Serna-Serna *et al.*
Environmental Sciences Europe (2026) 38:124
https://doi.org/10.1186/s12302-026-01403-x

Environmental Sciences Europe

RESEARCH Open Access

Are circular economy practices drivers of carbon neutrality? Cross-industry insights from European firms' perspective

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Abstract

Although carbon neutrality has become a strategic imperative, it is often implemented from a technical perspective, without considering the organization's strategic vision. This study therefore employs a management perspective to analyze Circular Economy (CE) practices—reduction, recycling, and redesign—as differential drivers of the adoption of corporate carbon neutrality (CCN) strategies. To offer comprehensive picture, we are also focusing on the moderating roles of different sectors of activities. Drawing on the (Natural) Resource-Based View and using binary logistic regression, we analyzed a sample of 6393 companies from 27 EU countries, extracted from Flash Eurobarometer 498. The results confirm the significance of redesigning and recycling in driving CCN adoption. By contrast, we show that reduction is only effective for companies in the service industry, where it exercises a pure moderating effect. Moreover, we show that service companies are more likely to adopt CCN than manufacturing ones. This study makes a threefold contribution. First, it transcends the technical approach to frame carbon neutrality as a strategic management challenge. Second, it disaggregates the CE construct, providing empirical evidence of the differential impact of CE practices. Third, it provides a decision-making framework for managers by demonstrating that the effectiveness of CE strategies for achieving carbon neutrality is not universal but depends fundamentally on sectoral context.

Keywords Corporate carbon neutrality, Service industry, Circular economy, Reduction, Recycling, Redesign

Introduction

Carbon neutrality, or *net-zero emissions*, has become a primary goal for global environmental sustainability [93], and is reflected in high-profile political commitments [64, 96]. In this context, companies face double pressure. They must both respond to government guidelines and project a sustainable image to their customers and society [92]. Facing these challenges requires achieving Corporate Carbon Neutrality (CCN), *"the process of measuring, mitigating, offsetting, and disclosing greenhouse gas (GHG) emissions, by which organizations then claim net-zero emissions from their activities"* [14].

However, limited attention has been paid to the management strategies needed to implement CCN [12, 15]. Research so far has focused predominantly on development of macro-level policies or technologies for carbon neutrality [19, 92] and on technical aspects of its implementation [14]. This resulted in the lack of studies on business management challenges, suggesting that carbon neutrality is perceived more as technical than strategic problem, potentially diluting managerial responsibility for its implementation [15]. It is important to state that in this paper, the terms "carbon neutrality" and "climate neutrality" are used as synonyms, reflecting the

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widespread practice in the literature where they are often applied with the same meaning [70].

Although there are multiple ways to reduce emissions, this study focuses on the potential of the Circular Economy (CE) and its practices, as a framework for promoting effective management strategies for CCN application. Since CE can contribute to decarbonization [92], it is assumed that CE and carbon neutrality are interrelated [61], yet little is known about how specific CE practices support management to achieve CCN. Thus, despite the consensus on the transformative potential of CE [59], the literature shows a gap in empirical understanding of how adopting specific CE practices impacts organizations [63], as well as their carbon neutrality achievement. These practices, also known as "R practices", include a set of actions that promote development of CE [60], whereas the European Commission prioritizes three of them: reducing material and resource waste, recycling materials and products, and redesigning an ecological production model [28, 47]. However, although such increased interest, prior research has not determined the differential impact of these CE ("R") practices on CCN.

This research therefore targets to address this gap and thus help managers make better-informed decisions about sustainable strategies [26]. Doing so, our very first research objective is to assess the impact of specific CE practices (reduce, recycle, redesign) on the corporate adoption of CCN and to determine if these impacts differ significantly.

Next, there is a need to point out that the transition to carbon neutrality involves balancing emissions produced and emissions removed [88]. This balance can be promoted through efficient use of resources and application of CE [61]. The impact of these practices may not be universal, however. It may depend on sectoral context, while research on CE has focused predominantly on the manufacturing industry, paying less attention to services (Hodgson, 2024). The manufacturing industry faces challenges involving resource optimization in production processes and direct emissions [54], whereas the service industry focuses on interaction with consumers and thus plays an influential role in the transition to CE [40]. In addition, Yin et al. [90] call for further empirical studies comparing mediating roles of manufacturing and service industries. In this vein, *the second research objective is to examine the moderating role of the business industry (manufacturing vs. services) on the relationship between CE practices and CCN.*

To meet our objectives, we employ and analyze a sample of 6393 companies from 27 European countries, 2592 in manufacturing and 3801 in services, based on the Flash Eurobarometer 498 database. Doing so, binary logistic regression is used. Moreover, to better understand these issues, we theoretically anchor this study in the Resource-Based View (RBV) and the Natural Resource-Based View (NRBV) [39]. Doing so, this study offers significant theoretical and practical contributions. Theoretically, it transcends the technical focus of CCN to frame it as a strategic management challenge. Furthermore, it disaggregates the CE construct, demonstrating that its practices have differential impacts. On a practical level, these findings provide a valuable decision-making framework for managers, underscoring the critical importance of the sectoral context.

The rest of the paper is structured as follows: next chapter 2 summarizes main theoretical insights and the current state of the art, leading to the definition of our research questions in chapter 3. Data and method are described in chapter 4, followed by our findings in chapter 5, discussed in chapter 6. Concluding remarks, together with implications and future research directions, are presented in chapter 7.

Theoretical foundations: linking CCN, NRBV and the CE

Initiating with carbon neutrality, it is defined as "*the entire set of policies that an institution uses when it estimates its known greenhouse gas emissions, takes measures to reduce them, and purchases carbon offsets to neutralize those emissions that remain*" [84]. Thus, companies need strategic objectives for their operations and goods or services to achieve net-zero carbon dioxide [12]. In line with these arguments, the RBV proposes that the heterogeneity of a firm's resources and capabilities can identify competitive advantages [10], and the NRBV—which builds upon natural resources [39]—can explain the factors that drive firms to adopt negative emission strategies [12].

Linking NRBV with CCN, it is considered a competitive advantage because CCN improves the company's sustainable image, attracting conscious investors and consumers [26]. Implementing CCN also shows that companies respond to pressure from consumers who demand more environmentally friendly products [11]. Furthermore, managing emissions reduces costs and legal risks, improving business opportunities [91].

To promote carbon neutrality and reduce emissions throughout their value chain [12], companies employ different practices, such as reducing energy consumption and improving energy efficiency [25], using renewable energy sources [88], adopting clean and innovative technologies [35], and improving waste management [5]. Many of these practices can be implemented through CE [61], which leads us to connect with this concept below.

The literature considers CE implementation indispensable for the transition to a low-carbon society [34, 58], as circular production processes are crucial to achieving net-zero carbon and thus carbon neutrality [58, 69]. CE, defined as "*an economic system that is based on business models which replace the 'end-of-life' concept* […]" [48], works towards cleaner production and sustainable development [71]. CE thus aims not to discard any portion of resources but rather to use them all through circular production rather than discarding them [66]. Implementing CE involves changes in technical elements, and these changes alter the functioning of traditional economic models [86]. Moreover, the CE (or "R") practices are organizational strategies that companies can adopt to improve their circularity within the CE paradigm. In addition to Reduction, Recycling, and Reusing, which are under scrutiny in this study, other activities are Refuse, Reuse, Repair, Re-manufacture, and Recover resources [22, 60].

The development of research questions

The impact of CE practices on CCN strategies

Starting with the reduction, the literature presents it as the most common practice organizations adopt when beginning their transition to CE [55, 60]. Reduction is a business strategy to decrease resource use in a production process or service [32]. Reducing waste generation and resource use helps establish sustainable closed-loop economic systems [50]. The practice of reducing waste and energy use directly reduces industrial carbon emissions from raw material processing [1].

Recycling is defined as "*any recovery operation by which waste materials are reprocessed into products, materials, or substances whether for original or other purposes*" [29]. Recycling is a priority in the process of achieving the CE paradigm throughout the European Union [28, 78]. In the European Commission's sustainability plans, recycling plays a crucial role in closed-loop economies and production [17]. By keeping materials within the same production system, it ensures that resources do not lose quality, minimizing waste [13]. In this process, recycling recovers materials used in one product to obtain others [56]. Recycling optimizes carbon emissions through waste management in the production of new goods [52]. According to Kullmann et al. [51], recycling can cost-effectively reduce GHGs in future production designs.

Circular redesign differs from traditional by heeding environmental requirements during product design [21] to develop sustainable goods and services that use fewer resources [80]. Redesign is another key CE practice, as it transforms design from a linear model of production and consumption into a circular one [68]. Redesign consists of developing a production scheme that prioritizes extending the product's useful life [27]. Soysal and Bloemhof [75] advise companies implementing redesign to increase their focus on redesigning production processes to improve resource efficiency and reduce carbon emissions [81].

The literature suggests that these three CE practices are not similar and require different levels of strategic involvement in CCN. Reduction involves decreasing resource use in a production process [15, 41] and can thus act more directly on CCN than other practices by addressing emissions from the beginning of the value chain. Recycling involves reprocessing or reusing products and materials [44], reducing dependence on raw materials [57]. In this case, recycling works to achieve CCN through waste recovery and raw material substitution. Finally, redesign integrates environmental requirements into products and services that improve sustainability, reducing resource use and waste [44]. Redesign thus promotes CCN through a more transformative perspective by integrating sustainability into companies. Based on the foregoing, each of the three practices boosts CCN in a different way.

Based on the arguments above, we ask the following research question (RQ) focused on the different effects of CE practices on CNN adoption:

RQ1 Does the implementation of a) reduction; b) recycling; c) redesign practices significantly and positively influence the probability of a company adopting CCN?

The moderating effect of business industry on the relationship between CE practices and CCN

Activity sector is of decisive importance for carbon neutrality, as different industries contribute differently to GHG emissions [89], through emissions reduction and carbon absorption [83]. Because achieving carbon neutrality implies differentiated strategic development of a low-carbon economy and thus a different transition to clean energy [94], each industry will approach adaptation to carbon neutrality from a different perspective. More in detail, manufacturing companies are engaged primarily in production and manufacture of physical goods or products [26]—that is, in converting raw materials and components into finished products [41]. Service companies, in contrast, are based on users paying to receive a service, not to purchase a product [40]. Services are thus "*produced to order and typically consist of changes in the conditions of the consuming units, due to the activities of producers at the demand of the consumers*" [30].

Because of this difference, the manufacturing industry is taking a more direct approach to carbon neutrality, adopting strategies that reduce energy consumption, carbon emissions, and material use [25]. Previous studies suggest that manufacturing companies focus on sustainable material and energy efficiency [95]—that is, on achieving the optimal balance between available resources and application of cleaner technologies [54]. By contrast, in the service industry, companies can implement sustainable actions more actively and can be strategically closer to end users [40]. Despite not being an energy-intensive sector, the service industry contributes to resource efficiency and mitigation of emissions [46]. Digital transformation provides tremendous opportunities to develop services in innovative ways by modifying resource consumption [40]. Both manufacturing and service industries are thus making strategic efforts to achieve carbon neutrality to improve resource efficiency, reduce costs, and increase competitiveness [14].

The manufacturing and service industries have different characteristics, however, when applying carbon neutrality strategies. As discussed, the manufacturing industry consumes more energy and produces high emissions [54], whereas services are less energy-intensive [40]. For manufacturers, reducing emissions requires optimization of processes and investment in clean technologies [25], whereas services' contribution to carbon neutrality focuses on changing consumption and improving resource efficiency [40].

Based on above arguments, we formulate the following research question:

RQ2 Does the a) manufacturing; b) service industry positively and significantly influence the likelihood of a company adopting CCN?

As mentioned above, manufacturers focus on product transformation to achieve CE [41], proposing direct actions to perform and improve production processes [40]. While services are not directly responsible for the use of raw materials, they do consume energy and produce carbon emissions [40]. Business models in the service industry can reduce both energy use [44] and resource use and waste [9].

Recycling has been widely implemented in the manufacturing industry, as it adapts well to production processes [73]. Recycling processes often require significant economic investment and adaptation of facilities [57]—more specifically, dismantling and support for recycling materials [74]. In the service industry, consumers' interaction with the sector's assets, such as computer applications, affects resource consumption and waste generation [87]. The industry thus promotes recovery of metals from electronic waste (e-waste) and reconditioning of ICT equipment [40]. Whereas manufacturing tends to focus on recycling products and materials in production processes [20], services aim to influence more sustainable consumer behavior, extend the useful life of products, and manage assets [40].

Redesign applies to the manufacturing industry's transformation of products and production processes into more sustainable systems [57], minimizing resources, producing less waste [65], and integrating new technologies and developing innovation [16]. In the service industry, redesign focuses on business model innovation, offering new services [73], and changing the way customers use products [40].

Both manufacturing and services are key agents in achieving carbon neutrality, but they differ in the specific ways they do so. We therefore pose the following research question:

RQ3 Does the a) manufacturing; b) service industry moderate the relationship between CE practices and CCN adoption? In other words, does the effectiveness of reduction, recycling, and redesign practices differ between the a) manufacturing, b) service industries?

Data and methodology

Data sample

The study data were drawn from the Flash Eurobarometer 498, a survey conducted by the European Commission [31] that collected information from more than 17,662 companies through telephone interviews in 2020. This survey is commonly used to analyze the commitment of European companies to sustainability [37] and to the circular economy) [72]. The initial selection included all 7135 companies from the manufacturing and service sectors available in the original database across the 27 EU member states. To ensure data integrity, we applied listwise deletion, excluding any observations with missing values in the dependent or independent variables. This protocol resulted in a final analytical sample of 6393 firms, 2592 in manufacturing and 3801 in services (see Appendix A and B). This sample size provides high statistical power ensures that the findings are representative of the total population of manufacturing and service firms in the European Unions.

To ensure the representativeness of the European firm population, all models were estimated using post-stratification weights. The weighting distribution presented in Appendix C illustrates the range of post-stratification adjustments applied to the 27 EU member states. The substantial adjustment ranges (reaching 380.00 in several countries) confirm the rigorous correction of sampling biases. This calibration ensures that the analysis of 6393 firms accurately reflects the structural proportion of the European manufacturing and service sectors, granting our findings high external validity across the EU.

Selected variables and method

This study uses *carbon neutrality* as a dependent variable. Companies were asked to answer the question: *Does your company have a concrete strategy in place to reduce your carbon footprint and become climate neutral or negative?* This is a binary variable, where 1 means *yes* and 0 means *no*.

In line with our main objectives, three independent variables were used to measure CE practices: reduce, recycle, and redesign. These variables, which have been used in previous studies with Eurobarometer data (e.g., [72]), were constructed as cumulative indices [7], as follows. Reduction was measured by four variables (saving water, saving energy, saving materials, and minimizing resources), recycling by three variables (using renewable energy, selling waste and scrap to another company, and recycling by reusing materials or waste within your company); and redesign by two variables (moving to more environmentally friendly material suppliers and designing products that are easier to maintain, repair, or reuse). The composite indices for CE practices were constructed following a strict data integrity protocol.

To detect differences in the behavior of the two industries analyzed, we used activity sector "*services (industry)*" as a moderating variable. The two industries analyzed are the manufacturing industry and the service industry. To ensure the robustness of the comparative analysis and the validity of the moderating variable, the sample was restricted exclusively to the manufacturing and services sectors following Eurostat's categorization for the Flash Eurobarometer 498 (see Appendix D), to ensure a distinction between product-based versus service-based business models.

Four control variables were included to improve the model's reliability: a) age of the company [23], calculated as the natural logarithm of number of years since the company was founded, b) size of the company [26], calculated as the natural logarithm of number of employees; and c) sustainable economic growth of the company's home country [85] (dimension constructed based on an index derived from three variables of *Sustainable economic growth* 2022) (see Appendix E). To ensure methodological rigor and temporal consistency of the analysis, the sustainable economic growth index has been constructed using 2020 indicators, thus aligning the national macroeconomic context with the period of data collection at the company level.

Each variable was analyzed as follows. Due to asymmetry of the variables' distribution, the natural logarithm of real GDP per capita was calculated and the result standardized. Since investment share of GDP is a percentage, this indicator was standardized directly. For material footprint, we applied a natural logarithm before standardizing. For sustainable economic growth, we used data from 2020. The sustainable economic growth index was constructed as a composite measure by calculating the arithmetic mean of the standardized values of real GDP per capita, investment share of GDP, and material footprint. Conceptually, this index captures the multidimensional nature of national progress, balancing economic prosperity and investment capacity with environmental resource intensity, thus providing a robust proxy for the macroeconomic context in which firms operate.

Because the dependent variable was binary, we used binary logit regression. Although logistic and probit regressions are also suitable econometric techniques for binary variables [42], logistic regression was chosen because this model assumes a logistic distribution of errors, consistent with the characteristics of our data. Data analysis was performed with Stata 18 [76].

Results

Analysis of the correlations between the variables showed sufficient correlation in all cases (see Table 1). Calculation of the Variance Inflation Factor (VIF) yielded less than or equal to 3 [38]. A Durbin-Watson statistic of 1.945, close to 2, discounts problems of collinearity. Similarly, the values of asymmetry and kurtosis were less than 2 in all cases (data available from the authors) and thus did not have highly abnormal values [38]. Variables are used as a summative index, as an average to measure the intensity or breadth of a practice. Following Segarra-Blasco et al. [72], who use the same variables of this study (Reduce, Recycle, Redesign) from the Eurobarometer, CE practices are modeled as strategic decisions and not as latent constructs. The CE practices (reduce, recycle, and redesign) were constructed as cumulative additive indices. Following Ahmadi-Gh and Bello-Pintado [3] and Aiello et al. [4], each binary item was assigned a value of 1 if adopted and 0 otherwise. These indices are designed to capture the intensity and breadth of CE adoption. In line with the methodology used by Gomes and Pinho [37] and Avelar et al. [8] for Flash Eurobarometer data, we utilized equal weighting for all items. Importantly, the Circular Economy (CE) indices used in this study are methodologically defined as cumulative additive indices, and the indicators are not expected to be highly correlated,this low correlation between indicators does not indicate unreliability, but rather the richness of the index in capturing the breadth of the practices adopted. Applying Cronbach's Alpha in this context would be inappropriate, as it would penalize the inclusion of diverse and unique practices that independently contribute to the total level of circularity [24]. The use of unit weighting is justified to avoid specification errors in the construction of the variables,

Table 1 Correlation and VIF

	Variable	1	2	3	4	5	6	7	8	VIF
1	CarbNeu	1.000								
2	Age	0.120***	1.000							1.152
3	Size	0.148***	0.323***	1.000						1.174
4	Economic growth	0.054***	0.008	– 0.013	1.000					1.012
5	Redu	0.108***	0.093***	0.108***	– 0.050***	1.000				1.334
6	Recy	0.156***	0.166***	0.195***	– 0.041***	0.405***	1.000			1.336
7	Rede	0.147***	0.052***	0.082***	– 0.006	0.412***	0.332***	1.000		1.278
8	Services (Industry)	– 0.014	– 0.162***	– 0.154***	0.018	– 0.141***	– 0.235***	– 0.126***	1.000	1.102

****p* < .001*

VIF Variance Inflation Factor

since it is intended to measure the intensity of the cumulative implementation. Keeping weights equal on the indicator allows you to observe the model's response cleanly. This approach avoids the potential instability of factor scores with binary data and ensures that the results are interpretable as a direct count of implemented initiatives, a standard procedure in the recent literature on business sustainability.

Table 2 presents the results of CE's influence on carbon neutrality. Logistic regressions analyze the direction of the effect (sign of the coefficient), significance (*p*-value), and *odds ratios*. In logit models, *odds ratios* measure the multiplicative change in the odds of the outcome for each unit increase in the predictor [43]. For our purposes, we have developed four models to analyze CE's influence on carbon neutrality. Model 1 included the control variables, which were positive and significant except for revenues.

Model 2, which includes the predictor variables for CE, answers RQ1 on the differential impact of CE practices. In Model 2, the reduction variable also had a nonsignificant effect, meaning that reduction practices would not significantly influence the probability of a company adopting carbon neutrality strategies. Recycling practices in Model 2 had a positive and significant influence on the probability of a company adopting climate neutrality actions. The *odds ratio* shows that the odds of adopting carbon neutrality strategies increase by 23.6% in companies that implement recycling practices compared to companies that do not. Further, redesign practices have a positive and significant effect on the likelihood of a company adopting carbon neutrality strategies. According to the *odds ratio*, companies that implement redesign practices showed 35.3% greater odds of adopting carbon neutrality strategies. The results obtained for RQ1 thus indicate a differential influence among the three CE practices. Redesign seems to have the greatest impact, followed by recycling.

Table 2 Results of the logistic regression on the adoption of carbon neutrality

Variable	Model 1	Model 2	Model 3	Model 4
Control variables				
Age	1.246***	1.201***	1.218***	1.221***
	(6.09)	(4.87)	(5.22)	(5.26)
Size	1.758***	1.601***	1.632***	1.640***
	(9.15)	(7.47)	(7.74)	(7.80)
Economic growth	1.536***	1.589***	1.586***	1.590***
	(4.24)	(4.36)	(4.34)	(4.37)
Constant	0.127***	0.091***	0.073***	0.083***
	(– 16.90)	(– 17.91)	(– 17.66)	(– 15.36)
Main variables (CE)				
Redu	–	1.020	1.024	0.963
		(.91)	(1.05)	(– 1.01)
Recy	–	1.236***	1.263***	1.245***
		(6.15)	(6.67)	(4.13)
Rede	–	1.353***	1.360***	1.430***
		(7.33)	(7.43)	(5.80)
Industry variable				
Services (Industry)	–	–	1.245***	0.912
			(3.65)	(– 1.10)
Terms of interaction				
Services × Redu	–	–	–	1.105**
				(2.14)
Services × Recy	–	–	–	1.028
				(.41)
Services × Rede	–	–	–	0.912
				(– 1.30)
Model statistics				
N	6393	6393	6393	6393
Log pseudo-likelihood	– 3815.26	– 3734.97	– 3728.16	– 3725.35
Wald chi2	182.92	33.67	34.74	344.54
Pseudo R2	0.0252	0.0457	0.0474	0.0481

Principle values *Odds Ratios*. The values in parentheses correspond to robust z-statistics

***p* < .01; ****p* < .001*

To answer RQ2, Model 3 includes variable *services (industry)*. This result indicates that business industry has a positive and significant influence on a company's probability of adopting carbon neutrality strategies. The *odds ratios* show that service companies have 24.5% greater odds of adopting carbon neutrality strategies than do manufacturers.

RQ3 is answered by Model 4, which analyzes the interaction of the *services (industry)* variable with each CE practice. This model shows that the interaction of sector (manufacturing vs. services) with the relationship between carbon neutrality and recycling practices is not significant, nor are redesign practices. We find no evidence of the impact of recycling and redesigning on carbon neutrality in either manufacturing or services. The industry does, however, moderate the relationship between carbon neutrality and reduction practices.

While nonsignificant in manufacturing, the interaction effect of reduction in the service industry is positive and significant. This finding indicates that reduction practices differ when firms adopt carbon neutrality in the service industry. The relationship is one of pure moderation, as Model 4 shows significant interaction between the reduction and the *services (industry)* variable but the main effect of this variable is not significant. In this model, *services (industry)* not only change the strength of a relationship but also determines whether it exists. Reduction is thus not a driver for all industries; it is contextual and industry-specific. While it is not a positive option for manufacturing companies, it is a viable activity for service companies.

To facilitate interpretation of the binary logistic regression results, we performed marginal effects analysis [62, 82]. This analysis provides a clearer measure of the effect of CE actions on the probability of carbon neutrality implementation. Marginal effects measure change in probability as percentage points, facilitating interpretation. The average marginal effects (Table 3) confirm that the effect of CE reduction activities on adoption of carbon neutrality strategies is not significant. This result suggests that reduction practices have no effect on CCN. Analysis of the marginal effects also confirms that the CE practices, recycling and redesign, have a significant and positive effect on carbon neutrality. A company that practices redesign has, on average, a 6.0% higher probability of achieving climate neutrality. Recycling also has a positive and significant effect, as recycling is associated with an average increase of 4.2% in adopting climate neutrality. The results further confirm that reduction does not have a significant effect. We verified that the marginal effects were consistent with the logistic regression results.

Table 3 Average marginal effects on carbon neutrality

Variable	dy/dx	z	p-value	95_CI_Lower	95_CI_Upper
Age	0.036***	5.02	0.000	0.022	0.051
Size	0.094***	7.66	0.000	0.070	0.118
Economic growth	0.092***	4.56	0.000	0.052	0.132
Redu	0.004	0.90	0.371	− 0.005	0.013
Recy	0.042***	6.21	0.000	0.029	0.056
Rede	0.060***	7.36	0.000	0.044	0.076
Services (Industry)	0.042***	3.49	0.000	0.019	0.066

***$p < 0.001$

The sequence of models improves progressively with each model. Log-likelihood approaches zero, LR chi^2 increases, and Pseudo R^2 increases with each block of variables added. Adding variables to each model provides additional and significant explanatory power for understanding what drives companies to adopt carbon neutrality.

To verify the interaction, we plot the graph of the moderating effect with a significant result [6]. The graph of predictive margins of the interaction (Fig. 1) verifies significant interaction between reduction practices and industry (manufacturing vs. services) that increases the probability of adopting carbon neutrality. The graph shows the predictive margins with their 95% confidence intervals, calculated from Model 4. The y-axis represents the predicted probability of adopting carbon neutrality, and the x-axis the different levels of intensity of reduction practices. That the slope is positive for the services industry and negative for the manufacturing industry confirms moderation of the difference by business industry (*services (industry)*).

Figure 1 shows that service companies that engage in more reduction practices increase their likelihood of adopting carbon neutrality, whereas this trend is negative for manufacturers. Manufacturing companies that increase their reduction efforts are less likely to adopt carbon neutrality. When reduction practices are low, the two industries do not differ significantly. It is the intensification of these practices that reveals the opposing contextual effects.

Figure 2 shows the average marginal effects, calculated from Model 4. The y-axis represents the change in the probability of adopting climate neutrality. The x-axis represents the different levels of intensity of reduction practices. For service companies, reduction practices only become a significant driver for adopting climate neutrality when implemented intensively.

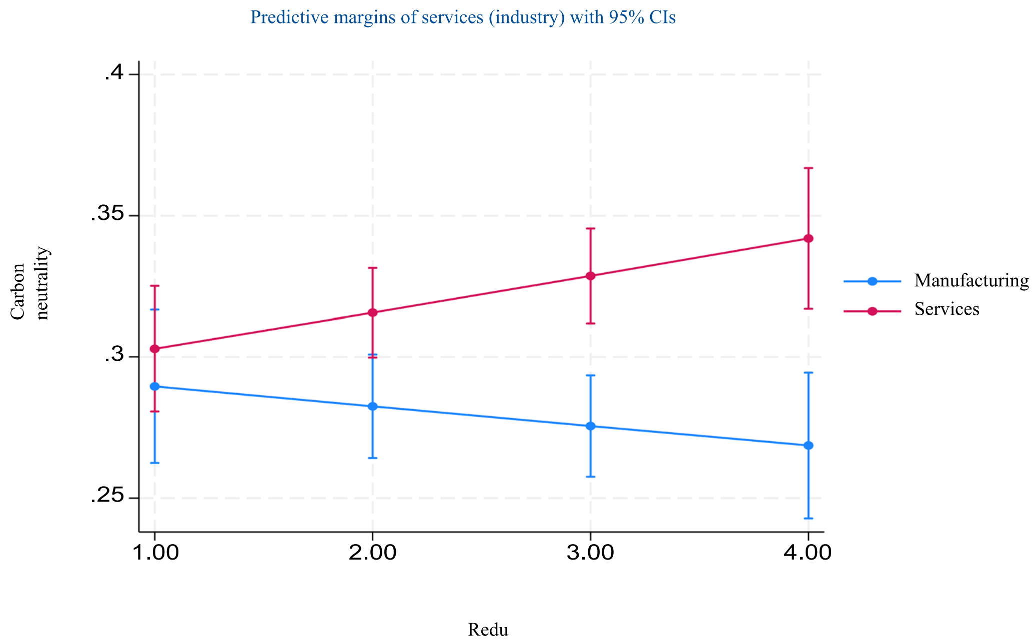

Fig. 1 Predictive margin chart: industry interaction between reduction practices and carbon neutrality

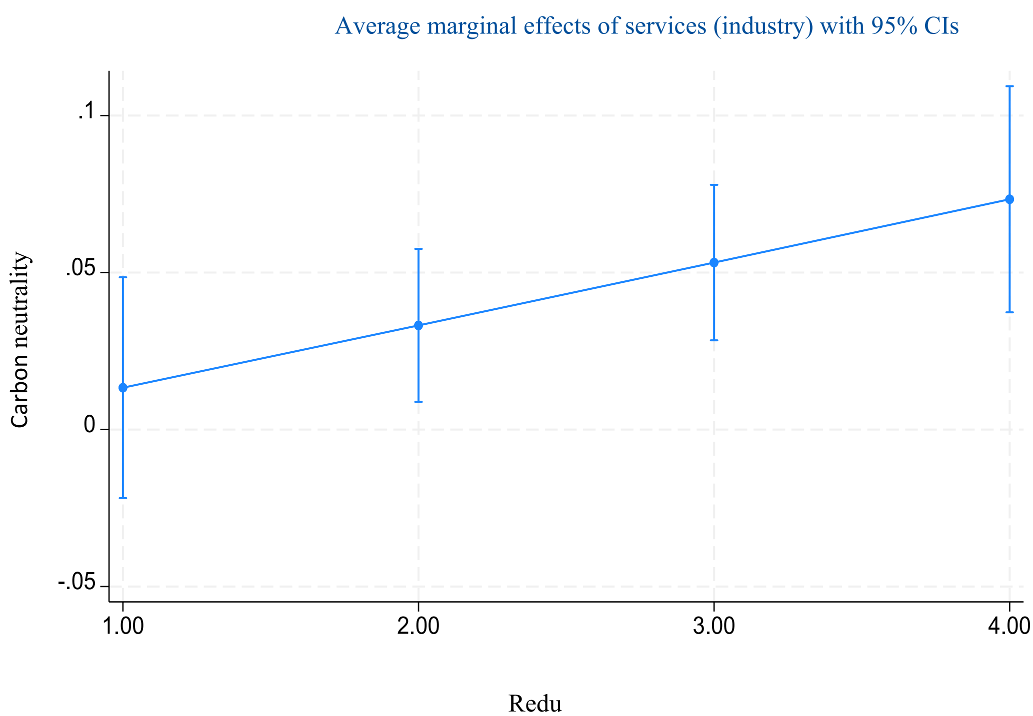

Fig. 2 Marginal effects chart: effect of interaction with reduction practices on probability of adopting carbon neutrality in the service industry

Implementing few reduction practices does not appear to have a statistically relevant impact.

To assess the robustness of the results to model specification, robust standard errors (i.e., robust) were calculated. The resulting *z*-statistics, *p*-values, and confidence intervals were remarkably close to the standard estimates. This consistency, with no changes in the significance of key variables, reinforces the reliability of the conclusions.

Summary of findings and discussion

Taking a closer look at findings of this study in the context of our RQs, the conclusions drawn from RQ1 demonstrate that the selected CE practices affect CCN differently, given our specific cross-sectional and observational data. Surprisingly and somewhat paradoxically—given previous claims about reduction being predominant practice adopted by organizations when initiating their transition to CE [55, 60]—such practice does not generally have a significant effect on the likelihood of a company adopting carbon neutrality strategies. This finding contradicts the conclusions of Boiral et al. [15] and Hodgson et al. [41], who suggested that reduction could have a more direct influence on CCN than other "R" practices by mitigating emissions throughout the entire value chain. In this context of selected European firms, and by considering the results discussed below (related to RQ3), analyzing the effects of reduction practices on CCN appears to be a more challenging task.

By contrast, in line with expectations based on prior related works [13, 56, 57], recycling practices positively and significantly influence the likelihood of a company adopting carbon neutrality strategies (23.6% more than companies that do not recycle). More in detail, to achieve CCN, this "R" practice may help to optimize carbon emissions. This can be done through waste management and recovery. It can also initiate raw material substitution in the production of new goods, according to Lin et al. [52] and Itanola et al. [44]. Finally, it can cost-effectively reduce GHGs in future production designs [51].

Moreover, companies under scrutiny in this study that adopt redesign practices are 35.3% more likely to embrace CCN. These findings suggest that—followed by recycling—redesign has the strongest impact on CCN across analyzed EU countries. This may be due to the nature of such "R" practice, which involves not only adhering to environmental requirements during product design, but also prioritizing the extension of the product's useful life [21, 27]. Next, as Tan et al. [79] point out in their research on reduce, reuse, recover and rethink design activities, redesign holds the potential for combining other "R" principles. Consequently, as redesign promotes CCN from a more forward-thinking angle by incorporating different sustainability practices into companies, its scope extends well beyond merely preventing environmental issues.

Next, considering the perspective of RQ2—highlighting that the industry is relevant for carbon neutrality due to the differentiated contribution of GHGs [89]—our results suggest that the business industry could positively and significantly influence on a company's probability of adopting CCN in Europe. In this vein, our empirical findings demonstrate that service companies are % more likely to adopt CCN strategies. From a first perspective view, these findings (based on selected indicators and available data) do not confirm the significant role of the manufacturing industry in achieving carbon neutrality [25, 95]. Rather, they highlight industry's potential dominance in terms of energy consumption and high emissions [54]. From a second perspective, we recognize the emerging importance of the service industry, which is reinforced by companies being able to pursue sustainable practices more effectively. Among others, it is because companies in this industry may benefit from "easier" digital transformation options when adopting CCN. This could potentially open new ways of providing services by optimizing resource consumption [40].

Finally, the results for RQ3 stem from analysis of the moderating effect of business industry on the relationship between CE practices and CCN. However, despite one would expect significant moderating effects—as the literature proposes that the manufacturing sector must optimize its resources and reduce emissions [54] and the services sector focuses more on influencing consumers to drive the CE [40]—the opposite is true within the sample we examined. In more detail, our results did not confirm the significance of the interaction between industry (manufacturing vs. services) and recycling and redesign practices. The only exception is reduction practices, which exert a positive and significant effect on the probability of adopting CCN for service companies but no significant effect for manufacturing. These findings seem to indicate that reduction does not drive adoption generally across all industries but rather is contextual and industry-specific.

Thus, when we consider the above features of the service industry that are associated with easier digitalization options, together with reduction practices that help to establish sustainable, closed-loop economic systems, and which are also the most prevalent practice that organizations employ when beginning their transition to CE [50, 55, 60], it becomes clear that there is a significant opportunity for service companies when adopting CCN. Such findings could be considered consistent with those demonstrated by Yin et al. [90], who point out that differences emerge across industries when considering their moderating roles. Such differences stem from product and service differentiation, budgetary constraints, sector-specific profit margins, turnover, or, for example, competitive landscape. In summary, Yin et al. [90] emphasize the importance of conducting further empirical analyses to compare the manufacturing and service industries.

Conclusions

This study targeted two research objectives, focusing on the impact of specific CE ("R") practices on the corporate adoption of CCN, including revealing their differences and examining the moderating role of the business industry (manufacturing vs. services) on such relationships. To address these objectives, we formulated three research questions offering valuable insights into this novel, microeconomic perspective. In more detail, we identified the diverse effects of "R" practices, with redesign emerging as the primary driver of carbon neutrality (followed by recycling practices; RQ1), consistent with the argument of Tan et al. [79] that redesign holds pivotal importance in achieving circularity. Furthermore, we provided empirical evidence that the business industry exerts a positive effect on a company's likelihood of pursuing carbon neutrality strategies (RQ2). Lastly, we demonstrated that analyzing the moderating role of the industry is not straightforward [90]. Notably, we highlighted that moderating effects of industries (manufacturing vs. services) are not significant when targeting recycling and redesign practices (RQ3). By contrast, for reduction practices, we showed that there is significant interaction with services industry when influencing adoption of CCN.

Contributions and implications

The main contribution of this study is that it transcends the traditional technical and productive perspective to frame carbon neutrality as a fundamental strategic challenge facing companies. The results demonstrate that CE practices encourage CCN adoption, but "one size does not fit all", as we show that their effectiveness depends on a deliberate strategic choice. We confirm that redesign and recycling are clearly robust and generally applicable drivers [33, 79]. By contrast, advancing prior related research, this study is one of the first to highlight the specific features of reduction practices. It shows that such practices are more selective and only relevant in the service industry. By doing so, we bring new industry-focused knowledge on the relationship between CE practices and corporate climate neutrality, as we demonstrate that reduction practices are not a "panacea" for all industries when it comes to adopting CCN. Furthermore, in our case, we highlight that the service industry is more likely to adopt CCN and has differentiated strategic pathways. This finding newly shifts the debate on carbon neutrality adoption from a predominantly technical approach to view it as a strategic option.

Moreover, unlike the traditional literature on the manufacturing industry [41], our findings indicate that service companies are considerably more likely to implement carbon neutrality strategies within our sample of EU countries. This result is especially important, given the economic prominence of the service industry in the EU and its growing focus on sustainability. Finally, we confirm that reduction practices could be an effective driver in the service industry. Unlike manufacturing companies, service companies can act directly and effectively on CE and CCN through this channel. To the best of our knowledge, and in line with the call outlined by Yin et al. [90], this is also one of the first studies showing whether and how business industry can moderate above relationships, making the CE practice of reduction a significant factor that positively impacts service companies' efforts to achieve carbon neutrality.

Additionally, as our analysis aimed to fill the research gap on carbon neutrality, which is often considered a technical and production-related problem rather than a strategic one [15], ignoring the fact that managers and organizations must commit to transformation to achieve CCN, its findings could help to reorient application of carbon neutrality from its technical and productive aspects to a more organizational and strategic approach. Next, a theoretical-practical contribution is brought by this approach in confirming rather multidisciplinary nature of adopting CCN (hard technical discipline), requiring a link with managerial perspectives (soft discipline), in our case anchored within the RBV and NRBV theory lenses. The integration of technical and managerial disciplines is considered a challenging task, forming a part of the broader "managerial puzzle" that demands a holistic approach from practitioners [49, 67].

This study also has several implications for companies. First, it shows that not all CE practices have the same impact on CCN. This finding is crucial for companies and governments designing strategies and policies, as it shows that redesign—commitment to profound transformation of processes, products, and services [44]—has the most significant influence on CCN adoption. Recycling, a practice that focuses on the recovery of materials and technology, is also a relevant factor. In a general context, however, reduction is not associated with the likelihood of a company adopting CCN strategies.

Moreover, managers should also consider "major changes" to their business models (BMs), ideally towards the adoption of circular business models (CBMs) [36] that are aligned with CCN. This is down to CBMs aid in reducing carbon emissions at every stage of a product's lifecycle. Furthermore, CBMs facilitate sustainable development, generate job vacancies and promote economic growth [2]. Therefore, despite the challenges of risk mitigation for investing in CBM innovation [53], it is still worthwhile as "*CBMs aligned with decarbonization is vital for industries to reduce emissions while maintaining profitability and driving a sustainable future*" [2].

Finally, as the use of "R" practices to enhance CCN adoption requires both managerial and technical knowledge, it is also necessary to focus on improving technical capabilities and know-how—together with "green" knowledge and awareness—of managerial staff [67].

Limitations and future research

Finally, this study is not without limitations. Despite the relevance of the findings, this study recognizes that the measurement of carbon neutrality is based on a binary item on the existence of a formal strategy. Although this constitutes a valid indicator of the firm's strategic intentionality, the results should be interpreted considering the possible social desirability bias and the potential gap between the formulation of the strategy and its effective implementation. We must acknowledge that we are primarily limited using secondary, cross-sectional and observational data, which limits our analytical capabilities, whether from the perspective of conducting more sophisticated country or territory-oriented additional analyses, or from the perspective of deeper investigation of the behavioral motives of the analyzed companies. This limitation is consistent with our research being confined to the manufacturing and services sectors. Future research should therefore also verify our findings in other sectors, such as those associated with a high degree of digitalization, material intensity, or, for example, regulatory pressures. Among others, examples of such sectors include ICT, agriculture and food, or tourism.

Next, we must note that our analysis is limited to three CE ("R") practices. Moreover, it only focuses on estimating the probability of CE practices being associated with CCN-related activities, rather than measuring actual emission reduction outcomes. This restricts our ability to draw more definite conclusions about the actual impact of CE practices on climate neutrality. Moreover, as our "R" practices consist of merged relevant indicators, our findings do not explain how specific CE practices contribute to reductions in CO_2 emissions at the firm level. Therefore, future research should use additional methods, such as linear or binary regressions, to reveal the effects of individual indicators, such as saving water, saving energy, saving materials, minimizing resource use, using renewable energy, selling waste and scrap to another company, and others. This could be done using the same data.

Another option would be to include additional data sources that provide information on other "R" practices, as well as on the possibilities for companies to reduce emissions. This is also because, despite being promoted by EU policies, recycling represents a relatively low level of circularity. Thus, while these practices facilitate the implementation of certain CCN-related actions, they also have limited potential to contribute to the achievement of actual carbon neutrality. However, to the best of our knowledge, the most commonly used company databases are also limited in terms of the required input or output variables. Examples include the Community Innovation Survey and the World Bank Enterprise Survey. Therefore, despite the limitations outlined, we believe that this study offers an intriguing perspective on this emerging topic from a company standpoint.

Future research should also use additional complementary data obtained through direct interviews, to reveal differences not only between sectors, but also between countries, or between different strategies that companies follow. Adopting a broader systemic [18, 77] and CBM [45] perspective when conceptualizing CE is also necessary in order to provide practitioners and policymakers with a more comprehensive picture and relevant information. At the same time, we recommend that future research also utilize additional fuzzy-set qualitative comparative analysis (fsQCA)-type analyses to better identify distinct configurational pathways leading to CCN.

Appendix A. Number of companies by country

	Country	Total_Firms	Total_Pct	Manufacturing	Manu_Pct	Services	Serv_Pct
1	Austria	199	3.1	77	3.0	122	3.2
2	Belgium	301	4.7	113	4.4	188	4.9
3	Bulgaria	245	3.8	107	4.1	138	3.6
4	Cyprus	81	1.3	33	1.3	48	1.3
5	Czech Republic	300	4.7	120	4.6	180	4.7
6	Germany	219	3.4	42	1.6	177	4.7
7	Denmark	208	3.3	91	3.5	117	3.1
8	Estonia	272	4.3	117	4.5	155	4.1
9	Spain	295	4.6	125	4.8	170	4.5
10	Finland	252	3.9	101	3.9	151	4.0
11	France	227	3.6	97	3.7	130	3.4
12	Greece	283	4.4	113	4.4	170	4.5
13	Croatia	239	3.7	100	3.9	139	3.7
14	Hungary	233	3.6	104	4.0	129	3.4
15	Ireland	199	3.1	73	2.8	126	3.3
16	Italy	247	3.9	111	4.3	136	3.6
17	Lithuania	223	3.5	90	3.5	133	3.5
18	Luxembourg	101	1.6	8	0.3	93	2.4
19	Latvia	237	3.7	104	4.0	133	3.5
20	Malta	118	1.8	43	1.7	75	2.0
21	Netherlands	286	4.5	120	4.6	166	4.4
22	Poland	281	4.4	100	3.9	181	4.8
23	Portugal	223	3.5	99	3.8	124	3.3
24	Romania	297	4.6	129	5.0	168	4.4
25	Sweden	313	4.9	151	5.8	162	4.3
26	Slovenia	285	4.5	111	4.3	174	4.6
27	Slovakia	229	3.6	113	4.4	116	3.1
	TOTAL	6393	100.0	2592	100.0	3801	100.0

Appendix B. Number of employees by industry and country

Country	Total_1—9	Total_10—49	Total_50—249	Total_250+	Total_DK_NA	Total_Sum	Manu_1—9	Manu_10—49	Manu_50—249	Manu_250+	Manu_DK_NA	Manu_Sum	Serv_1—9	Serv_10—49	Serv_50—249	Serv_250+	Serv_DK_NA	Serv_Sum
Austria	68	73	41	17	0	199	30	26	13	8	0	77	38	47	28	9	0	122
Belgium	87	111	64	39	0	301	16	38	31	28	0	113	71	73	33	11	0	188
Bulgaria	100	76	47	20	2	245	28	34	28	16	1	107	72	42	19	4	1	138
Cyprus	39	32	9	1	0	81	14	15	4	0	0	33	25	17	5	1	0	48
Czech Republic	119	100	63	18	0	300	24	47	39	10	0	120	95	53	24	8	0	180
Germany	70	78	56	15	0	219	9	13	14	6	0	42	61	65	42	9	0	177
Denmark	60	73	52	23	0	208	20	30	26	15	0	91	40	43	26	8	0	117
Estonia	95	105	65	7	0	272	34	40	39	4	0	117	61	65	26	3	0	155
Spain	107	110	50	27	1	295	37	45	26	16	1	125	70	65	24	11	0	170
Finland	109	100	33	10	0	252	36	45	15	5	0	101	73	55	18	5	0	151
France	77	71	53	26	0	227	23	36	24	14	0	97	54	35	29	12	0	130
Greece	121	111	39	11	1	283	48	41	18	6	0	113	73	70	21	5	1	170
Croatia	80	90	42	27	0	239	21	31	29	19	0	100	59	59	13	8	0	139
Hungary	81	84	48	20	0	233	28	38	28	10	0	104	53	46	20	10	0	129
Ireland	61	77	48	13	0	199	36	18	13	6	0	73	25	59	35	7	0	126
Italy	95	66	48	38	0	247	49	35	13	14	0	111	46	31	35	24	0	136
Lithuania	76	88	41	17	1	223	25	31	24	10	0	90	51	57	17	7	1	133
Luxembourg	53	28	15	5	0	101	3	2	2	1	0	8	50	26	13	4	0	93
Latvia	135	79	19	4	0	237	56	36	10	2	0	104	79	43	9	2	0	133
Malta	47	36	27	8	0	118	14	16	12	1	0	43	33	20	15	7	0	75
The Netherlands	73	115	68	30	0	286	21	45	37	17	0	120	52	70	31	13	0	166
Poland	128	95	48	9	1	281	31	30	32	7	0	100	97	65	16	2	1	181
Portugal	87	78	41	17	0	223	41	29	20	9	0	99	46	49	21	8	0	124
Romania	135	103	43	16	0	297	48	46	24	11	0	129	87	57	19	5	0	168
Sweden	122	119	45	27	0	313	43	70	24	14	0	151	79	49	21	13	0	162
Slovenia	108	101	55	21	0	285	18	46	34	13	0	111	90	55	21	8	0	174
Slovakia	110	86	25	8	0	229	36	53	19	5	0	113	74	33	6	3	0	116
TOTAL	2443	2285	1185	474	6	6393	789	936	598	267	2	2592	1654	1349	587	207	4	3801

Appendix C: Summary of post-stratification weights and adjustment ranges by country

Country_name	Max_weight	Min_weight	Adjustment_range
Austria	380.01	0.05	379.95
Belgium	380.01	0.01	379.99
Bulgaria	283.52	0.03	283.49
Cyprus	355.87	0.08	355.79
Czech Republic	380.01	0.03	379.98
Denmark	380.01	0.04	379.97
Estonia	360.64	0.06	360.58
Finland	332.81	0.07	332.74
France	380.01	0.02	379.99
Germany	366.07	0.08	365.99
Greece	369.68	0.02	369.66
Hungary	380.00	0.03	379.98
Ireland	380.00	0.04	379.96
Italy	380.01	0.01	380.00
Latvia	302.00	0.15	301.85
Lithuania	380.01	0.03	379.98
Luxembourg	249.47	0.08	249.39
Malta	282.54	0.02	282.51
Netherlands	380.01	0.02	379.99
Poland	232.81	0.04	232.76
Portugal	380.01	0.02	379.99
Romania	264.16	0.07	264.10
Slovakia	240.88	0.04	240.84
Slovenia	380.00	0.03	379.97
Spain	373.44	0.02	373.42
Sweden	380.01	0.03	379.98
Croatia	380.01	0.03	379.98

N = 6393

Appendix D: Distribution of the categories in four groups (NACE classification) of European Commission and Flash Eurobarometer 498

Manufacturing	C. Manufacturing
Retail	G. Wholesale and retail trade, repair of motor vehicles and motorbikes
Services	H. Transport and storage
	I. Accommodation and food service activities
	J. Information and communication
	K. Financial and insurance activities
	L. Real estate activities
	M. Professional, scientific and technical activities
Industry	B. Mining and quarrying
	D. Electricity, gas, steam and air conditioning supply
	E. Water supply; sewerage, waste management and remediation activities
	F. Construction

To ensure a robust comparative analysis, the grouping rule assigned NACE Section C to 'Manufacturing' and Sections H to M to 'Services'. Other industrial (B, D, E, F) and commercial (G) sections were excluded from the regression analysis to avoid strategic focus on the fundamental contrast between product-based and service-based business models (N = 6393)

Appendix E. Data—Sustainable economic growth by country studied for 2020, 2021, and 2022

Sustainable economic growth	2020			2021			2022		
	Real GDP per capita	Investment share of GDP	Material footprint	Real GDP per capita	Investment share of GDP	Material footprint	Real GDP per capita	Investment share of GDP	Material footprint
Austria	42,650	25.13	21.8	44,520	25.88	25.4	46,350	25.47	24.2
Belgium	40,190	24.03	13.0	42,510	23.91	13.8	43,960	23.85	12.8
Bulgaria	9450	18.98	20.7	10,250	16.27	21.5	10,740	17.00	24.1
Croatia	12,840	22.35	14.8	14,560	20.94	16.1	15,640	21.60	15.0
Cyprus	24,630	20.82	19.1	27,030	19.22	19.9	28,440	19.89	19.9
Czech Republic	20,980	25.54	16.0	21,830	26.24	19.0	21,910	27.69	18.6
Denmark	53,540	22.18	22.5	56,780	23.21	22.6	56,530	23.09	23.3
Estonia	20,960	31,18	27.89	22,670	29,98	27.08	22,370	25,16	24.98
Finland	42,740	24.66	45.1	43,800	24.42	46.0	44,010	24.66	49.3
France	34,280	22.44	13.5	36,470	23.48	15.0	37,320	23.65	14.5
Germany	41,480	21.35	14.8	42,990	21.19	15.2	43,260	21.71	14.6
Greece	15,660	12.30	11.0	17,110	13.79	10.9	18,200	14.93	11.6
Hungary	14,370	26.51	14.4	15,470	27.26	14.4	16,170	27.85	14.1
Ireland	75,820	41.34	18.7	87,160	22.04	13.5	91,760	21.17	14.6
Italy	28,100	18.20	9.6	30,760	20.77	10.8	32,310	21.78	10.7
Latvia	15,370	23.03	17.0	16,580	22.93	18.7	16,870	23.02	19.9
Lithuania	17,890	21.43	20.8	19,040	22.49	23.0	19,360	22.48	20.7
Luxembourg	102,190	17.18	27.4	107,570	18.15	27.6	104,100	16.60	31.7
Malta	27,890	21.02	11.6	31,410	22.93	11.6	31,910	24.24	11.9
Netherlands	46,810	21,27	9.47	49,490	20,69	8.87	51,480	20,47	8.97
Poland	14,310	18.40	15.8	15,380	16.93	16.1	15,840	16.44	16.1
Portugal	19,360	19.50	14.6	20,390	20.50	17.2	21,690	20.57	15.6
Romania	11,460	23.33	29.1	12,190	24.37	30.7	12,730	25.04	30.2
Slovakia	17,270	19.78	13.6	18,320	19.59	13.5	18,350	20.92	13.9
Slovenia	22,230	19.02	14.3	24,040	20.27	16.6	24,660	21.92	17.0
Spain	23,850	20.62	9.9	25,440	20.20	10.0	26,770	20.41	9.6
Sweden	46,180	24.53	24.8	48,300	25.12	24.6	48,390	25.59	25.2

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12302-026-01403-x.

Supplementary Material 1.

Acknowledgements

The authors acknowledge that the paper was also created as part of the authors' cooperation within the EU COST Action CA22110—Cooperation, development and cross-border transfer of Industrial Symbiosis among industry and stakeholders (LIAISE).

Author contributions

Paula Serna-Serna and Lirios Alos-Simo were responsible for the conceptualization, methodology, and application of statistical techniques. They wrote the original draft of the manuscript and created the tables and figures. Viktor Prokop and Aleksandar Erceg reviewed each part of the project, supervised, and performed the final editing of the document.

Funding

EU COST Action CA22110—Cooperation, development and cross-border transfer of Industrial Symbiosis among industry and stakeholders (LIAISE).

Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 18 November 2025 Accepted: 30 April 2026
Published online: 16 May 2026

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