims to promote an even more sustainable economic growth model in the EU (European Commission, 2020). This policy began several years ago, and the 7th Environment Action Programme to 2020 (Decision 1386/2013/EU) included its first actions, when it defended the transformation of the EU's economy into a low-carbon and resource-efficient economy. The relationship between resource efficiency and waste was developed in two Communications by the Commission, issued in 2014 and 2015.

The first one, "Towards a circular economy: A zero waste programme for Europe", pointed out the need to evolve towards a more circular economy, to achieve the goal of intelligent, sustainable, and integrated development (European Commission, 2014). The second one, "Closing the loop – An EU action plan for the Circular Economy", contained a specific section on waste management, in which it was announced that legislative changes in areas related to waste management would be adopted (European Commission, 2015).

These modifications would include establishing long-term goals for recycling municipal waste, promoting economic instruments to reduce the amount of waste produced, implementing general requisites for extended producer responsibility schemes, and simplifying and harmonising definitions and calculation methods. It is also important to remark that the convergence of all countries on the best practice levels related to waste-management is one of the plan's main objectives (European Commission, 2015, p.2).

The legislative modifications announced in 2015 materialised into the so-called "Circular Economy Package", which involved modifying six directives related to waste management. The most important of these modifications affected the basic legislation on the matter: The Framework Directive on Waste, passed in 2008 (Directive 2008/98/EC).

The Directive amending the Framework Directive (Directive (EU) 2018/851) implied reforming significant aspects of the waste management policy. Firstly, it changed the subject matter and scope of the Framework Directive (art. 1), including therein the need to reduce waste generation and the importance of transitioning towards a circular economy, which is essential for guaranteeing the Union's long-term competitiveness. This is a significant modification, as it opens the door to including waste management systems in the global objective of achieving a real circular economy.

Waste hierarchy, the priority of actions related to waste prevention and management, was already included in the original Framework Directive (art. 4), which included the following preference order: prevention, preparing for re-use, recycling, other recovery (e.g., energy recovery) and disposal. This hierarchy was not modified in the 2018 reform, but, as pointed out by Stankevičius et al. (2020), the modification of art. 1 implies the need for a systematic reinterpretation of art. 4, reinterpretation that should also be extended to other precepts such as art. 13, which refers to the adoption of measures to ensure that resource management does not entail a risk to the environment or human health.

Moreover, although it does not introduce changes to waste hierarchy, the 2018 reform added a third paragraph to article 4, introducing the obligation to adopt economic instruments to promote the implementation of all levels of the hierarchy, beginning with the preferred one: waste prevention.

The changes introduced in 2018 did not modify the original definition of "waste", but introduced the definition of "municipal waste" as:

> The mixed waste and separately collected waste from households, including paper and cardboard, glass, metals, plastics, biowaste, wood, textiles, packaging, waste electrical and electronic equipment, waste batteries and accumulators, and bulky waste, including mattresses and furniture (art. 3).

Harmonisation and adaptation of definitions was precisely one of the objectives pursued by the Commission in 2015. However, the definition of "municipal waste" has been criticised on the grounds that it is not sufficiently precise and, in particular, it is not clear what is not "municipal waste" (Stankevičius et al., 2020).

Another significant modification, especially important for the subject of this article, was the establishment of new objectives for the recycling of municipal waste. According to the Directive, 55% of all municipal waste should be recycled or prepared for re-use in 2025, 60% in 2030 and 65% in 2035 (art. 11).

More generally speaking, the objective of the 2018 modifications is also related to the achievement of the objectives of the UN's 2030 Agenda for sustainable development, and the G-7 alliance for resource efficiency (European Commission, 2015).

The EU's recent policy has promoted the development of innovation projects within industrial processes, which will contribute to the

transition towards a more circular economy, in addition to economic growth, job creation and the promotion of a more environmentally-friendly productive system. However, it should be recalled that, as pointed out in the above-mentioned 7th Environmental Action Programme (Decision 1386/3013/EU), one of the priority objectives of the EU's environmental policy is to "maximise the benefits of the Union's environment legislation by improving implementation" (priority objective 4). By establishing this objective, the Commission recognised the implementation gap of the EU's environmental law which, despite being one of the most advanced environmental protection schemes in the world, presents several implementation problems. From this perspective, the European Environmental Agency (2019) indicates the reinforcement of policy implementation and the improvement of its coherence as one of the main action areas to advance in the transition towards a sustainable society. The Agency especially stresses the need to have access to a wide knowledge base on this matter (European Environmental Agency, 2019, p. 15).

All this effort by the EU to get Member States to implement legislation to achieve a more circular economy should lead to a convergence in the values of treatment rates. In this article, it is hypothesised that countries are converging, but still show some differences. This convergence, while maintaining some differences, has been pointed out by Castillo-Giménez et al. (2019).

Following this line, various papers have analysed waste management and treatment in the EU. The aim of this article is to provide new information on how the economic characteristics of EU countries explain the performance related to the objectives established by waste management directives.

In this paper, the authors assume that countries with the highest economic development, measured through real GDP per capita, have a higher consumption and consequently generate more waste. This assumption is supported by the results of other researchers (Egüez, 2021; Škrinjarić, 2020; Sverko Grdic et al., 2020; Minelgaitė and Liobikienė, 2019). Likewise, the positive relationship between high income and consumption is widely proven (Diacon and Maha, 2015), as well as between consumption and waste generation (He et al., 2020). Using Eurostat data from 2018, the Pearson correlation coefficient between the total waste generated and the real GDP per capita of the 28 EU Member States is 72.4%. Consequently, economic development is an important variable in this research.

Another variable that can help to differentiate waste treatment among countries is the number of years each one has been an EU Member State. It is expected that the longer a country has been in the EU, the greater discipline it will have in waste treatment. In addition, there are two variables that the literature highlights as relevant for waste treatment: the productivity of resources and expenditure on research and development (R&D expenditure). As in this paper, Tantau et al. (2018) empirically examine some economic variables which could affect the waste recycling rate of the EU Member States, although these authors use a statistical panel data model. The authors find that the productivity of resources (defined as the gross domestic product [GDP] divided by domestic material consumption) is one of the most influential variables on the recycling rate. However, Banacu et al. (2019) consider that, in addition to resource productivity, another relevant factor for recycling is R&D expenditure. The importance of the latter variable for convergence across Member States has, moreover, been highlighted by Marín et al. (2018).

The objective of this paper is to analyse recycling activity and other waste treatments in the EU, using a comparative approach among its Member States. The two working hypotheses are as follows:

1. Member States show a certain convergence in their recycling rates, due to the EU's effort to bring them all into alignment.
2. There are various behaviour patterns in waste treatments, particularly in recycling, according to the country clusters and based on their real GDP per capita, R&D expenditure, resource productivity and number of years as an EU Member State.

In order to test the hypotheses, firstly, the recycling, energy recovery and total treatment rates are calculated, using several waste indicators from the database of the EU's Statistical Office (Eurostat). Secondly, the evolution of the rates between 2010 and 2018 is described and analysed to determine whether they are converging due to the EU's effort to get them all aligned. Upon observing that the disparities still remain, the countries have been grouped into three clusters through a K-means non-hierarchical cluster statistical analysis, using the variables considered in the hypothesis. Subsequently, a non-parametric Kruskal-Wallis test has been applied to examine whether the differences in these observed rates among the clusters are significant in 2018, the last year of the period analysed.

The article is structured as follows. In this section 1, the literature on waste management and treatment, as well as the EU regulatory framework are reviewed. In section 2, data collection and methods are explained. Next, the statistical results are presented (section 3) and discussed (section 4). In section 5, the final conclusions are described. Finally (section 6), some future lines of research are proposed.

2. Data collection and methods

In the context of the circular economy, waste treatments could be classified according to the following three basic principles within the framework of the current EU waste hierarchy: i) they do not exist (reduce and reuse); ii) they add value to the production system to close the circle, i.e., recovery treatments (material recycling, composting and digestion, and energy recovery); iii) they do not generate any value, and consequently are waste disposal treatments (incineration without energy recovery and landfill).

The second principle, where they add value to the production system, is the underlying motivation of this research, which aims to analyse the situation and evolution of waste management in terms of the treatments that can add value to the circular economy (recovery treatments). In this sense, although the recycling rate is taken as the main variable to be analysed (including material recycling, composting and digestion), another type of treatment - energy recovery – is also considered an interesting variable to study. Therefore, after a first description of the evolution of recycling activity in the EU Member States, energy recovery is incorporated into the statistical analysis.

Thus, firstly, the evolution of the recycling rates of the 28 EU Member States from 2010 to 2018 is studied, showing that there is a great disparity between countries in terms of levels and, in some cases, with respect to the trend (downward for Austria, Belgium, Romania and Sweden, and stable or upward for the rest of the countries). It should be noted that, since the United Kingdom was a member of the EU until 2020 and the period under study in this paper is from 2010 to 2018, it has been included in the statistical analysis.

Figure 1 shows that Germany's recycling rate is the highest in the EU over the whole period analysed (62.46% in 2010 and 67.16% in 2018), while the rate in Lithuania is the fastest growing over the last eight years (from 4.95% in 2010 to 52.59% in 2018), ranking above the EU average in the last year of the period analysed (46.93%). At the other extreme is Malta, which has the lowest recycling rate of the 28 Member States in 2018 (9.95%), followed by Romania (11.03%). It can also be seen that on average the 55% target set by the EU for 2025 has not yet been reached, with some countries exceeding it and others falling far short of it.

Taking into account the corpus of European regulation, a convergence in the recycling rates of EU countries should be expected. Therefore, the first step is to analyse whether the values are getting closer over time.

After that, having noted the differences in the levels of national recycling rates within the EU, and as a contribution to the comparative analysis of waste treatment in its Member States, it is then studied whether the different treatment rates - recycling, energy recovery, and treatment as a whole - in the last year of the period analysed (2018)
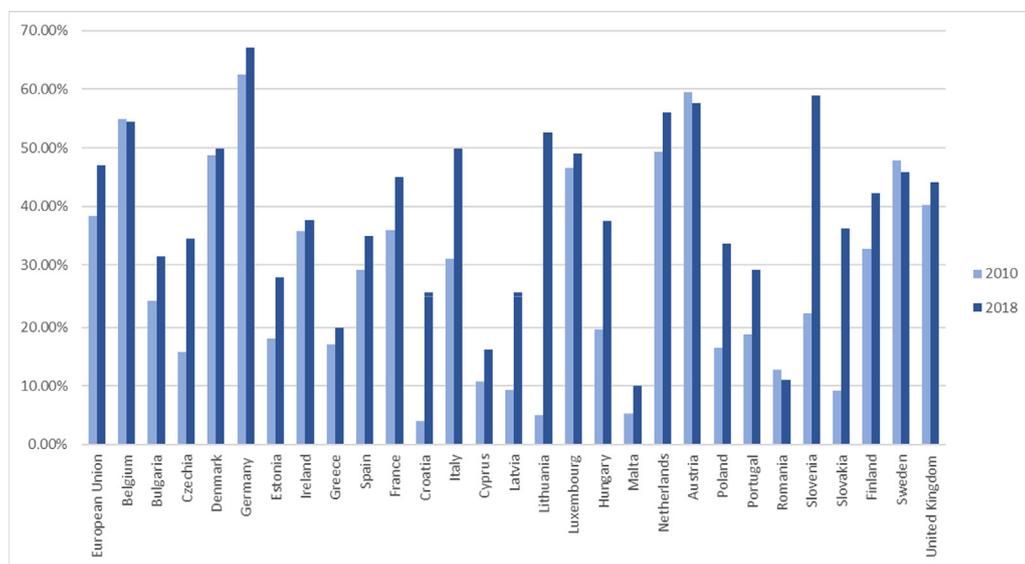
depend on the level of economic development, as measured by real GDP per capita and the number of years of each country's membership in the EU, among other factors. The working hypothesis of this research is that there are large discrepancies in the recycling rates and other waste treatment rates of Member States, due to their varying degrees of economic development, different levels of resource productivity and R&D expenditure, and different years of EU membership.

In the empirical study, the dependent variables to be analysed are:

- Recycling rate, obtained as the ratio "kilograms of material recycling and composting and digestion divided by kilograms of total waste generated in each country", following the Eurostat methodology.
- Energy recovery rate, obtained as the ratio "kilograms of energy recovery divided by kilograms of total waste generated in each country".
- Total waste treatment rate, where the recycling rate and the energy recovery rate of each country are added together. The landfill rate is

not included, since it is not considered a waste recovery treatment, but rather a waste disposal treatment.

These variables are calculated based on several indicators from the waste database of the European Union's statistical office (Eurostat) for the last year of the period of analysis, 2018 (the date of data update being 23-12-2020).

The evolution of the average values of the three rates in the EU can be observed in Figure 2:

Figure 2 shows that overall, both the EU average recycling rate and energy recovery rate have been increasing from 2010 to 2018, bringing the total treatment rate - which does not include landfill - to 74.6% in 2018. Taking into account this increase, it could be expected that the levels of these rates are converging in all countries. To analyse whether this is true, following the methodology of Castillo-Giménez et al. (2019), we observe whether the coefficients of variation of each of the analysed rates are decreasing (Figure 3):
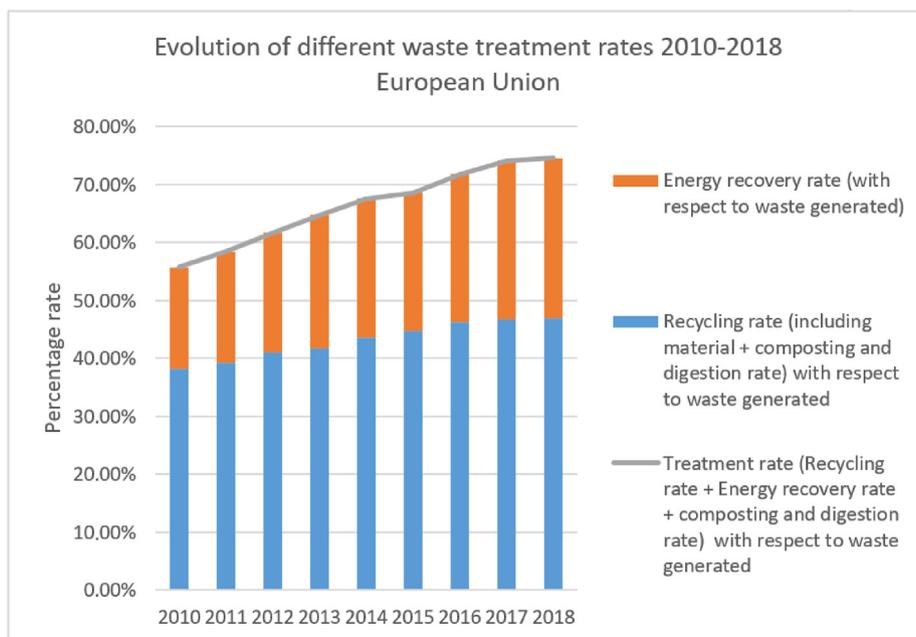

Figure 2. Evolution of different waste treatment rates (with respect to waste generated) in the EU (%). 2010–2018. Source: Prepared by the author with Eurostat data.
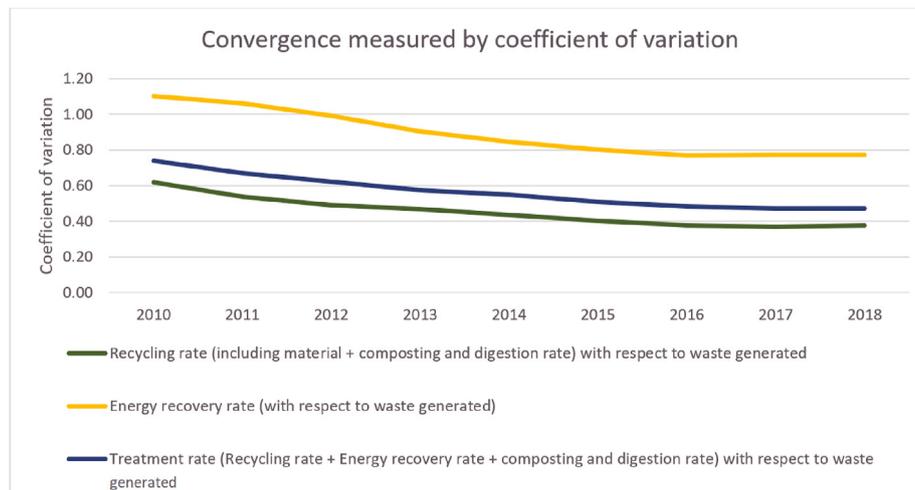
Figure 3. Evolution of coefficient of variation of the waste treatment rates (with respect to waste generated) in the EU (%). 2010–2018. Source: Prepared by the author with Eurostat data.

Figure 3 shows that the coefficient of variation of waste treatment rates has been decreasing from 2010 to 2018, which means that EU countries are converging and homogenising their values. The recycling rate is the most homogeneous from the beginning, while the energy recovery rate shows the greatest difference.

Although this convergence is present, different degrees of waste treatment are still observed. The central hypothesis of this paper is that these country differences depend on their economic characteristics (level of economic development, R&D investment, resource productivity) and the length of time they have been in the EU. The explanatory variables of the model have been extracted from Eurostat (2018): Real GDP per capita (as a proxy of the level of economic development), Gross domestic expenditure on R&D and Resource Productivity, with date of data update being 21-12-2020, 11-01-2021 and 7-07-2020.

Of the 28 Member States that made up the European Union in 2018, Luxembourg has been left out of the analysis of the statistical model, as the extremely high value of its real GDP per capita made it an outlier that could not be grouped with the rest of the countries. Therefore, the number of countries included in the statistical analysis now presented is 27.

The steps followed in the statistical analysis to test the central hypothesis (differences in the 2018 rates are due to economic characteristics) are the following:

Step 1. Descriptive statistics of the variables to be analysed (Recycling, Energy recovery, and Global Treatment rate) and the variable waste generated per capita, in order to observe whether there are differences between the EU countries.

Step 2. Analysis of the Spearman correlation coefficient between the position taken by each country in the ranking of waste treatment rates in 2010 and 2018, trying to observe whether there is concordance or if the positions fluctuate.

Step 3. Analysis of the correlation coefficient of the waste treatment rates and the selected economic variables (number of years of EU membership, the productivity of economic resources and the rate of R&D investment), in order to analyse the relationship between the variables, as hypothesised.

Step 4. Cluster analysis using the classification technique called "K-means non-hierarchical cluster analysis". This is an automatic data classification technique that recognises the clusters underlying the dataset based on the differences between the data, measured by the Euclidean distance between them.

Step 4.1. Selection of the variables used to group the countries (the national indicators of real GDP per capita as a proxy measure of each country's economic development, the number of years of EU membership, the productivity of economic resources and the rate of R&D investment).

Step 4.2. Standardisation of the variables, as the scale of measurement of each variable is different.

Step 4.3. Decision about the number of clusters after observing the dendrogram. In our case, we decided to make 3 clusters.

Step 4.4. Descriptive analysis of the main economic characteristics of each cluster, observing the differences between them.

Step 4.5. Descriptive analysis of the different waste treatment rates in each cluster.

Step 4.6. Kruskal-Wallis test in order to determine whether the observed differences are statistically significant. As it is the case, we can say that the hypothesis is proven and that the economic differences among the EU countries can explain the differences in waste treatment rates.

3. Results

Table 1 presents the results of the descriptive statistics for these three rates (Recycling, Energy recovery, and Treatment) in 2018, showing that, on average, recycling is used more than energy recovery as a waste treatment method, with significant differences between the minimum and maximum for each rate. Furthermore, the dispersion (measured by the coefficient of variation) is greater in the energy recovery rate than in the recycling rate.

As shown in Table 1, dispersion of the variables is quite high among the different countries. The energy recovery rate presents the highest dispersion (with a coefficient of variation of 0.81), with a minimum value of 0% in countries such as Croatia, Cyprus and Malta and a maximum of 57% in Finland. The recycling rate per capita also fluctuates between 9.95% in Malta and 67.16% in Germany. The same is true for the overall treatment rate, which ranges from 10% in Malta to 99% in Denmark, Finland and Sweden. It should be noted that, although smaller, there are also differences in waste generated per capita, which is the denominator variable in the ratios used to find the above rates, with a minimum of 272 kg/inhabitant in Romania and 814 kg/inhabitant in Denmark. It is therefore true that the higher the GDP per capita the more waste generated, as indicated in section 1.

Table 1. Descriptive statistics of the variables.

Variable	N	Minimum	Maximum	Arithmetic mean	Standard deviation	Coefficient of variation
Treatment rate (Recycling, Energy recovery + composting and digestion with respect to waste generated)	27	10.00%	99.00%	61.08%	29.77%	0.49
Recycling rate (with respect to waste generated)	27	9.95%	67.16%	38.31%	14.98%	0.39
Energy recovery rate (with respect to waste generated)	27	0.00%	57.00%	22.77%	18.38%	0.81
Waste generated (kg) per capita	27	272	814	483.33	115.58	0.24

Source: Prepared by the author with 2018 Eurostat data (results obtained by IBM SPSS Statistics 21).

Looking at the differences between the countries, it is considered necessary to analyse whether the position in the ranking of those that recycle the most or the least is maintained over the analysed years or whether there is a fluctuation. To analyse this, the Spearman correlation coefficient is calculated as follows: $p = 1 - \frac{6\sum_{i=1}^{N} d_i^2}{N^3 - N}$

Table 2 shows that the positions taken by the countries in the ranking have not changed much from 2010 to 2018, as the Spearman correlation coefficients are quite close to 1. Some important changes can be observed in some countries such as Estonia and Ireland, which have made a significant effort to increase the energy recovery rate between 2010 and 2018. Lithuania and Slovenia have also significantly increased their recycling rates compared to the rest of the countries. In terms of the total waste treatment rate, Lithuania has changed the most favourably.

As for the countries that have decreased their position in the ranking, in the case of the energy recovery rate, Portugal and Slovakia have dropped 7 places, the main reason for this being that they have kept their rate practically the same from 2010 to 2018, even decreasing slightly. In the case of the recycling rate, Bulgaria and Greece stand out, having dropped 6 places, despite having increased their values. In the total treatment rates, Portugal and Spain are the countries that drop 6 places, although their values have increased.

To test the main hypothesis of this paper that "there are differences in recycling and other waste treatments between EU Member States according to various characteristics, such as their economic development, resource productivity, R&D expenditure and length of EU membership", we will analyse the correlation between the explanatory variables and the recycling rates to see if it makes sense to perform this analysis (Table 3):

Table 2. Country rankings in terms of waste treatment rates.

Energy recovery rate (with respect to waste generated)			Recycling rate (including material + composting and digestion rate) with respect to waste generated			Treatment rate (Recycling rate + Energy recovery rate + composting and digestion rate) with respect to waste generated		
	2010	2018		2010	2018		2010	2018
Finland	9	1	Germany	1	1	Sweden	1	1
Sweden	1	2	Slovenia	15	2	Finland	10	2
Denmark	2	3	Austria	2	3	Denmark	2	3
Luxembourg	3	4	Netherlands	4	4	Germany	7	4
Ireland	17	5	Belgium	3	5	Netherlands	6	5
Belgium	4	6	Lithuania	27	6	Belgium	4	6
Netherlands	7	7	Italy	12	7	Austria	3	7
Estonia	21	8	Denmark	5	8	Luxembourg	5	8
Austria	5	9	Luxembourg	7	9	United Kingdom	9	9
United Kingdom	13	10	Sweden	6	10	Ireland	12	10
France	6	11	France	9	11	France	8	11
Germany	11	12	United Kingdom	8	12	Estonia	20	12
Poland	21	13	Finland	11	13	Slovenia	18	13
Italy	10	14	Ireland	10	14	Italy	11	14
Portugal	8	15	Hungary	16	15	Lithuania	27	15
Czechia	12	16	Slovakia	25	16	Poland	22	16
Hungary	14	17	Spain	13	17	Hungary	16	17
Lithuania	21	18	Czechia	21	18	Czechia	15	18
Spain	16	19	Poland	20	19	Portugal	13	19
Slovenia	18	20	Bulgaria	14	20	Spain	14	20
Bulgaria	20	21	Portugal	17	21	Slovakia	19	21
Slovakia	15	22	Estonia	18	22	Bulgaria	17	22
Romania	19	23	Latvia	24	23	Latvia	25	23
Latvia	21	24	Croatia	28	24	Croatia	28	24
Greece	21	25	Greece	19	25	Greece	21	25
Cyprus	21	26	Cyprus	23	26	Cyprus	24	26
Croatia	21	27	Romania	22	27	Romania	23	27
Malta	21	27	Malta	26	28	Malta	26	28
Spearman's Rho		0.7813	Spearman's Rho		0.7329	Spearman's Rho		0.8451

Table 3. Correlations of the waste treatment rates and the economic variables.

		Gross domestic product at market prices (euros per capita) 2018	Years in European Union (2018)	Resource productivity (euro per kilogram)	Gross domestic expenditure on R&D (Percentage of gross domestic product)
Recycling rate (with respect to waste generated) 2018	Pearson correlation coefficient	0.528**	0.565**	0.508**	0.752**
	Sig. (bilateral)	0.005	0.002	0.007	0.000
	N	27	27	27	27
Energy recovery rate (with respect to waste generated) 2018	Pearson correlation coefficient	0.781**	0.500**	0.427*	0.797**
	Sig. (bilateral)	0.000	0.008	0.026	0.000
	N	27	27	27	27
Treatment rate (Recycling rate + Energy recovery rate + composting and digestion rate) 2018	Pearson correlation coefficient	0.748**	0.593**	0.519**	0.870**
	Sig. (bilateral)	0.000	0.001	0.006	0.000
	N	27	27	27	27

Source: Prepared by the author with 2018 Eurostat data (results obtained by IBM SPSS Statistics 21).
* Correlation is statistically significant at level 0.05 (bilateral).
** Correlation is statistically significant at level 0.01 (bilateral).

Table 3 shows that the correlation is significant and positive between different waste treatment rates and levels of R&D expenditure and resource productivity, in line with the findings of Banacu et al. (2019). Although these authors study these variables exclusively in relation to the recycling rate, this table shows that all waste treatment rates are related to these two variables. We also find a significant and positive correlation with years of EU membership and GDP per capita, as we hypothesised.

Once the relationship between the variables has been observed, in order to test the hypothesis the calculated waste treatment rates in 2018 are comparatively analysed by grouping the countries into three clusters using a classification technique called "K-means non-hierarchical cluster analysis". This is an automatic data classification technique that recognises clusters underlying the dataset based on the differences between the data, measured by the Euclidean distance between them. The grouping variables used are the national indicators of real GDP per

Table 4. Countries in each cluster.

CLUSTER 1	CLUSTER 2	CLUSTER 3
Belgium	Austria	
France	Denmark	Croatia
Germany	Finland	Cyprus
Ireland	Sweden	Czechia
Italy		Estonia
Netherlands		Greece
Spain		Hungary
United Kingdom		Latvia
		Lithuania
		Malta
		Poland
		Portugal
		Romania
		Slovakia
		Slovenia

Source: Prepared by the author with 2018 Eurostat data (results obtained by IBM SPSS Statistics 21).

Table 5. Cluster characteristics.

Cluster		Real Gross domestic product at market prices (euros per capita) 2018	Years in European Union (2018)	Resource productivity (euro per kilogram)	Gross domestic expenditure on R&D (of gross domestic product)
1	N	8	8	8	8
	Arithmetic mean	35956.25	**57.50**	**3.13**	1.96%
	Median	34185.00	67.00	2.92	1.94%
	Standard deviation	10236.63	13.71	0.72	0.70%
	Minimum	24910.00	33.00	2.39	1.14%
	Maximum	57780.00	67.00	4.42	3.12%
	Coefficient of variation	0.2847	0.23846	0.23057	0.35993
2	N	4	4	4	4
	Arithmetic mean	**41717.50**	29.50	1.72	**3.06%**
	Median	40780.00	24.00	1.88	3.08%
	Standard deviation	5486.58	11.00	0.45	0.23%
	Minimum	36780.00	24.00	1.07	2.76%
	Maximum	48530.00	46.00	2.05	3.32%
	Coefficient of variation	0.1315	0.37288	0.26370	0.07678
3	N	15	15	15	15
	Arithmetic mean	15200.00	16.73	0.98	1.09%
	Median	15070.00	15.00	1.07	0.97%
	Standard deviation	4781.84	8.05	0.42	0.46%
	Minimum	6550.00	6.00	0.32	0.50%
	Maximum	24120.00	38.00	1.62	1.95%
	Coefficient of variation	0.3146	0.4810	0.42849	0.42247

Source: Prepared by the author with 2018 Eurostat data (results obtained by IBM SPSS Statistics 21).

capita as a proxy measure of each country's economic development, the number of years of EU membership, the productivity of economic resources and the rate of R&D investment. As the scale of measurement of each variable is different, we make the classification with the standardised variables. We decided to make 3 clusters after observing the dendrogram.

Tables 4 and 5 show the three country clusters obtained in the cluster analysis and their characteristics, respectively. The grouping variables are GDP per capita, R&D expenditure, years of EU membership and resource productivity, so the cluster analysis groups countries according to their similarity in the values of these four variables.

It is interesting to note that the three countries with the highest percentage of global waste treatment (Denmark, Finland and Sweden) are in the same cluster, considering that the countries have been classified exclusively according to their economic variables.

Table 5 shows that cluster 1, composed of eight countries, has the highest values for average EU membership (57.5 years) and resource productivity (3.13 €/kg). However, the average real GDP per capita (€ 35,956.25) and R&D expenditure is in the middle range.

Real GDP per capita fluctuates between € 24,910 in Spain and the maximum of € 57,780 in Ireland. Most countries in this cluster have been in the EU since its foundation, except Spain, which has been in the EU since 1986 and United Kingdom and Ireland which have been in the EU since 1973.

As for R&D expenditure as a percentage of GDP, it varies from 1.14% in Ireland to 3.12% in Germany. It is the variable with the highest dispersion in this cluster. Resource productivity has the lowest value of 2.39 €/kg in Germany and the highest value of 4.42 €/kg in the Netherlands.

Cluster 2 is composed of 4 countries. It stands out for having the highest average value of real GDP per capita (€ 41,717.50) and also the highest percentage of GDP devoted to R&D expenditures (3.06%). In terms of the number of years of EU membership (29.5 years) and resource productivity (1.72 €/kg), their average values are somewhere in between the other two clusters. In this cluster, dispersion in the variables is quite low, except for the number of years of EU membership, with three countries that joined in 1995 (Austria, Finland, Sweden) and one that joined earlier, in 1973, Denmark. Resource productivity fluctuates between 1.07 €/kg in Finland and 2.05 €/kg in Denmark.

The third cluster, made up of 15 countries, has the lowest average values for the four variables. On the other hand, it is the cluster with the greatest dispersion in these variables based on the coefficient of variation, although it remains small. Real GDP per capita ranges from €6,550 in Bulgaria to €24,120 in Cyprus. They have also been EU Member States for the least number of years, fluctuating between Croatia, which joined in 2013, and Greece, which joined in 1981. In terms of resource productivity, the lowest is 0.32 €/kg in Bulgaria and the highest is in Malta at 1.62 €/kg. Finally, the percentage of GDP spent on R&D varies from 0.5% in Romania to 1.95% in Slovenia.

We can see from the coefficients of variation that the internal dispersion within each cluster is not very high and that each cluster has internal homogeneity. Moreover, the Kruskal-Wallis test shows that the observed differences in all the economic variables among the clusters are statistically significant.

In order to check whether there are differences in the treatment rates in each cluster, their main descriptive statistics are analysed below (Table 6).

Considering the data obtained in the descriptive statistics, we proceed to perform a comparative analysis of the values of the waste treatment rates in the clusters obtained.

Clusters 1 and 2 have very similar average recycling rate values. However, in cluster 2 there is very little dispersion, the recycling rate ranging between 42% and 58%. This little dispersion can be further observed in the case of material recycling (not including composting and digestion), where the recycling rate of cluster 2 is around 30% (25%–

Table 6. Descriptive statistics of waste management by cluster.

Cluster		Recycling rate (with respect to waste generated) 2018	Energy recovery rate (with respect to waste generated) 2018	Treatment rate (Recycling rate + Energy recovery rate) 2018	Waste generated per capita 2018
1	N	8	8	8	8
	Arithmetic mean	48.64%	32.53%	81.17%	512.125
	Median	47.43%	36.08%	81.17%	505.00
	Standard deviation	10.53%	11.70%	17.69%	66.93
	Minimum	34.95%	11.58%	46.53%	409
	Maximum	67.16%	42.64%	98.35%	606
	Coefficient of variation	0.22	0.36	0.22	0.13
2	N	4	4	4	4
	Arithmetic mean	48.93%	49.48%	98.40%	594.50
	Median	47.86%	51.11%	98.96%	565.00
	Standard deviation	6.61%	7.94%	1.39%	159.24
	Minimum	42.29%	38.69%	96.37%	434.00
	Maximum	57.69%	56.99%	99.31%	814.00
	Coefficient of variation	0.14	0.16	0.01	0.27
3	N	15	15	15	15
	Arithmetic mean	29.97%	10.44%	40.41%	443.73
	Median	29.19%	7.37%	43.24%	414.00
	Standard deviation	13.57%	11.14%	20.07%	107.08
	Minimum	9.95%	0.00%	9.95%	272.00
	Maximum	58.85%	41.23%	69.14%	663.00
	Coefficient of variation	0.45	1.07	0.50	0.24

Source: Prepared by the author with 2018 Eurostat data (results obtained by IBM SPSS Statistics 21).

32%). The maximum recycling rate of all the countries is in cluster 1, with Germany having with a value of 67.16%.

Cluster 3 has the highest variability and a lower average. The lowest average recycling value is in cluster 3 with 9.95% in Malta. On average, this cluster is the furthest away from meeting the target set by the EU where the recycling rate in 2025 should be 55%.

Cluster 2, whose countries stand out in terms of real GDP per capita and percentage of R&D expenditure, has the highest average values for energy recovery rate (49.48%) and total waste treatment rate (not including landfill), 98.40%. The coefficients of variation are very small, with little variability between the different member countries of the cluster, except when analysing the composting and digestion rate individually, which has a larger variation that ranges from 13% in Finland to 32% in Austria. The low variability in the total waste treatment rate is remarkable with all countries having a rate higher than 96%. As mentioned above, three of the four countries in the cluster have the highest values for the global waste treatment rate in the EU.

Cluster 1, whose countries stand out in resource productivity and length of membership in the EU, has intermediate values, except for the recycling rate, which has a value very similar to that of cluster 2. On the other hand, although they do not have a very high coefficient of variation, the overall dispersion is higher than in cluster 2.

Cluster 3 has the lowest average values for all waste treatment rates. We find a high degree of internal dispersion in the values of the Energy Recovery rate variable. In particular, Malta has a 0% rate for this treatment category and a very low value, in general, for recovery treatments

(10%). Of the total waste generated in this country, around 90% is disposed of through landfills.

From this analysis it should be noted that real GDP per capita and the gross domestic expenditure on R&D as a percentage of GDP are the most influential variables on waste treatment compared to the two other variables analysed, resource productivity and length of membership in the EU.

Regarding the variable of waste generated per capita, it can be observed that cluster 2 has the highest average value, followed by cluster 1. Cluster 3, despite having worse waste treatment rates, is nevertheless the one with the lowest value of waste generated per capita. As for the internal dispersion within each cluster, it is not very high, being especially low in cluster 1, where the countries have very similar values of generated waste per capita.

Next, by a non-parametric Kruskal-Wallis analysis, we will check whether the differences among the means of the previously calculated rates of the three clusters are significant:

Table 7. Kruskal-Wallis тest.

Ranks

	Cluster	N	Mean Rank
Recycling rate (with respect to waste generated) 2018	1	8	19.63
	2	4	20.00
	3	15	9.40
	Total	27	
Energy recovery rate (with respect to waste generated) 2018	1	8	18.50
	2	4	24.50
	3	15	8.80
	Total	27	
Treatment rate (Recycling rate + Energy recovery rate + composting and digestion rate) 2018	1	8	18.75
	2	4	24.75
	3	15	8.60
	Total	27	
Waste Generated per Capita 2018	1	8	16.88
	2	4	20.25
	3	15	10.80
	Total	27	

Test statistics[a,b]

	Recycling rate (with respect to waste generated) 2018	Energy recovery rate (respect to waste generated) 2018	Treatment rate (Recycling rate + Energy recovery rate + composting and digestion rate) 2018	Waste Generated Per Capita 2018
Chi-squared	11.342	16.014	17.145	5.970
df	2	2	2	2
Asymp.Sig.	0.003	0.000	0.000	0.051

Source: Prepared by the author with 2018 Eurostat data (results obtained by IBM SPSS Statistics 21).
[a] Kruskal & Wallis, 1952.
[b] Grouping variable: Cluster.

Table 7 shows that the differences are significant in all rates. The recycling rate is more homogeneous between two of the three clusters analysed and, nevertheless, the differences found are statistically significant at a significance level of 5%. Therefore, it can be stated that there are differences between countries in waste treatment rates according to their economic development, their years of EU membership, the productivity of their resources, and R&D expenditure as a percentage of GDP, where economic development and the R&D expenditure as a percentage of GDP are the most important variables.

However, the observed difference in waste generated per capita between the clusters is not statistically significant at the 5% significance level, although it is very close.

4. Discussion

Through an empirical analysis, some of the variables that may have had an influence on the differences among waste treatment policies of EU countries have been examined. The waste treatment methods considered are those which add value to the economy, for which reason disposal treatments (landfill) have not been considered.

Having analysed different patterns in the evolution of recycling rates in different member states, countries have been classified into three different groups according to their GDP per capita, number of years since their entry into the EU, resource productivity, and R&D expenditure as a percentage of GDP. They have been grouped by means of a K-means non-hierarchical cluster analysis.

The classification has been followed by a non-parametric Kruskal-Wallis Test to check the statistical significance of the differences in recycling rates among the three different groups. The results of such analysis verify the main working hypothesis of this paper: there are differences in the recycling rate (both recycling of materials and composting and digestion), energy recovery rate and total waste treatment rate of member states due to the different degrees of economic development (measured by GDP per capita), number of years as an EU Member State, resource productivity and R&D expenditure as a percentage of GDP.

Considering these results, it is suggested that the variables analysed (economic development, number of years as an EU Member State, resource productivity and R&D expenditure as a percentage of GDP) are factors that influence waste treatment policies and, consequently, may help explain the differences in recycling, energy recovery and total treatment rates among different EU countries.

The statistical analysis has revealed different performance patterns across each cluster.

Cluster 2 has the highest waste treatment rate (and also recycling and energy recovery rate), followed by cluster 1 and, at a much greater distance, cluster 3.

These differences are consistent, to some extent, with the study by Castillo-Giménez et al. (2019). These authors developed a waste treatment performance index using mathematical programming techniques (Data Development Analysis, Slack-Based Measure and Multi-Criteria Decision-Making). The index was directly correlated with waste treatment by incineration, recycling or composting, while it was inversely correlated with landfill use. When the EU countries are ordered according to the average of this index from 2012 to 2016, a similar, but not equal, result is obtained as with the cluster ranking shown in this paper. Denmark and Austria (included in cluster 1) are in the top two positions, while the bottom thirteen countries according to the index are all in Cluster 3. There are, however, differences between the ranking position according to the index and the countries included in clusters 1 and 2. Furthermore, Castillo-Giménez et al. (2019) analysed the possible convergence of the values of waste treatment rates in EU countries using the coefficient of variation. Like them, this article recognises a narrowing of the differences between countries between 2010 and 2018, although they are still significant.

On the other hand, the countries included in cluster 2 are also those with the highest percentage of GDP spent on research and development. In this sense, Marin et al. (2018) pointed out, with data from 1995 to 2010, the importance of technological changes for achieving greater convergence in waste reduction policies and, consequently, for fulfilling the Union's waste reduction objectives.

By focusing on compliance with the waste hierarchy established by the Waste Framework Directive and the specific objectives it sets out, interesting conclusions can be drawn from the analysis. As commented above (see section 1), the concept of "municipal waste" was not defined

in the original Waste Framework Directive. This is the reason why the definition of the recycling and preparing for re-use objective for 2020 was based on *"waste materials such as at least paper, metal, plastic and glass from households"*. It was established that 50% by weight of these waste materials should be recycled or prepared for reuse that year. Considering this definition is similar (although not equivalent) to "municipal waste" (the variable used in this article), it is relevant to point out that 6 out of 8 countries in cluster 1 were close to achieving the objective (recycling at least 40% of their municipal waste in 2018), and 4 out of 4 countries in cluster 2 did the same. However, only 2 out of 15 countries in cluster 3 registered recycling rates above 40% in 2018.

In 2018, none of the clusters registered an average waste recycling rate high enough to comply with the objectives established for 2025 (55% of municipal waste by weight to be prepared for re-use or recycled). However, average recycling rates for cluster 1 (Belgium, France, Germany, Ireland, Italy, Netherlands, Spain, and United Kingdom) and cluster 2 (Austria, Denmark, Finland, and Sweden) were near this objective (48.64% for cluster 1 and 48.93% for cluster 2). These figures contrast with the average recycling rate (29.97%) for cluster 3 (Bulgaria, Croatia, Cyprus, Czechia, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia and Slovenia), which indicates a difficult path toward complying with the established objectives.

It should be noted, however, that although clusters 1 and 2 are the closest to meeting the waste treatment targets of the Framework Directive, they are also the largest generators of waste. In this regard, Minelgaitė and Liobikienė (2019) confirmed in their study the positive relationship between waste generation and increased living standards. Indeed, countries included in clusters 1 and 2 have, on average, higher waste generation and higher real GDP per capita.

In addition, cluster 1 and 2, especially the latter, present high energy recovery rates which, despite being a system preferable to landfill disposal, occupies a lower position in the waste hierarchy, compared to recycling.

This finding is consistent with the work of Egüez (2021), who found that there is a positive relationship between GDP per capita and the share of Waste to Energy treatment systems. Precisely, cluster 2 is the one with a higher average energy recovery rate and it is also the one with a higher average GDP per capita. Egüez also found a positive relationship between heating demand and the share of Waste to Energy treatment systems. Although heating demand has not been studied in this paper, it is obvious that it is high in countries included in cluster 2.

As for the relationship between energy recovery and compliance with the Waste Framework Directive, its use as a waste treatment system should be reduced in the following years if countries are to comply with it. This fact is especially important if we consider that the preparing for re-use and recycling objectives increase to 55% by 2025, 60% by 2030 and 65% by 2035. This increase implies that reducing the role of energy recovery in favour of recycling and preparing for re-use will be the only way to meet the objectives for clusters 1 and 2, especially the latter.

5. Conclusions

From the research carried out, the following conclusions have been reached:

- There is a certain convergence in the levels of waste treatment rates in EU countries between the years of 2010–2018, derived from the effort to comply with European regulations.
- Despite this convergence, most countries that were leaders in waste treatment in 2010 continue to be leaders in 2018.
- The remaining differences among Member States can be explained by their economic characteristics. EU countries (except Luxembourg) are classified into 3 clusters according to their real GDP per capita, R&D investment per capita, years of EU membership and resource

productivity. We observe that in these three clusters the differences in the average levels of waste treatment rates are statistically significant.

- Cluster 1 consists of 8 countries, which have the highest average values for years of EU membership and resource productivity. This cluster has intermediate values for waste treatment rates.
- Cluster 2 in turn is formed by 4 countries, which have the highest average values for real GDP per capita and R&D investment. This cluster has the highest values for waste treatment rates, especially for energy recovery.
- Cluster 3, made up of 15 countries, has the lowest average values for the economic variables considered. This cluster is the furthest from meeting EU requirements.
- By grouping the countries into clusters, it has been possible to analyse which characteristics are the most important. It can be observed that countries with higher GDP per capita and higher R&D investment rates have the highest waste treatment rates. In second place are countries with the longest EU membership and the highest resource productivity. Countries that do not stand out in any of these four characteristics have the lowest waste treatment rates, while generating the least waste per capita. This can help shape decisions at the EU level.

6. Future lines of research

It should be noted that this research provides empirical evidence in the analysis of waste treatment, as there is currently little background in the study of variables that affect energy recovery, recycling (both material and composting) and total waste treatment in the EU. However, new issues have been raised during this research, which require further analysis to solve them. Next, the following future lines of research are proposed.

It is especially noticeable that differences in average energy recovery rates are larger than the ones observed for average recycling rates. This fact implies that different treatment/disposal systems have been implemented in the different clusters, and only cluster 2 seems to have clearly chosen energy recovery as a central waste management system. As mentioned above, this method, one of the preferred ones in the past, is not valid for complying with the objectives of the Waste Framework Directive, which only refer to recycling and preparing for re-use. Consequently, it would be interesting to analyse the future evolution of waste treatment policies in these countries, in favour of higher recycling and preparing for re-use rates.

In addition, it is especially significant and important for future research that the cluster with longer average EU memberships and higher resource productivity (cluster 1) records worse results compared to the cluster with higher GDP per capita and higher R&D expenditure (cluster 2).

Declaration

Author contribution statement

María Pilar López-Portillo, Guillermo Martínez-Jiménez, Eva Ropero-Moriones and María Concepción Saavedra-Serrano: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data associated with this study has been deposited online at Eurostat. Waste Treatments: https://ec.europa.eu/eurostat/databrowser/view/ENV_WASMUN/default/table?lang=en.

Real GDP per capita: https://ec.europa.eu/eurostat/databrowser/view/NAMA_10_PC_custom_874015/default/table?lang=en.

Resource productivity: https://ec.europa.eu/eurostat/databrowser/view/ENV_AC_RP/default/table?lang=en.

Gross domestic expenditure on R&D: https://ec.europa.eu/eurostat/databrowser/view/T2020_20/default/table.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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