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RESEARCH ARTICLE

# REVISED How are European small enterprises dealing with the circular economy?

[version 2; peer review: 1 approved, 2 approved with reservations]

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## Abstract

### Background

Environmental sustainability and energy savings are crucial for economic development, yet European SMEs account for 63.3% of total CO2 firms emissions. Understanding how these businesses behave when transitioning to a Circular Economy is essential for policymakers to design appropriate measures and incentives for preventing negative environmental externalities.

### Methods

The study analyzed data from the fifth wave of the "SMEs, resource efficiency, and green markets" survey conducted in late 2021, which included 14,008 enterprises across 27 European Union member states. To categorize the companies, researchers applied a K-modes clustering algorithm—a machine learning method designed specifically for categorical data— to evaluate six qualitative business characteristics and nine environmental actions.

### Results

The analysis identified three distinct business behavior clusters. Cluster 1 (6,195 firms) primarily provides services to other businesses and focuses heavily on energy savings and waste minimization. Cluster 2 (4,002 firms) is the least environmentally proactive group, predominantly selling products directly to consumers, with 21.14% taking no environmental action at all. Cluster 3 (3,811 firms) is the

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most active and diverse group, exhibiting the highest participation in minimizing waste and saving energy but also reporting the most difficulties. Regardless of the cluster, the primary barrier to sustainability is the complexity of administrative or legal procedures, followed by the high costs of environmental actions. Consequently, the support most requested by these companies consists of grants or subsidies along with greater cooperation between companies across sectors and consultancy.

**Conclusions**

The transition to sustainable practices remains a significant challenge for most European SMEs, who often perceive current macro-level environmental regulations (such as the Circular Economy Action Plan) as bureaucratic hurdles rather than sources of help. To effectively foster a sustainable economy, policymakers must focus on simplifying administrative procedures, providing financial support, and encouraging inter-firm cooperation and technological consultancy.

**Keywords**
Circular Economy; Clusters; European SME

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**REVISED** **Amendments from Version 1**

Introduction has been revised with The Circular Economy has become one of the main policy instruments through which the European Union seeks to contribute to the Sustainable Development Goals, particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). Consequently, European SMEs play a pivotal role because they represent the largest share of businesses in Europe and are directly affected by the regulatory framework derived from the Circular Economy Action Plan.

Methodology part revised with Table 1 and Table 3 and Table 4 revised. Figures 1-8 were revised and provided new one.

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## 1. Introduction

Climate change, resource scarcity, and rising energy prices drive economic actors, especially businesses, to focus on efficiency and sustainability. In response to these concerns, in 2015, the European Commission implemented its first action plan for a Circular Economy. This plan aimed to transform the traditional linear economic model into a circular model, promoting the recycling and reuse of products to generate environmental benefits, reduce negative externalities, and enhance business benefits. According to Geissdoerfer et al. (2017), the Circular Economy is a regenerative system in which resource input and waste, emissions and energy leakage are minimized through slowing, closing and narrowing material and energy loops. This broader perspective extends beyond recycling and includes strategies aimed at preserving the value of products, components and materials throughout their life cycle.

Economic growth in recent decades has been described as unsustainable (Ghisellini et al., 2016), largely because it is based on a linear model. This type of model uses resources and raw materials discarded at the end of the production process, leading to a very negative environmental impact. By contrast, the Circular Economy model aims to replace the linear economy in production and consumption systems, replacing the 'use and throw away' approach with one that seeks to minimize waste as much as possible (Christis et al., 2019; Turcu and Gillie, 2020).

The Circular Economy has become one of the main policy instruments through which the European Union seeks to contribute to the Sustainable Development Goals, particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). Consequently, European SMEs play a pivotal role because they represent the largest share of businesses in Europe and are directly affected by the regulatory framework derived from the Circular Economy Action Plan.

However, achieving a Circular Economy requires a series of changes in production processes, either by increasing energy efficiency or reusing materials. The transition from a linear to a Circular Economy has become a political priority at both the international and local levels, and this has led to the enactment of legislation to drive firms to change their production processes.

The Circular Economy Action Plan initially focused on ecological and economic issues (European Commission, 2015, 2020). Nevertheless, the European Union currently finds itself in a complex geopolitical landscape (Baldassarre, 2025). As a result, some industries have been experiencing a scarcity of basic resources and problems with their energy supply in recent years. In response, the European Parliament reacted to The Critical Raw Materials Act (European Parliament and Council, 2024).

The business sector is responding accordingly, both to comply with current legislation and to reduce costs, prompted by growing awareness of the need for environmental sustainability and to reduce their dependence on international suppliers. In this context, it is especially important to understand the firms' current situation, to identify the initiatives they are implementing, the obstacles they face in the transition towards sustainable production, and, above all, whether environmental administrations and legislation act as facilitators or barriers to achieving sustainable economic growth.

In this study, we focus on small and medium-sized firms (SMEs) in countries that comprise EU-27. Although European SMEs have limited environmental impact at the individual level, they account for 63.3% of the total $CO_2$ firms emissions in Europe, according to the European Commission's annual report on European SMEs 2021/22 (2022b).

Understanding business behavior in this area and the difficulties and challenges they face is essential to implement appropriate policies to incentivize the reduction of these negative externalities.

Studies on SMEs and sustainability, such as Chatzistamoulou and Tyllianakis (2022), identify factors that influence firms to implement and commit to renewable efficiency actions. A similar approach was adopted by Vasilescu et al. (2023), although their study focused on entrepreneurship and the supply of green products and services.

Unlike studies that analyze the factors that influence firms' decisions to adopt more environmentally sustainable policies, this study focuses on the current situation. As such, it has a twofold objective: on the one hand, to analyze the responses of firms by country to the environmental measures proposed in the EU regulation, and on the other hand, to categorize firms in terms of the actions taken in response to these environmental measures on a country-by-country basis.

According to the Circular Economy hierarchy, circular strategies differ substantially in their capacity to preserve the value of products, components and materials. Actions aimed at extending product life, promoting reuse, repair or industrial symbiosis generally represent higher levels of circularity than resource-efficiency measures such as saving water or energy. Consequently, the environmental practices analysed in this study should not be interpreted as equivalent but rather as complementary dimensions of firms' transition towards Circular Economy principles. The remainder of this paper is organized as follows. In Section 2, we examine the methodology used; this, in turn, is divided into three parts. First, we set out the database used and the descriptions of the sample, and then we analyzed the clustering methodology used to categorize the firms. In Section 3, we consider the results, and in Section 4, we present the discussion and conclusions.

## 2. Methodology

In this study, we used data from the latest wave of the 'SMEs, resource efficiency, and green markets' survey, selecting European Union member states. This data is published as Flash Eurobarometer 498. SMEs, Resource Efficiency and Green Markets, wave 5 (2022a) First, we provide a descriptive overview of the survey data. We then identified the variables to be analyzed before performing a K-mode clustering analysis to categorize the companies.

### 2.1 Database

#### 2.1.1 Firm characteristics

The database includes a set of variables that describe the structural characteristics of the firms surveyed. These variables capture differences in firms' structural and market profiles, including country, sector of activity, firm size, recent turnover performance, type of output, and customer orientation. These characteristics are commonly associated with firms' resources, capabilities, and market positioning, which may influence both their capacity and their incentives to adopt Circular Economy practices. The variables included in the analysis are presented in Table 1.

#### 2.1.2 Circular economy practices

The Eurobarometer survey includes a set of environmental practices capturing different dimensions of Circular Economy implementation. Some actions mainly focus on improving resource efficiency (e.g., saving water or energy), whereas others are more closely aligned with core Circular Economy strategies such as reuse, repair, recycling or industrial symbiosis. Consequently, the practices analyzed in this study should not be interpreted as having the same environmental relevance but rather as complementary dimensions of firms' transition towards Circular Economy principles. Following the Circular Economy literature, these practices can be grouped according to the main strategy they represent, ranging from resource-efficiency measures to actions aimed at closing material loops and extending product life. Each practice was coded as a binary variable indicating whether the firm reported implementing the corresponding action.

For ease of interpretation, these practices can be broadly grouped into four Circular Economy strategies. This categorization is descriptive only and is not used in the clustering procedure, which relies on the original binary variables.

Taken together, these variables provide a multidimensional representation of firms' engagement with Circular Economy practices and constitute the basis for the clustering analysis presented in Section 2.3.

### 2.2 Analysis of the business structure in Europe

We used the 'SMEs, resource efficiency, and green market surveys as the basis for our analysis of European SMEs. The data used were from the latest wave of the survey, the fifth wave, which covers November and December 2021. We selected from the database only the 27 European Union member states. After the database was cleaned, (delating all missing values), there are a total of 14,008 firms in the survey sample. Below, we can see the main characteristics of the database cleaned: number of firms by country, age of the firms, main productive sector by country, distribution of the size of the firms by country and, finally, the type of client they target. Table 3 shows the distribution of the number of firms in the database by country.

**Table 1. Structural and market characteristics of the surveyed firms.**

| Variable | N° options | Options |
|---|---|---|
| Country | 27 States | |
| Sector | 12 sectores | (B/C/D/E/F/G/H/I/J/K/L/M) |
| Size | 4 | *Large*<br>*Medium*<br>*Small*<br>*Micro* |
| Annual turnover growth | 5 | *Decreased*<br>*Increased*<br>*Remained unchanged*<br>*Not applicable*<br>*Don't know, no answer* |
| Type of output | 3 | *Sell products,*<br>*Sell services,*<br>*Sell both* |
| Type of customer | 8 | All to the public administration;<br>All to other companies;<br>To other companies and the public administration;<br>Directly to consumers;<br>Directly to consumers and the public administration;<br>Directly to consumers and other companies;<br>Directly to consumers;<br>Other companies and the public administration |

Source: Own elaboration.

**Table 2. Circular Economy practices included in the analysis and their corresponding circularity dimensions.**

| Circular Economy practice | Circularity dimension |
|---|---|
| Saving water | Reduce |
| Saving energy | |
| Saving materials | |
| Switching to greener suppliers of materials | |
| Minimising waste | |
| Using renewable energy | |
| Designing products that are easier to maintain, repair or reuse | Reuse |
| Selling your residues and waste to another company | |
| Recycling, by reusing material or waste within the company | Recycling |

Source: Own elaboration.

With regard to the age of the firms, we can observe that in 52% of the EU countries, the firms established after 2010 (considered the youngest) constitute the majority of respondents to the survey. The longest-established firms represented only 4% of the base, as shown in Table 4.

The survey allowed us to distinguish between the different production sectors. We can see that the predominant sector is G (wholesale and retail trade and repair of motor vehicles and motorbikes) across all countries except Sweden and Estonia, where C (manufacturing) predominates.

Table 5 shows the percentages for each productive sector.

We analyzed the invoicing of firms in the survey from a triple perspective. First, we looked at the sums invoiced; second, we looked at the recipients – that is, who is being invoiced – and, third, at what is being invoiced (whether it is a service, a production, or both).

**Table 3.** **Number of firms per country that have answered the survey.**

| Country | No. Firms | Country | No. Firms | Country | No. Firms | Country | No. Firms |
|---|---|---|---|---|---|---|---|
| Austria | 509 (3,6) | Finland | 498 (3,6) | Latvia | 503 (3,6) | R. of Cyprus | 252 (1,8) |
| Belgium | 587 (4,2) | France | 599 (4,3) | Lithuania | 499 (3,6) | Romania | 609 (4,3) |
| Bulgaria | 514 (3,7) | Germany | 560 (4) | Luxembourg | 248 (1,8) | Slovakia | 496 (3,5) |
| Croatia | 546 (3,9) | Greece | 601 (4,3) | Malta | 255 (1,8) | Slovenia | 554 (4) |
| Czechia | 596 (4,3) | Hungary | 529 (3,8) | Netherlands | 602 (4,3) | Spain | 597 (4,3) |
| Denmark | 492 (3,5) | Ireland | 472 (3,4) | Poland | 607 (4,3) | Sweden | 593 (4,2) |
| Estonia | 505 (3,6) | Italy | 599 (4,3) | Portugal | 586 (4,2) | | |

**Table 4.** **Percentage of firms in the base by date of creation.**

| Established before 1970 | Established between 1970 and 1990 | Established between 1990 and 2010 | Established after 2010 |
|---|---|---|---|
| 4% | 15% | 30% | 52% |

Source: Own elaboration.

**Table 5.** **Productive sector by percentage.**

| PRODUCTIVE SECTOR | % |
|---|---|
| B - Mining and quarrying | 1.05 |
| C - Manufacturing | 20.21 |
| D - Electricity, gas, steam and air conditioning supply | 1.86 |
| E - Water supply, sewerage, waste management and remediation activities | 1.51 |
| F - Construction | 17.25 |
| G - Wholesale and retail trade, repair of motor vehicles and motorcycles | 28.16 |
| H - Transportation and storage | 7.25 |
| I - Accommodation and food service activities | 6.49 |
| J - Information and communication | 5.14 |
| K - Financial and insurance activities | 3.17 |
| L - Real estate activities | 2.38 |
| M - Professional, scientific and technical activities | 5.54 |

Source: Own elaboration.

Regarding the sums invoiced, we observe in Table 6 that in countries such as Sweden, Denmark, and Belgium, there is a significant presence of firms invoicing more than 50 million.

In contrast, Table 7 shows the countries with the smallest firms, with an average turnover of less than 2 million.

The geographical concentration of the firms with the highest turnover is noteworthy. The 164 firms with a turnover of more than €50 million were located in Sweden, Denmark, and Belgium, although only 1% (164/14008) of the entire base of firms surveyed accounted for 38% (164/433) of all firms with a turnover above this amount. For example, in Sweden, 9.3% of all firms surveyed reported a turnover of more than €50 million, constituting 13% of all European firms with a turnover of more than €50 million.

Regarding the firms reporting the lowest turnover (below €2 million), those in Greece, Latvia, Malta, Romania, and Slovakia accounted for 13% (1840/14008) of the surveyed firm base, as shown in Table 5, while they accounted for 23% (1840/8069) of all firms with a turnover below this amount. For example, in Latvia, 81% of the surveyed firms had a turnover below EUR 2 million, but only 5% of all European firms had a turnover below this threshold.

**Table 6. Distribution of firms by country with a turnover of over 50 million euros.**

| Country | No. Firms | % of firms < 2 m € (1840 firms) | % overall on each country |
|---|---|---|---|
| Greece | 424 | 5% | 71% |
| Latvia | 406 | 5% | 81% |
| Malta | 188 | 2% | 74% |
| **Country** | **No. Firms** | **% over those >50 m € (433 firms)** | **% overall in each country** |
| Belgium | 54 | 12 | 9.2 |
| Denmark | 55 | 13 | 11.2 |
| Sweden | 55 | 13 | 9.3 |
| ***TOTAL*** | ***164*** | ***38*** | |

**Table 7. Distribution of firms by country with turnover below 2 million euros.**

| Country | No. Firms | % of firms < 2 m € (1840 firms) | % overall in each country |
|---|---|---|---|
| Greece | 424 | 5 | 71 |
| Latvia | 406 | 5 | 81 |
| Malta | 188 | 2 | 74 |
| Romania | 461 | 6 | 76 |
| Slovakia | 361 | 4 | 73 |
| ***TOTAL*** | ***1840*** | ***23*** | |

For the typology of customers, we studied firms according to their main client base. The questionnaire answer options were as follows: all to the public administration; all to other firms; and the public administration; directly to consumers; directly to consumers and the public administration; directly to consumers and other firms; directly to consumers; and to other firms and the public administration.

We find that, across all countries, a higher percentage of firms do not have the government as a customer. However, this distribution was not symmetrical. Figure 1 shows that in Finland and Sweden, the percentage of firms that have public administration as a customer is as high as 40%, while in Portugal and Bulgaria, this percentage is less than 20%.

Finally, in terms of invoicing, Table 8 shows an even distribution between firms that sell only products, only services, or both.

The distribution across the firms is shown in Figure 2. For each country, the distribution of firms according to whether they sell products, services, or both, is shown as a percentage. Thus, Croatia and Finland firms that sell both services and products dominate. Italy and Portugal show a higher percentage of firms selling services only, while Malta and Cyprus stand out for selling products.

## 2.3 Method

In the second stage, a clustering analysis is performed based on the distribution of the firms' responses in each of the countries included in the database. This study identifies groups of firms according to their environmental policies and business characteristics using categorical variables. For this, we use the K-modes method,[1] although in a different way to studies such as Gomonov et al. (2021), which use the K-means method. The K-mode clustering algorithm (Cao et al., 2009), an adaptation of the K-means algorithm, was specifically designed for clustering categorical data. The K-mode

[1]A clustering mechanism for non-numeric data, K-modes, has been used. This procedure for grouping categorical data uses the simple coincidence similarity measure, using the modes to represent the cluster centres and updating the modes with the most frequent categorical values in each of the iterations of the clustering process. The dissimilarity metric used for K-modes is the information-theoretic Hamming distance. The mode vector minimizes the sum of the distances between each object in the cluster and the centre of the cluster.The analysis has been carried out using Python and the following libraries: Numpy, pandas, matplotlib, seaborn, kmodes (we used "cao" as an initializer). A priori it was assumed that the initial number of clusters was 3.

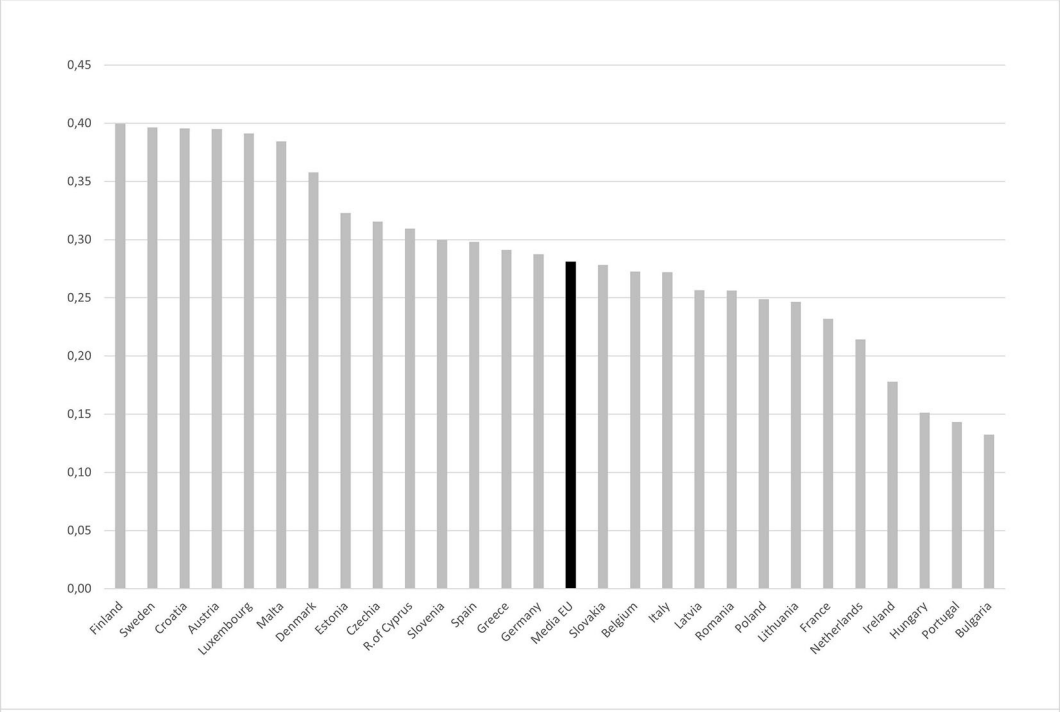


**Figure 1. Percentage of firms by country contracting with public administration.** Source: Own elaboration.

**Table 8. Number of firms that sell products, services or both.**

| OUTPUT | No. Firms | % |
|---|---|---|
| Both products and services | 4669 | 33.33% |
| Products | 4416 | 31.52% |
| Services | 4923 | 35.14% |
| TOTAL | 14008 | 100% |

Source: Own elaboration.

clustering method is an unsupervised machine learning technique used to group a set of data objects into a specific number of groups based on qualitative variables. The algorithm is called 'K-modes' because it uses modes (i.e., the most frequent values) instead of means or medians to represent the groups. (The development and explanation of the proposed K-modes model are presented in Appendix I.).

The qualitative business variables that we take into account for the K-modes analysis are six variables that characterize the firms (country and productive sector in which they operate, size, level of growth, type of product, and type of customer) and nine variables that reflect the environmental actions implemented by the 14008 firms in the database (all the variables are described in section 2.1).

In the third stage, we analyze the problems and requirements of firms to become more environmentally sustainable. This information is valuable for the optimal design of environmental policies. As such, we use the answers given by the firms in the survey to the following questions: "Did your company encounter any of the following difficulties when trying to set up resource efficiency actions?" and "Which of the following will help your company the most to be more resource efficient?"

## 3. Results

This section presents the results of this study. First, the analysis of the environmental actions carried out by the firms in the sample, taking into account the country in which they operate, allows us to identify in which country each action

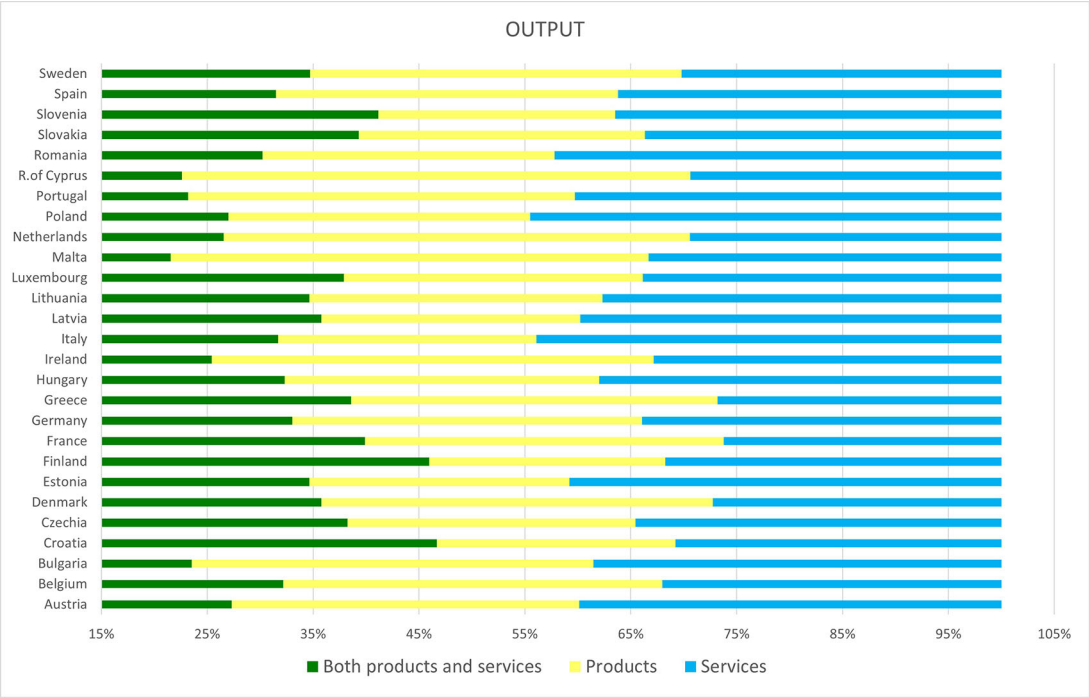


**Figure 2. Distribution of the type of output sold by firms by country.** Source: Own elaboration.

predominates. Second, we analyze the clustering results by identifying groups of firms and their characteristics. Finally, we detect the difficulties experienced by firms and support that they need to be sustainable and identify the differences between the clusters.

### 3.1 Environmental actions carried out by firms in each country

We then analyzed the actions that firms take to make their resources more efficient and thus avoid negative externalities in the environment. The actions are classified according to the following list: saving water (SW); designing products that are easier to maintain, repair, or reuse (DP); recycling, reusing materials or waste within their company (R); selling their waste and residues to another company (SR); minimizing waste (MW); switching to greener material suppliers (GR); saving energy (SE); saving materials (SM); using predominantly renewable energy (including own production with solar panels, etc.) (RE); other; or none.

Table 9 shows the number of actions developed by firms according to country. Thus, we can see which type of activity each country focuses more on. It can be seen that, in general, waste minimization MW) and/or energy saving (SE) actions predominate in all countries. In general, countries show homogeneous behavior. There are some exceptions, such as Ireland and Portugal, where recycling is prioritized and Malta, where material and water savings are prioritized. If we look at Spain, its focus is to minimize waste and save materials, but what is most striking is that it is the country where water conservation has the highest priority. Of the Spanish firms, 72.19% saved water, a higher percentage than in other countries for this action.

Next, we focused on the overall set of shares. Table 10 shows the average number of actions taken by firms in each country. Spanish firms report the highest number of actions on average (an average of 5.64 actions per firm out of nine possible 9 actions), closely followed by Swedish firms (an average of 5.62 actions per company). At the other end of the scale, Bulgaria is the country where firms report the lowest average number of actions (2.29 actions per firm).

We now group the nine actions into three figures (Figures 3, 4, and 5) to analyze the performance of each country against each of the environmental actions studied.

Regarding Action a (water saving), the results show that Spanish firms are the best performers, with 72.2%, closely followed by Slovakian firms. Bulgarian and Irish firms have the least importance for this action.

**Table 9.** **Percentage of a given action across all firms in a country.**

| | SW | DP | R | SR | MW | GR | SE | SM | RE | Others | None |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Austria | 44.99% | 23.18% | 47.94% | 29.67% | 65.62% | 29.86% | 66.21% | 54.81% | 31.43% | 0.39% | |
| Belgium | 55.03% | 32.71% | 46.51% | 46.00% | 83.48% | 45.49% | 76.32% | 65.93% | 45.66% | 3.07% | |
| Bulgaria | 25.10% | 9.92% | 24.51% | 28.60% | 39.88% | 13.81% | 42.02% | 30.93% | 9.14% | 5.06% | |
| Croatia | 44.87% | 22.71% | 35.90% | 38.28% | 68.13% | 26.37% | 56.59% | 52.38% | 10.07% | 0.18% | |
| Czechia | 47.99% | 35.91% | 47.48% | 39.43% | 74.50% | 33.56% | 64.60% | 57.21% | 13.59% | 0.67% | |
| Denmark | 29.88% | 23.98% | 31.10% | 25.41% | 43.29% | 28.66% | 54.67% | 38.01% | 22.97% | 5.08% | |
| Estonia | 32.28% | 20.99% | 34.26% | 30.30% | 51.49% | 24.55% | 51.68% | 51.88% | 12.67% | 0.40% | |
| Finland | 36.14% | 31.33% | 47.19% | 31.73% | 69.08% | 35.74% | 65.86% | 65.26% | 26.91% | 2.41% | |
| France | 40.07% | 27.38% | 47.75% | 30.88% | 55.43% | 28.05% | 47.25% | 41.24% | 10.18% | 1.50% | |
| Germany | 41.25% | 27.50% | 48.75% | 33.04% | 58.21% | 38.04% | 71.07% | 53.39% | 37.86% | 1.07% | |
| Greece | 39.77% | 28.79% | 45.26% | 33.78% | 52.58% | 42.10% | 56.41% | 55.91% | 15.97% | 0.50% | |
| Hungary | 55.77% | 29.68% | 36.11% | 35.16% | 66.16% | 31.00% | 73.91% | 64.27% | 23.25% | 0.95% | |
| Ireland | 28.18% | 15.25% | 53.60% | 11.44% | 50.85% | 30.93% | 40.47% | 25.64% | 12.71% | 1.91% | |
| Italy | 42.40% | 23.21% | 45.08% | 25.21% | 82.97% | 32.89% | 61.94% | 59.43% | 26.21% | 1.17% | |
| Latvia | 38.17% | 23.66% | 24.25% | 28.63% | 46.52% | 27.63% | 57.65% | 55.27% | 5.77% | 2.39% | |
| Lithuania | 53.51% | 25.45% | 25.25% | 37.47% | 59.32% | 37.68% | 65.33% | 64.93% | 12.42% | 2.00% | |
| Luxembourg | 41.53% | 35.48% | 46.37% | 29.03% | 67.34% | 43.95% | 55.65% | 50.00% | 14.52% | 4.84% | |
| Malta | 49.02% | 21.18% | 43.53% | 23.92% | 49.80% | 38.43% | 41.57% | 49.41% | 27.84% | 3.92% | |
| Netherlands | 38.70% | 33.72% | 56.64% | 40.86% | 76.08% | 40.70% | 75.75% | 63.46% | 50.33% | 0.66% | |
| Poland | 50.25% | 17.63% | 31.30% | 30.97% | 57.50% | 27.35% | 64.25% | 60.63% | 14.66% | 1.15% | |
| Portugal | 37.20% | 15.87% | 53.92% | 25.43% | 32.76% | 19.97% | 50.68% | 41.64% | 11.09% | 4.44% | |
| R. of Cyprus | 35.71% | 13.10% | 43.65% | 19.84% | 37.70% | 25.40% | 58.33% | 46.43% | 21.03% | 0.00% | |
| Romania | 63.88% | 35.80% | 44.17% | 45.32% | 76.03% | 45.98% | 70.61% | 73.07% | 11.00% | 0.82% | |
| Slovakia | 70.77% | 31.45% | 52.82% | 30.04% | 79.03% | 40.52% | 74.80% | 73.79% | 9.07% | 0.40% | |
| Slovenia | 36.28% | 23.29% | 39.89% | 38.27% | 63.72% | 38.81% | 54.87% | 47.83% | 17.51% | 2.35% | |
| Spain | 72.19% | 39.20% | 76.72% | 45.06% | 85.43% | 52.60% | 83.75% | 84.09% | 24.46% | 1.01% | |
| Sweden | 46.21% | 47.89% | 70.99% | 40.47% | 85.67% | 60.03% | 77.91% | 82.80% | 48.57% | 1.35% | |

Source: Own elaboration.



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**Table 10. Average number of actions by firms in each country.**

| Country | Firms per Country | Number of total actions | Number of total actions in average | Country | Firms per Country | Number of total actions | Number of total actions in average |
|---|---|---|---|---|---|---|---|
| Austria | 509 | 2006 | 3.94 | Latvia | 503 | 1559 | 3.10 |
| Belgium | 587 | 2936 | 5.00 | Lithuania | 499 | 1913 | 3.83 |
| Bulgaria | 514 | 1177 | 2.29 | Luxembourg | 248 | 964 | 3.89 |
| Croatia | 546 | 1941 | 3.55 | Malta | 255 | 889 | 3.49 |
| Czechia | 596 | 2473 | 4.15 | Netherlands | 602 | 2871 | 4.77 |
| Denmark | 492 | 1491 | 3.03 | Poland | 607 | 2159 | 3.56 |
| Estonia | 505 | 1568 | 3.10 | Portugal | 586 | 1717 | 2.93 |
| Finland | 498 | 2050 | 4.12 | R. of Cyprus | 252 | 759 | 3.01 |
| France | 599 | 1975 | 3.30 | Romania | 609 | 2842 | 4.67 |
| Germany | 560 | 2297 | 4.10 | Slovakia | 496 | 2295 | 4.63 |
| Greece | 601 | 2230 | 3.71 | Slovenia | 554 | 2010 | 3.63 |
| Hungary | 529 | 2202 | 4.16 | Spain | 597 | 3370 | 5.64 |
| Ireland | 472 | 1279 | 2.71 | Sweden | 593 | 3332 | 5.62 |
| Italy | 599 | 2399 | 4.01 | | | | |

Source: elaboration of our own.

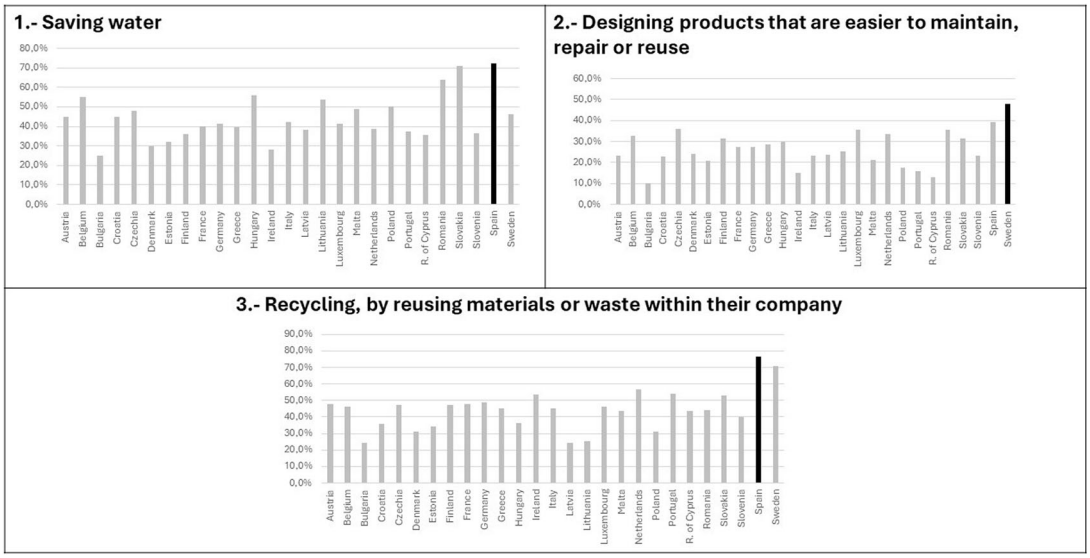


**Figure 3. Actions: a. 'Saving water'; b. 'Designing products that are easier to maintain, repair or reuse'; c. 'Recycling, by reusing materials or waste within their company'.** Source: Own elaboration.

The objective of Action b 'Design products that are easier to maintain, repair, or reuse is to move away from the attitude of the linear economy to avoid excessive waste that degrades the environment.' However, this action is least directly related to economic savings. As can be seen, Swedish firms, with 47.9%, give most importance to this action.

Action c 'Recycle, by using materials or waste within your company,' also sees Spanish firms stand out. A total of 76.72% stated that they carried out this action, followed by Swedish firms in second place.

Figure 4 shows that Belgian firms stand out for Action d 'Sell your waste and residues to other firms,' with 46% of firms reporting that they sell their waste; Romanian firms occupy second place. Regarding Action e (minimize waste), Swedish

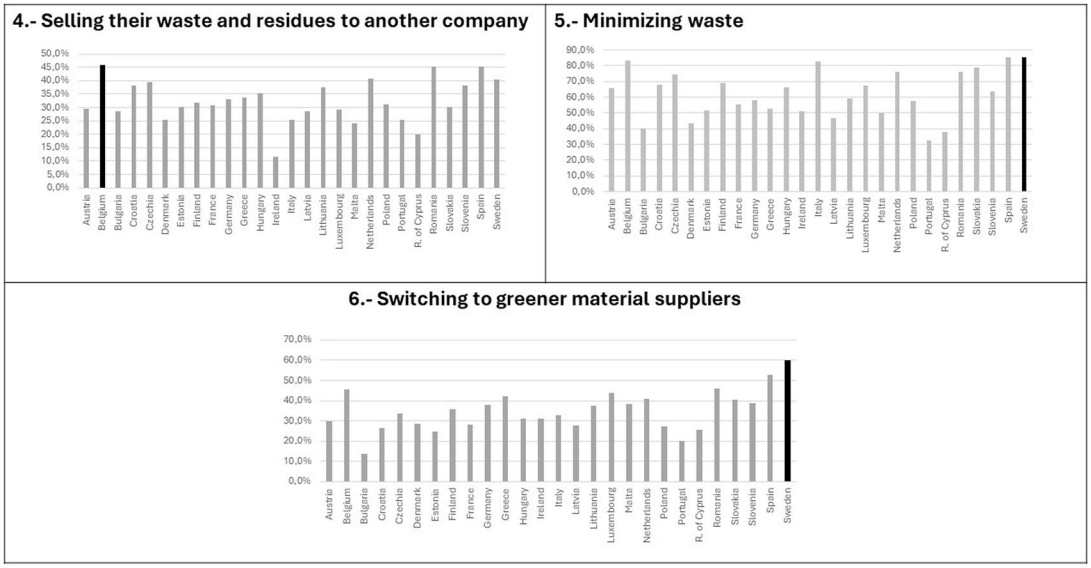


**Figure 4. Actions: d. 'Selling their waste and residues to another company'; e. 'Minimizing waste'; f. 'Switching to greener material suppliers'.** Source: Own elaboration.

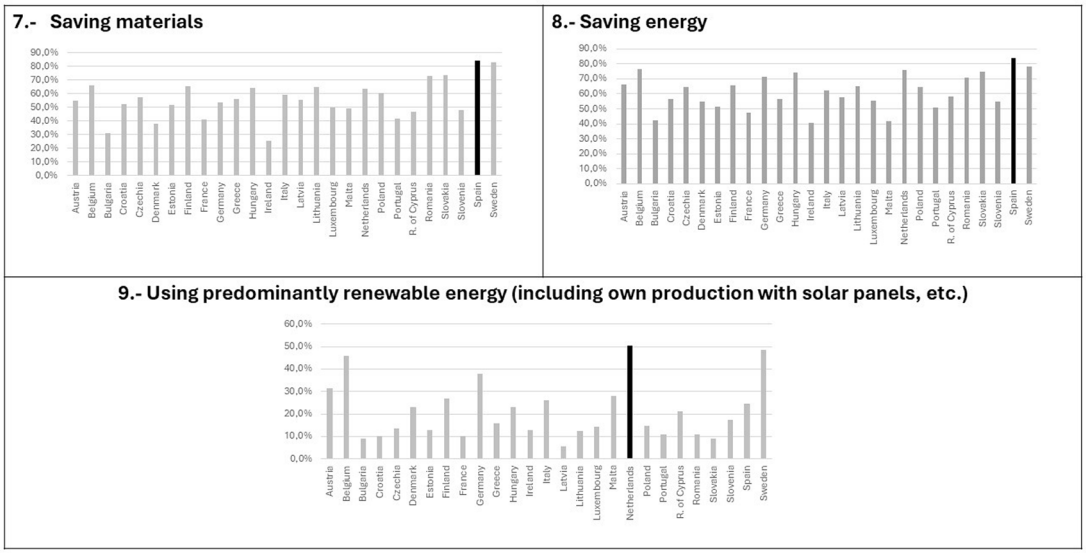


**Figure 5. Actions: g. 'Saving materials', h. 'Saving energy' y i. 'Using predominantly renewable energy (including own production with solar panels, etc.)'** Source: Own elaboration.

firms again stood out at 85.7%. For Action f (switch suppliers of more environmentally friendly materials), Swedish firms again stand out at 60%.

For Action g ('Save energy') and Action h ('Save materials'), Spanish firms were once again leading the way, showing 83.8% and 84.1%, respectively. For Action i 'Use predominantly renewable energy (including own production with solar panels, etc.), Dutch firms stand out from the rest at 50.3%.

Taking into account the three types of actions for which Swedish firms stand out (designing products that are easier to maintain, reduce waste, and look for greener suppliers), we can deduce that firms in this country are more aware of environmental sustainability, as these actions do not in the first instance lead to savings in terms of cost, but can even reduce economic profitability.

On the other hand, Spanish firms give more importance to saving water, energy, materials, and to recycling. This suggests that they are more concerned with cost savings in order to increase their competitiveness.

### 3.2 Clustering analysis

Using the K-mode clustering method, we could differentiate the three clusters. Cluster 1 consists of 6,195 firms, Cluster 2 consists of 4,002 firms, and Cluster 3 consists of 3,811 firms. Before examining the relationship between the environmental actions carried out by the firms and the clusters, we performed a significance analysis before drawing up the contingency tables.

Table 11 summarizes the main characteristics of the three clusters. These are the number of firms contained in each cluster, the Circular Economy activities they carry out, whether they sell products and/or services, and the type of customers they target.

As shown in Table 11, Cluster 1, consisting of 6,195 firms, is the largest cluster. The activities carried out by these firms in terms of sustainability were mainly energy saving (71.65% of the firms stated that they saved energy) and waste minimization (72.90% of the firms). They focus on selling the services to other firms.

The second group comprises 4,002 firms and is characterized by the fact that it is the group that performs the fewest actions. If we look at this group, the most common action is recycling, which is only carried out by 29.51% of the firms, followed by energy-saving (22.31% of the firms). In addition, 21.14% of the firms declared that they did not carry out any of the activities related to energy and/or resource saving. This cluster is also characterized by the fact that firms sell products to end consumers.

The third group, Cluster 3, was the smallest, consisting of 3,811 firms. It places the greatest emphasis on minimizing waste (91.13% of the firms) and/or saving energy (89.50% of the firms). It is more heterogeneous in terms of what they sell and to whom, as more than half of the firms sell services and products and their clients can be other firms, end consumers, or public administrations. This is the cluster in which firms declare more environmental actions, in contrast to Cluster 2.

According to Masi et al. (2018), CE initiatives can be carried out at three levels: the micro-, meso-, and macro-levels. They find evidence that most CE actions are at the micro level, and our findings concur with this. Micro-level initiatives refer to the 3R Principles: Reduce, Reuse, and Recycle. Meso-level initiatives refer to an inter-firm level, which in this study corresponds to actions: 'Sell your waste and residues to other firms' and 'Switch to suppliers of more environmentally friendly materials.' Macro-level initiatives cannot be checked directly in this survey, as they correspond to the government level.

Table 12 is a contingency table showing the relationship between the environmental variables and clusters.

Table 12 shows the relative weights, that is, the percentage of firms in each cluster that perform each of the different actions. For example, in Cluster 1, 72.9% of firms carried out the action of minimizing waste. In general, we can see that

**Table 11. Number of firms and characteristics per cluster.**

| Cluster | Firms | Characteristics |
|---|---|---|
| Cluster 1 | 6195 | Saving energy (71.65%),<br>Minimizing waste (72.90%)<br>Selling services (43,04%).<br>Sell to other firms |
| Cluster 2 | 4002 | Saving energy (22.31%),<br>Recycling (29,51%)<br>None (21,14%)<br>Selling products (45,18%).<br>Selling directly to consumers |
| Cluster 3 | 3811 | Saving energy (89.50%),<br>Minimizing waste (91,13%)<br>Selling services and products (51,01%).<br>Selling to other companies, directly to consumers or to the public administration |

Source: Own elaboration.

**Table 12.** Cross-tabulation of environmental actions and clusters.

| Actions | Cluster 1 | Cluster 2 | Cluster 3 | EST- Chi^2 | Cramer's V |
|---|---|---|---|---|---|
| Minimizing waste | 72.90% | 21.94% | 91.13% | | |
| Saving materials | 66.49% | 14.52% | 85.46% | | |
| Saving energy | 71.65% | 22.31% | 89.50% | | |
| Saving water | 40.02% | 16.44% | 82.29% | | |
| Switching to greener suppliers of materials | 25.31% | 15.24% | 71.69% | | |
| Selling your residues and waste to another company | 22.11% | 18.44% | 66.83% | | |
| Recycling, by reusing material or waste within the company | 35.50% | 29.51% | 76.36% | | |
| None | 2.57% | 21.14% | 0.00% | | |
| Designing products that are easier to maintain, repair or reuse | 24.39% | 12.69% | 46.29% | | |
| Using renewable energy | 20.48% | 10.79% | 33.61% | | |

the firms in Cluster 3 are the most environmentally active because the percentage of firms participating in each of the actions is higher than that of the firms in the other two clusters.

Since these environmental actions constitute the variables used to generate the K-modes partition, Table 12 should not be interpreted as an independent statistical validation of the clustering. Instead, it provides a descriptive profile of the environmental characteristics that define each cluster.

Finally, the previously analyzed clustering results can be mapped, showing which cluster predominates in each EU country.

The map in Figure 6 shows the importance of each cluster for each country. Thus, Area A is composed of countries whose firms belong mainly to Cluster 1. In area B, we find the countries whose firms belong mainly to Cluster 2, and in C, we

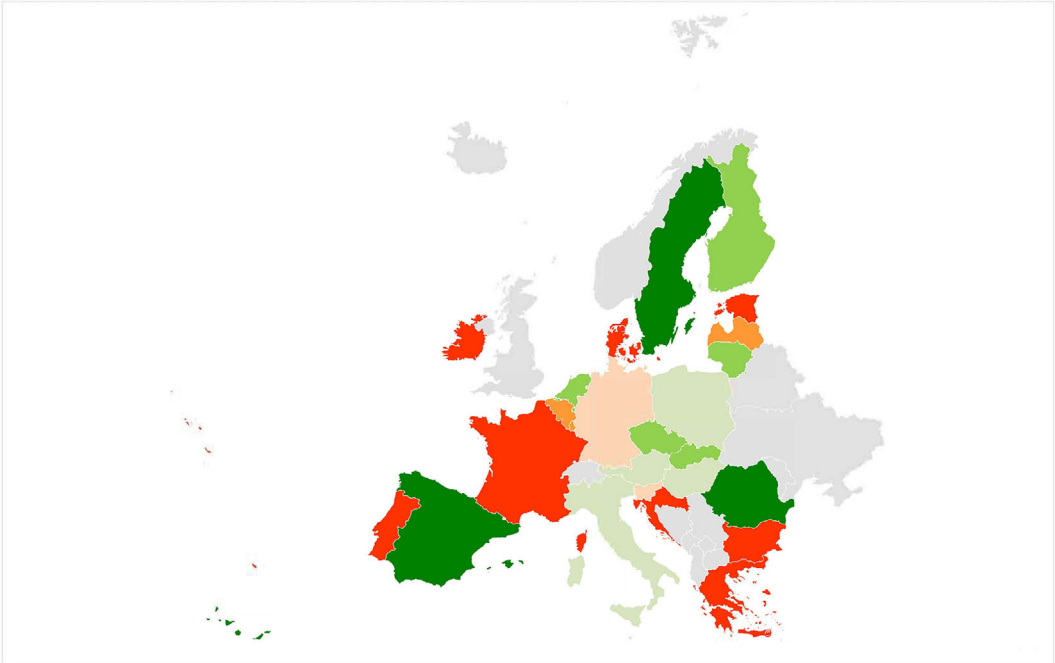

**Figure 6. Predominant clusters in each country.**

**Table 13. Distribution of countries by area.**

| Area A | Area B | Area C | Area X | Area Y | Area Z |
|---|---|---|---|---|---|
| Austria | Bulgaria | Romania | Belgium | Czechia | Germany |
| Hungary | Croatia | Spain | Latvia | Finland | Slovenia |
| Italy | Denmark | Sweden | Luxembourg | Lithuania | |
| Poland | Estonia | | | Netherlands | |
| | France | | | Slovakia | |
| | Greece | | | | |
| | Ireland | | | | |
| | Malta | | | | |
| | Portugal | | | | |
| | R. of Cyprus | | | | |

Source: Own elaboration.

find those in Cluster 3. In areas X, Y, and Z, no single predominant cluster was observed. In area X, Clusters 1 and 2 were predominant. In area Y, Clusters 1 and 3 were predominant. In area Z, Clusters 2 and 3 show similar representations. To determine whether a particular cluster predominates in a country, we first calculated the average number of companies belonging to each cluster. If a country exceeds that average, we consider that cluster to be predominant in that country. Thus, there are countries where only one cluster predominates, and others where two clusters predominate at the same time. To summarize, we represent countries by area in Table 13.

As can be seen, area C shows the countries that carry out the most actions, that is, where the firms that make up Cluster 3 predominate. However, this does not mean that they perform the same type of action. For example, as we have seen in Table 9 and as Vasilescu et al. (2023) have also found, Swedish firms focus more on the design of environmentally sustainable products, whereas Spanish firms focus more on cost savings such as saving water or recycling materials.

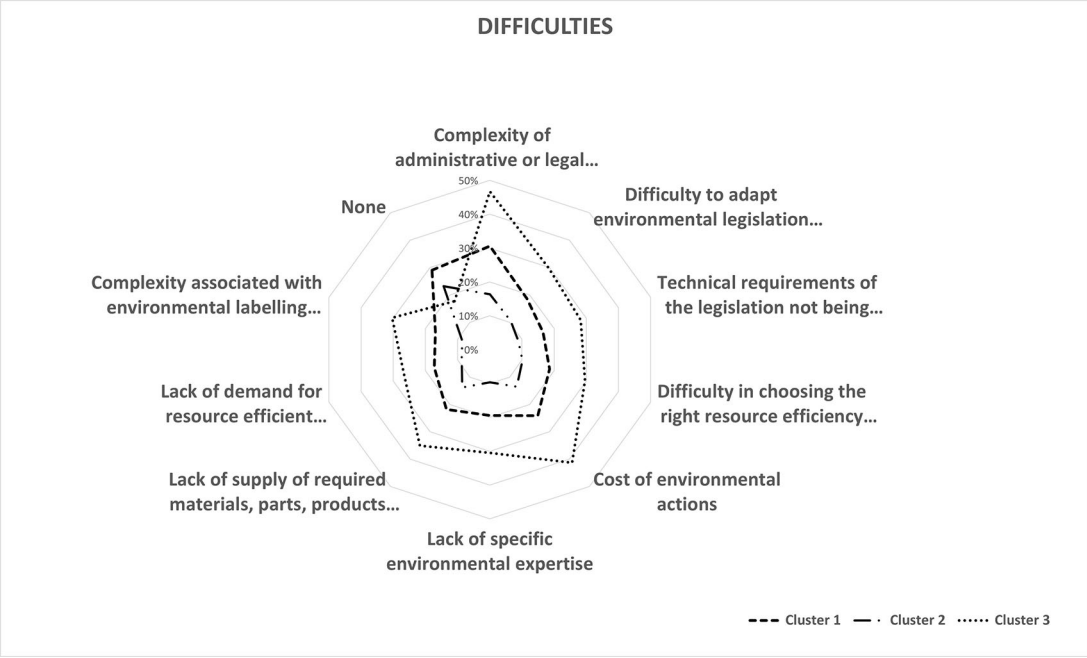


**Figure 7. Distribution of clusters according to the perceived barriers faced by firms.** Source: Own elaboration.

### 3.3 Barriers encountered by firms and type of support they request

In this section, we examine the firms' perceptions of the barriers they face when implementing environmental policy measures. Additionally, we present the types of aid requested by these firms. Both variables are shown by the type of cluster to which firms belong.

Figure 7 shows how firms are most affected by the cost of environmental actions and administrative procedures. These results are in line with Rizos et al. (2016) and Garcés-Ayerbe et al. (2019) which conclude that financial constraints and administrative complexity are among the most frequently documented obstacles. Kirchherr et al. (2018) relativizes it, they consider regulatory barriers as main important, but not the among the five most pressing barriers. As might be expected, the firms that carried out the most actions, those in Cluster 3, reported the most difficulties.

Table 14 presents a contingency analysis of these difficulties. This table confirms that administrative and legal procedures are perceived as the principal difficulties faced by firms in any cluster. This difficulty had the highest percentage of all clusters. That is, it does not depend on whether firms take more or fewer actions or on the type of action they take.

When analyzing the help sought by the firms, we can see in Figure 8 that they mainly request subsidies; however, in addition to this economic incentive to meet the cost of environmental actions, they also want greater cooperation with other firms. In terms of the significance of these variables, we can see that all are relevant.

We can observe that the percentage of firms in Cluster 3, which are the most sustainable firms, are those that request more support. That is the reason we can see in Figure 8 "None" support is close to 0. There is also a relevant percentage of firms in the less environmentally active cluster that do not claim any aid.

A contingency analysis of these demands is presented in Table 15. All responses regarding the requested aid were significant. As shown in Figure 8, firms seek financial aid or subsidies as expected. However, it is striking that for firms in Clusters 1 and 3, the second most requested aid was cooperation between firms. However, for Cluster 2 (the least active in this area), the main request is for help in the form of consultancy on how to improve the efficiency of their use of resources.

**Table 14. Perceived barriers contingency analysis.**

| DIFFICULTIES | Cluster 1 | Cluster 2 | Cluster 3 | EST- Chi^2 | Cramer's V |
|---|---|---|---|---|---|
| Complexity of administrative or legal procedures | 30.64% | 16.39% | 46.71% | 2826.97 | 0.449 |
| The technical requirements of the legislation not being up to date | 16.58% | 8.80% | 28.26% | 2519.14 | 0.440 |
| Difficulty in choosing the right resource efficiency actions for your company | 18.60% | 10.17% | 29.57% | 2510.67 | 0.440 |
| Difficulty adapting environmental legislation to your company | 18.64% | 10.52% | 29.70% | 2494.65 | 0.435 |
| Lack of specific environmental expertise | 24.08% | 13.54% | 41.33% | 2715.98 | 0.424 |
| Lack of supply of required materials, parts, products or services | 21.82% | 13.79% | 35.08% | 2504.39 | 0.423 |
| Lack of demand for resource efficient products or services | 17.27% | 8.72% | 26.48% | 2496.42 | 0.422 |
| Complexity associated with environmental labelling and certification | 17.27% | 8.72% | 26.48% | 2496.42 | 0.422 |
| Cost of environmental actions | 24.08% | 13.54% | 41.33% | 2715.98 | 0.440 |

Source: Own elaboration.

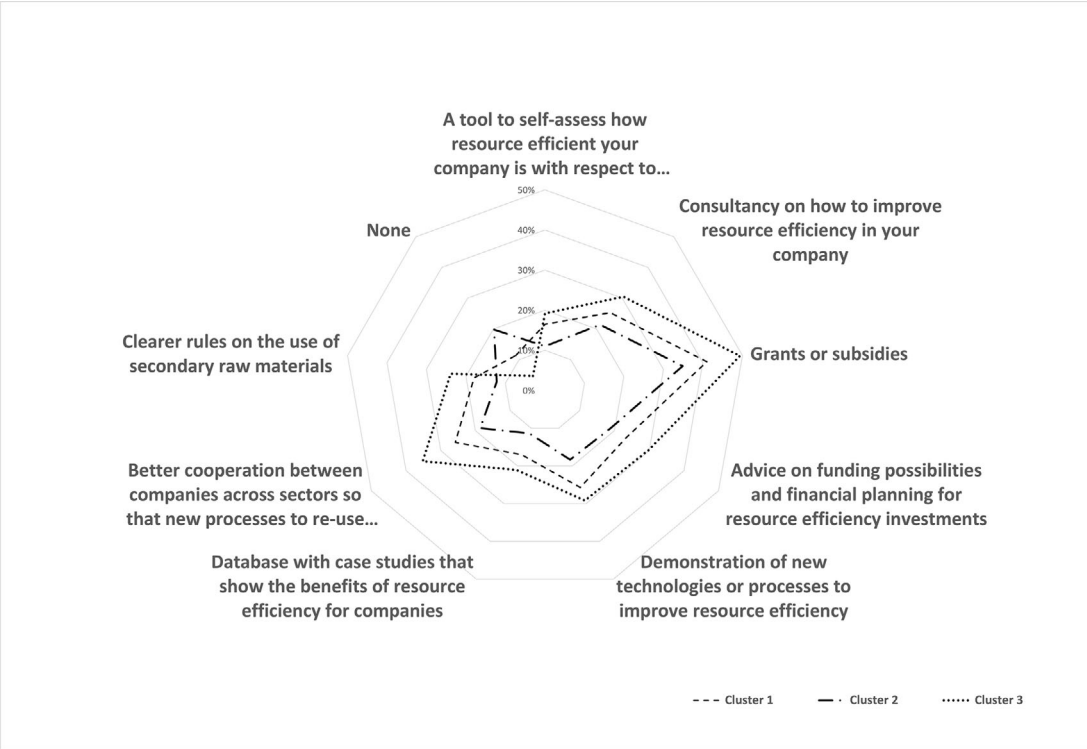


**Figure 8. Distribution of clusters according to the support received by firms.** Source: Own elaboration.

**Table 15. Requests contingency analysis.**

| Support requested | Cluster 1 | Cluster 2 | Cluster 3 | EST- Chi^2 | Cramer's V |
|---|---|---|---|---|---|
| Better cooperation between companies across sectors so that new processes to reuse waste and byproducts can be ... | 25.83% | 18.67% | 35.16% | 2388.75 | 0.415 |
| A tool to self-assess how resource efficient your company is with respect to other companies | 16.48% | 10.97% | 19.18% | 2276.02 | 0.413 |
| Clearer rules on the use of secondary raw materials | 17.92% | 12.19% | 23.85% | 2301.02 | 0.412 |
| Advice on funding possibilities and financial planning for resource efficiency investments | 23.42% | 18.89% | 29.76% | 2270.74 | 0.405 |
| Database with case studies that show the benefits of resource efficiency for companies | 17.00% | 11.37% | 21.07% | 2284.88 | 0.404 |
| Demonstration of new technologies or processes to improve resource efficiency | 25.71% | 18.34% | 29.18% | 2373.70 | 0.403 |
| Grants or subsidies | 40.98% | 34.91% | 49.38% | 2410.99 | 0.402 |
| Consultancy on how to improve resource efficiency in your company | 25.29% | 21.39% | 30.46% | 2260.33 | 0.385 |

Source: Own elaboration.

## 4. Discussion

This study contributes to a better understanding of SMEs in the context of a Circular Economy in the EU. This is essential for policymakers, both for ecological reasons and given the uncertain geopolitical situation. We detected three clusters based on the company characteristics. Cluster 3 was the most proactive in terms of environmental issues and Cluster 2 was

the least proactive. The following observations can be made. On the one hand, the EU's Circular Economy Action Plan was implemented to help firms become more sustainable. In this sense, Govindan and Hasanagic (2018) demonstrated in an empirical study of the supply chain that the government is the actor that has the most impact on the implementation of the Circular Economy. In this context, it is surprising that the principal difficulty that firms identify is the complexity of administrative or legal requirements, except for Cluster 1, which focuses on the costs of these actions. Additionally, more environmentally proactive firms face the most difficulties. Further, after subsidies, firms' second strongest call is for better cooperation between firms in Cluster 3 and for consultancy in Cluster 2. It seems that less proactive firms need technical assistance in implementing environmental actions.

In sum, first, most firms seem to find the implementation of environmentally sustainable practices to be expensive and entail administrative difficulties. As such, it is noteworthy that macro-level initiatives such as the Circular Economy Action Plan are considered a problem for firms rather than a source of help. Second, firms are seeking a more dynamic connection with their commercial counterparts and are requesting support to encourage meso-level initiatives. In this regard, the problem of asymmetric information could be best addressed by active engagement on the part of public administrations or bodies designed for this purpose. Finally, the least proactive cluster does not see a way forward to implement green practices.

All of these are considerations for policymakers to consider for the improvement of the sustainable economy process across the European Union.

## 5. Conclusions

This study grouped the European firms according to their environmental actions. We found three types of clusters, each with different characteristics and identified the countries in which each group was principally located.

The first cluster comprises the largest number of firms, mainly those that provide services to other firms. They are characterized by a strong focus on energy savings and waste minimization.

The second group, Cluster 2, stands out because it constitutes the firms that carry out the fewest actions.

At the other extreme, we have Cluster 3, whose main characteristic is that it carries out the most actions. It is also the most diverse cluster in terms of the type of targeted customer. Companies ask for financial support to become more environmentally sustainable, as they state that the actions carried out are costly and for more information, as they see a benefit in collaboration with other firms in this area. Difficulties in administrative processes are the second problem faced by firms, and firms also ask for help in implementing new technologies or processes to become more efficient.

In short, they request financial support, on the one hand, and, on the other hand, greater simplicity in terms of administrative procedures, along with information regarding possible cooperation between firms regarding new technologies or processes.

## Ethics and consent

Ethical approval and consent were not required for this study.

## Data availability

All the data underlying the results presented in this article are publicly available under open licences permitting reuse.

Garcia-Alcober, M. P., Mateos Ansótegui, A. I., Pastor Gosálbez, M. T., & Navarro, J. (2026). Extended data "How are European Small Enterprises dealing with the Circular Economy?" [Data set]. Zenodo. https://doi.org/10.5281/zenodo.19691797 García-Alcober (2026).

Data are available under the terms of the Creative Commons Attribution 4.0 International.

All datasets are freely available and distributed under open licenses permitting reuse (CC-BY or equivalent), depending on the source). These datasets can be used to replicate the analyses and findings presented in this study.

## Acknowledgements

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## References


Baldassarre B: **Circular economy for resource security in the European Union (EU): Case study, research framework, and future directions.** *Ecol. Econ.* 2025; **227**: 108345.
**Publisher Full Text**

Cao F, Liang J, Bai L: **A New Initialization Method for Categorical Data Clustering.** *Expert Syst. Appl.* 2009; **36**(7): 10223–10228.
**Publisher Full Text**

Chatzistamoulou N, Tyllianakis E: **Commitment of European SMEs to resource efficiency actions to achieve sustainability transition. A feasible reality or an elusive goal?.** *J. Environ. Manag.* 2022; **321**: 115937.
**Publisher Full Text**

Christis M, Athanassiadis A, Vercalsteren A: **Implementation at a city level of circular economy strategies and climate change mitigation–the case of Brussels.** *Journal of Cleaner Production.* 2019; **218**: 511–520.
**Publisher Full Text**

European Commission: *Closing the loop—An EU action plan for the circular economy.* Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions; 2015.

European Commission: **A new Circular Economy Action Plan for a cleaner and more competitive Europe.** 2020.
**Reference Source**

European Commission: *Flash Eurobarometer 498. SMEs, Resource Efficiency and Green Markets, wave 5.* GESIS;Cologne: 2022a. ZA7806 Data file Version 1.0, Brussels 2022.
**Publisher Full Text**

European Commission: *Annual Report on European SMEs 2021/22. SMEs and environmental sustainability.* Brussels: 2022b; vol. **2022**.

European Parliament and Council: **Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 Establishing a Framework for Ensuring a Secure and Sustainable Supply of Critical Raw Materials and Amending Regulations (EU) no 168/2013, (EU) 2018/858, (EU) 2018/17.** *Off. J. Eur. Union.* 2024; **2024**: 1–67.

Garcés-Ayerbe C, Rivera-Torres P, Suárez-Perales I, *et al.*: **Is it possible to change from a linear to a circular economy? An overview of opportunities and barriers for European small and medium-sized enterprise companies.** *Int. J. Environ. Res. Public Health.* 2019; **16**(5): 851.
**PubMed Abstract** | **Publisher Full Text** | **Free Full Text**

García-Alcober M: **Online Appendix to "How are European Small Enterprises dealing with the Circular Economy?".** *Zenodo.* 2026.
**Publisher Full Text**

Ghisellini P, Cialani C, Ulgiati S: **A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems.** *Journal of Cleaner Production.* 2016; **114**: 11–32.
**Publisher Full Text**

Gomonov K, Ratner S, Lazanyuk I, *et al.*: **Clustering of EU countries by the level of circular economy: An objective-oriented approach.** *Sustainability.* 2021; **13**: 7158.
**Publisher Full Text**

Govindan K, Hasanagic M: **A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective.** *Int. J. Prod. Res.* 2018; **56**(1–2): 278–311.
**Publisher Full Text**

Kirchherr J, Piscicelli L, Bour R, *et al.*: **Barriers to the circular economy: evidence from the European Union (EU).** *Ecological Economics.* 2018; **150**: 264–272.
**Publisher Full Text**

Masi D, Kumar V, Garza-Reyes JA, *et al.*: **Towards a more circular economy: exploring the awareness, practices, and barriers from a focal firm perspective.** *Prod. Plan. Control.* 2018; **29**(6): 539–550.
**Publisher Full Text**

Rizos V, Behrens A, Van der Gaast W, *et al.*: **Implementation of Circular Economy Business Models by Small and Medium-Sized Enterprises (SMEs): Barriers and Enablers.** *Sustainability.* 2016; **8**(11): 1212.
**Publisher Full Text**

Turcu C, Gillie H: **Governing the circular economy in the city: Local planning practice in London.** *Plan. Pract. Res.* 2020; **35**(1): 62–85.
**Publisher Full Text**

Vasilescu MD, Dimian GC, Gradinaru GI: **Green entrepreneurship in challenging times: a quantitative approach for European countries.** *Economic research-Ekonomska istraživanja.* 2023; **36**(1): 1828–1847.
**Publisher Full Text**

# Open Peer Review

## Current Peer Review Status: ? ✓ ?

**Version 2**

Reviewer Report 08 October 2026

https://doi.org/10.21956/openreseurope.27144.r82634

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✓ **Grigorios L. Kyriakopoulos**
National Technical University of Athens, Athens, Greece

This revised manuscript can be accepted for indexing in the Open Research Europe journal as is.

**References**

1. García-Alcober MP, Mateos-Ansótegui AI, Pastor-Gosálbez MT and Navarro-Ortiz J. How are European small enterprises dealing with the circular economy?.

***Competing Interests:*** No competing interests were disclosed.

***Reviewer Expertise:*** Engineering, Environment, Renewable Energy, Analytical Techniques, Business and Management, Low Carbon Economy, Development Economics, Circular Economy, Behavioural Ecology

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.**

**Version 1**

Reviewer Report 14 July 2026

https://doi.org/10.21956/openreseurope.25210.r76121

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? **Francisco Villegas Pinuer**

Universidad Diego Portales, Santiago, Chile

Dear authors,
The article is interesting for its approximation of circular economy actions in the Eurobarometer data.
In this regard, there are some aspects to consider.

Introduction
This section should be reinforced in light of the circular economy hierarchy framework. The circular economy practices considered in the survey have varying levels of circularity, which lead to different environmental effects. In addition, the first paragraph would benefit from adding the circular economy definition of Geissdoerfer, considering their whole scope (materials, energy)

Methodology
The section is well presented. Nonetheless, 2.2 should be titled "Method" rather than "Methodology". Then, the procedure used should be explained in more detail, considering the underlying assumptions of the process.
In addition, the presentation of grouped circular economy practices should be introduced in the first section of the article. In this regard, it is relevant to define the conceptual approximation of the circular economy phenomenon clearly.

Results
The section is straightforward in its presentation. The clustering description is concise.

Discussion
The section needs to emphasize the article's contributions. Actually, the presentation is descriptive.

**Is the work clearly and accurately presented and does it engage with the current literature?**
Partly

**Is the study design appropriate and is the work technically sound?**
Yes

**Are sufficient details of methods and analysis provided to allow replication by others?**
Partly

**Are all the source data and materials underlying the results available?**
Yes

**If applicable, is the statistical analysis and its interpretation appropriate?**
Yes

**Are the conclusions drawn adequately supported by the results?**
Partly

***Competing Interests:*** No competing interests were disclosed.

***Reviewer Expertise:*** Environmental sustainability and circular economy

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.**

Author Response 27 Aug 2026

**Josep Navarro-Ortiz**

**Dear authors, The article is interesting for its approximation of circular economy actions in the Eurobarometer data. In this regard, there are some aspects to consider. Introduction This section should be reinforced in light of the circular economy hierarchy framework. The circular economy practices considered in the survey have varying levels of circularity, which lead to different environmental effects. In addition, the first paragraph would benefit from adding the circular economy definition of Geissdoerfer, considering their whole scope (materials, energy)**
Thank you for your comment. We have added a second part in the 1st paragraph mentioning Geissdoerfer et al. (2017) .We have also added a final paragraph noting that not all environmental activities are equally effective in achieving a circular economy.

**Methodology The section is well presented. Nonetheless, 2.2 should be titled "Method" rather than "Methodology". Then, the procedure used should be explained in more detail, considering the underlying assumptions of the process.**
Thank you for your observation. We have modified the section 2 “Methodology. We added a new subsection 2.1. “database” to explain the data; We modified the name of the subsection 2.2. that now is “Analysis of the business structure in Europe. As a result, the “methodology” subsection has been renumbered as subsection 2.3. and is now titled “method.”

**In addition, the presentation of grouped circular economy practices should be introduced in the first section of the article. In this regard, it is relevant to define the conceptual approximation of the circular economy phenomenon clearly.**
We have added a new section 2.1. to explain the data. We have also categorized the actions taken based on their characteristics for better clarification.

**Results The section is straightforward in its presentation. The clustering description is concise. Discussion The section needs to emphasize the article's contributions. Actually, the presentation is descriptive.**
Thank you for your comment. We have rewritten the discussion based on your comments.

***Competing Interests:*** No competing interests were disclosed.

Reviewer Report 30 June 2026

https://doi.org/10.21956/openreseurope.25210.r76120

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**Grigorios L. Kyriakopoulos**
National Technical University of Athens, Athens, Greece

A general comment is that authors include a number of different terms to mention the same thing, which are the terms of: enterprises, firms, companies, in different parts of their study. The consistent terminology throughout the text content, including Tables and Figures, should be mostly welcome.

In section 1. Introduction, there should be a more solidified cross-citing or EU SMEs with the SDGs and the EU regulations, since this is a core emerging topic of theoretical coverage in the study.

From data of Table 1, all numbers of companies per country to be summed and the total to be calculated. Then the percentages of each one participant country to be added in parentheses next to these numbers, for example in the case of Austria: 509 (.....percentage, to be added here.....%), and the same to the other countries.

In subsection 2.1 authors mentioned that “We selected companies from 27 European Union member states. After the database was cleaned, 14,008 enterprises were included in the sample”. However, while this statement is clearly noted in Table 6, it is not clearly conveyed or outlined in data of Tables 1-5 and Figure 1, in which a reader should obtain the false perception/imply that the clustering and numerical data per country are representative for the whole country, but they are actually survey-derived allocations. This misconception is clearer in Table 4 in which the referencing of 1840 firms are contradicting to the sampling size of 14008 enterprises. Therefore, for these types of information, Tables 1-5 and Figure 1, it could be more realistic if -besides to survey-based allocation- authors could retrieve national-based, placing them either as separate Table-columns, or in parentheses next to the survey-based data.

In Tables in which there is an extensive repetition of the percentage symbol (%) to all Table-columns, this percentage symbol (%) can be transferred in the corresponding Table-heading-line and to remove from the cells underneath it.

In the y-axis of Figure 1, the missing legend and the percentage symbol (%) can be added, as: “Percentage of businesses (%)”. Besides, in Figures 3,4,5 the subgraphs have to be numbered as a, b, c, not 1,2,3, since this Arabic numbering 1,2, 3....., follows the main Figures, not their subfigures, for which the alphabetical numbering is suitable.

In subsection 3.3 the term of “difficulties” sounds informal for scientific research. In my opinion the upgrading of the “difficulties” term can be approached by a more systematic and in-depth manner, thus, the adoption and presentation of the following 2 types of analysis: SWOT and PESTLE, can offer a more systematic approach of the findings. The formulation of relevant 2X2 Table, per dimension: Strengths, Weakness, Opportunities, Threads, can plausibly transforms the Difficulties (implied by the dimensions, W and T) into advantages S and O, respectively. Similarly, the dimensions of Political, Economic, Social, Technological, Legal, and Environmental can provide

a more comprehensive understanding of the clustered companies in alignment with their perceptions of the difficulties to cope with when implementing environmental policy measures under intra-governmental EU restrictions and specifications, motivations, national rules and directions.

In response of setting/study statements:

-two-fold research objectives: “on the one hand, to analyze the responses of companies by country to the environmental measures proposed in the EU regulation, and on the other hand, to categorize companies in terms of the actions taken in response to these environmental measures on a country-by-country basis”
-The research focuses on “a better understanding of SMEs in the context of a Circular Economy in the EU”,

authors are recommended to elaborate the rather weakly developed section 4. Discussion by enriching it and succinctly addressing the following SMEs-oriented issues (indicatively) of environmental and circular economy interest among the conducted survey on the participating companies:

-The role of extroversion and internationalization of the national markets towards a liberal international marketplace.
-The contribution of microfinancing and environmental education in order to instill the pro-environmental perceptions in the SMEs trading.
-The involvement of the digitalization and transaction economy types, which can activate the role of social communities and vulnerable social groups: women, children, migrants, in collecting recyclable materials and running FabLabs networks of digital fabrication laboratories through platforms for cooperation in urban locations.

For this reason, the Discussion section can be extended up to one extra, and cross-citing, text page.

**Is the work clearly and accurately presented and does it engage with the current literature?**
Yes

**Is the study design appropriate and is the work technically sound?**
Yes

**Are sufficient details of methods and analysis provided to allow replication by others?**
Partly

**Are all the source data and materials underlying the results available?**
Yes

**If applicable, is the statistical analysis and its interpretation appropriate?**
Partly

**Are the conclusions drawn adequately supported by the results?**

Yes

***Competing Interests:*** No competing interests were disclosed.

***Reviewer Expertise:*** Engineering, Environment, Renewable Energy, Analytical Techniques, Business and Management, Low Carbon Economy, Development Economics, Circular Economy, Behavioural Ecology

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.**

Author Response 27 Aug 2026

**Josep Navarro-Ortiz**

**A general comment is that authors include a number of different terms to mention the same thing, which are the terms of: enterprises, firms, companies, in different parts of their study. The consistent terminology throughout the text content, including Tables and Figures, should be mostly welcome.**
Thank you for your observation. We have modified, we use the term “firms” in the text

**In section 1. Introduction, there should be a more solidified cross-citing or EU SMEs with the SDGs and the EU regulations, since this is a core emerging topic of theoretical coverage in the study.**
Thank you for your comment. We have replaced the third paragraph with a new one, reinforcing the proposed idea.

**From data of Table 1, all numbers of companies per country to be summed and the total to be calculated. Then the percentages of each one participant country to be added in parentheses next to these numbers, for example in the case of Austria: 509 (.....percentage, to be added here.....%), and the same to the other countries.**
Thank you for your observation. We have modified. We considered the data provided by the survey; it did not include the total number of companies per country. We have rewritten the text for a better understanding.

**In subsection 2.1 authors mentioned that “We selected companies from 27 European Union member states. After the database was cleaned, 14,008 enterprises were included in the sample”. However, while this statement is clearly noted in Table 6, it is not clearly conveyed or outlined in data of Tables 1-5 and Figure 1, in which a reader should obtain the false perception/imply that the clustering and numerical data per country are representative for the whole country, but they are actually survey-derived allocations. This misconception is clearer in Table 4 in which the referencing of 1840 firms are contradicting to the sampling size of 14008 enterprises. Therefore, for these types of information, Tables 1-5 and Figure 1, it could be more realistic if - besides to survey-based allocation- authors could retrieve national-based, placing them either as separate Table-columns, or in parentheses next to the survey-based**

**data.** Thank you for your comment. The study analyses the Eurobarometer survey sample rather than the complete population. Table 4 represents only firms over 50 million €, not the total of firms. We rewrite the 1st paragraph of this section to ensure that it´s clear.

**In Tables in which there is an extensive repetition of the percentage symbol (%) to all Table-columns, this percentage symbol (%) can be transferred in the corresponding Table-heading-line and to remove from the cells underneath it**
Thank you for your comment. We removed the percentage symbol from the cells.

**In the y-axis of Figure 1, the missing legend and the percentage symbol (%) can be added, as: "Percentage of businesses (%)". Besides, in Figures 3,4,5 the subgraphs have to be numbered as a, b, c, not 1,2,3, since this Arabic numbering 1,2, 3……, follows the main Figures, not their subfigures, for which the alphabetical numbering is suitable.**
Thank you for your comment. We added the legend and modified the subgraphs numbering.

**In subsection 3.3 the term of "difficulties" sounds informal for scientific research. In my opinion the upgrading of the "difficulties" term can be approached by a more systematic and in-depth manner, thus, the adoption and presentation of the following 2 types of analysis: SWOT and PESTLE, can offer a more systematic approach of the findings. The formulation of relevant 2X2 Table, per dimension: Strengths, Weakness, Opportunities, Threads, can plausibly transforms the Difficulties (implied by the dimensions, W and T) into advantages S and O, respectively. Similarly, the dimensions of Political, Economic, Social, Technological, Legal, and Environmental can provide a more comprehensive understanding of the clustered companies in alignment with their perceptions of the difficulties to cope with when implementing environmental policy measures under intra-governmental EU restrictions and specifications, motivations, national rules and directions.**
Thank you for your comment. We modified the term "difficulties" by "barriers". About the SWOT and PESTLE analysis, it´s out of our focus. A SWOT and PESTLE analysis could be use on a new paper using new databases and different information for all the different countries. Your contribution is very interesting and we´ll estimate on another paper.

**In response of setting/study statements: -two-fold research objectives: "on the one hand, to analyze the responses of companies by country to the environmental measures proposed in the EU regulation, and on the other hand, to categorize companies in terms of the actions taken in response to these environmental measures on a country-by-country basis" -The research focuses on "a better understanding of SMEs in the context of a Circular Economy in the EU", authors are recommended to elaborate the rather weakly developed section 4. Discussion by enriching it and succinctly addressing the following SMEs-oriented issues (indicatively) of environmental and circular economy interest among the conducted survey on the participating companies: -The role of extroversion and internationalization of the national markets towards a liberal international marketplace. -The contribution of microfinancing and environmental education in order to instill the pro-environmental perceptions in the SMEs trading. -The involvement of the digitalization and transaction economy types, which can activate the role of social communities and**

**vulnerable social groups: women, children, migrants, in collecting recyclable materials and running FabLabs networks of digital fabrication laboratories through platforms for cooperation in urban locations. For this reason, the Discussion section can be extended up to one extra, and cross-citing, text page.**
Thank you for your asportation. We improved the discussion section. We include new references and comments. Nevertheless, we are using a Eurobarometer database that doesn´t contain so many indicators. The analysis proposed is very interesting, however, it´s not our focus and we don´t have so much information.

***Competing Interests:*** No competing interests were disclosed.

Reviewer Report 27 June 2026

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**Antonis Skouloudis**
University of the Aegean, Lesvos, Greece

The study is a useful descriptive baseline, but in its current form several choices and inconsistencies reduce confidence in the precision of the findings. The most important is that the segmentation is partly circular: the variables used to test cluster differences are the same variables used to construct the clusters.
Alongside this, the number of clusters is fixed a priori without selection diagnostics, the role of survey weights in the clustering and inference is unclear, and there are reproducible errors in several tables. With methodological clarification, sensitivity analysis and correction of the descriptive inconsistencies, the paper would meet the expected standards.

Major points:

- The nine environmental actions are used as inputs to the K-modes clustering, and Table 10 then tests the association between those same nine actions and the resulting clusters using chi-square and Cramér's V. Variables used to define the clusters will, almost by construction, show strong associations with them, so the very large statistics reported (chi-square up to 4,463; Cramér's V up to 0.564) are largely tautological and do not constitute independent validation of the segmentation. I recommend either (i) clustering on the environmental actions only and then testing genuinely independent variables (sector, size, country, output type) against cluster membership, or (ii) presenting the action-cluster associations explicitly as a description of how the algorithm partitioned the data rather than as evidence of significance. The same caution applies to Table 11 if those variables also entered the clustering.
- Number of clusters fixed a priori without selection evidence: the footnote on p.7 states that the initial number of clusters was assumed to be three. No model-selection procedure is

reported (e.g. a cost or elbow curve for K-modes, stability across random seeds, or an internal validity index suitable for categorical data). Please report diagnostics across a range of k (for example k = 2 to 6) and justify the choice of three on both fit and interpretability grounds.

- Inclusion of "country" as a clustering feature: country is listed on p.7 among the variables fed into K-modes, yet the analysis subsequently compares clusters across countries (fig.6, table 12). Using geography to build the clusters and then interpreting their geographic distribution risks confounding behaviour with location. I suggest clustering on the behavioural variables only and profiling clusters by country, sector and size ex post, with a sensitivity run that includes the attributes so readers can see how robust the partition is.
- Treatment of survey weights in clustering and inference is unclear. The descriptive section (page 4) notes that the data were weighted to the SME population in each country, but it is not stated whether weights were applied in the clustering or in the chi-square and Cramér's V calculations. This matters in two ways: unweighted clustering may bias the segments given cross-country differences in sample composition, and chi-square statistics computed on weighted counts are not interpretable in the usual way because the effective sample size is distorted. Please state explicitly how weights were handled and, ideally, compare weighted and unweighted results.
- The paper frames the analysis around SMEs throughout, yet discusses 164 firms with turnover above €50 million, which exceeds the EU SME turnover ceiling. Please either justify their inclusion or report whether the findings are materially affected when these firms are excluded or when results are stratified by size class (micro, small, medium).

Further points for improvement:

- Accuracy of the headline emissions figure. The abstract and introduction state that European SMEs account for 63.3% of total $CO_2$ emissions in Europe. The cited source (European Commission, 2022, Annual Report on European SMEs 2021/22) reports 63.3% of $CO_2$ and greenhouse-gas emissions by enterprises, that is, within the business sector, which excludes households, agriculture and much of transport. "Total $CO_2$ emissions" overstates the figure and should be corrected to refer to emissions by enterprises or the business sector.
- Non-standard description of the dissimilarity metric. Footnote 1 (p.7) is internally inconsistent: it describes both a "simple coincidence similarity measure" (which is correct for K-modes) and an "information-theoretic Hamming distance" (which is not standard terminology and not the default of the kmodes package; "cao" refers to the initialisation method, not the dissimilarity). Please correct the terminology and confirm the exact objective function used.
- Transposed captions on Tables 4 and 5. The caption of Table 4 reads "turnover of over €50million," but its contents (Greece, Latvia, Malta, Romania, Slovakia, with shares of 71 - 81%) and its column header describe the sub-2M group. Conversely, Table 5 is captioned "turnover below 2 million euros" but its contents (Belgium, Denmark, Sweden; total 164 firms, 38%) describe the above-€ 50 million group. The captions appear to be swapped and should be corrected.
- Table 13 errors: wo pairs of rows are identical across all three clusters and the chi-square value ("lack of demand for resource-efficient products" and "complexity associated with environmental labelling" are both 17.27 / 8.72 / 26.48, chi-square 2,496.42; "lack of specific environmental expertise" and "cost of environmental actions" are both 24.08 / 13.54 / 41.33, chi-square 2,715.98). Duplicated rows suggest a copy-paste error. In addition, the latter two

rows share an identical chi-square (2,715.98) but are assigned different Cramér's V values (0.424 and 0.422), which is not possible at equal degrees of freedom and sample size. Please re-check the underlying numbers.
- Inconsistent listing of the six firm characteristics; in p.7 lists the characterising variables as country, productive sector, size, level of growth, type of product and type of customer, whereas Table 11 lists country, output, "to whom do you sell," productive sector, size and revenues from last year. "Level of growth" and "revenues from last year" are not obviously the same variable. Please reconcile the two descriptions and state precisely which variables entered the algorithm and which were used only for profiling.
- On p.14 the authors cite Table 6 to support the contrast between Swedish (design-oriented) and Spanish (cost-oriented) behaviour, but Table 6 reports output type (products, services or both). The intended reference appears to be Table 7, or figs 3 to 5.
- Area coding (A to Z) underspecified; the mapping in Figure 6 and Table 12 uses areas A, B, C and the mixed categories X, Y and Z. The threshold that defines a "predominant" cluster, and the rule used to assign the mixed cases, are not stated. Please quantify these so the map can be reproducible.
- The text notes only that the database was "cleaned" to 14,008 firms. Please report how missing or "don't know" responses across the categorical variables were handled, whether any categories were collapsed, and how this might affect cluster composition.
- The underlying data are openly archived (Zenodo). Given the table errors noted above, sharing the analysis code (the -python- scripts used for clustering and the contingency analyses) would allow numerical inconsistencies to be resolved transparently.
- A careful proofreading is needed - e.g. check the sentence on p.9 ("72.19 Of the Spanish companies, 72.19%"), "elaboration of our own," the sentence in the Data availability statement, the Spanish-derived action codes in Table 7 (AA, AE, AM and so on) used before they're defined on p.9, "Tyllianankis" vs. "Tyllianakis" in the ref list.

The manuscript treats the barriers-and-enablers literature thinly relative to its empirical focus. The discussion of why administrative complexity and cost dominate, and why cooperation and consultancy are sought, would benefit from sustained engagement with the established empirical work on SME circular-economy barriers and drivers. I suggest the authors draw on, among others:

- Rizos et al. (2016), on barriers - enablers to circular-economy business models in SMEs
- Kirchherr et al. (2018), on barriers to the circular economy with EU evidence
- Garcés-Ayerbe et al. (2019), on opportunities-barriers for EU SMEs in the linear-to-circular transition

These could/would help the authors position their descriptive findings against prior cross-national evidence and sharpen the discussion of the policy levers they identify.

The following suggestion is optional and is not a condition of approval. I mention the following papers (whose I'm a co-author) only because they bear directly on the enablers, barriers and performance dimensions that this paper raises and draw on European, and specifically Spanish and Greek, SME samples that overlap with the cases highlighted here. Should the authors find them useful for the literature review or the discussion of barriers and support needs, they may wish to consult Moursellas et al. (2023) on sustainability practices and performance in European SMEs, Moursellas et al. (2024) on perceived enablers and barriers across four European countries,

and Moursellas et al. (2026) on sustainability dynamics in Greek SMEs.
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European Commission (2022) Annual Report on European SMEs 2021/22: SMEs and environmental sustainability. Luxembourg: Publications Office of the European Union.
Garcés-Ayerbe, C., Rivera-Torres, P., Suárez-Perales, I. and Leyva-de la Hiz, D.I. (2019) 'Is it possible to change from a linear to a circular economy? An overview of opportunities and barriers for European Union SMEs', International Journal of Environmental Research and Public Health, 16(5), 851.
Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A. and Hekkert, M. (2018) 'Barriers to the circular economy: evidence from the European Union (EU)', Ecological Economics, 150, pp. 264–272.
Moursellas, A., De, D., Wurzer, T., Skouloudis, A., Reiner, G., Chaudhuri, A., Manousidis, T., Malesios, C., Evangelinos, K. and Dey, P.K. (2023) 'Sustainability practices and performance in European small-and-medium enterprises: insights from multiple case studies', Circular Economy and Sustainability, 3(2), pp. 835–860.
Moursellas, A., Malesios, C., Skouloudis, A., Evangelinos, K. and Dey, P.K. (2024) 'Perceived enablers and barriers impacting sustainability of small-and-medium sized enterprises: a quantitative analysis in four European countries', Environmental Quality Management, 33(3), pp. 433–448.
Moursellas, A., Malesios, C., Skouloudis, A., Kantartzis, A., Sepetis, A., Sfakianaki, E. and Evangelinos, K. (2026) 'Sustainability dynamics in Greek small and medium-sized enterprises: a multimethod analysis', Journal of the International Council for Small Business (advance online publication).
Rizos, V., Behrens, A., van der Gaast, W., Hofman, E., Ioannou, A., Kafyeke, T., Flamos, A., Rinaldi, R., Papadelis, S., Hirschnitz-Garbers, M. and Topi, C. (2016) 'Implementation of circular economy business models by small and medium-sized enterprises (SMEs): barriers and enablers', Sustainability, 8(11), 1212.

**Is the work clearly and accurately presented and does it engage with the current literature?**
Partly

**Is the study design appropriate and is the work technically sound?**
Partly

**Are sufficient details of methods and analysis provided to allow replication by others?**
Not applicable

**Are all the source data and materials underlying the results available?**
Yes

**If applicable, is the statistical analysis and its interpretation appropriate?**
Partly

**Are the conclusions drawn adequately supported by the results?**
Partly

***Competing Interests:*** No competing interests were disclosed.

***Reviewer Expertise:*** organisational sustainability; SMEs; nonfinancial performance

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.**

Author Response 27 Aug 2026

**Josep Navarro-Ortiz**

**The study is a useful descriptive baseline, but in its current form several choices and inconsistencies reduce confidence in the precision of the findings. The most important is that the segmentation is partly circular: the variables used to test cluster differences are the same variables used to construct the clusters. Alongside this, the number of clusters is fixed a priori without selection diagnostics, the role of survey weights in the clustering and inference is unclear, and there are reproducible errors in several tables. With methodological clarification, sensitivity analysis and correction of the descriptive inconsistencies, the paper would meet the expected standards. Major points: The nine environmental actions are used as inputs to the K-modes clustering, and Table 10 then tests the association between those same nine actions and the resulting clusters using chi-square and Cramér's V. Variables used to define the clusters will, almost by construction, show strong associations with them, so the very large statistics reported (chi-square up to 4,463; Cramér's V up to 0.564) are largely tautological and do not constitute independent validation of the segmentation. I recommend either**

1. **clustering on the environmental actions only and then testing genuinely independent variables (sector, size, country, output type) against cluster membership,**
1. **presenting the action-cluster associations explicitly as a description of how the algorithm partitioned the data rather than as evidence of significance. The same caution applies to Table 11 if those variables also entered the clustering.**

**Number of clusters fixed a priori without selection evidence: the footnote on p.7 states that the initial number of clusters was assumed to be three. No model-selection procedure is reported (e.g. a cost or elbow curve for K-modes, stability across random seeds, or an internal validity index suitable for categorical data). Please report diagnostics across a range of k (for example k = 2 to 6) and justify the choice of three on both fit and interpretability grounds. Inclusion of "country" as a clustering feature: country is listed on p.7 among the variables fed into K-modes, yet the analysis subsequently compares clusters across countries (fig.6, table 12). Using geography to build the clusters and then interpreting their geographic distribution risks confounding behaviour with location. I suggest clustering on the behavioural variables only and profiling clusters by country, sector and size ex post, with a sensitivity run that includes the attributes so readers can see how robust the partition is.**

We thank the reviewer for this important observation. We agree that, since the nine environmental actions were included as input variables in the K-modes procedure, the chi-square tests and Cramér's V statistics reported in the previous version should not be interpreted as independent statistical validation of the resulting clusters. The strong

associations partly reflect the fact that these variables contributed directly to the construction of the clusters. Our analytical objective, however, differs from that of a clustering exercise based exclusively on environmental behaviour. The purpose of the study is to identify multidimensional firm profiles combining environmental practices with firms' structural and market characteristics. For this reason, environmental actions, country, sector, size, turnover evolution, type of output and customer orientation were intentionally incorporated into the clustering procedure. Removing the structural variables from K-modes would therefore change the analytical objective of the study rather than simply provide an alternative validation procedure. Following the reviewer's recommendation, we have adopted option (ii). Specifically, we have removed the chi-square tests and Cramér's V statistics from the revised manuscript (tables 10 and 11) and no longer interpret the associations between the clustering variables and cluster membership as evidence of statistical significance or independent validation. Instead, these results are presented descriptively to show how the K-modes algorithm partitioned the observations and to facilitate interpretation of the multidimensional profiles obtained. We have also revised the interpretation of the association matrix accordingly. The matrix is retained only as a descriptive tool for examining the association structure among the variables within the resulting profiles and is not presented as an independent validation of the clustering solution. About the number of clusters, we estimated it with a cost or elbow curve for K-modes. This analysis has been added in an annex at the end of the paper.

**Treatment of survey weights in clustering and inference is unclear. The descriptive section (page 4) notes that the data were weighted to the SME population in each country, but it is not stated whether weights were applied in the clustering or in the chi-square and Cramér's V calculations. This matters in two ways: unweighted clustering may bias the segments given cross-country differences in sample composition, and chi-square statistics computed on weighted counts are not interpretable in the usual way because the effective sample size is distorted. Please state explicitly how weights were handled and, ideally, compare weighted and unweighted results.**
We have rewritten the text to clarify. We didn´t weighted the SMEs population, we just used the Eurobarometer database.

**The paper frames the analysis around SMEs throughout, yet discusses 164 firms with turnover above €50 million, which exceeds the EU SME turnover ceiling. Please either justify their inclusion or report whether the findings are materially affected when these firms are excluded or when results are stratified by size class (micro, small, medium).** We used the data as proposed by the Eurobarometer. Although, the large firms represent only the 0,01% of the sample. We didn´t remove this firms in order to maintain the same sample proposed by the Eurobarometer.

**Further points for improvement: Accuracy of the headline emissions figure. The abstract and introduction state that European SMEs account for 63.3% of total $CO_2$ emissions in Europe. The cited source (European Commission, 2022, Annual Report on European SMEs 2021/22) reports 63.3% of $CO_2$ and greenhouse-gas emissions by enterprises, that is, within the business sector, which excludes households, agriculture and much of transport. "Total $CO_2$ emissions" overstates the figure and**

**should be corrected to refer to emissions by enterprises or the business sector.** Thank you for the observation. We have specified in the introduction in the abstract and paragraph 7 that we are referring to firms only.

**Non-standard description of the dissimilarity metric. Footnote 1 (p.7) is internally inconsistent: it describes both a "simple coincidence similarity measure" (which is correct for K-modes) and an "information-theoretic Hamming distance" (which is not standard terminology and not the default of the kmodes package; "cao" refers to the initialisation method, not the dissimilarity). Please correct the terminology and confirm the exact objective function used.**
Thank you for your comment. We modified the structure of the Method section. We added a new section 2.1 with database descriptions, and we have rewritten section 2.2. for a better understanding. Moreover, we provided more specifications of the method used in the annex.

**Transposed captions on Tables 4 and 5. The caption of Table 4 reads "turnover of over €50million," but its contents (Greece, Latvia, Malta, Romania, Slovakia, with shares of 71 - 81%) and its column header describe the sub-2M group. Conversely, Table 5 is captioned "turnover below 2 million euros" but its contents (Belgium, Denmark, Sweden; total 164 firms, 38%) describe the above-€ 50 million group. The captions appear to be swapped and should be corrected.**
Thank you for the observation. There was an error and we modified tables 4 and 5.

**Table 13 errors: wo pairs of rows are identical across all three clusters and the chi-square value ("lack of demand for resource-efficient products" and "complexity associated with environmental labelling" are both 17.27 / 8.72 / 26.48, chi-square 2,496.42; "lack of specific environmental expertise" and "cost of environmental actions" are both 24.08 / 13.54 / 41.33, chi-square 2,715.98). Duplicated rows suggest a copy-paste error. In addition, the latter two rows share an identical chi-square (2,715.98) but are assigned different Cramér's V values (0.424 and 0.422), which is not possible at equal degrees of freedom and sample size. Please re-check the underlying numbers. HECHO, revisar en 2024 10 ciencia regional la fila 197 y 199**
Thank you for the observation. There was an error with different Cramér's V values (0.424 and 0.422), we modified it in the table.

**Inconsistent listing of the six firm characteristics; in p.7 lists the characterising variables as country, productive sector, size, level of growth, type of product and type of customer, whereas Table 11 lists country, output, "to whom do you sell," productive sector, size and revenues from last year. "Level of growth" and "revenues from last year" are not obviously the same variable. Please reconcile the two descriptions and state precisely which variables entered the algorithm and which were used only for profiling.**
Thank you for your comment. Table 11 was confusing and did not provide any useful information. We have removed it. In addition, we have added Section 2.1, which specifies the variables to be analyzed.

**On p.14 the authors cite Table 6 to support the contrast between Swedish (design-**

**oriented) and Spanish (cost-oriented) behaviour, but Table 6 reports output type (products, services or both). The intended reference appears to be Table 7, or figs 3 to 5.**
Thank you for your comment. We modified the text and substitute “Table 6” for “Table 7”

**Area coding (A to Z) underspecified; the mapping in Figure 6 and Table 12 uses areas A, B, C and the mixed categories X, Y and Z. The threshold that defines a “predominant” cluster, and the rule used to assign the mixed cases, are not stated. Please quantify these so the map can be reproducible.**
Thank you for your comment. We clarified it in the text, before figure 6 we introduced a new paragraph explaining what is considered a “predominant” cluster.

**The text notes only that the database was “cleaned” to 14,008 firms. Please report how missing or “don’t know” responses across the categorical variables were handled, whether any categories were collapsed, and how this might affect cluster composition.** Thank you for your comment. We added more specifications in the text paragraph 2.2.

**The underlying data are openly archived (Zenodo). Given the table errors noted above, sharing the analysis code (the -python- scripts used for clustering and the contingency analyses) would allow numerical inconsistencies to be resolved transparently.**
Thank you. We have shared the package python used in the section “method” part 2.2. More specifications in the annex. We removed the contingency analyses of table 10. The codes for tables 12 “perceive barriers contingency analyses” and 13 “request contingency analyses” have been included in the annex II.

**A careful proofreading is needed - e.g. check the sentence on p.9 (“72.19 Of the Spanish companies, 72.19%”), “elaboration of our own,” the sentence in the Data availability statement, the Spanish-derived action codes in Table 7 (AA, AE, AM and so on) used before they’re defined on p.9, “Tyllianankis” vs. “Tyllianakis” in the ref list.**
Thank you. We modified the action codes according to English language (SW Saving Water, …). We also modified grammar errors for the text and bibliography.

**The manuscript treats the barriers-and-enablers literature thinly relative to its empirical focus. The discussion of why administrative complexity and cost dominate, and why cooperation and consultancy are sought, would benefit from sustained engagement with the established empirical work on SME circular-economy barriers and drivers. I suggest the authors draw on, among others: Rizos et al. (2016), on barriers - enablers to circular-economy business models in SMEs Kirchherr et al. (2018), on barriers to the circular economy with EU evidence Garcés-Ayerbe et al. (2019), on opportunities-barriers for EU SMEs in the linear-to-circular transition These could/would help the authors position their descriptive findings against prior cross-national evidence and sharpen the discussion of the policy levers they identify. The following suggestion is optional and is not a condition of approval. I mention the following papers (whose I’m a co-author) only because they bear directly on the enablers, barriers and performance dimensions that this paper raises and draw on European, and specifically Spanish and Greek, SME samples that overlap with the**

**cases highlighted here. Should the authors find them useful for the literature review or the discussion of barriers and support needs, they may wish to consult Moursellas et al. (2023) on sustainability practices and performance in European SMEs, Moursellas et al. (2024) on perceived enablers and barriers across four European countries, and Moursellas et al. (2026) on sustainability dynamics in Greek SMEs. <><><> European Commission (2022) Annual Report on European SMEs 2021/22: SMEs and environmental sustainability. Luxembourg: Publications Office of the European Union. Garcés-Ayerbe, C., Rivera-Torres, P., Suárez-Perales, I. and Leyva-de la Hiz, D.I. (2019) 'Is it possible to change from a linear to a circular economy? An overview of opportunities and barriers for European Union SMEs', International Journal of Environmental Research and Public Health, 16(5), 851. Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A. and Hekkert, M. (2018) 'Barriers to the circular economy: evidence from the European Union (EU)', Ecological Economics, 150, pp. 264–272. Moursellas, A., De, D., Wurzer, T., Skouloudis, A., Reiner, G., Chaudhuri, A., Manousidis, T., Malesios, C., Evangelinos, K. and Dey, P.K. (2023) 'Sustainability practices and performance in European small-and-medium enterprises: insights from multiple case studies', Circular Economy and Sustainability, 3(2), pp. 835–860. Moursellas, A., Malesios, C., Skouloudis, A., Evangelinos, K. and Dey, P.K. (2024) 'Perceived enablers and barriers impacting sustainability of small-and-medium sized enterprises: a quantitative analysis in four European countries', Environmental Quality Management, 33(3), pp. 433–448. Moursellas, A., Malesios, C., Skouloudis, A., Kantartzis, A., Sepetis, A., Sfakianaki, E. and Evangelinos, K. (2026) 'Sustainability dynamics in Greek small and medium-sized enterprises: a multimethod analysis', Journal of the International Council for Small Business (advance online publication). Rizos, V., Behrens, A., van der Gaast, W., Hofman, E., Ioannou, A., Kafyeke, T., Flamos, A., Rinaldi, R., Papadelis, S., Hirschnitz-Garbers, M. and Topi, C. (2016) 'Implementation of circular economy business models by small and medium-sized enterprises (SMEs): barriers and enablers', Sustainability, 8(11), 1212.**

Thank you for your comments, we included new bibliography proposed among the paper: Garcés-Ayerbe et al., 2019; Kirchherr et al., 2018; Rizos et al., 2016; Mourellas et al., 2024.

***Competing Interests:*** No competing interests were disclosed.