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Procedia CIRP 134 (2025) 289–294

www.elsevier.com/locate/procedia

Proceedings of the 58th CIRP Conference on Manufacturing Systems 2025

Advancing Circular Manufacturing: Benchmarking SME Practices in a German Metal Products Hub Against European Trends

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Abstract

This study examines circular economy (CE) practices in a German region dominated by small and medium-sized enterprises (SMEs) in the metal products manufacturing sector. We compare CE strategies adopted by 39 regional companies against a broader sample of 172 European firms. Our analysis focuses on the prevalence of various CE goals and 10R strategies across these geographical contexts. Findings reveal significant disparities, particularly for the 'reduce' and 'recycle' strategies. These insights form the foundation for developing targeted interventions to enhance CE implementation in the region's manufacturing systems. The study contributes to the growing body of research on CE in manufacturing and provides valuable insights for policymakers and industry practitioners aiming to promote sustainable production practices in SME-dominated regions. Future work will explore the establishment of a competence center to facilitate CE activities within the region.

Keywords: Circular economy ; manufacturing ; SME ;

1. Introduction

A circular economy (CE) is central to transitioning towards a sustainable society [20, 6]. The *10R strategies* (e.g., reuse, repair, recycle) describe approaches to close, slow, and narrow resource flows, moving the linear economy towards circularity [3, 18]. Analyzing companies' adoption of these strategies can provide insights into their applicability and highlight potential for future uptake.

In the European Union (EU), small and medium-sized enterprises (SMEs) contribute significantly to economic value [7]. Manufacturing SMEs provide numerous jobs across educational levels [7]. The Bergische City Triangle (BCT) in Germany is one such region where SMEs and manufacturing dominate. The BCT comprises Wuppertal, Remscheid, Solingen, with over 600,000 inhabitants. It hosts numerous SMEs, many producing metal products like tools and kitchenware.

1.1. Study objectives & structure

The research presented in this study is part of an ongoing research project to establish a CE competency center in the BCT. The center shall enable companies in the BCT to engage in and expand on existing CE activities. This study presents a first step towards this goal.

We investigate how companies in the BCT apply the 10R strategies and compare them to EU companies. The findings will help identify which strategies to focus on and explore which ones have been neglected. The results are relevant not only for the BCT but also for other EU regions with similar economic structures.

The article is structured as follows: subsection 1.2 reviews relevant literature. Section 2 provides definitions and project context. Section 3 outlines the method and data used for identifying companies and their 10R strategies. Section 4 analyzes the distribution of 10R strategies among assessed companies. Section 5 discusses the results and study limitations. Section 6 concludes with a summary, key insights, and future research directions.

1.2. Literature review

A number of studies have been conducted that address the 10R strategies contributing to a CE (1), as well as the implementation of CE in manufacturing companies (2) and SMEs (3). To the best of the author's knowledge, no study has combined all these aspects (1-3) in one study, as can be seen in the literature review below.

Ormazabal et al. review 17 SME case studies from the Basque Country, analyzing their motivations to address environmental issues [15]. While focusing on SMEs and including some manufacturing firms, they do not analyze different 10R strategies.

10.1016/j.procir.2025.03.058

Two studies focus on manufacturing but are not limited to SMEs. Jaeger et al. identify dominant barriers for the manufacturing industry's move towards a CE [12]. Deviatkin et al. analyze the implementation of five CE strategies (narrow, slow, close, regenerate, inform) in Finnish electronics companies, finding CE strategies implemented in only 25% of cases, with narrow' being the most common [4].

Eleven studies, though not explicitly focusing on manufacturing or SMEs, contribute relevant knowledge on CE and 10R strategies in companies. Bocken et al. introduce the concepts of slowing, closing, and narrowing resource loops as mechanisms for achieving CE, deriving CE product design and business model strategies [3]. Lüdeke-Freund et al. analyze 26 CE business models (CEBM), identifying six major patterns mostly covered by the 10R strategies [13]. Blomsma et al. organize the 10R strategies according to applicable business functions [2]. Schöggl et al. review 20 years of CE and sustainable development research, finding that recycling is the most referenced R strategy by an order of magnitude, followed by remanufacturing, repair, and reuse [19]. Several studies find recycling to be the most common CE practice among companies [11, 14, 16, 21, 17, 22]. Uvarova et al. cluster 60R strategies into four groups (reduce, reuse, recycle, reverse logistics), finding reverse logistics less prevalent [23]. The literature suggests that recycling is frequently relied upon by companies, while other 10R strategies are less commonly applied.

Analyzing the frequency of 10R strategy implementation at the EU level and in a manufacturing- and SME-dominated region like the BCT could provide deeper insights.

2. Background

This section introduces the 10R framework by Potting et al. (subsection 2.1) used in our analysis, and presents some key indicators about the region of interest, the BCT (subsection 2.2).

2.1. The 10R framework

We adopted Potting et al.'s 10R framework, which includes the strategies *Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle*, and *Recover*. The first three strategies align with 'Smarter product use'; the next five support the 'Extension of product and part lifespans'; and the last two promote the 'Useful application of materials'. Generally speaking, the first group of strategies promises a higher degree of circularity than the second one, which again promises a higher degree than the third one. [18]

2.2. The BCT region in the EU context

To better comprehend the BCT region and develop a CE competence center that caters to the companies located there, it is helpful to understand its economic structure and contrast it against the wider EU context.

Out of the 448 M people living in the EU [10], 635,000 inhabitants (0.14%) live in the BCT, distributed over the cities of Wuppertal, Remscheid, Solingen [1]. The total gross domestic product (GDP) of the EU amounts to 16.1 €T [8], 24 €B of which (0.15%) is generated in the BCT [1]. The average per capita GDP in the BCT is quite on par with the EU figure, with 37,825 € for the BCT [1] and 35,505 € for the EU [9]. In the BCT, just as in the EU as a whole, the majority of companies are SMEs. Of all the companies in the EU, 99.8 % have fewer than 250 employees [7], while in the manufacturing industry of the BCT (the only sector for which data is available), this fraction is 98.4 % [1]. The manufacturing sector (not including construction) contributes almost half of the GDP of the BCT region (11.3 €B out of 24 €B, 47.1%). In comparison, in the whole of the EU these numbers are 9.96 €T out of 38.3 €T (26.0%) [7].

A more detailed analysis of the mining and the manufacturing sector reveals that the manufacturing of metal products is the most relevant category in these sectors in terms of the number of companies, the number of employees and the net turnover for the BCT (cf. Fig. 1b). In comparison, this category is less relevant for the whole of the EU, especially in terms of number of employees and net turnover (cf. Fig. 1a).

The figure also reveals that a relatively small number of companies (3.7%) in the electrical equipment category employ a disproportionate number of people (12.2%) and generate an even more disproportionate net turnover (19.9%)—exactly opposite to the metal products category, with many companies (38.7%), disproportionately few employees (30.5%), and even less revenue (27.9%). One could therefore say the metal products industry in the BCT is made up by many relatively small companies, generating relatively little turnover.

3. Method and data

To find out to which degree the 10R strategies are currently being implemented at the EU level and in the BCT, we analyzed different data sources.

For the EU, the European Circular Economy Stakeholder Platform database [5] proved to be a valuable resource. It contains 788 case study examples of CE practices in companies and other organizations (as of 17 July 2024). The companies and organizations register the cases themselves voluntarily in the database.

Since it does not contain any examples from the BCT, we had to rely on different data to analyze 10R strategy implementation in this region. Therefore, we decided to conduct a targeted internet search using keywords like 'circular economy', 'sustainability in the BCT', 'sustainability in Wuppertal/Solingen/Remscheid', 'SMEs in the BCT', 'Chamber of Industry and Commerce', and 'Bergisch Chamber of Industry and Commerce', in both German and English. The search yielded a total of 150 case studies of companies in the region that advertise any CE practices. Similar to the EU database, this sample can also be considered a voluntary sample (as opposed to data collected as a consequence of legal requirements).

To both the EU and the BCT initial sample of cases, we applied the following filter criteria: 1) the case must display one (or multiple) strategy(ies) from the 10R framework, 2) the practice must relate to a company (not any other type of organization, e.g. a charity or a public administration) and 3) the company shall not belong to the urban development or food waste management sector, since these were deemed less relevant to the BCT's metalworking and manufacturing focus. Applying these three criteria reduced the sample size from 788 to 194 cases in 172 companies (EU) and from 150 to 39 cases in 39 companies (BCT), respectively.

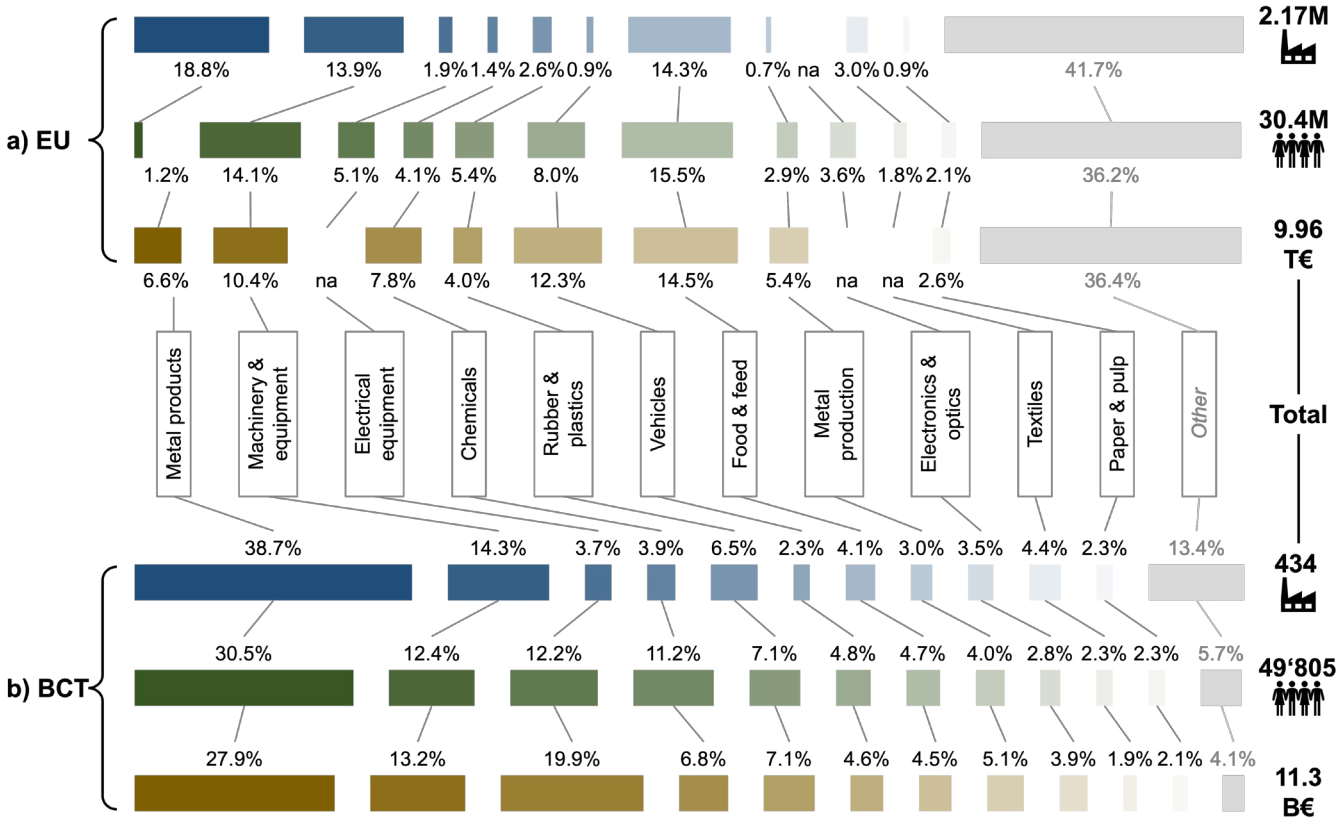

Fig. 1. Relative distribution of the number of companies (blue), number of employees (green) and annual revenue (yellow) per industry sector in the mining and manufacturing industry a) in the EU (top) and b) in the Bergische City Triangle (BCT, bottom) for 2022 [1, 7]. Depicted are only the top 11 categories for the BCT by number of employees.

For this sample of cases, we analyze how frequently each 10R strategy is pursued, and match these strategies with industry sectors in a subsequent analysis. We limit this analysis to the mining and manufacturing sector due to data availability, matching the sectors displayed in 1.

4. Results

This section provides a detailed breakdown of the frequency with which each 10R strategy is implemented in our samples of EU and BCT companies and analyzes the prevalence of the strategies in individual industrial sectors.

Table 1 lists examples for each 10 R strategy included in our two separate datasets for EU and BCT companies.

Table 1. Examples for 10R strategies in the European Union (EU) and the Bergische City Traingle (BCT) dataset.

10R Strategy	Example	Dataset
Refuse	Avoid hazardous chemicals in production processes	BCT
Rethink	Clothing as a service (promoting non-ownership)	EU
Reduce	Eliminate product packaging	both
Reuse	Resell outlet clothes as received	EU
Repair	Provide repair services and spare parts	both
Refurbish	Sell pre-used laptops with upgraded hard drives	EU
Remanufacture	Utilize second-life EV batteries in speedboats	EU
Repurpose	Create shopping bags from old T-shirts	EU
Recycle	Company A uses production waste of Company B	EU
Recover	Food waste to bio-methane for energy generation	EU

To find out which of the 10R strategies enjoy popularity in the companies of the BCT, and to compare this to the popularity in the EU as a whole, we analyze their prevalence as described in section 3.

The results, shown in Fig. 2, indicate that the most popular strategies in the BCT (right) are repair, reduce and rethink. In comparison, the most popular strategies on the EU level are recycle, rethink, repurpose and reuse. The shades indicate which goal, according to Potting et al. [18], each of the strategies contributes to, indicated by the hierarchy on the far left of the figure. This classification illustrates that the strategies are fairly evenly distributed among the three goals in the EU, while in the BCT, more than half of the cases employ strategies towards smarter product use & manufacture (blue), close to half contribute to extending the lifespan of products & its parts (green), and only one case relates to the useful application of materials (yellow).

Combining the information from Figs. 1 & 2 for the case of the BCT, Fig. 3 illustrates which sector category each of the cases belongs to. This allows for an analysis of which strategy and goal is pursued in which sector.

The figure highlights that the sample of cases on the EU level reflect that state of research, in that recycling is the strategy that is communicated most frequently (55/194). The sample of BCT cases is atypical in the sense that recycling does not appear at all, and instead repairing (10/39), reducing (9/39) and rethinking (8/39) are most popular. The industry sector that contributes most cases on the EU level is the textile industry (47/194), followed by the electrical equipment (27/194)

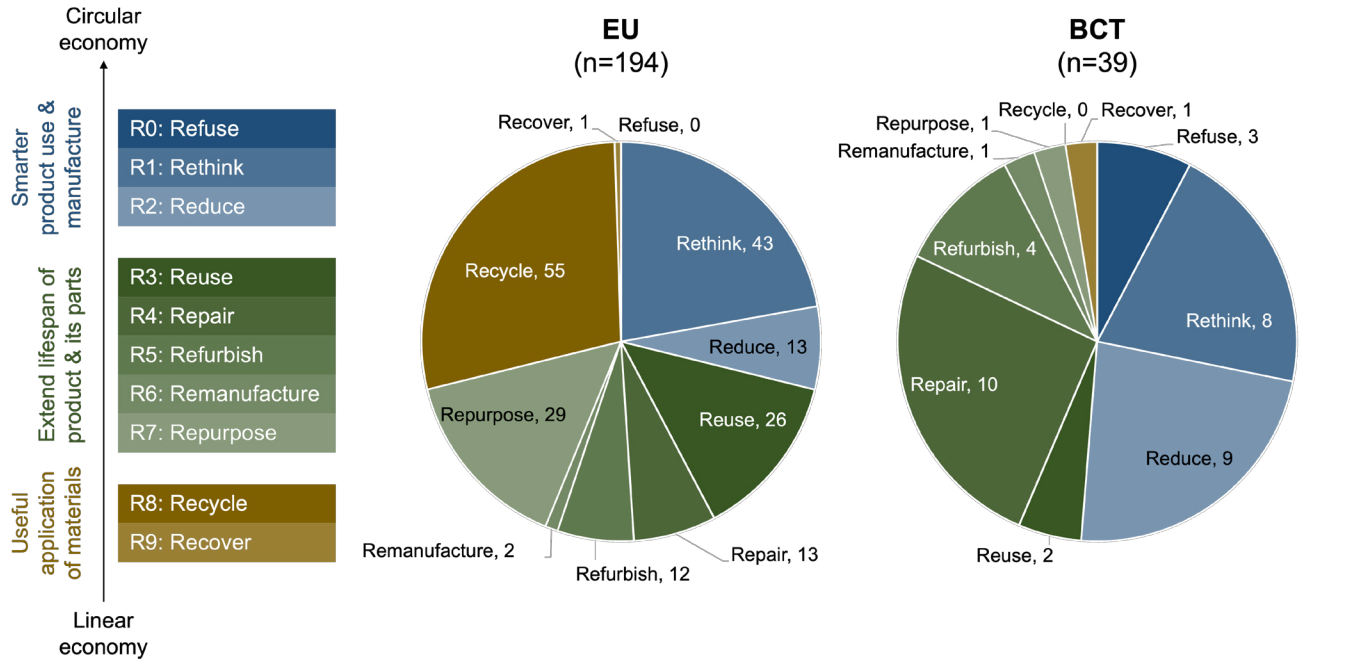

Fig. 2. The 10R strategies (according to Potting [18]), and their prevalence in 194 cases spread across 172 companies in the European Union (EU, left) and in 39 cases in the Bergische City Triangle (BCT, right). Some companies employ multiple strategies, thus the number of cases is not necessarily identical to the number of companies.

and the rubbers & plastics industry (22/194). In the BCT region, most cases are in the machinery & equipment (12/39) and in the metal products industry (9/39). The distribution of cases in the BCT region reflects the structure of its mining and manufacturing sector (cf. Fig. 1).

5. Discussion

In this section, we analyze the results from the previous section (subsection 5.1) and address some limitations of this study (subsection 5.2).

5.1. Analysis

The REFUSE strategy (EU: 0% of all cases, BCT: 7.7%) presents the greatest economic challenge, while also offering the highest potential impact on the environment and resources. The data shows that more cases of this strategy can be found in the BCT than in the EU as a whole.

RETHINK (EU: 22.1%, BCT: 20.5%) encompasses product and process innovation aimed at doing things differently. Although the total number of cases in the EU exceeds that in the BCT by more than five times, a relative analysis reveals that the BCT applies this strategy similarly frequently compared to the EU.

Global trends toward greater sustainability, evident in both society and the economy, have clearly begun to influence SMEs. Moreover, reducing the environmental impact of products and production processes is now a requirement by governments in some EU market segments. As a result, REDUCE (EU: 6.7%, BCT: 23.1%) strategies are increasingly important for businesses. Overall, we found more cases (relatively speaking) in the category ‘smarter products used & manufacture’ for the BCT than for the EU sample.

The REUSE of products (EU: 13.4%, BCT: 5.1%) also requires a suitable customer base from a sales perspective. However, this study only includes products publicly disclosed by companies. It can be assumed that very small companies rely on using pre-owned production equipment internally, though this cannot be further analyzed with the available dataset. In terms of numbers, the BCT lags behind the EU in the sample of cases that we assessed.

The REPAIR option (EU: 6.7%, BCT: 25.6%) represents economically viable service alternatives, provided the customer base and product align well from an economic standpoint. It also relies on a customer base with sufficient means to purchase spare parts. Additionally, a product line must include durable items of base value, making repair worthwhile. While both regions show a similar number of cases, BCT has a much higher relative share of repair business cases.

The REFURBISH strategy (EU: 6.2%, BCT: 10.3%) requires strong product value, customer trust in refurbished products, and high product reliability. These requirements appear to met to some degree in both the EU and the BCT, with roughly similar levels of adoption in relative terms.

REMANUFACTURE (EU: 1.0%, BCT: 2.6%) appears to be underutilized as a strategy for resource efficiency and sustainability in both regions. The authors assume that this strategy will show more economic potential as global resources become scarcer.

The REPURPOSE strategy (EU: 14.9%, BCT: 2.6%) may generally require sacrificing the added economic value of selling new goods. Consequently, this strategy may not yet be viable for many small SMEs, especially in the BCT. Future societal or governmental incentives could help SMEs improve in this area. Overall, there are a similar number of cases (relatively speaking) in the category ‘extend lifespan of products & its parts’ for the BCT and for the EU sample.

The RECYCLE strategy (EU: 28.4%, BCT: 0%) often necessitates collaboration or establishing a network structure

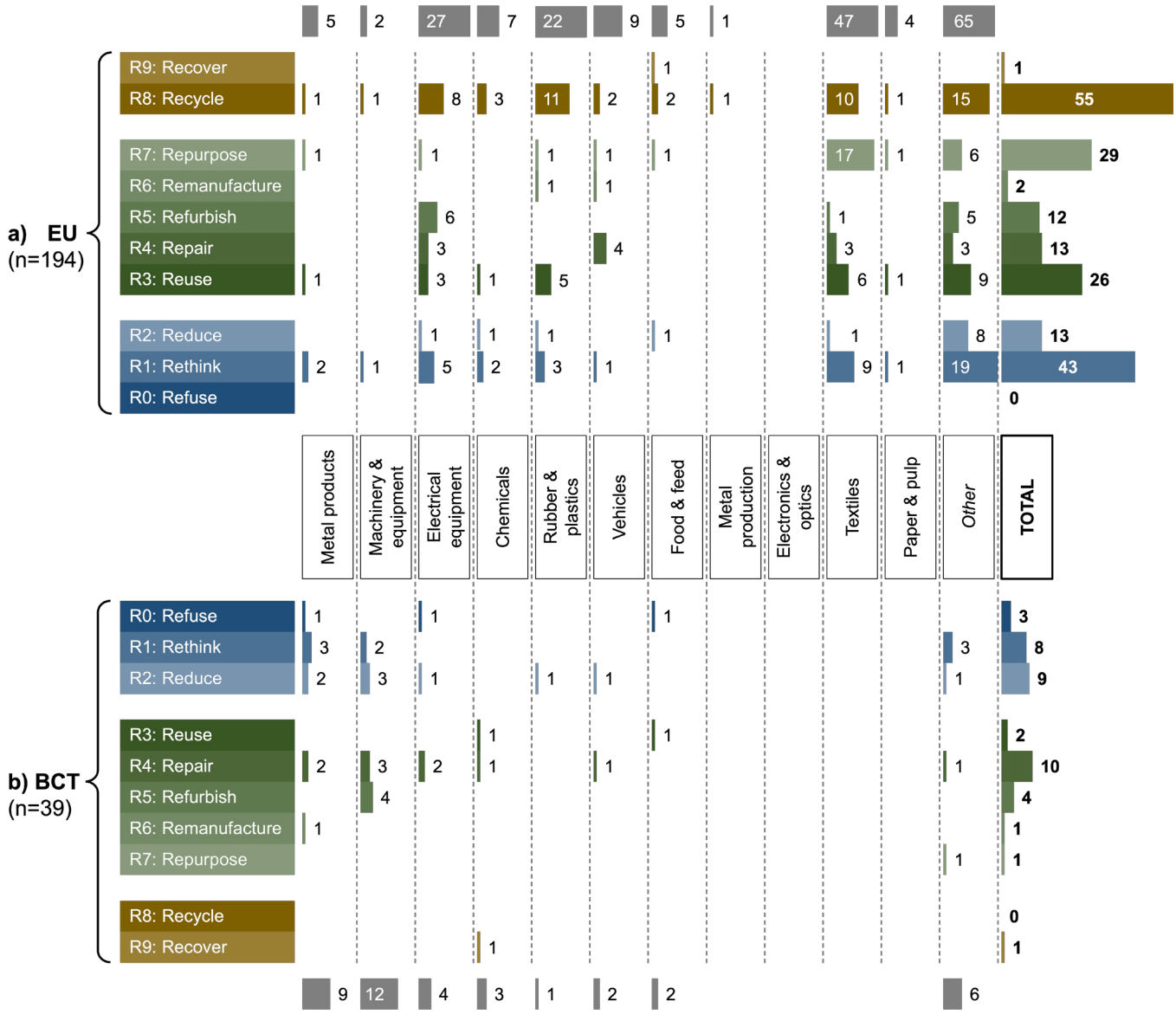

Fig. 3. The 10R Strategies broken down by industry sector, for a) a sample of 194 cases in 172 companies at the EU level (top) and b) a sample of 39 cases (in 39 companies) in the Bergische City Triangle (BCT, bottom). Only the top 11 categories from the mining and manufacturing sector by number of employees for the BCT are depicted, the rest are grouped together as 'other'.

among companies. The data shows no specific business cases or service concepts related to this 10R strategy in the BCT region, although regular industrial waste recycling services are not included. This could suggest that insufficient incentives currently exist for smaller companies to adopt a recycle-specific product or service concept. Facing intense competition, international pressures, and low profit margins in this sector (cf. Fig. 1), SMEs in BCT may need external assistance to pursue this specific 10R strategy. On the other hand, SMEs might already perform such strategies but are not yet communicating their efforts publicly.

RECOVER(Y) (EU: 0.5%, BCT: 2.6%) of resources, in the context of urban or waste mining, is similarly underutilized as remanufacturing strategies in our dataset. This may change in the near future as global resources diminish. Overall, there are a lot more cases (relatively speaking) in the category 'useful application of materials' for the EU and compared to the EU sample.

5.2. Limitations

The correlations presented are based on a database compiled with expert opinion and publicly accessible information. The EU database, in addition to the BCT database, primarily includes information voluntarily provided by companies. Thus, the data may not be entirely independent or objective. Further independent analyses of these correlations are necessary to make objective statements.

Furthermore, we use different data sources for the EU and the BCT, which negatively affects the validity of the results. If a significant number of cases within the BCT were present in the EU database, we would limit our investigation to this one data source only. Since this is not the case, we had to rely on the next best alternative, using different data sources. Accordingly, the results presented here should be regarded as preliminary indications.

6. Summary, conclusion & outlook

This study explores the adoption of circular economy (CE) practices among small and medium-sized enterprises (SMEs) in a German metal products manufacturing hub, comparing it to broader European trends. Using the 10R framework, the research evaluates the prevalence and distribution of resource-efficient strategies among 39 SMEs in the Bergische City Triangle (BCT) and a wider European sample of 194 cases in 172 firms. The findings highlight a significant disparity between the regions, with the BCT SMEs demonstrating lower engagement e.g. in recycling than EU companies. This analysis offers insights for targeted support initiatives to enhance CE practices in SME-dominated regions.

The comparative analysis reveals that while certain CE strategies, such as repair, rethink and reduce, appear well-adopted in the BCT, other resource-intensive practices, such as recycling, are underutilized. This limited implementation suggests that existing barriers, such as insufficient collaboration networks and low profit margins, hinder BCT SMEs from embracing certain CE strategies. The study underscores the need for policy and industry-driven interventions to bridge these gaps, thereby fostering a more sustainable and resilient manufacturing sector. It also highlights the self image of companies reporting CE practices, as the relative distribution of 10R strategies may not reflect the degree to which companies actually engage in individual strategies, but rather the degree to which they are aware of and report them.

To improve CE awareness and adoption, future research should focus on creating centralized support structures and government incentives that could assist SMEs in overcoming economic and logistical barriers. Additionally, expanding collaborative networks within the BCT region could facilitate resource-sharing and material recovery efforts. Continuing these initiatives may position the BCT as a model for CE transformation in SME-intensive regions, while further research on broader implementation barriers will be essential for refining CE policies and practices at the regional and EU levels. Finally, a database that consistently tracks the engagement in 10R strategies by European companies (including those located in the BCT)—to a wider extent than currently existing databases—would provide a valuable resource for decision-making and further research.

Acknowledgments

This research was funded by the European Regional Development Fund (ERDF) as part of the EFRE/JTF NRW 2021-2027 program, under the 'Regio.NRW – Transformation' initiative implemented by the Ministry of Economic Affairs, Industry, Climate Action and Energy of the State of North Rhine-Westphalia (MWIKE).

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