Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

Finanziato nell'ambito del Piano Nazionale di Ripresa e Resilienza PNRR. Missione 4, Componente 2, Investimento 1.3 Creazione di "Partenariati estesi alle università, ai centri di ricerca, alle aziende per il finanziamento di progetti di ricerca di base"

GRINS FOUNDATION

1.3.2 Open-source data platform/s based on multiple data and sources to support companies of different production sectors in the transition processes toward a more decarbonized and circular economy

Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA | GRINS FOUNDATION

Document data	
Title	**Spoke 1** **Work Package 3** **D1.3.2** **OPEN-SOURCE DATA PLATFORM/S BASED ON MULTIPLE DATA AND SOURCES TO SUPPORT COMPANIES OF DIFFERENT PRODUCTION SECTORS IN THE TRANSITION PROCESSES TOWARD A MORE DECARBONIZED AND CIRCULAR ECONOMY**
Owner	**Scuola Superiore Sant'Anna** **Università degli Studi di Bari Aldo Moro** **Università di Catania** **Università degli Studi di Roma Tor Vergata**
Contributor/s	**Scuola Superiore Sant'Anna,** **Università degli Studi di Bari Aldo Moro,** **Università di Catania** **Università degli Studi di Roma Tor Vergata**
Document version	**D1.3.2 – v2**
Last version date	**30/04/2026**

1 Executive summary

This deliverable presents the results of Work Package 3 (WP3), which focuses on the development and application of methodologies and tools to support companies in their transition toward a more decarbonized and circular economy. In particular, the work aims to contribute to the design of an open-source data platform integrating multiple data sources and analytical approaches, enabling more informed and data-driven decision-making processes across different production sectors.

The report adopts an interdisciplinary approach that combines methodological analysis, empirical research, and sector-specific applications. A systematic literature review highlights the central role of Life Cycle Assessment (LCA) and related life cycle–based methodologies in evaluating circular business models, while also identifying key limitations and areas for further methodological development. In parallel, a large-scale survey conducted among companies in Italy and Germany provides insights into the adoption of circular economy practices, the role of sustainability-oriented strategies, and the importance of organizational capabilities and managerial commitment in supporting the transition process.

The findings are further enriched by a set of sectoral case studies, including applications in the tissue paper, plasterboard, and agrifood sectors. These analyses demonstrate how circular economy principles can be operationalized through the integration of technological innovation, data availability, and collaboration across value chains. In particular, the use of advanced tools such as Geographic Information Systems (GIS) and Unmanned Aerial Vehicles (UAV) highlights the potential of high-resolution data to improve environmental assessments and support more precise and context-specific interventions.

Overall, the deliverable underscores that the transition toward circularity is a complex and multifaceted process, requiring the integration of robust analytical methodologies, reliable data infrastructures, and strong organizational capabilities. The development of open-source data platforms emerges as a key enabler to enhance transparency, interoperability, and accessibility of sustainability-related information. The results presented in this report provide valuable insights for researchers, policymakers, and practitioners, contributing to the advancement of knowledge and the practical implementation of circular and sustainable business models.

2 List of Abbreviations

AI - Artificial Intelligence

CE - Circular Economy

CGIS - Canada Geographic Information System

CONOU - National Consortium of Used Oils

DEM - Digital Elevation Model

DQIs -Data Quality Indicators

ENEA - National Agency for New Technologies, Energy and Sustainable Development.

EPA - Environmental Protection Agency

EPCLA - European Platform on LCA

EUROSTAT - Statistical office of the European Union

EVOO - Extra Virgin Olive Oil

FPCM - Fat and Protein Corrected fresh Milk

FU - Functional Unit

GIP - Guidelines for Integrated Production

GIS - Geographic Information Systems

GSD - Geometric Standard Deviation

ILCD - International Reference Life Cycle Data System

ILCD-EL - ILCD Entry-Level

INGV - National Institute of Geophysics and Volcanology

IPCC - Intergovernmental Panel on Climate Change

ISMEA - Institute of Services for the Agricultural and Food Market

ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale

ISTAT - Istituto Nazionale di Statistica Italiano

KDE - Kernel Density Estimation

LCA - Life Cycle Assessment

LCI -Life Cycle Inventory

LCIA - Life Cycle Impact Assessment

LCT - Life Cycle Thinking

LISA - Local Indicators of Spatial Association

LULC - Land Use Land Cover

OOMW - Olive Oil Mill wastewater

OSM - OpenStreetMap

TAN - Total Amount of Nitrogen

TC - Total Cost

TR - Total Revenues

VW - Vegetation Waters

WFLDB - World Food LCA Database

WoS - Web of Science

Table of contents

3 Introduction

The transition toward a more sustainable and circular economic system represents one of the most pressing challenges for contemporary societies. Increasing environmental degradation, resource scarcity, and climate change impacts are driving both policymakers and firms to reconsider traditional linear production and consumption models in favor of more regenerative and resource-efficient approaches. Within this context, the circular economy (CE) has emerged as a key paradigm, promoting the reduction of waste, the extension of product lifecycles, and the valorization of residual resources across value chains.

However, the implementation of circular economy principles at the firm level requires not only strategic commitment but also the availability of robust analytical tools and data-driven approaches capable of supporting decision-making processes. In particular, the integration of Life Cycle Thinking (LCT) and its related methodologies—such as Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and other life cycle–based approaches—has become essential to assess environmental impacts, compare alternative business models, and guide companies toward more sustainable configurations.

In this framework, the activities developed within Work Package 3 (WP3) aim to contribute to the advancement of knowledge and tools supporting the transition toward a decarbonized and circular economy. Specifically, WP3 focuses on the development and application of an open-source data platform integrating multiple data sources, methodologies, and analytical approaches to assist companies operating in different production sectors. The objective is to provide a comprehensive and interoperable framework capable of supporting environmental assessment, strategic planning, and the implementation of circular business models.

The methodological approach adopted in WP3 is inherently interdisciplinary and combines qualitative and quantitative research methods. It includes systematic literature reviews, large-scale surveys targeting companies in different national contexts, sector-specific case studies, and advanced analytical techniques such as Geographic Information Systems (GIS) and remote sensing. These approaches are complemented by the application of life cycle–based methodologies, which enable the evaluation of environmental, economic, and, to some extent, social dimensions of sustainability.

The methodological framework followed in WP3 is represented in Figure 1: showing the main methodologies used to conduct the research, main activities and results as well as the output.

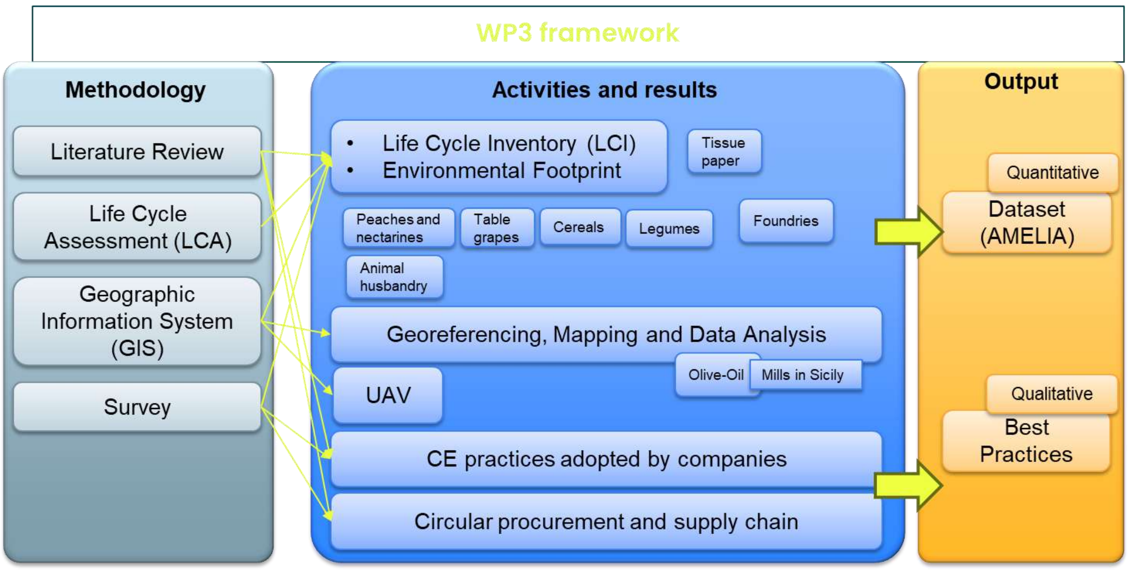


Figure 1: Methodological framework of WP3

More specifically, the work carried out in WP3 is structured around several core research activities. First, an in-depth investigation of the use of LCA and related methodologies to assess circular business models provides a conceptual and methodological foundation for the analysis. Second, a large-scale survey conducted among companies in Italy and Germany offers empirical insights into the adoption of circular economy practices, the role of LCA tools, and the organizational capabilities supporting sustainability transitions.

These analytical efforts are complemented by sectoral applications that demonstrate how circular economy principles can be operationalized in practice. The report includes case studies in sectors such as tissue paper and plasterboard, as well as in the agrifood domain, where innovative approaches based on GIS and UAV technologies are employed to assess resource use, emissions, and circularity opportunities. Additionally, the analysis of circular procurement and supply chain management highlights the importance of integrating sustainability considerations across the entire value chain.

Overall, this deliverable aims to bridge the gap between theoretical frameworks and practical implementation by providing both methodological insights and empirical evidence. By combining data-driven tools, interdisciplinary approaches, and sector-specific analyses, WP3 contributes to enhancing the capacity of companies to design, evaluate, and implement circular and sustainable business models.

The remainder of this document is structured as follows. Chapter 4 presents an investigation of the use of Life Cycle Assessment (LCA) and related methodologies to evaluate business models in a circular economy context, providing a conceptual and methodological foundation for the subsequent analyses. Chapter 5 reports the results of a large-scale survey conducted among companies in Italy and Germany, offering empirical insights into the adoption of circular economy practices, organizational capabilities, and the role of LCA and carbon footprint tools in supporting sustainability strategies.

Chapters 6 and 7 focus on sector-specific applications, illustrating best practices and methodological developments in the tissue paper sector and in the definition of Product Environmental Footprint Category Rules (PEFCR) for the plasterboard sector. These contributions highlight how circular economy principles can be operationalized in different industrial contexts.

Chapters 8 and 9 extend the analysis to the agrifood sector, presenting innovative approaches based on Geographic Information Systems (GIS) and Unmanned Aerial Vehicles (UAV) to assess resource use, emissions, and circularity opportunities. These chapters demonstrate the potential of advanced data-driven tools to support environmental assessment and decision-making processes.

Finally, Chapter 10 examines circular procurement and supply chain management, emphasizing the importance of integrating sustainability considerations across the entire value chain. The document concludes with Chapter 11, which synthesizes the main findings, discusses implications for research and practice, and outlines future research directions

4 Investigation on the use of LCA to assess business models in a circular economy context

4.1 Introduction

Given the well-established link between economic activity and environmental impact (Böckin et al., 2022), companies are increasingly under pressure to reshape their business models (BMs) toward more circular and sustainable configurations (Goffetti et al., 2022). Circular business models (CBMs) represent a practical alternative to traditional linear production systems and are considered a key strategy for advancing the circular economy at the micro level (e.g., Bjørnbet & Vildåsen, 2021; Bocken et al., 2016).

Nonetheless, although CBMs are designed to enhance circularity, they are not automatically more sustainable from an environmental perspective unless they are properly designed and effectively implemented (Blum et al., 2020). While these models can foster more sustainable consumption, they may also trigger rebound or backfire effects (Bączyk et al., 2024). This underscores the importance of evaluating and monitoring CBMs' environmental impacts (Böckin et al., 2022).

The Life Cycle Assessment (LCA) methodology has emerged as the most widely used approach for evaluating Circular Business Models (CBMs) (De Carvalho Araújo et al., 2022). However, knowledge of how to apply LCA most effectively in this context remains fragmented. This has highlighted the need for a structured and comprehensive synthesis capable of guiding both methodological advancement and practical application, and of examining how LCA and other LC-based methodologies—including Life Cycle Sustainability Assessment (LCSA), Life Cycle Costing (LCC), Social LCA (S-LCA), and Business Model LCA (BM-LCA)—have been applied to assess the environmental impacts of CBMs.

The results of the systematic literature review conducted on 60 studies[1] were organized into three main themes:

- LC-based methodologies used to quantify the environmental impact of business models in a circular economy context;
- The purposes for which LC-based methodologies are applied;
- The types of CBMs assessed using LC-based methodologies;

These main themes are discussed below.

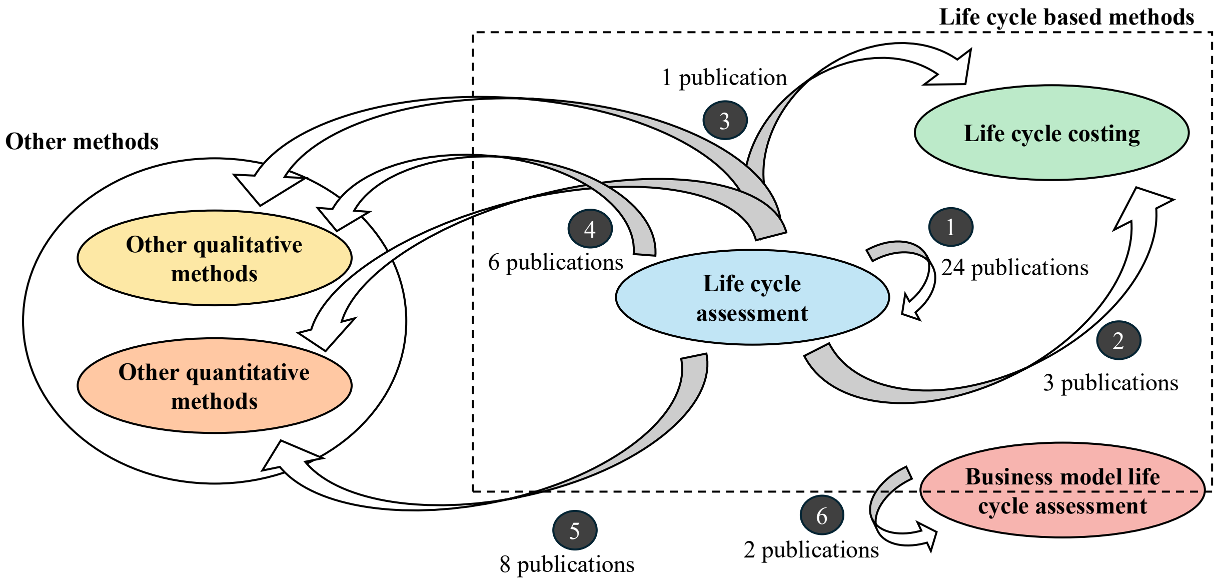
[1] Of the 60 publications reviewed, most (44) present quantitative analyses that apply various LC-based methodologies to assess different types of CBMs, pursuing diverse objectives across multiple sectors. The remaining 16 studies consist of literature reviews, meta-analyses, and qualitative investigations. These works address topics such as sustainability assessment frameworks and tools for business models, the adoption of environmental impact assessment methods, how companies measure and anticipate environmental performance, the role of LCA in CBM implementation, methodological challenges in assessing PSS and industrial symbiosis, and the application of life cycle thinking within specific sectors.

4.2 LC-based methodologies employed

The reviewed publications employed the following combinations of LC-based methodologies (see Table 1):

- **LCA**. LCA offers key advantages for assessing CBMs, enabling companies to compare circular strategies, validate their effectiveness, prevent greenwashing, and avoid problem shifting across the product life cycle (Bjørnbet & Vildåsen, 2021). However, LCA has notable limitations: it requires extensive data, involves multiple impact categories, and often depends on assumptions that introduce uncertainty (Bjørnbet & Vildåsen, 2021; Das et al., 2022). Despite these challenges, LCA remains the most widely used approach for CBM evaluation. Among the reviewed studies, 24 employed LCA—often combined with scenario or sensitivity analyses—to address uncertainties in environmental performance assessment.
- **LCA combined with LCC**. The combination of LCA with LCC provides an integrated approach for assessing both the environmental and economic performance of CBMs. While LCA evaluates environmental aspects and impacts, LCC examines the costs incurred and benefits generated (Böckin et al., 2022; Mura et al., 2024). Among the reviewed studies, three publications combined LCA with LCC.
- **LCA combined with LCC and other qualitative and quantitative methods**. Among the reviewed studies, only one publication combined LCA with LCC, other qualitative methods (i.e., quality function deployment method), and other quantitative methods (i.e., screening life cycle modelling) (Fargnoli et al., 2018).
- **LCA combined with qualitative methods**. LCA is frequently combined with qualitative methods to complement its environmental assessment and support broader analytical objectives. Such methods include the Business Model Canvas, user interviews, focus groups, user trials, surveys, provider interviews, workshops, and sociological assessments. They are used to understand the current context, identify potential CBMs and scenarios, and provide additional insights that enrich the LCA results (Kambanou et al., 2024). Six publications in the reviewed sample adopted these combinations of LCA with qualitative approaches.
- **LCA combined with quantitative methods**. LCA is often combined with quantitative methodologies to enhance its effectiveness and achieve specific objectives. For example, discrete event simulation can provide a more comprehensive evaluation of CBMs (Mann et al., 2022), net present value analysis enables the assessment of economic impacts alongside environmental evaluation (Gonzalez-Salazar et al., 2023), and methods such as surveys, stock-flow models, or energy flow models supply the data needed to strengthen and refine LCA results (Schulz-Mönninghoff et al., 2021). Eight publications in the reviewed sample adopted such combinations of LCA with these quantitative methods.
- **BM-LCA**. BM-LCA shifts the focus from products to BMs, integrating environmental and economic aspects for a systemic assessment. BM-LCA involves two phases: a descriptive phase, which defines goals, system boundaries, environmental impact categories, and characterizes the BMs and associated products; and a coupling phase, which establishes a functional unit based on expected profit, links material and monetary flows, and calculates the production and transactions required to achieve the defined outcomes (Böckin et al., 2022). Two publications in the reviewed sample adopted the BM-LCA (Böckin et al., 2022; Goffetti et al., 2022).

LCA plays a central role: it is primarily used independently, though it is often combined with other methods (Figure 2).



Legend:

1. Life Cycle Assessment (including sensitivity analysis and/or scenario analysis)
2. Life Cycle Assessment (including sensitivity analysis and/or scenario analysis) combined with Life Cycle Costing
3. Life Cycle Assessment (including sensitivity analysis and/or scenario analysis) combined with Life Cycle Costing, other qualitative methods, and other quantitative methods
4. Life Cycle Assessment (including sensitivity analysis and/or scenario analysis) combined with other qualitative methods
5. Life Cycle Assessment (including sensitivity analysis and/or scenario analysis) combined with other quantitative methods
6. Business Model Life Cycle Assessment (including sensitivity analysis)

Figure 2 Relationships among LC-based (Life cycle based) methodologies to assess CBMs

4.3 Purpose of analysis

The environmental impact assessment of CBMs is typically conducted for four main purposes (Table 1):

- To evaluate the environmental performance of individual CBMs across one or more impact categories;
- To compare the environmental impacts of different BMs and CBMs, identifying their relative advantages and disadvantages and determining the most environmentally favourable model;
- To assess the transition from a traditional BM to a CBM, quantifying potential environmental benefits and verifying whether the new CBM reduces overall impacts;
- To support the design and implementation of CBMs by evaluating alternative design options and identifying potential environmental issues.

Among the publications reviewed, nearly half (22 studies, 49%) focused on comparing the environmental impacts of BMs and CBMs. Nine studies (20%) evaluated the transition from a traditional BM to a CBM, while another nine (20%) assessed the environmental impacts of individual CBMs. Only five studies (11%) addressed CBM design and implementation.

Table 1 Purpose of analysis of LC-based methodologies to assess CBMs

Purpose of analysis	Number of publications	Percentage of publications
Compare the environmental impacts of BMs/CBMs	22	49%
Evaluate the transition from a BM to a CBM	9	20%
Evaluate the environmental impacts of singular CBM	9	20%
Design and implement CBMs	5	11%
Total	45	100%

4.4 Types of circular business models

Various types of CBMs have been subject to environmental impact assessment. The most studied are use-oriented Product Service Systems (examined in 25 publications, 45%), while the least studied are circular supplies (studied in 1 publication, 2%) and models promoting sufficiency (not assessed in any study, 0%) (Table 2).

Table 2 Types of CBMs

Type of CBM	Number of publications	Percentage of publications
Use-oriented Product Service Systems. The provider makes the product available in different forms to the user(s), while it retains its ownership and is usually responsible for maintenance, repair and control	25	45%
Result-oriented Product Service Systems. A business activity is outsourced, the provider and the client agree on the delivery of a result, leaving the provider free as to how realise the result	8	15%
Extending product life. This CBM focuses on maintain or improve products and components that would otherwise be discarded, using strategies such as repairing, upgrading, remanufacturing, reselling, and remarketing	7	13%
Industrial symbiosis. This CBM is a process-orientated solution that uses residual outputs from one process as inputs for another, leveraging the geographical proximity between companies	6	11%
Extending resource value. This CBM involves collecting and sourcing materials or resources that would otherwise go to waste, transforming them into new value	4	7%
Product-oriented Product Service Systems. The BM is based on sales, but some services (e.g., maintenance, financing, supply of consumables, professional advice, logistic optimisation) are added	4	7%

Circular supplies. This CBM involves providing renewable, recyclable, or biodegradable resources (including energy) to production and consumption systems	1	2%
Encourage sufficiency. This CBM includes solutions aimed at reducing end-user consumption (e.g., high-quality, durable products; product upgradability; provision of services like warranties and reparability)	0	0%
Total	55	100%

4.5 Conclusion

CBMs hold significant potential to reduce environmental impacts and costs, but their benefits are not automatic. Well-designed CBMs can achieve substantial sustainability gains, yet poorly implemented models may result in higher emissions, rebound effects, or even worse outcomes than conventional business models (Mura et al., 2024). Ex-ante assessments during design and implementation stages are critical for guiding strategic choices, optimising system design, and engaging users effectively, while ex-post evaluations are essential for verifying outcomes, understanding contextual influences, and refining future CBM strategies (Kjaer et al., 2016). Managerial decisions should also consider economic feasibility, logistical constraints, and stakeholder involvement to ensure that CBMs deliver intended benefits.

From a research perspective, notable advancements have been made in CBM evaluation methodologies. LC-based approaches, particularly LCA, remain central but require further standardisation to improve reliability and comparability (Pigosso, 2024). Methodological development should focus on integrating rebound effects, refining guidelines for complex CBMs such as Product-Service Systems, and extending the BM-LCA to incorporate social impacts alongside environmental and economic considerations (Kjaer et al., 2016; Böckin et al., 2022; Mura et al., 2024; Koide et al., 2022). Moreover, future studies should explore underexamined CBMs and sectors, compare multiple models simultaneously, and adopt integrated approaches that capture environmental, economic, and social dimensions in a holistic manner.

5 Survey to understand circular economy practices adopted by companies, with focus on the role of LCA

5.1 Introduction

In a global context strongly influenced by climate change, the scarcity of natural resources, and the massive generation of waste, companies are required to modify their strategies and value creation models in order to increasingly incorporate environmental sustainability into their operations. In particular, it is extremely important to rely on scientific tools to guide sustainability strategies, especially instruments that allow the measurement of the environmental performance of products, systems, and services. In this context, the GRINS project highlights the importance of the Life Cycle Thinking (LCT) approach, which aims to analyse the impacts of products and services throughout their entire life cycle.

Within the activities of the GRINS project, a survey was therefore conducted to investigate how companies address the transition towards greater sustainability and the adoption of circular economy models, as well as how they use tools based on Life Cycle Thinking to support these strategies.

The objective of the survey was to understand the circular economy practices adopted by companies, the strategies they have implemented, and how these strategies are supported by performance measurement processes based on tools such as Life Cycle Assessment (LCA) and Carbon Footprint (CF).

This chapter presents the results of a questionnaire administered to investigate these topics in two contexts, Italy and Germany. The choice to compare these two contexts is strategic, as it allows the analysis of the two largest manufacturing systems in Europe and enables a comparison of corporate choices, as well as an examination of how certain potential drivers for the adoption of environmental sustainability strategies may operate differently.

The research does not simply analyse the adoption of specific practices; rather, it investigates the use of LCA and CF tools as drivers for the adoption of these strategies and as instruments capable of supporting the fine-tuning of business models.

The data collected through this survey can be used to design future interventions and support companies through targeted actions aimed at facilitating their transition towards increasingly circular business models.

5.2 Methods

The research methodology is based on the administration of a questionnaire to a large sample of companies in Italy and Germany, with the aim of enabling a direct comparison between the two national contexts. Specifically, the questionnaire was designed to collect companies' perceptions regarding a wide range of questions on corporate sustainability and the implementation of circular economy strategies.

The questions were divided into sections and included items measured through a 7-point Likert scale. For each item, respondents were asked to indicate their level of agreement or perception with respect to specific statements on a scale from 1 to 7, where 1 represented complete disagreement and 7 represented complete agreement. The use of a 7-point Likert scale allows for a more detailed capture of nuances in respondents' attitudes and behaviours. In some cases, multiple-choice questions were also included to collect factual information, such as the adoption of Life Cycle Assessment (LCA) or Carbon Footprint (CF) tools.

The questionnaire was organised into several sections. The first section concerned the company profile and included questions aimed at identifying the company's geographical location, sector of activity, number of employees, and turnover for the year 2024. The following sections were aimed at investigating companies' sustainable business strategies, their environmental production capabilities, and the organisation's performance in environmental as well as social and economic terms. Specific sections were dedicated to analysing the use of life cycle assessment tools, such as Life Cycle Assessment and Carbon Footprint. Additional sections were designed to investigate potential drivers behind the use of LCA tools, including employees' skills, organisational learning capabilities, and the use of technologies such as artificial intelligence.

Once the questionnaire was developed, it was tested with 30 Italian companies in order to identify possible weaknesses in its structure and to improve the clarity and comprehensibility of some questions.

For the administration of the survey, a sample of companies was created for the Italian population and a separate sample for the German population. The sampling was carried out using a stratified approach, taking into account the number of employees (as a proxy for company size) and the sector to which the companies belong.

The questionnaire was administered through a collaboration with Noto Ricerche, which was responsible for both the sampling process and the distribution of the questionnaire.

A total of 2,003 responses were collected from Italian companies and 2,002 responses from German companies. The analysis of the collected data focused on the use of descriptive statistics; in particular, for each question the absolute frequency and the percentage distribution of responses were calculated and subsequently presented through tables and figures. In the results section, the responses provided by Italian companies and those provided by German companies are presented side by side. This approach made it possible to outline the main trends in each country and to conduct a comparative analysis, highlighting both convergences and divergences.

5.3 Results

5.3.1 Demographics

This section presents the profile of the 2,003 Italian companies that participated in the questionnaire. In particular, the following table shows the Italian companies distributed by geographical area.

Table 3 - Descriptive statistics of the responding companies: geographical distribution of Italian companies

Geographical area

	Frequency	Percentage	Percentage correct	Comulative percentage

Nord Ovest	565	28.2	28.2	28.2
Nord Est	373	18.6	18.6	46.8
Centre	403	20.1	20.1	66.9
Sud	487	24.3	24.3	91.3
Island	175	8.7	8.7	100.0
Total	2003	100.0	100.0	

The following table presents the Italian respondent companies by their respective sector of economic activity. As shown in the table, at the national level, most of the companies that participated in the questionnaire operate in the food and beverage industry and in the textile industry.

Table 4 - Descriptive statistics of the responding companies: economic sector of Italian companies

Economic activity sector

	Frequency	Percentage	Percentage correct	Comulative percentage
(10-11-12) Food and beverage industry	272	13.6	13.6	13.6
(13-14-15) Textile industry. textile products. leather and leather goods	276	13.8	13.8	27.4
(16) Manufacture and processing of wood and products of wood and cork. excluding furniture	159	7.9	7.9	35.3
(17-18) Paper and printing industries	143	7.1	7.1	42.4
(19-20-21) Chemical and pharmaceutical industries	114	5.7	5.7	48.1
(22) Manufacture of rubber and plastic products	118	5.9	5.9	54.0
(26-27) Computer and electronics industry	133	6.6	6.6	60.7
(28) Manufacture of machinery and equipment n.e.c.	152	7.6	7.6	68.2
(29-30) Manufacture of motor vehicles and other transport equipment	103	5.1	5.1	73.4
(31) Manufacture of furniture	140	7.0	7.0	80.4
(32) Other manufacturing activities	185	9.2	9.2	89.6
(33) Repair and installation of machinery and equipment	208	10.4	10.4	100.0
Total	2003	100.0	100.0	

The following table presents the distribution of the responding Italian companies by number of employees.

Table 5 - Descriptive statistics of the responding companies: number of employees of Italian companies

Number of employees (2024)

	Frequency	Percentage	Percentage correct	Comulative percentage
1 – 10 employees	867	43.3	43.3	43.3
11 – 50 employees	446	22.3	22.3	65.6
51 – 250 employees	419	20.9	20.9	86.5
Oltre 250 employees	271	13.5	13.5	100.0
Total	2003	100.0	100.0	

Finally, the table below shows the distribution of the responding Italian companies by annual turnover achieved in 2024.

Table 6 - Descriptive statistics of the responding companies: turnover of Italian companies

Annual turnover (2024)

	Frequency	Percentage	Percentage correct	Comulative percentage
Less than € 2,000,000	738	36.8	36.8	36.8
Between € 2,000,000 and € 10,000,000	688	34.3	34.3	71.2
Between € 10,000,000 and € 50,000,000	315	15.7	15.7	86.9
More than € 50,000,000	262	13.1	13.1	100.0
Total	2003	100.0	100.0	

As regards the German companies, 2,002 companies participated in the questionnaire survey. The following table shows the distribution of the participating German companies by geographical area.

Table 7 - Descriptive statistics of the responding companies: geographical distribution of German companies

Geographical area

	Frequency	Percentage	Percentage correct	Comulative percentage
Schleswig-Holstein (SH)	115	5.7	5.7	5.7
Amburgo (HH)	128	6.4	6.4	12.1
Bassa Sassonia (NI)	142	7.1	7.1	19.2
Brema (HB)	99	4.9	4.9	24.2
Nord Reno-Westfalia (NW)	337	16.8	16.8	41.0
Assia (HE)	90	4.5	4.5	45.5

	Renania-Palatinato (RP)	89	4.4	4.4	50.0
	Baden-Württemberg (BW)	148	7.4	7.4	57.3
	Baviera (BY)	228	11.4	11.4	68.7
	Saarland (SL)	32	1.6	1.6	70.3
	Berlino (BE)	341	17.0	17.0	87.4
	Brandeburgo (BB)	78	3.9	3.9	91.3
	Meclemburgo-Pomerania Occidentale (MV)	36	1.8	1.8	93.1
	Sassonia (SN)	68	3.4	3.4	96.5
	Sassonia-Anhalt (ST)	41	2.0	2.0	98.5
	Turingia (TH)	30	1.5	1.5	100.0
	Total	2002	100.0	100.0	

The following table presents the economic activity sectors of the German companies that participated in the survey.

Table 8 - Descriptive statistics of the responding companies: economic sector of German companies

Economic activity sector

		Frequency	Percentage	Percentage correct	Comulative percentage
	(10-11-12) Food and beverage industry	324	16.2	16.2	16.2
	(13-14-15) Textile industry. textile products. leather and leather goods	174	8.7	8.7	24.9
	(16) Manufacture and processing of wood and products of wood and cork. excluding furniture	118	5.9	5.9	30.8
	(17-18) Paper and printing industries	158	7.9	7.9	38.7
	(19-20-21) Chemical and pharmaceutical industries	143	7.1	7.1	45.8
	(22) Manufacture of rubber and plastic products	107	5.3	5.3	51.1
	(26-27) Computer and electronics industry	304	15.2	15.2	66.3
	(28) Manufacture of machinery and equipment n.e.c.	180	9.0	9.0	75.3

(29-30) Manufacture of motor vehicles and other transport equipment	125	6.2	6.2	81.6
(31) Manufacture of furniture	81	4.0	4.0	85.6
(32) Other manufacturing activities	186	9.3	9.3	94.9
(33) Repair and installation of machinery and equipment	102	5.1	5.1	100.0
Total	2002	100.0	100.0	

The following table shows the German companies that participated in the survey, distributed by number of employees in 2024.

Table 9 - Descriptive statistics of the responding companies: number of employees of German companies

Number of employees (2024)

	Frequency	Percentage	Percentage correct	Comulative percentage
1 – 10 employees	491	24.5	24.5	24.5
11 – 50 employees	593	29.6	29.6	54.1
51 – 250 employees	448	22.4	22.4	76.5
Oltre 250 employees	470	23.5	23.5	100.0
Total	2002	100.0	100.0	

Completing the profile of the German companies, the following table shows their distribution by turnover achieved in 2024.

Table 10 - Descriptive statistics of the responding companies: turnover of German companies

Annual turnover (2024)

	Frequency	Percentage	Percentage correct	Comulative percentage
Less than € 2,000,000	375	18.7	18.7	18.7
Between € 2,000,000 and € 10,000,000	649	32.4	32.4	51.1
Between € 10,000,000 and € 50,000,000	582	29.1	29.1	80.2
More than € 50,000,000	396	19.8	19.8	100.0
Total	2002	100.0	100.0	

5.3.2 Sustainable corporate strategy

An initial section of the questionnaire investigated the adoption of sustainable strategies within the company. In particular, this section explored the adoption of sustainability-oriented strategies, how top management adopts such strategies, and whether the strategies implemented included approaches aimed at promoting the use of tools such as Life Cycle Assessment (LCA) for the evaluation and improvement of business processes.

Specifically, the first question aimed to measure the level of agreement with a series of statements designed to investigate the adoption of environmentally sustainable strategies within the company. Respondents were asked to indicate their level of agreement on a scale from 1 to 7, where 7 represented the highest level of agreement and 1 the lowest level of agreement with the proposed statement. The results are presented in the following table and figure.

Table 11 - Level of agreement with the strategies adopted at the organizational level in Italian companies

	1	2	3	4	5	6	7
My organization aims to contribute to the common good.	2.20%	2.85%	4.44%	12.33%	22.12%	29.61%	26.46%
My organization seeks to create a positive change in the world.	1.95%	2.90%	5.74%	11.33%	20.87%	31.10%	26.11%
My organization aims to achieve outcomes that go beyond its own benefit.	2.05%	3.30%	5.34%	11.28%	20.17%	32.30%	25.56%
My organization remains faithful to its core values even when conflicts arise.	2.15%	3.30%	5.34%	11.28%	20.17%	32.30%	25.56%
My organization is fully committed to its broader goals of social and environmental sustainability.	2.10%	3.25%	5.69%	11.83%	19.27%	33.40%	24.46%
My organization embodies its core values in a credible manner.	2.50%	2.45%	4.94%	11.13%	19.92%	32.65%	26.41%
The broader goals of my organization provide direction in complex situations.	1.60%	2.90%	5.64%	11.73%	22.22%	32.25%	23.66%
The higher-level goals of my organization guide decisions and actions.	2.25%	2.50%	5.34%	9.89%	20.62%	33.70%	25.71%
The broader goals of my organization offer a stable guide in times of rapid change.	1.60%	2.90%	5.64%	11.73%	22.22%	32.25%	23.66%

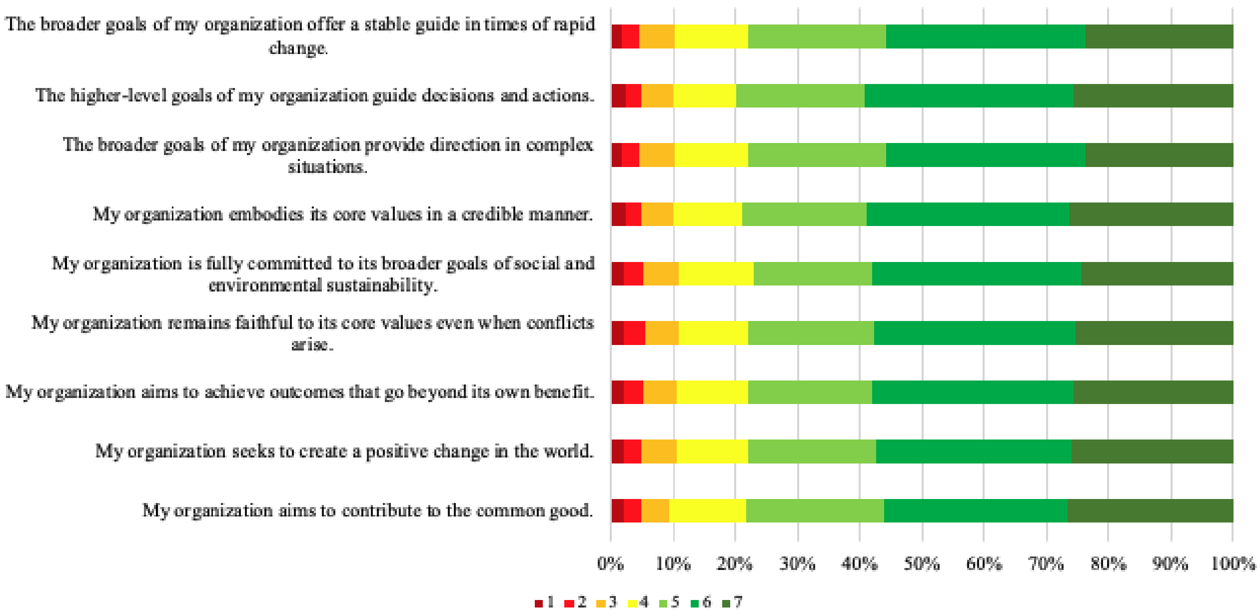


Figure 3 - Level of agreement with the strategies adopted at the organizational level in Italian companies

As shown in the previous table and figure, the majority of the responding Italian companies report taking environmentally sustainable strategies into consideration.

The adoption of environmentally sustainable strategies among German companies is instead presented in the following table and figure.

Table 12 - Level of agreement with the strategies adopted at the organizational level in German companies

	1	2	3	4	5	6	7
My organization aims to contribute to the common good.	2.80%	4.00%	7.84%	12.29%	21.03%	26.32%	25.72%
My organization seeks to create a positive change in the world.	3.10%	4.70%	7.94%	11.09%	19.23%	27.07%	26.87%
My organization aims to achieve outcomes that go beyond its own benefit.	2.50%	4.30%	8.14%	12.79%	20.08%	27.57%	24.63%
My organization remains faithful to its core values even when conflicts arise.	3.00%	4.30%	8.14%	12.79%	20.08%	27.57%	24.63%
My organization is fully committed to its broader goals of social and environmental sustainability.	2.50%	5.29%	8.34%	12.94%	20.03%	25.47%	25.42%
My organization embodies its core values in a credible manner.	2.75%	3.20%	6.54%	12.44%	20.48%	28.52%	26.07%
The broader goals of my organization provide direction in complex situations.	2.60%	3.25%	8.04%	13.79%	21.23%	29.07%	22.03%
The higher-level goals of my organization guide decisions and actions.	2.30%	4.25%	7.19%	12.24%	20.03%	30.07%	23.93%
The broader goals of my organization offer a stable guide in times of rapid change.	2.60%	3.25%	8.04%	13.79%	21.23%	29.07%	22.03%

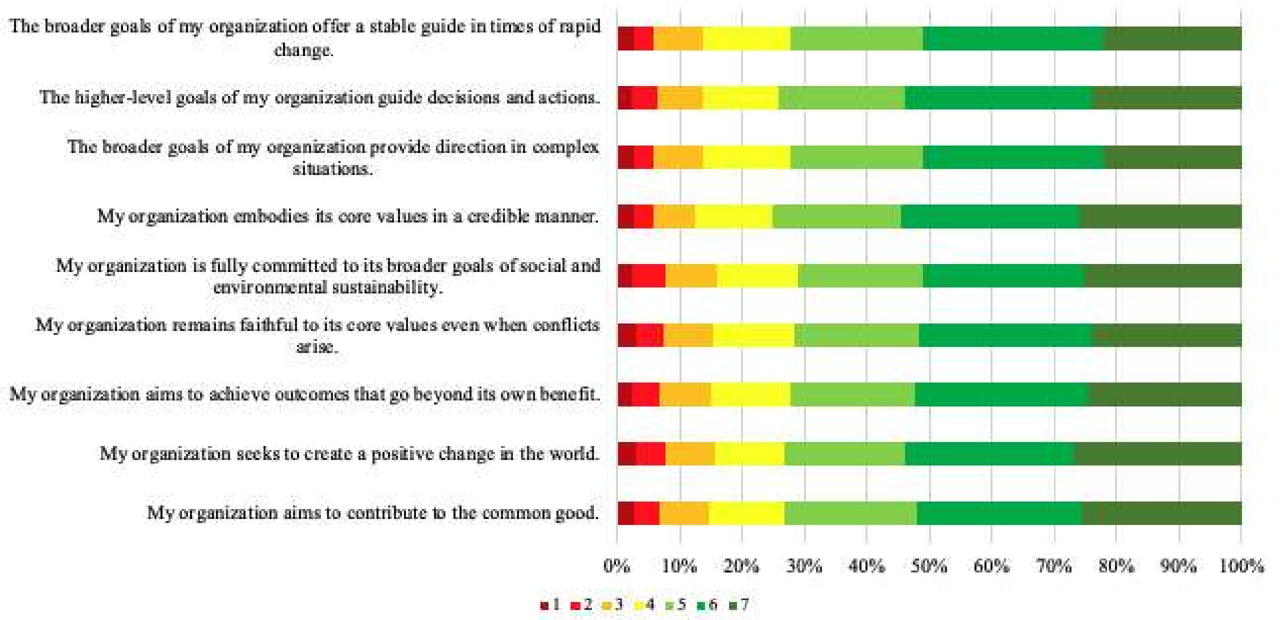


Figure 4 - Level of agreement with the strategies adopted at the organizational level in German companies

Although the values reported by the responding Italian and German companies are very similar, it can be observed that Italian companies more frequently declare that they integrate sustainability objectives and values into their decision-making processes and governance, while German companies show a slightly more cautious distribution on these issues.

A second question in this section aimed to investigate how environmentally sustainable strategies are adopted by the organization's top management. In particular, this set of questions explored whether the organization's top management actively participates in key decisions related to environmental solutions, whether top management periodically evaluates the company's environmental performance, and other similar aspects. As in the previous case, respondents were asked to indicate their level of agreement on a scale from 1 to 7, where 7 represented the highest level of agreement and 1 the lowest level of agreement with the proposed statement.

The responses provided by Italian companies are presented in the following table and figure.

Table 13 - Level of agreement on the integration of sustainability strategies into daily work activities in Italian companies

	1	2	3	4	5	6	7
The top management of my organization actively participates in key decisions related to environmental solutions	1.70%	2.55%	5.49%	12.08%	20.67%	33.55%	23.96%
Top management ensures the integration of strategies into the organization's business processes	1.90%	3.00%	5.99%	10.88%	20.82%	33.95%	23.46%
My organization has set specific objectives aligned with its overarching goals	1.35%	2.10%	4.59%	9.69%	21.27%	34.25%	26.76%
Top management periodically evaluates whether the organization is correctly pursuing its overarching goals	1.80%	2.10%	4.59%	9.69%	21.27%	34.25%	26.76%
My organization adapts its operational activities in line with its overarching goals	1.60%	2.85%	5.54%	12.43%	21.32%	32.75%	23.51%

My organization ensures transparent and proactive communication of its overarching goals to external stakeholders (e.g., local communities, public authorities, etc.)	2.65%	3.74%	4.94%	10.78%	22.52%	31.70%	23.66%

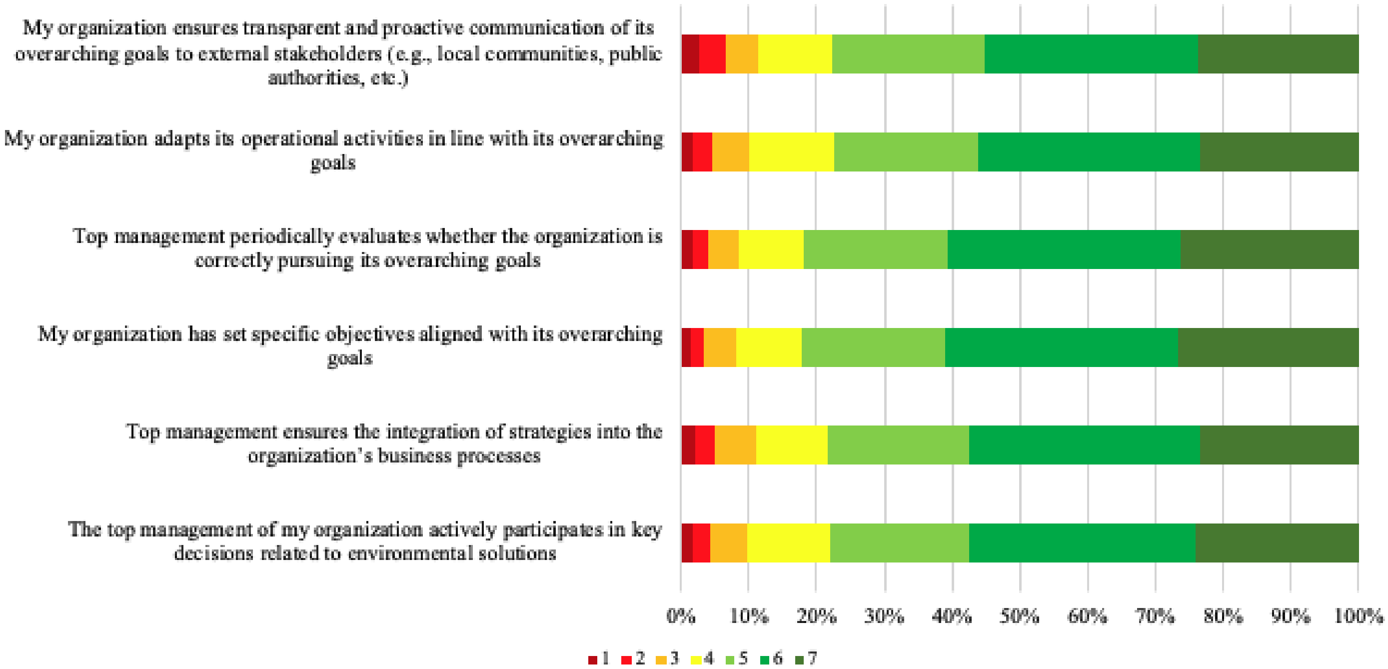


Figure 5 - Level of agreement on the integration of sustainability strategies into daily work activities in Italian companies

The responses provided by the German companies participating in the survey are presented in the following table and figure.

	1	2	3	4	5	6	7
The top management of my organization actively participates in key decisions related to environmental solutions	3.05%	4.80%	8.04%	13.19%	21.18%	25.42%	24.33%
Top management ensures the integration of strategies into the organization's business processes	2.70%	5.19%	7.64%	12.39%	19.48%	28.22%	24.38%
My organization has set specific objectives aligned with its overarching goals	2.50%	4.00%	6.89%	11.99%	20.18%	30.27%	24.18%
Top management periodically evaluates whether the organization is correctly pursuing its overarching goals	2.95%	4.00%	6.89%	11.99%	20.18%	30.27%	24.18%
My organization adapts its operational activities in line with its overarching goals	2.35%	4.65%	6.84%	13.04%	20.53%	29.47%	23.13%
My organization ensures transparent and proactive communication of its overarching goals to external stakeholders (e.g., local communities, public authorities, etc.)	2.85%	4.40%	7.14%	13.19%	22.18%	27.12%	23.13%

Table 14 Level of agreement on the integration of sustainability strategies into daily work activities in German companies

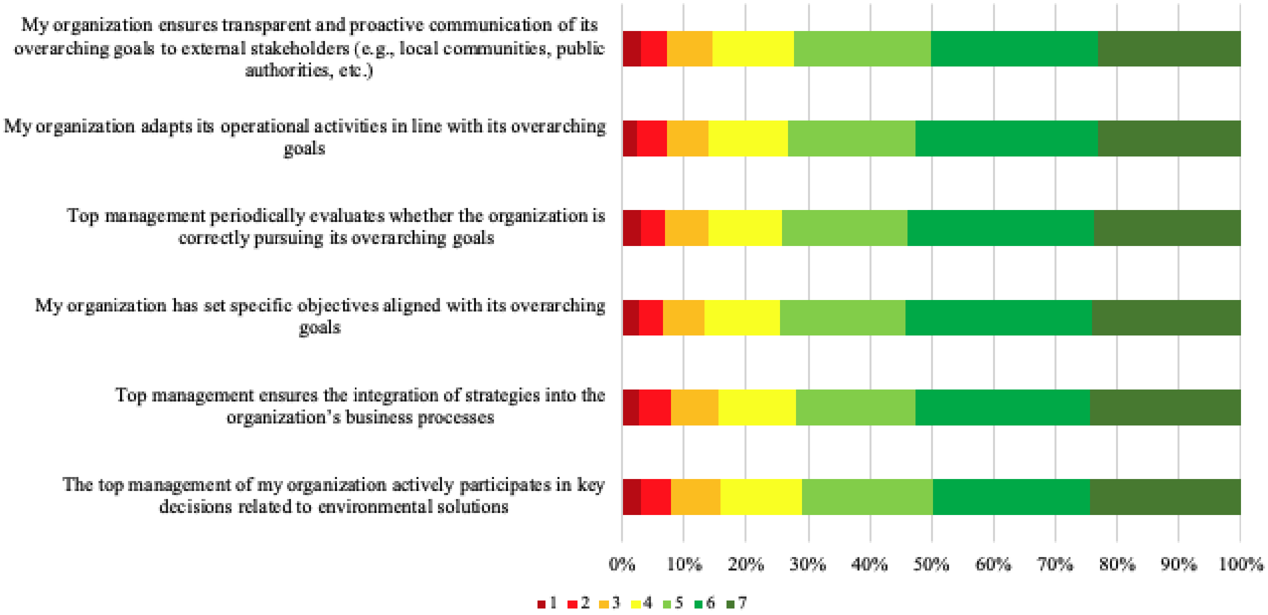


Figure 6 Level of agreement on the integration of sustainability strategies into daily work activities in German companies

Also in this case, the results are very similar between the two groups. However, it can be observed that Italian companies more frequently report that top management participates in, integrates, and evaluates environmental strategies, while German companies show a slightly more cautious distribution on these issues.

Another question in this section aimed to investigate the extent to which companies are influenced by life cycle assessment tools or carbon footprint evaluations in their organizational decisions. In particular, this set of questions included items designed to understand whether the organization considers the results of life cycle assessments in its decision-making processes, whether the organization continuously reviews its objectives also based on life cycle or carbon footprint evaluations, and other similar aspects. Respondents were asked to indicate their level of agreement on a scale from 1 to 7, where 7 represented the highest level of agreement and 1 the lowest level of agreement with the proposed statement.

The results for the Italian companies are presented in the following table and figures.

Table 15 Level of agreement on the influence of Life Cycle Assessment (LCA) or Carbon Footprint tools on the strategies of Italian companies

	1	2	3	4	5	6	7
My organization continuously reviews its overarching goals based on the results of life cycle assessment and/or carbon footprint evaluations	2.40%	3.89%	6.84%	13.08%	21.97%	31.40%	20.42%
My organization considers the results of life cycle assessment and/or carbon footprint evaluations in its decision-making processes	1.75%	3.44%	6.49%	14.08%	21.17%	31.50%	21.57%
The results of life cycle assessment and/or carbon footprint evaluations strongly influence the organization's daily work activities	2.20%	3.30%	6.34%	13.13%	23.17%	33.05%	18.82%
The results of life cycle assessment and/or carbon footprint evaluations are regularly communicated to external stakeholders	1.90%	3.30%	6.34%	13.13%	23.17%	33.05%	18.82%

If the organization's objectives and strategies are revised, the life cycle assessment and/or carbon footprint evaluation are also updated	2.30%	3.74%	6.59%	13.53%	21.72%	32.20%	19.92%
The objectives set by the organization are based on the results of life cycle assessment and/or carbon footprint evaluations	2.00%	3.39%	7.39%	13.88%	21.97%	30.70%	20.67%
The organization's business model is reviewed/adapted also based on life cycle assessment and/or carbon footprint evaluations	1.95%	3.59%	6.59%	13.18%	22.47%	32.10%	20.12%

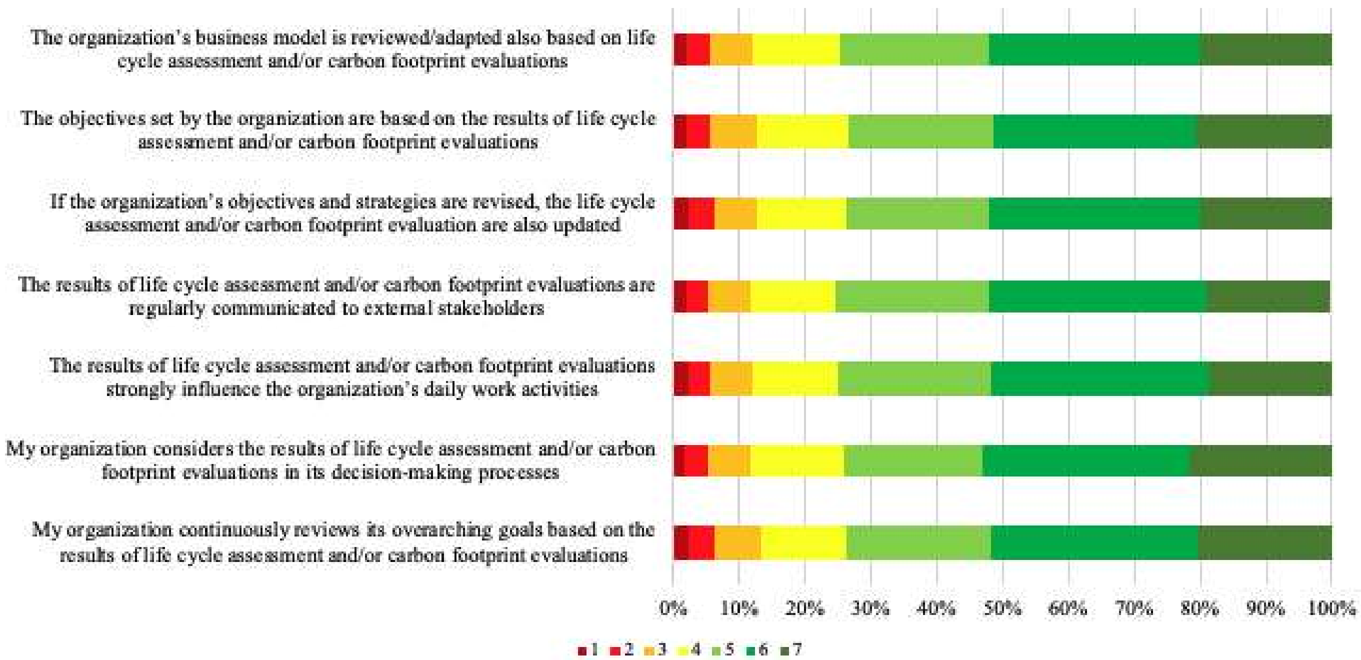


Figure 7 Level of agreement on the influence of Life Cycle Assessment (LCA) or Carbon Footprint tools on the strategies of Italian companies

The results of the German companies responding to the questionnaire are presented in the following table and figure.

Table 16 Level of agreement on the influence of Life Cycle Assessment (LCA) or Carbon Footprint tools on the strategies of German companies

	1	2	3	4	5	6	7
My organization continuously reviews its overarching goals based on the results of life cycle assessment and/or carbon footprint evaluations	3.39%	5.04%	8.14%	14.08%	21.17%	27.11%	21.02%
My organization considers the results of life cycle assessment and/or carbon footprint evaluations in its decision-making processes	3.74%	5.54%	8.14%	13.08%	22.37%	27.06%	20.02%
The results of life cycle assessment and/or carbon footprint evaluations strongly influence the organization's daily work activities	3.44%	4.79%	7.99%	13.33%	22.07%	27.11%	21.22%

The results of life cycle assessment and/or carbon footprint evaluations are regularly communicated to external stakeholders	3.20%	4.79%	7.99%	13.33%	22.07%	27.11%	21.22%
If the organization's objectives and strategies are revised, the life cycle assessment and/or carbon footprint evaluation are also updated	3.05%	4.39%	7.44%	12.13%	22.17%	29.51%	21.27%
The objectives set by the organization are based on the results of life cycle assessment and/or carbon footprint evaluations	4.04%	5.49%	7.94%	12.48%	20.87%	27.86%	21.27%
The organization's business model is reviewed/adapted also based on life cycle assessment and/or carbon footprint evaluations	3.49%	4.89%	8.04%	12.93%	22.22%	27.41%	20.97%

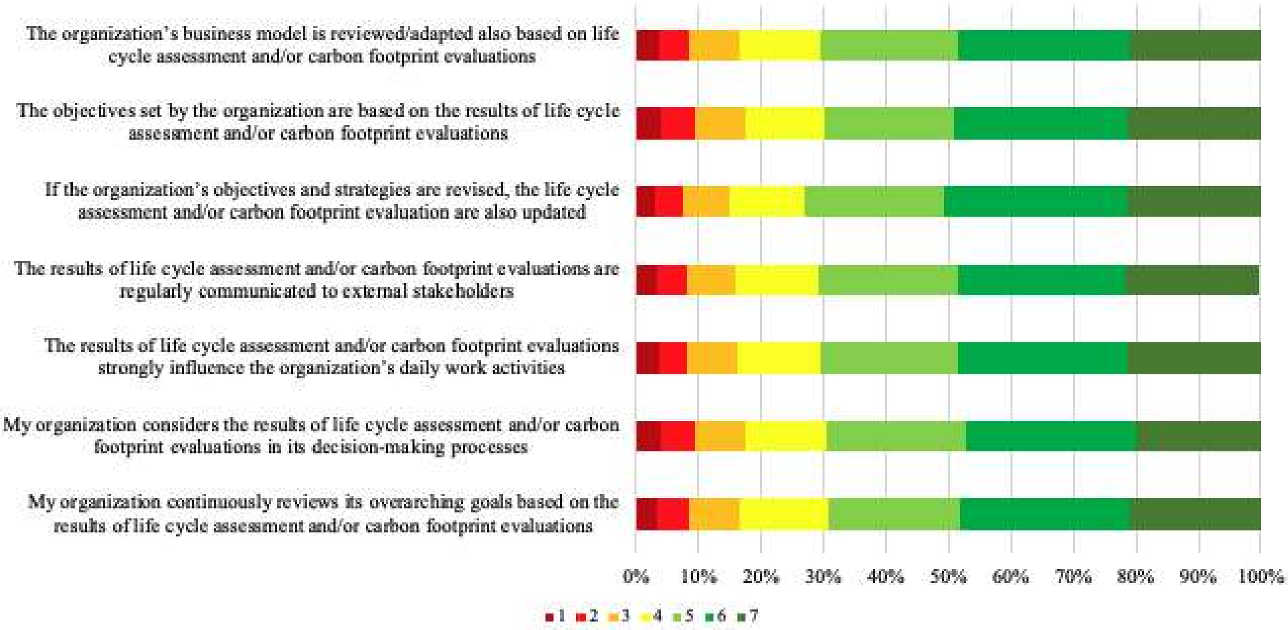


Figure 8 Level of agreement on the influence of Life Cycle Assessment (LCA) or Carbon Footprint tools on the strategies of German companies

From the analysis of the responses provided by Italian and German companies, it can be observed that Italian companies report a higher influence of LCA and CF on corporate decision-making. German companies show similar response levels, but greater emphasis is placed on the use of these tools to update assessments when strategies change.

5.3.3 Environmental proactive capabilities of companies

Another section of the questionnaire aimed to investigate the environmental proactive capabilities of companies. In particular, this section sought to understand the extent to which companies are able to absorb external knowledge, identify external opportunities, and develop and refine internal routines.

The first question aimed to understand the extent to which companies are able to absorb knowledge. In this case, the proposed items aimed to assess how quickly the organization recognizes market changes, the extent to which the organization has the capability to assimilate new technologies and innovations, and whether employees regularly participate in training courses. Respondents were asked to indicate their level of agreement on a scale from 1 to 7, where 7 represented the highest level of agreement and 1 the lowest level of agreement with the proposed statement. The results for Italian companies are presented in the following table and figures.

Table 17 Level of agreement on the organization's ability to absorb external knowledge (Italian companies)

	1	2	3	4	5	6	7
My organization quickly recognizes changes in our market (e.g., competition, regulation, demographics)	1.65%	2.60%	6.09%	12.38%	22.02%	32.05%	23.22%
My organization quickly understands new opportunities to serve our customers	1.50%	3.15%	5.59%	11.48%	20.57%	33.25%	24.46%
My organization has the capability to assimilate new technologies and innovations that are useful or have demonstrated potential	1.55%	2.75%	5.99%	12.18%	20.97%	33.15%	23.41%
Employees regularly participate in training courses	0.75%	2.75%	5.99%	12.18%	20.97%	33.15%	23.41%
Top management encourages the exchange of information and experiences with other companies in the same sector	2.00%	3.94%	6.49%	11.13%	21.47%	32.40%	22.57%
Top management is involved in joint research projects with companies and research institutes outside the sector	1.95%	3.74%	5.79%	12.73%	21.92%	32.05%	21.82%

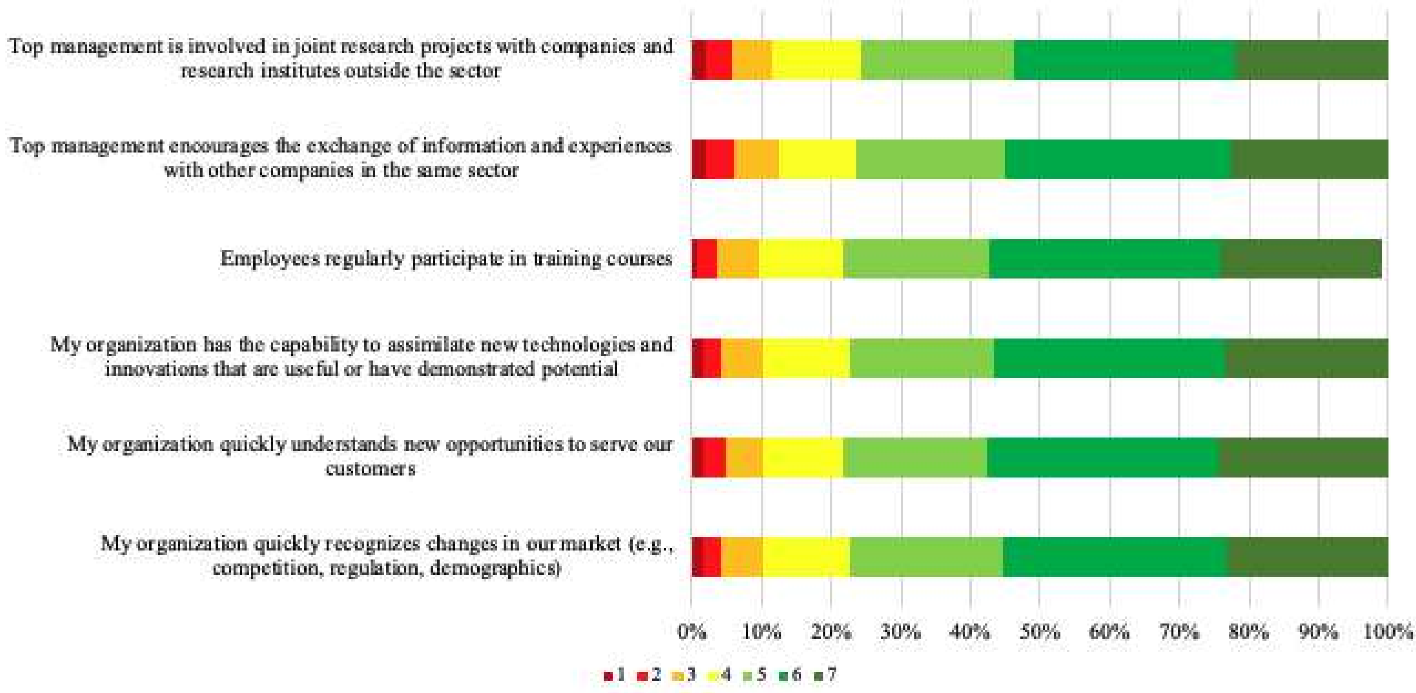


Figure 9 Level of agreement on the organization's ability to absorb external knowledge (Italian companies)

The responses provided by German companies are shown in the following table and figure.

Table 18 Level of agreement on the organization's ability to absorb external knowledge (German companies)

	1	2	3	4	5	6	7
My organization quickly recognizes changes in our market (e.g., competition, regulation, demographics)	1.35%	3.54%	7.09%	13.28%	20.67%	30.25%	23.81%
My organization quickly understands new opportunities to serve our customers	1.45%	3.49%	6.94%	11.43%	23.32%	29.56%	23.81%
My organization has the capability to assimilate new technologies and innovations that are useful or have demonstrated potential	1.55%	3.99%	7.84%	12.88%	20.52%	28.66%	24.56%
Employees regularly participate in training courses	1.85%	3.99%	7.84%	12.88%	20.52%	28.66%	24.56%
Top management encourages the exchange of information and experiences with other companies in the same sector	1.75%	3.69%	7.04%	11.98%	22.67%	29.31%	23.56%
Top management is involved in joint research projects with companies and research institutes outside the sector	3.00%	4.84%	8.34%	14.08%	20.97%	27.31%	21.47%

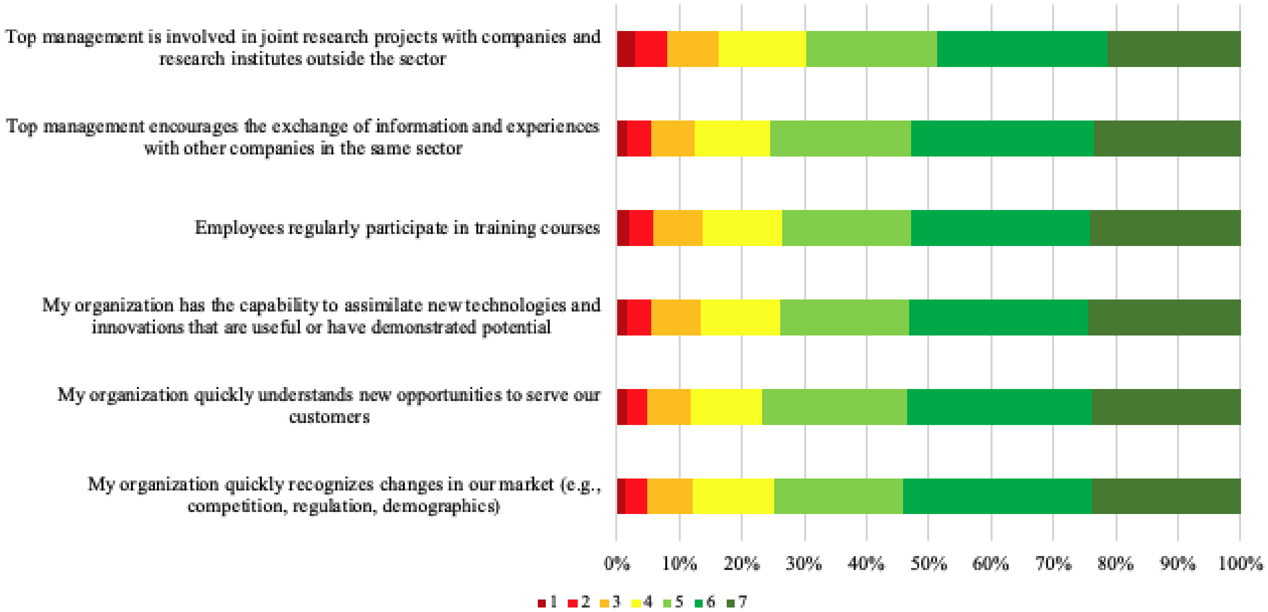


Figure 10 Level of agreement on the organization's ability to absorb external knowledge (German companies)

In this case, very similar performance can be observed between Italian and German companies. The areas in which Italian companies appear to have a more significant advantage compared to German ones are the understanding of opportunities for customers, the assimilation of new technologies, and the engagement in joint research projects.

Another question in this set aimed to investigate the extent to which companies are able to identify opportunities. The objective was, for example, to understand the extent to which the organization encourages the exchange of ideas and concepts between departments, how much top management encourages support between different departments, and how fast internal information exchange takes place.

Respondents were asked to indicate their level of agreement on a scale from 1 to 7, where 7 represented the highest level of agreement and 1 the lowest level of agreement with the proposed statement. The results for Italian companies are presented in the following table and figures.

Table 19 Level of agreement on the organization's ability to identify external opportunities (Italian companies)

	1	2	3	4	5	6	7
Business units and departments strongly interact with higher management levels to acquire new knowledge	1.85%	3.00%	5.49%	11.33%	21.22%	33.55%	23.56%
Different departments in my organization (business units/functional groups such as procurement, legal office, R&D) strongly interact to acquire new knowledge	1.80%	3.15%	6.94%	10.98%	20.67%	34.50%	21.97%
My organization encourages the interdepartmental exchange of ideas and concepts	1.30%	2.30%	4.99%	12.28%	20.77%	35.75%	22.62%
Top management encourages interdepartmental support to solve problems	1.35%	2.30%	4.99%	12.28%	20.77%	35.75%	22.62%
Top management periodically organizes interdepartmental meetings to share new developments, problems, and results	1.55%	3.15%	5.09%	11.63%	21.77%	33.05%	23.76%
In my organization there is a rapid flow of information (e.g., if one business unit obtains important information, it promptly communicates this information to all other departments)	1.05%	2.75%	5.79%	12.78%	21.12%	33.70%	22.82%

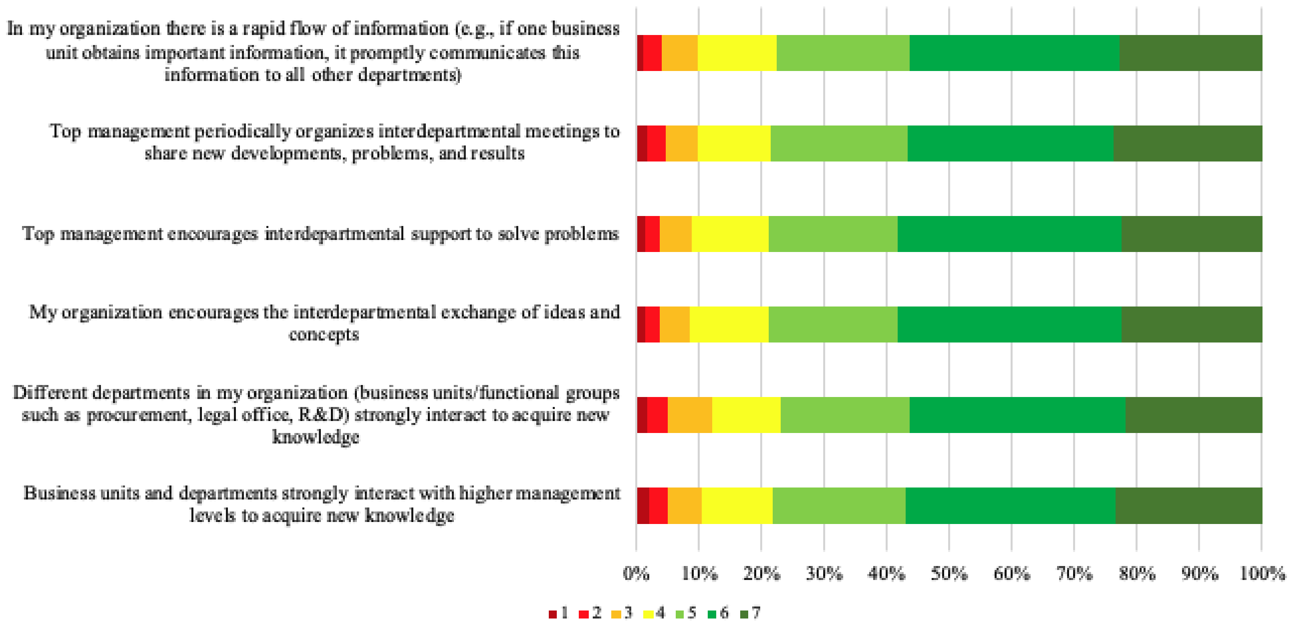


Figure 11 Level of agreement on the organization's ability to identify external opportunities (Italian companies)

The responses provided by German companies are shown in the following table and figure.

Table 20 Level of agreement on the organization's ability to identify external opportunities (German companies)

	1	2	3	4	5	6	7
Business units and departments strongly interact with higher management levels to acquire new knowledge	1.95%	3.69%	6.99%	12.48%	20.47%	30.35%	24.06%
Different departments in my organization (business units/functional groups such as procurement, legal office, R&D) strongly interact to acquire new knowledge	2.15%	4.24%	8.19%	11.83%	21.17%	30.15%	22.27%
My organization encourages the interdepartmental exchange of ideas and concepts	1.95%	3.79%	6.14%	11.93%	23.27%	29.11%	23.81%
Top management encourages interdepartmental support to solve problems	2.05%	3.79%	6.14%	11.93%	23.27%	29.11%	23.81%
Top management periodically organizes interdepartmental meetings to share new developments, problems, and results	2.70%	4.14%	6.79%	13.08%	21.52%	29.36%	22.42%
In my organization there is a rapid flow of information (e.g., if one business unit obtains important information, it promptly communicates this information to all other departments)	1.80%	4.44%	7.44%	12.58%	21.27%	29.51%	22.97%

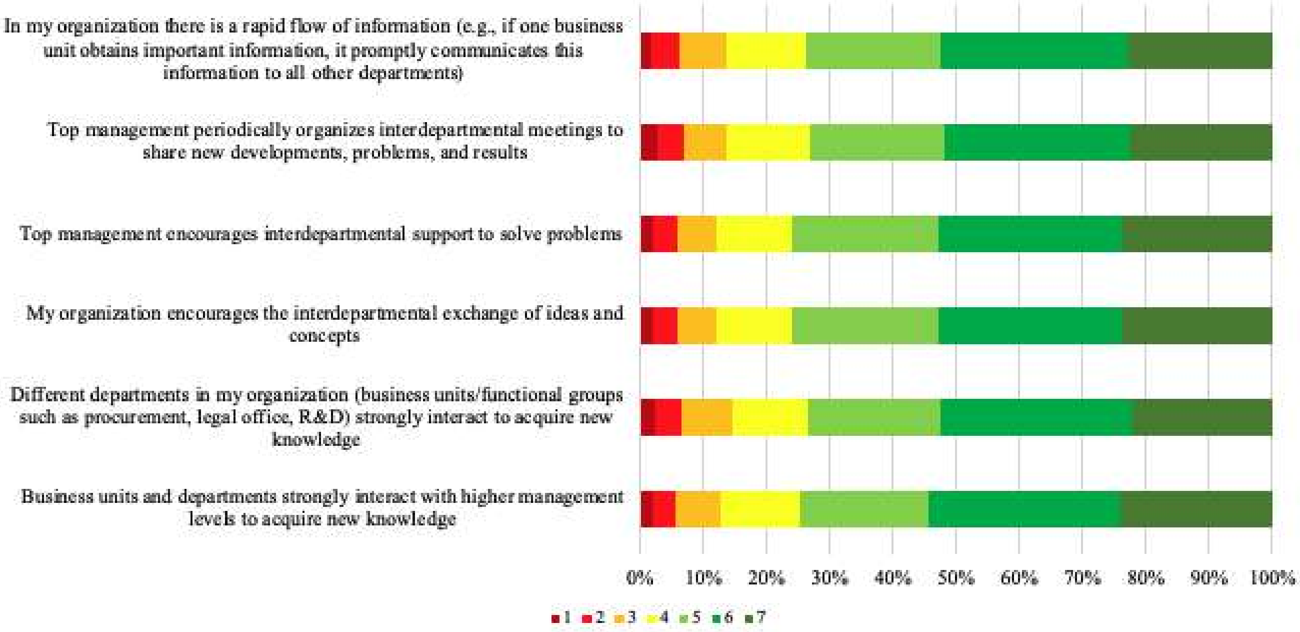


Figure 12 Level of agreement on the organization's ability to identify external opportunities (German companies)

Although the values are again very similar between Italy and Germany, a larger gap can be observed in the organization of regular interdepartmental meetings, where Italy performs better than Germany. More generally, Italian organizations appear to place greater emphasis on creating a collaborative internal environment that supports the identification of new opportunities.

Finally, a last question in this section aimed to investigate the organization's ability to develop and refine internal routines. Respondents were asked to indicate their level of agreement on a scale from 1 to 7, where

7 represented the highest level of agreement and 1 the lowest level of agreement with the proposed statement. The results for Italian companies are presented in the following table and figures.

Table 21 Level of agreement on the organization's ability to develop and refine internal routines (Italian companies)

	1	2	3	4	5	6	7
In my organization, meetings dedicated to new operations and new products are very effective (meeting objectives are defined and achieved, etc.)	1.75%	3.10%	6.39%	12.48%	20.27%	33.95%	22.07%
In my organization, newly acquired knowledge is documented and shared within the organization	1.05%	2.35%	5.54%	12.93%	21.92%	34.00%	22.22%
My organization quickly recognizes the applicability of new knowledge to our business activities	0.95%	2.85%	4.84%	13.23%	22.42%	34.20%	21.52%
In my organization, all stages of the R&D process are connected with the functional activities of engineering, production, and marketing	1.55%	3.44%	6.24%	12.63%	21.42%	34.10%	20.62%
Employees have the capability to structure and use the knowledge collected	1.25%	3.44%	6.24%	12.63%	21.42%	34.10%	20.62%
Employees are able to apply new knowledge in their practical work	1.00%	2.30%	6.14%	12.83%	21.37%	33.15%	23.22%
In my organization, all employees are familiar with the specific procedures and/or operating instructions related to their activities (e.g., operating procedures, standards, etc.)	1.25%	3.10%	5.89%	12.33%	22.07%	33.70%	21.67%
My organization constantly evaluates how to best exploit knowledge (e.g., lesson-learned-based processes, etc.)	1.05%	3.10%	6.59%	11.58%	20.72%	33.75%	23.22%
My organization is able to respond quickly to competitors' actions	1.45%	3.10%	5.99%	11.63%	20.17%	34.15%	23.51%
My organization promptly launches innovative products/services based on new knowledge	1.40%	2.35%	6.24%	11.13%	21.57%	34.30%	23.02%
My organization periodically reviews technologies and adapts them based on new knowledge	1.30%	3.05%	5.69%	11.98%	23.66%	31.50%	22.82%

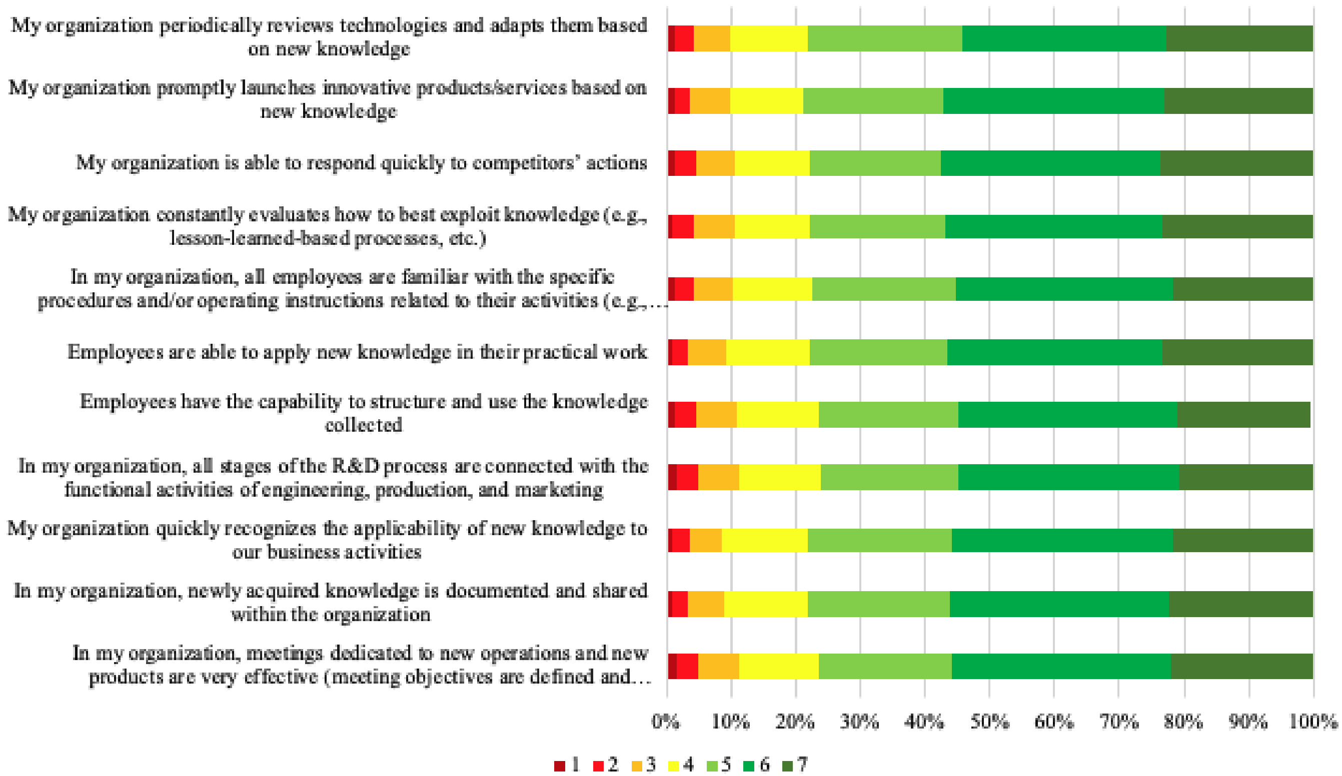


Figure 13 Level of agreement on the organization's ability to develop and refine internal routines (Italian companies)

The responses provided by German companies are shown in the following table and figure.

Table 22 Level of agreement on the organization's ability to develop and refine internal routines (German companies)

	1	2	3	4	5	6	7
In my organization, meetings dedicated to new operations and new products are very effective (meeting objectives are defined and achieved, etc.)	1,70%	4,09%	6,79%	12,03%	23,22%	29,56%	22,62%
In my organization, newly acquired knowledge is documented and shared within the organization	2,05%	4,14%	7,09%	11,93%	21,67%	29,21%	23,91%
My organization quickly recognizes the applicability of new knowledge to our business activities	1,75%	3,99%	6,39%	11,53%	22,52%	28,81%	25,01%
In my organization, all stages of the R&D process are connected with the functional activities of engineering, production, and marketing	1,90%	4,39%	6,39%	13,98%	22,42%	29,71%	21,22%
Employees have the capability to structure and use the knowledge collected	2,20%	4,39%	6,39%	13,98%	22,42%	29,71%	21,22%
Employees are able to apply new knowledge in their practical work	1,95%	2,85%	6,09%	12,33%	21,42%	30,85%	24,51%
In my organization, all employees are familiar with the specific procedures and/or operating instructions	2,60%	4,19%	6,99%	13,18%	22,67%	28,16%	22,22%

related to their activities (e.g., operating procedures, standards, etc.)							
My organization constantly evaluates how to best exploit knowledge (e.g., lesson-learned-based processes, etc.)	2,10%	4,19%	6,89%	12,38%	23,27%	28,31%	22,87%
My organization is able to respond quickly to competitors' actions	1,45%	4,24%	6,74%	12,28%	20,92%	29,76%	24,61%
My organization promptly launches innovative products/services based on new knowledge	2,00%	3,84%	6,79%	12,18%	22,87%	28,71%	23,61%
My organization periodically reviews technologies and adapts them based on new knowledge	1,90%	3,79%	7,69%	12,38%	22,87%	28,66%	22,72%

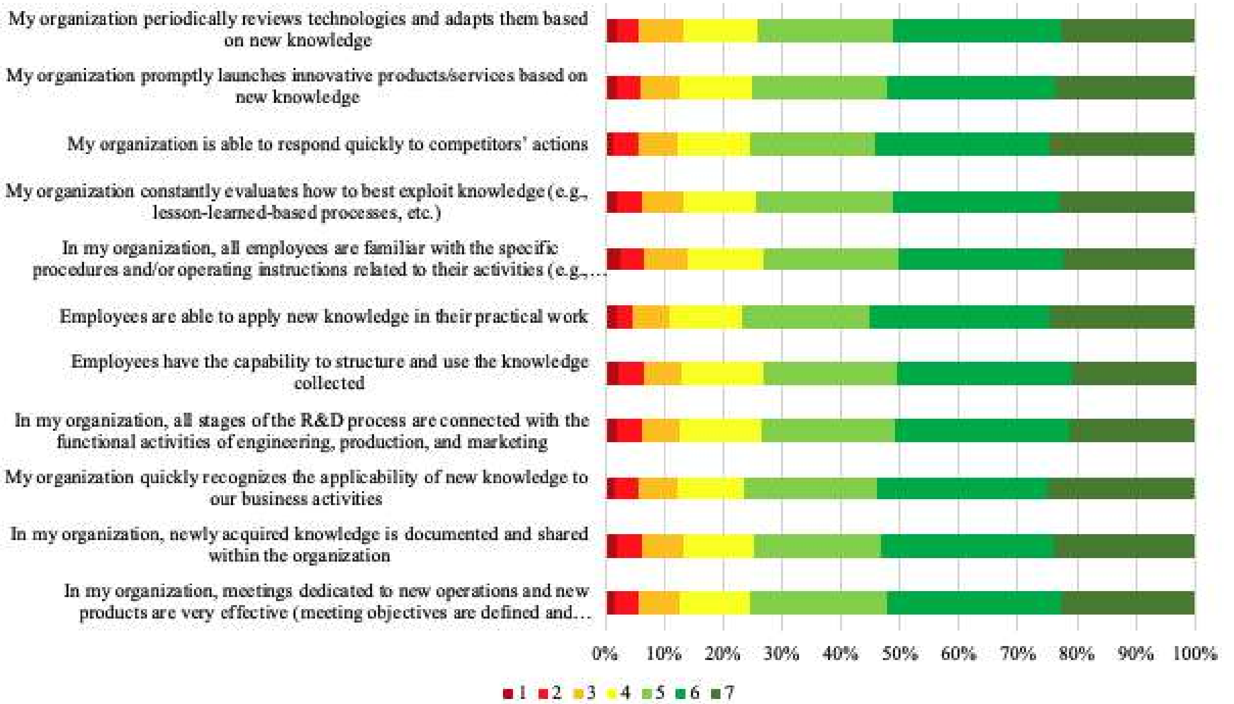


Figure 14 Level of agreement on the organization's ability to develop and refine internal routines (German companies)

The comparison between Italian and German companies in this case shows a slight advantage for Italian companies in developing internal routines. In particular, there appears to be a greater ability to transform knowledge into concrete actions, innovate, and maintain operational procedures that are efficient and up to date.

5.3.4 Organisational performance

The section of the questionnaire related to organizational performance aimed to investigate several aspects. In particular, some questions focused on the environmental performance of the organization, examining aspects such as the level of energy efficiency, water consumption, and waste generation. Other questions concerned the implementation of actions aimed at reducing impacts related to CO_2 emissions. Additional questions in the section investigated the environmental performance of organizations in terms of circular economy practices, such as the adoption of circular business models. The section also aimed to examine the company's economic and financial performance, as well as its corporate reputation.

The first question aimed to investigate the company's environmental performance in recent years in several areas, such as energy efficiency, material use, the quality and quantity of atmospheric emissions, water consumption, and waste generation. The responses are presented in the following table and refer to the Italian respondents.

Table 23 Level of agreement on the organization's environmental performance (Italian companies)

	1	2	3	4	5	6	7
Energy efficiency	1.40%	3.20%	6.54%	12.83%	22.67%	31.20%	22.17%
Efficiency in the use of materials (e.g., chemicals, raw materials)	1.30%	2.90%	5.79%	14.53%	23.07%	32.50%	19.92%
Quality/quantity of atmospheric emissions	2.10%	3.74%	7.14%	13.73%	21.82%	31.05%	20.42%
Quality/quantity of wastewater	2.00%	3.15%	7.69%	14.73%	22.62%	32.60%	17.22%
Water consumption	2.25%	3.15%	7.69%	14.73%	22.62%	32.60%	17.22%
Waste production	1.90%	3.30%	7.94%	14.28%	23.41%	30.50%	18.67%

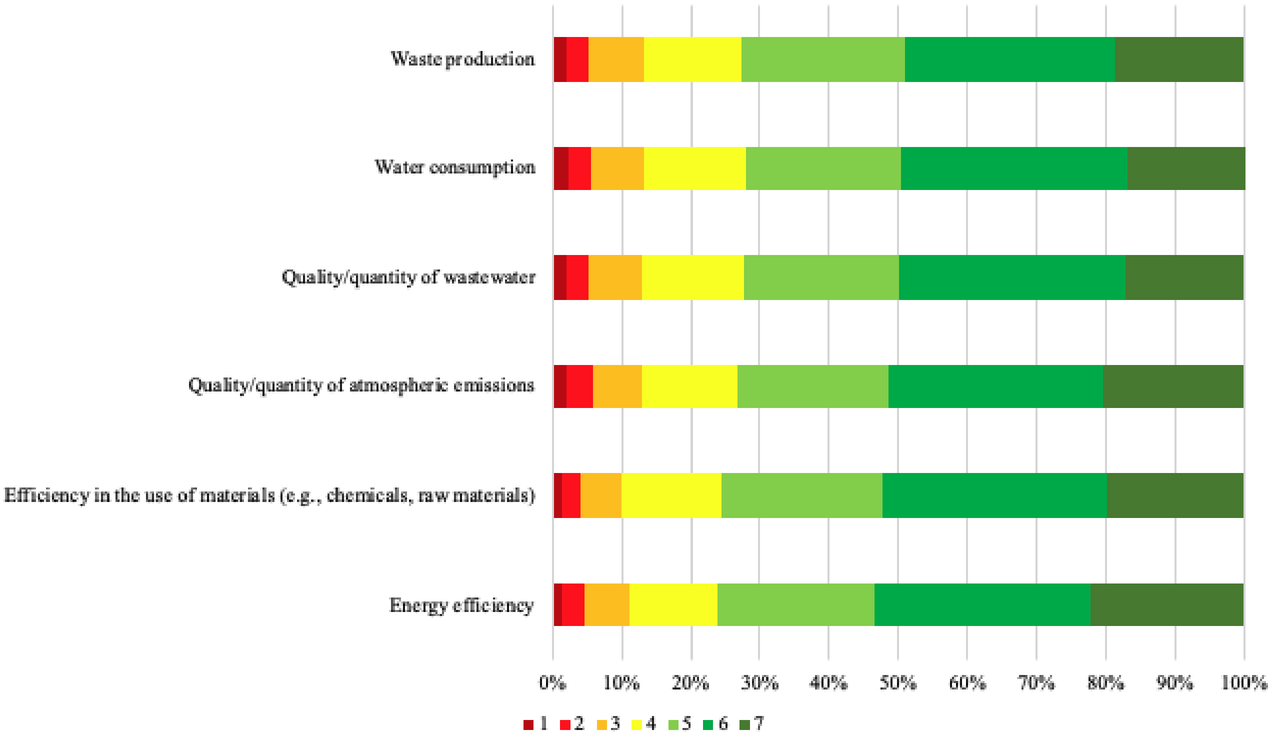


Figure 15 Level of agreement on the organization's environmental performance (Italian companies)

The responses provided by German companies are shown in the following table and figure.

Table 24 Level of agreement on the organization's environmental performance (German companies)

	1	2	3	4	5	6	7
Energy efficiency	1.65%	4.34%	7.84%	14.63%	22.97%	26.71%	21.87%
Efficiency in the use of materials (e.g., chemicals, raw materials)	1.95%	3.89%	7.79%	14.18%	23.51%	27.91%	20.77%

Quality/quantity of atmospheric emissions	1.50%	3.79%	8.34%	14.53%	23.32%	27.66%	20.87%
Quality/quantity of wastewater	2.00%	3.89%	7.14%	14.83%	23.46%	27.71%	20.97%
Water consumption	1.85%	3.89%	7.14%	14.83%	23.46%	27.71%	20.97%
Waste production	2.05%	3.94%	7.69%	15.73%	23.66%	27.11%	19.82%

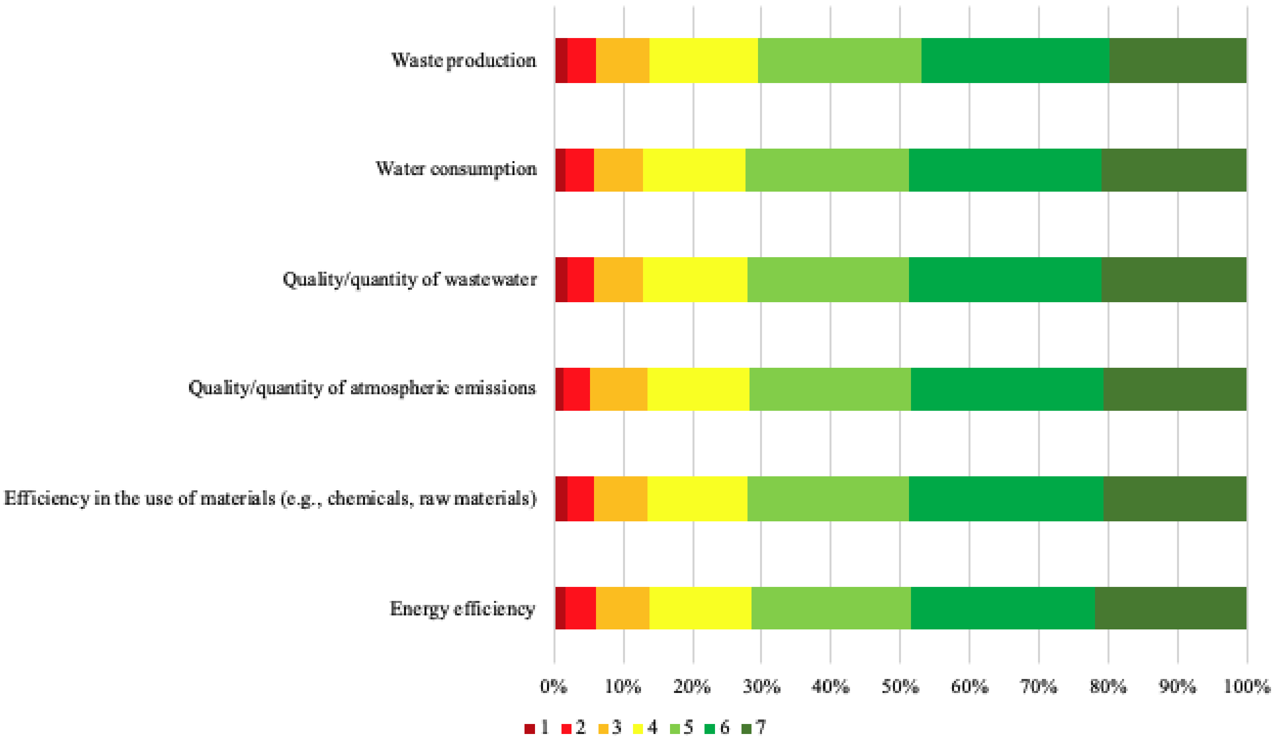


Figure 16 Level of agreement on the organization's environmental performance (German companies)

Also in this case, the responses provided by Italian and German companies are very similar; however, some differences can be observed. For example, in terms of energy performance, Italian companies perceive slightly better performance than German companies, while regarding the use of water resources, German companies perceive slightly better performance than Italian ones.

Another question aimed to investigate how respondents evaluate their company's performance in terms of biodiversity and climate change. In particular, the level of agreement was assessed with several statements regarding the extent to which the organization is committed to reducing impacts on local ecosystems, protecting ecosystem services, and integrating biodiversity protection into strategic planning. Additional statements for which respondents were asked to indicate their level of agreement focused on the company's commitment to reducing CO_2 emissions. Also in this case, the responses from Italian companies are presented in the following table and figure.

Table 25 Level of agreement on the company's performance in terms of biodiversity and climate change mitigation/adaptation (Italian companies)

	1	2	3	4	5	6	7

Reduction of impacts on local ecosystems, natural habitats, and biodiversity (flora and fauna species)	1.15%	3.05%	6.69%	15.23%	22.67%	32.10%	19.12%
Protection of ecosystem services on which the organization depends (e.g., water sources, fertile soil, clean air, etc.)	1.15%	2.60%	5.94%	14.18%	22.22%	34.15%	19.77%
Reduction of land consumption (land use) and protection of groundwater resources	1.95%	3.44%	6.29%	13.43%	23.22%	32.15%	19.52%
Integration of biodiversity protection into strategic planning	1.65%	3.74%	7.39%	13.93%	21.47%	32.70%	19.12%
Reduction of the carbon footprint of products, services, or processes	1.00%	3.74%	7.39%	13.93%	21.47%	32.70%	19.12%
Measurement of the carbon footprint of the organization or its products/services (GHG Protocol, ISO 14067, ISO 14044, PAS 2050)	2.00%	3.89%	7.94%	13.83%	20.92%	32.15%	19.27%
Development and implementation of a decarbonization plan or strategy aligned with the objectives of the Paris Agreement	1.95%	3.30%	7.04%	14.73%	20.97%	32.55%	19.47%
Reduction of exposure to climate impacts (e.g., modification of facilities and business practices to adapt to climate change)	2.30%	3.59%	7.04%	13.23%	23.07%	32.30%	18.47%
Risk management through insurance	1.35%	2.20%	6.09%	13.03%	22.77%	34.10%	20.47%
Modification of activities and/or resources used to adapt to climate change	1.30%	3.00%	6.59%	14.08%	22.22%	32.45%	20.37%
Restoration of assets to their original condition following damages related to climate change	1.20%	3.99%	7.19%	14.83%	21.97%	33.25%	17.57%

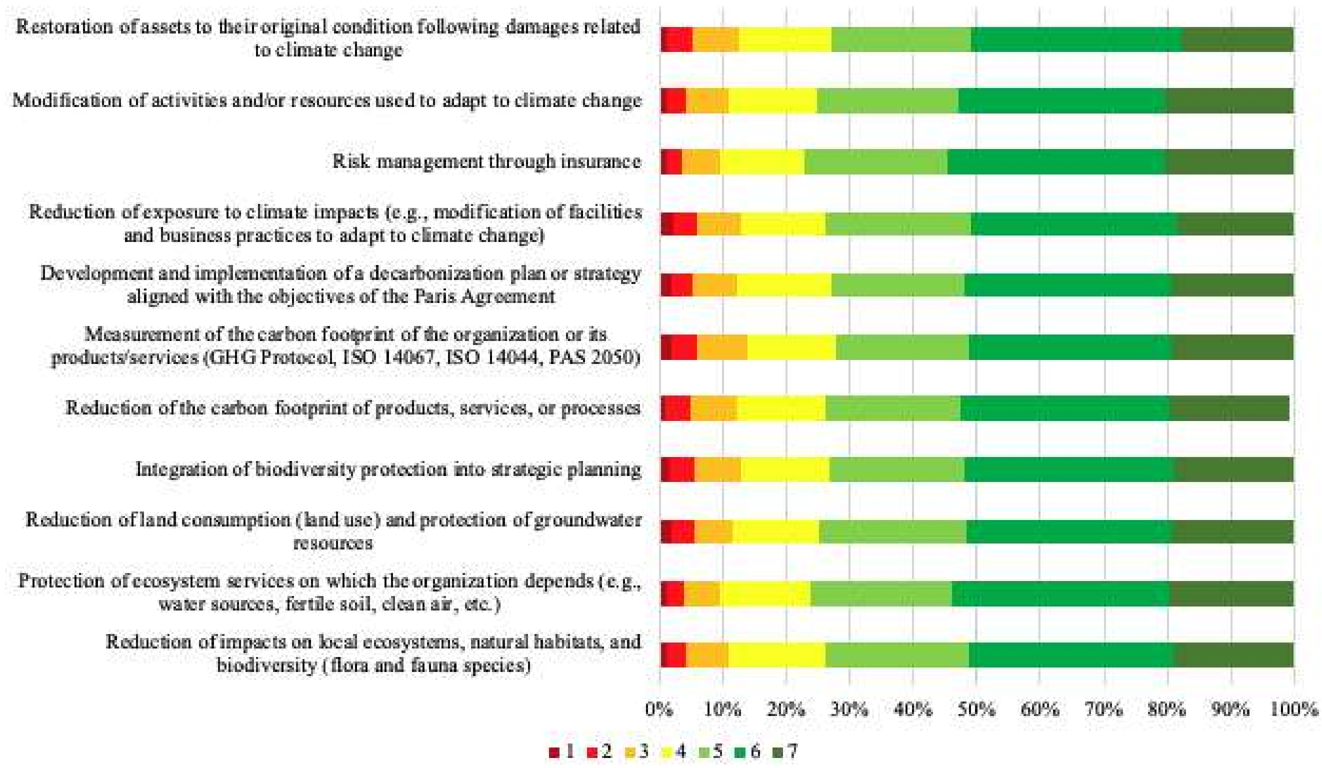


Figure 17 Level of agreement on the company's performance in terms of biodiversity and climate change mitigation/adaptation (Italian companies)

The responses provided by German companies are shown in the following table and figure.

	1	2	3	4	5	6	7
Reduction of impacts on local ecosystems, natural habitats, and biodiversity (flora and fauna species)	2.10%	4.19%	6.74%	15.48%	21.72%	29.11%	20.67%
Protection of ecosystem services on which the organization depends (e.g., water sources, fertile soil, clean air, etc.)	2.40%	4.74%	7.24%	14.63%	23.27%	28.41%	19.32%
Reduction of land consumption (land use) and protection of groundwater resources	1.70%	4.19%	7.54%	14.18%	23.17%	28.11%	21.12%
Integration of biodiversity protection into strategic planning	2.20%	4.94%	9.14%	14.73%	22.07%	28.46%	18.47%
Reduction of the carbon footprint of products, services, or processes	1.70%	4.94%	9.14%	14.73%	22.07%	28.46%	18.47%
Measurement of the carbon footprint of the organization or its products/services (GHG Protocol, ISO 14067, ISO 14044, PAS 2050)	2.30%	3.99%	8.14%	15.13%	23.91%	27.71%	18.82%
Development and implementation of a decarbonization plan or strategy aligned with the objectives of the Paris Agreement	2.30%	4.69%	8.99%	15.58%	21.52%	26.81%	20.12%

Reduction of exposure to climate impacts (e.g., modification of facilities and business practices to adapt to climate change)	2.00%	3.89%	8.49%	14.73%	22.22%	27.61%	21.07%
Risk management through insurance	1.95%	4.44%	7.09%	14.58%	21.42%	26.76%	23.76%
Modification of activities and/or resources used to adapt to climate change	2.15%	3.84%	7.19%	14.43%	22.47%	27.26%	22.67%
Restoration of assets to their original condition following damages related to climate change	2.25%	4.14%	6.94%	14.93%	23.17%	27.21%	21.37%

Table 26 Level of agreement on the company's performance in terms of biodiversity and climate change mitigation/adaptation (German companies)

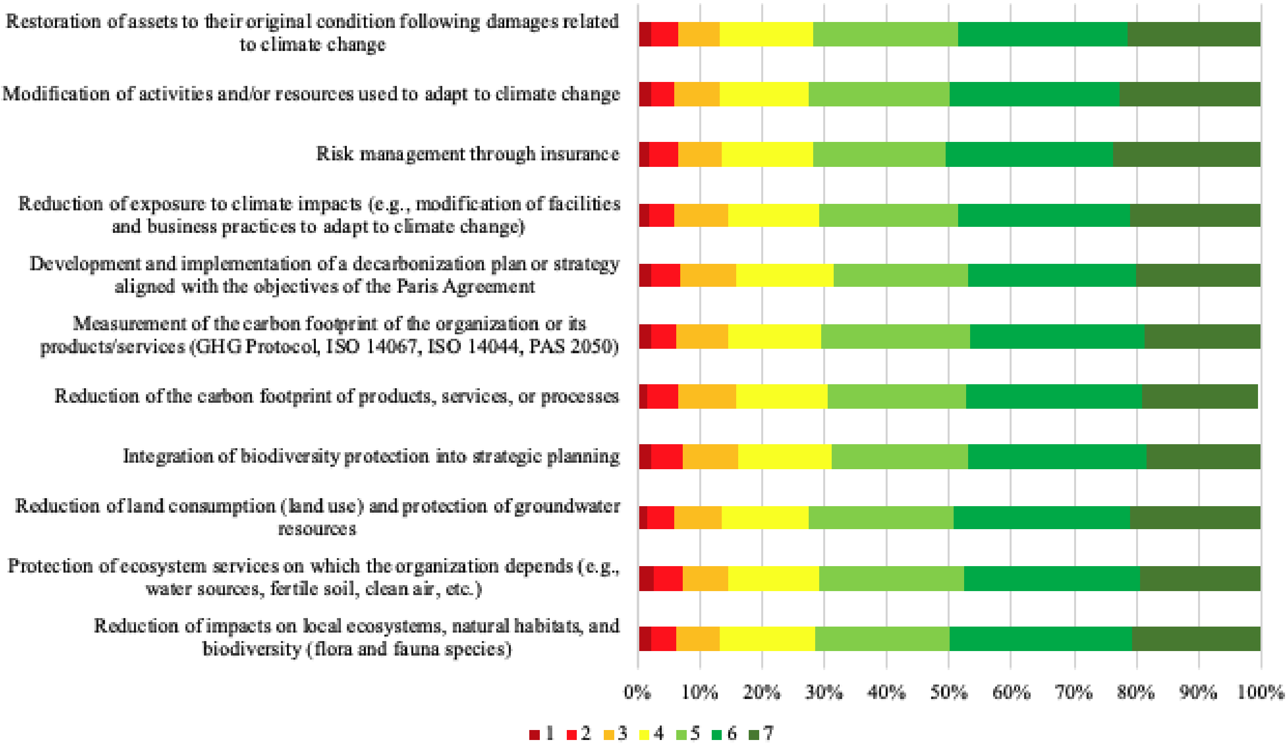


Figure 18 Level of agreement on the company's performance in terms of biodiversity and climate change mitigation/adaptation (German companies)

Also in this case, the responses suggest that Italian companies show greater overall confidence in their environmental performance, with slightly higher average scores on almost all the actions investigated, especially those related to the implementation of decarbonization strategies.

Another set of questions aimed to investigate the company's performance in terms of circular economy. In this context, aspects such as strategic collaborations for the circular economy along the value chain were examined, as well as the extent to which the organization encourages the co-creation of circular products and services through relationships with partners, and how circular the value proposition of the company's product and service portfolio is. Also in this case, the responses provided by Italian companies are reported in the following table and figure.

Table 27 Level of agreement on the company's performance in terms of circularity (Italian companies)

	1	2	3	4	5	6	7

My organization is transforming into a circular organization	1.85%	2.50%	5.69%	13.58%	24.26%	33.55%	18.57%
My organization aims to create value by adapting our product/service portfolio towards a more circular approach	1.45%	3.30%	5.99%	13.13%	22.77%	32.55%	20.82%
My organization promotes cooperation with other market actors to close or slow material cycles	1.40%	2.50%	6.09%	12.53%	23.07%	35.00%	19.42%
My organization fosters circular strategic collaborations along the entire value chain, focusing on long-term efficiency	1.35%	3.49%	6.04%	14.63%	22.97%	31.75%	19.77%
My organization encourages the co-creation of new circular products or services with our partners	1.55%	3.49%	6.04%	14.63%	22.97%	31.75%	19.77%
My organization supports collaboration with public and private partners, including end users, to optimize the overall value of our offering	1.60%	3.49%	6.74%	12.23%	23.56%	32.55%	19.82%
My organization aims to ensure the availability and reliability of data on material flows within value chains in order to close loops	1.30%	2.55%	6.59%	14.63%	22.62%	33.60%	18.72%
My organization promotes resource efficiency by engaging actors on both the supply and demand sides, in order to expand the network of circularity	1.45%	2.70%	5.64%	12.98%	22.62%	35.00%	19.62%
My organization aims to transform its resources and capabilities in order to become more circular	1.60%	2.90%	5.99%	12.08%	22.57%	34.50%	20.37%

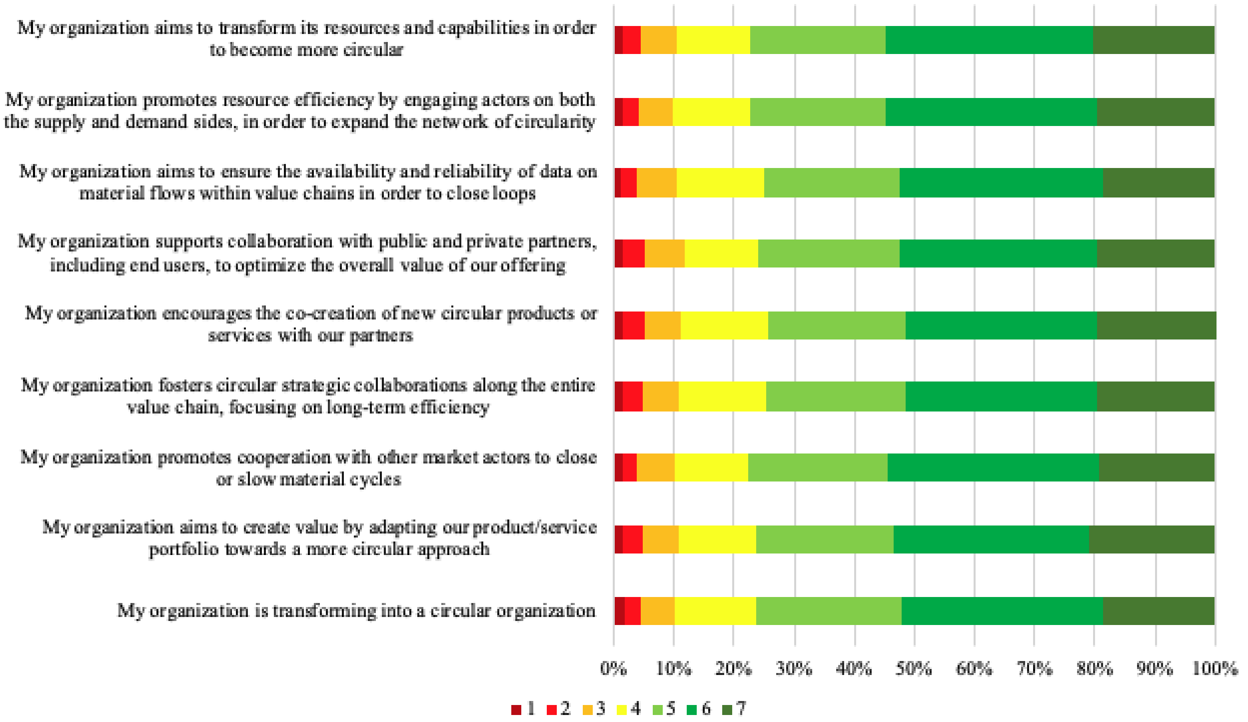


Figure 19 Level of agreement on the company's performance in terms of circularity (Italian companies)

The responses provided by German companies are shown in the following table and figure.

Table 28 Level of agreement on the company's performance in terms of circularity (German companies)

	1	2	3	4	5	6	7
My organization is transforming into a circular organization	3.05%	4.44%	7.64%	14.08%	23.12%	27.16%	20.52%
My organization aims to create value by adapting our product/service portfolio towards a more circular approach	2.00%	3.49%	7.69%	12.98%	23.91%	28.81%	21.12%
My organization promotes cooperation with other market actors to close or slow material cycles	1.65%	5.04%	8.19%	13.98%	23.41%	27.26%	20.47%
My organization fosters circular strategic collaborations along the entire value chain, focusing on long-term efficiency	2.20%	4.44%	7.14%	14.23%	22.82%	29.41%	19.77%
My organization encourages the co-creation of new circular products or services with our partners	2.25%	4.44%	7.14%	14.23%	22.82%	29.41%	19.77%
My organization supports collaboration with public and private partners, including end users, to optimize the overall value of our offering	2.55%	4.44%	7.44%	12.98%	23.02%	28.86%	20.72%
My organization aims to ensure the availability and reliability of data on material flows within value chains in order to close loops	2.40%	4.44%	8.04%	13.23%	24.41%	26.36%	21.12%
My organization promotes resource efficiency by engaging actors on both the supply and demand sides, in order to expand the network of circularity	2.55%	3.54%	7.99%	13.03%	22.92%	30.15%	19.82%
My organization aims to transform its resources and capabilities in order to become more circular	1.80%	4.04%	6.84%	12.73%	24.21%	29.91%	20.47%

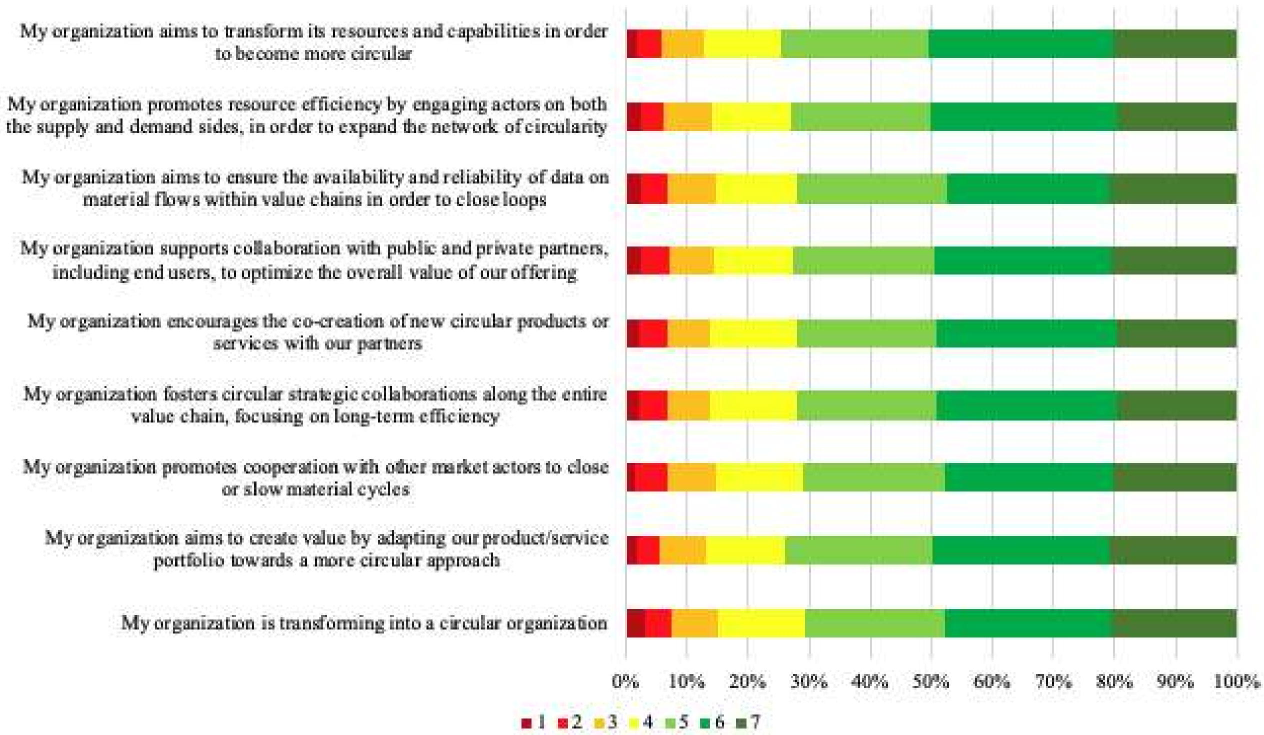


Figure 20 Level of agreement on the company's performance in terms of circularity (German companies)

Also in this context, it appears that Italian companies feel more confident about their transition pathway, relying particularly on their ability to activate synergies and collaborations for sustainability. On the other hand, German companies, while slightly more cautious in their self-assessment, show greater confidence in related areas such as product innovation.

Another set of questions aimed to investigate performance in terms of corporate social responsibility. In particular, aspects such as the communication of the organization's social commitments and the reduction of conflicts with local communities were examined. Also in this case, the responses from Italian companies are presented in the following table and figure.

Table 29 Level of agreement on the company's performance in terms of corporate social responsibility (Italian companies)

	1	2	3	4	5	6	7
Communicating the organization's social commitments	1.40%	2.75%	6.19%	12.28%	21.17%	34.80%	21.42%
Improving the management of social aspects (e.g., workers' rights, health, safety, etc.)	1.60%	3.49%	5.64%	12.38%	22.37%	33.45%	21.07%
Identifying and addressing relevant social issues and stakeholders' expectations	1.45%	3.10%	5.29%	13.93%	22.37%	33.85%	20.02%
Improving relationships with relevant stakeholders	1.05%	2.95%	5.94%	12.73%	21.12%	33.95%	22.27%
Reducing conflicts with local communities (e.g., public complaints)	1.10%	2.95%	5.94%	12.73%	21.12%	33.95%	22.27%

Improving transparency and accountability towards external stakeholders (e.g., partners, customers, public institutions, local communities, etc.)	1.05%	2.50%	6.39%	13.88%	22.57%	33.80%	19.82%
Demonstrating regulatory compliance to the public (e.g., partners, customers, public institutions, local communities, etc.)	1.10%	2.90%	6.24%	13.93%	21.62%	33.55%	20.67%
Collaborating with universities, research centers, and other educational institutions and/or participating in research projects at national and international level	2.45%	3.54%	6.24%	12.53%	21.82%	33.75%	19.67%

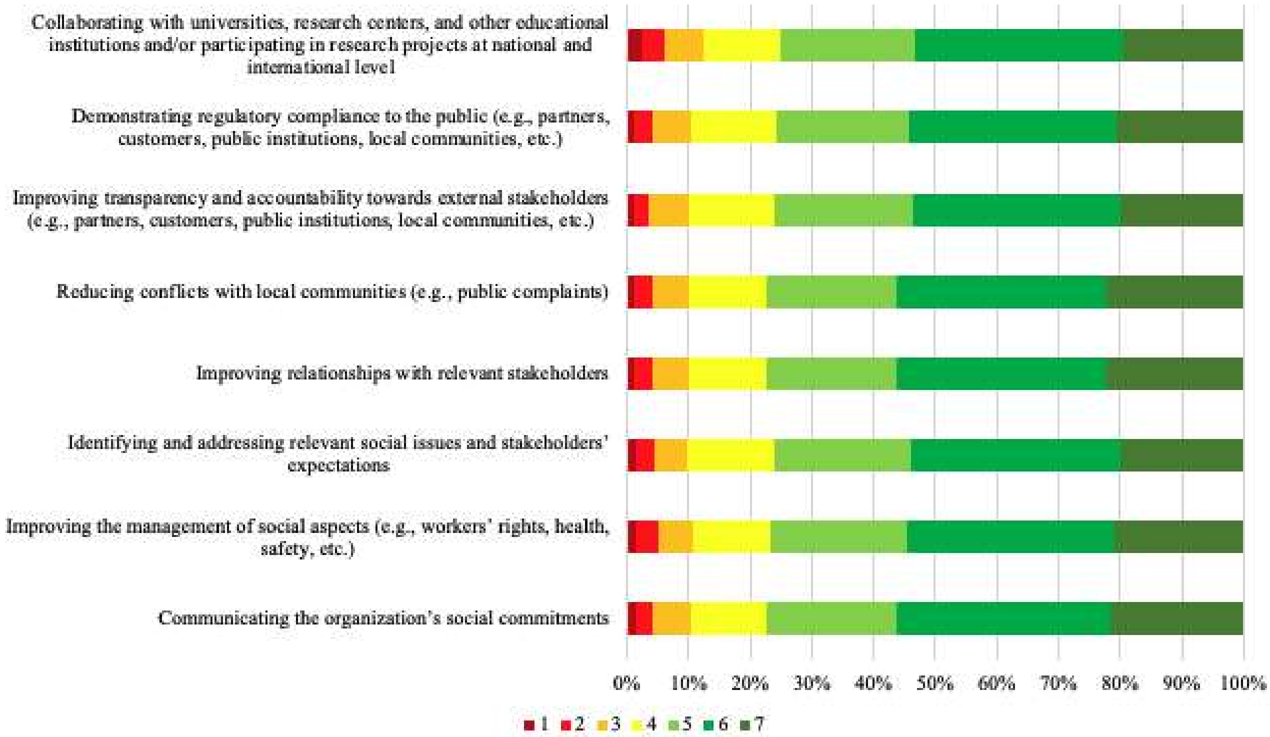


Figure 21 Level of agreement on the company's performance in terms of corporate social responsibility (Italian companies)

The responses provided by German companies are shown in the following table and figure.

Table 30 Level of agreement on the company's performance in terms of corporate social responsibility (German companies)

	1	2	3	4	5	6	7
Communicating the organization's social commitments	1.40%	3.64%	6.44%	14.78%	23.41%	29.91%	20.42%
Improving the management of social aspects (e.g., workers' rights, health, safety, etc.)	1.15%	3.59%	6.94%	14.58%	23.96%	28.96%	20.82%
Identifying and addressing relevant social issues and stakeholders' expectations	1.70%	4.29%	7.49%	14.23%	23.17%	29.11%	20.02%
Improving relationships with relevant stakeholders	1.55%	3.49%	6.64%	13.58%	22.17%	31.00%	21.57%

Reducing conflicts with local communities (e.g., public complaints)	1.75%	3.49%	6.64%	13.58%	22.17%	31.00%	21.57%
Improving transparency and accountability towards external stakeholders (e.g., partners, customers, public institutions, local communities, etc.)	2.25%	4.54%	6.79%	13.53%	23.22%	28.66%	21.02%
Demonstrating regulatory compliance to the public (e.g., partners, customers, public institutions, local communities, etc.)	2.50%	4.39%	7.89%	14.08%	21.07%	29.01%	21.07%
Collaborating with universities, research centers, and other educational institutions and/or participating in research projects at national and international level	2.45%	4.09%	8.24%	13.93%	22.97%	28.01%	20.32%

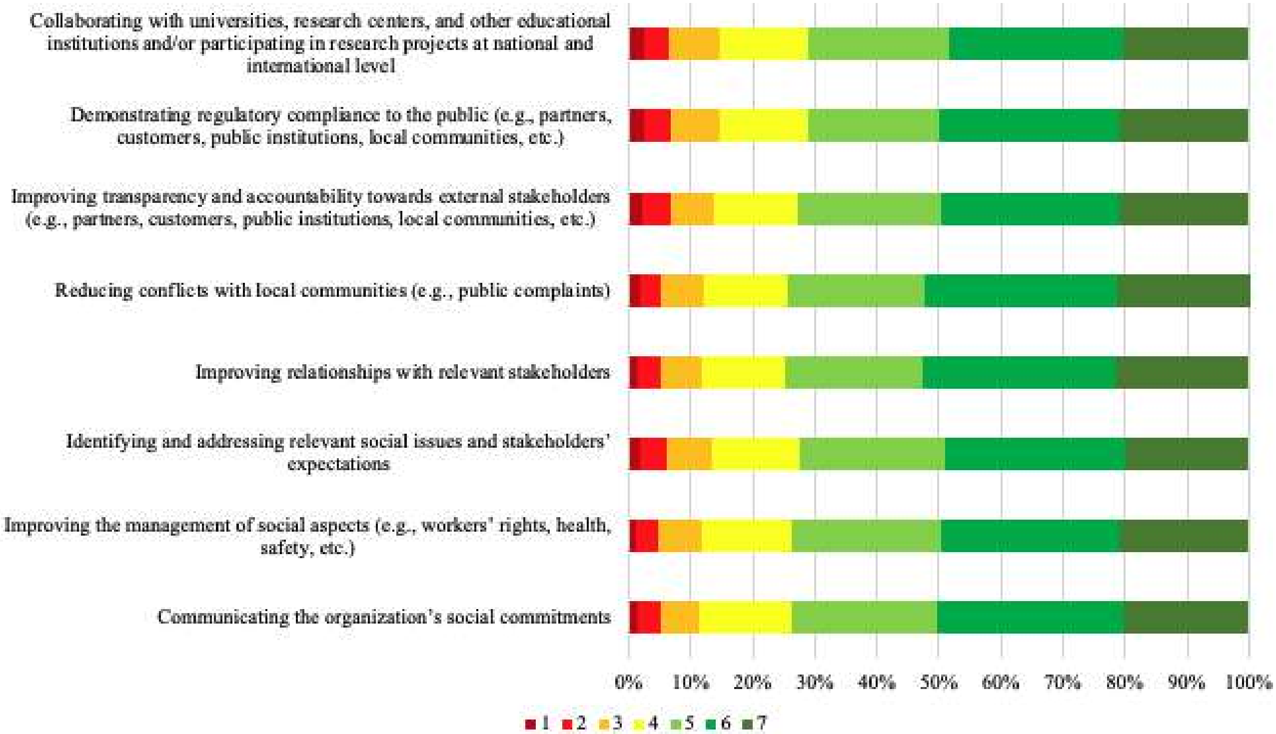


Figure 22 Level of agreement on the company's performance in terms of corporate social responsibility (German companies)

Also in this case, the results show greater confidence among Italian companies in their ability to manage social aspects, particularly excelling in the management of relationships with local communities. German companies, while confirming a more cautious approach, demonstrate good performance in the concrete management of social aspects within their strategic relationships with stakeholders.

Finally, in the last section, the economic and financial performance of companies in relation to the implementation of environmental strategies was investigated. For example, aspects such as cost reductions resulting from more efficient use of resources, increased customer satisfaction with the company's sustainable products and services, and improvements in competitiveness following the implementation of sustainability actions were examined. The responses provided by Italian companies are presented in the following table and figures.

Table 31 Level of agreement on the economic or financial performance of companies in relation to the implementation of environmental strategies (Italian companies)

	1	2	3	4	5	6	7
Reduction of costs through more efficient use of resources (water, raw materials, energy, and other inputs)	1.25%	2.50%	5.04%	14.13%	22.32%	34.40%	20.37%
Reduction of costs through lower emissions (air, water, noise, etc.) and waste	1.00%	3.15%	5.84%	12.58%	21.82%	34.10%	21.52%
Increasing customer satisfaction with the organization's products or services	1.00%	2.20%	5.49%	12.73%	22.62%	33.30%	22.67%
Improving competitive advantage in the market	1.25%	2.45%	5.89%	12.33%	22.02%	34.35%	21.72%
Expanding market share	1.30%	2.45%	5.89%	12.33%	22.02%	34.35%	21.72%
Identification of new market opportunities (e.g., markets for products with reduced environmental impact)	1.05%	2.75%	5.49%	13.33%	23.46%	33.55%	20.37%
Developing and introducing innovative products to the market or improving their quality	1.15%	2.40%	6.54%	12.08%	21.32%	32.85%	23.66%
Adopting environmentally friendly technologies or BAT (Best Available Techniques)	1.35%	2.65%	6.69%	13.13%	21.47%	32.65%	22.07%
Access to public funding or procurement procedures (including service contracts)	1.55%	3.25%	8.14%	14.38%	21.42%	32.10%	19.17%
Increasing attractiveness to private investors	1.20%	3.15%	6.54%	13.53%	21.42%	32.85%	21.32%
Increase in shareholder value	1.75%	2.70%	6.34%	12.28%	21.87%	34.30%	20.77%
Access to capital markets	1.40%	2.40%	7.44%	13.78%	21.57%	33.00%	20.42%

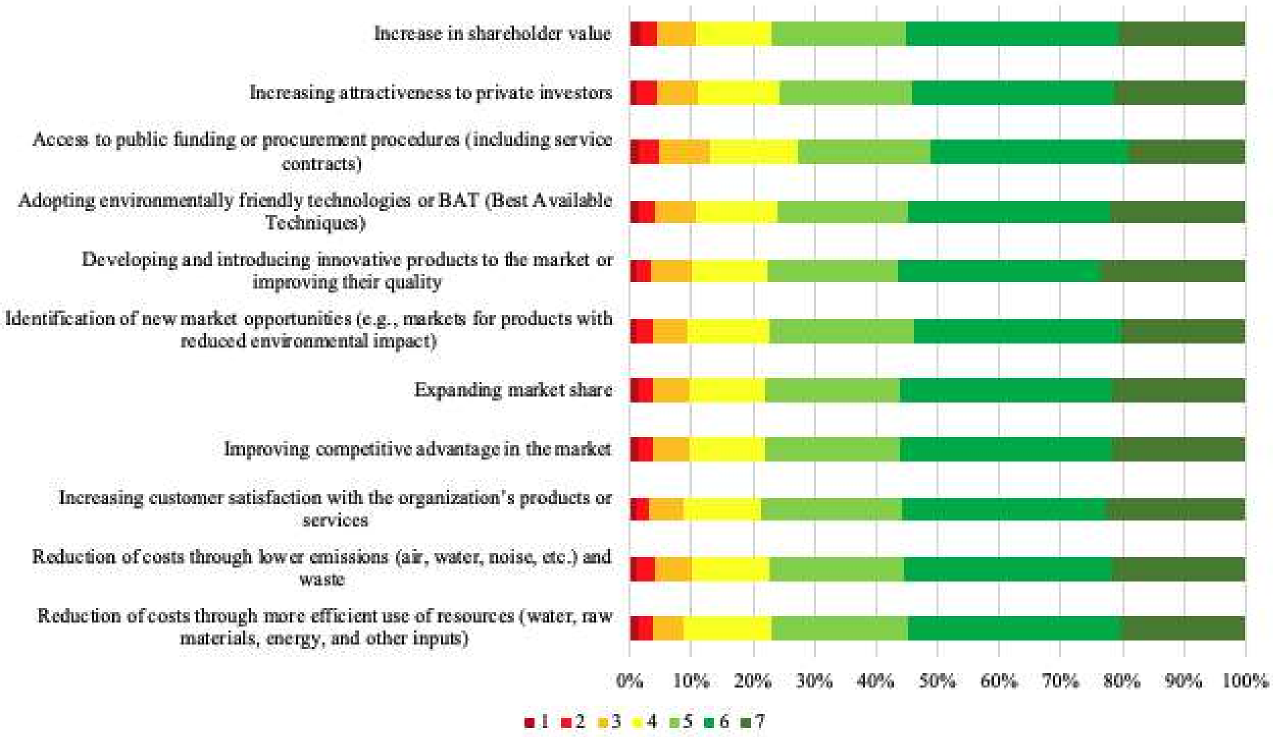


Figure 23 Level of agreement on the economic or financial performance of companies in relation to the implementation of environmental strategies (Italian companies)

The responses provided by German companies are shown in the following table and figure.

Table 32 Level of agreement on the economic or financial performance of companies in relation to the implementation of environmental strategies (German companies)

	1	2	3	4	5	6	7
Reduction of costs through more efficient use of resources (water, raw materials, energy, and other inputs)	1.55%	4.09%	7.64%	14.13%	22.82%	28.61%	21.17%
Reduction of costs through lower emissions (air, water, noise, etc.) and waste	1.80%	4.19%	7.69%	14.38%	23.07%	29.61%	19.27%
Increasing customer satisfaction with the organization's products or services	1.45%	3.79%	7.69%	13.13%	21.82%	28.81%	23.32%
Improving competitive advantage in the market	1.35%	3.00%	6.04%	12.93%	24.41%	28.66%	23.61%
Expanding market share	1.25%	3.00%	6.04%	12.93%	24.41%	28.66%	23.61%
Identification of new market opportunities (e.g., markets for products with reduced environmental impact)	1.85%	3.89%	7.19%	14.18%	22.42%	29.26%	21.22%
Developing and introducing innovative products to the market or improving their quality	1.60%	3.34%	7.94%	12.78%	22.82%	28.96%	22.57%
Adopting environmentally friendly technologies or BAT (Best Available Techniques)	1.80%	3.54%	7.09%	13.78%	23.86%	27.86%	22.07%

Access to public funding or procurement procedures (including service contracts)	2.45%	4.09%	7.84%	14.18%	23.17%	28.11%	20.17%
Increasing attractiveness to private investors	1.85%	3.69%	7.29%	13.63%	22.92%	28.06%	22.57%
Increase in shareholder value	2.20%	4.19%	7.29%	13.73%	22.22%	28.21%	22.17%
Access to capital markets	2.25%	3.84%	7.99%	14.48%	23.36%	27.41%	20.67%

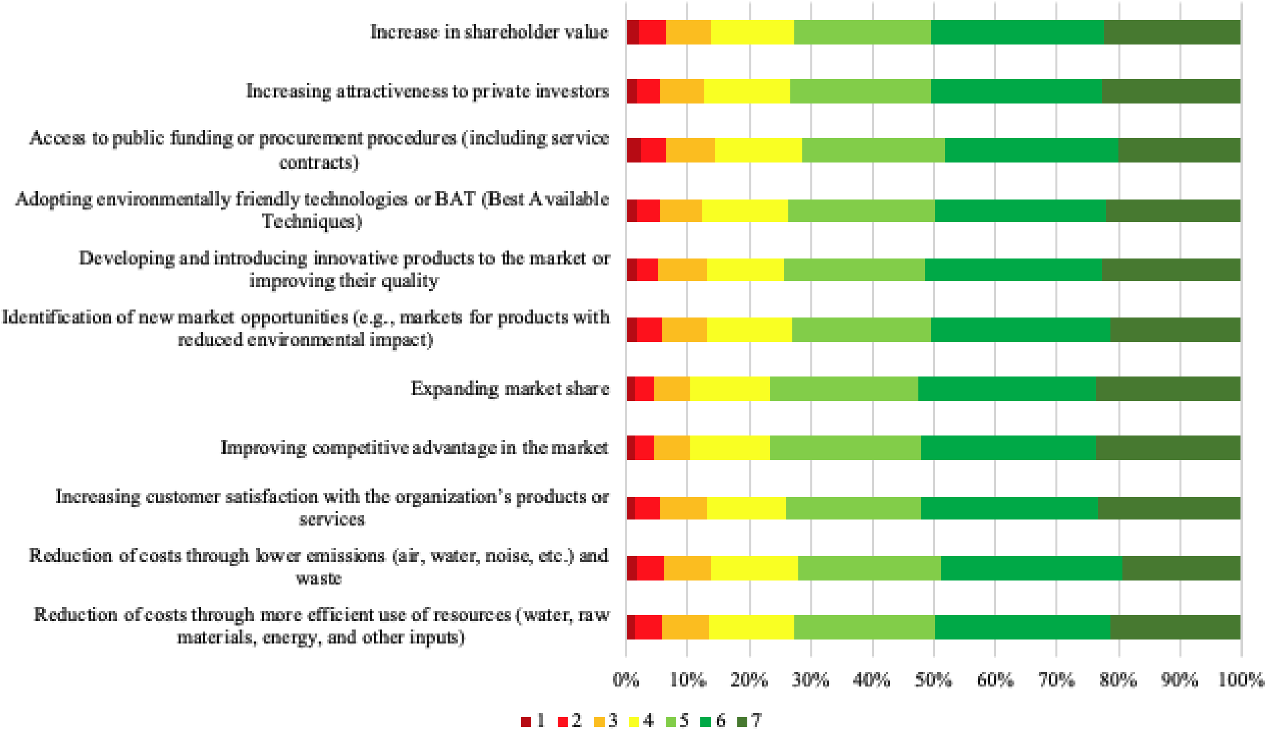


Figure 24 Level of agreement on the economic or financial performance of companies in relation to the implementation of environmental strategies (German companies)

Also in this case, although the differences are minimal, Italian companies perceive the economic benefits of sustainability as being more closely linked to competitive advantages, cost reductions, and increases in shareholder value; on the other hand, German companies tend to perceive the benefits as being more strongly focused on product innovation.

5.3.5 Market challenges

Another section of the questionnaire aimed to investigate the markets in which Italian and German companies operate. In particular, this section sought to understand how companies use their market analysis capabilities to also develop environmental sustainability strategies. One set of questions in this section examined the frequency with which an organization engages in identifying new opportunities in terms of products, processes, and services. Another set of questions measured the extent to which organizations undertake certain activities following the identification of new opportunities and, finally, how the organization has been able to introduce significant changes and improvements over the last ten years.

The following table and figure present the responses of Italian companies to the question aimed at investigating how frequently the organization engages in certain activities to identify new opportunities in terms of new products, processes, or services. The responses provided by Italian companies are presented in the following table and figure.

Table 33 Level of agreement on the organization's ability to identify new opportunities (Italian companies)

	1	2	3	4	5	6	7
My organization analyzes competitors' actions	1.25%	3.10%	6.49%	13.93%	22.32%	32.15%	20.77%
My organization involves customers, suppliers, or other stakeholders in the development process of new products/services	1.45%	2.95%	6.94%	12.83%	22.62%	32.95%	20.27%
My organization undertakes R&D activities to create new knowledge or to solve technical problems (e.g., to develop new or significantly improved products/production processes)	1.75%	3.05%	6.19%	14.03%	22.77%	32.45%	19.77%
My organization undertakes research and development activities to increase the stock of knowledge (e.g., by experimenting with new ideas with strategic or operational implications)	1.90%	3.64%	6.74%	14.23%	20.82%	33.00%	19.67%
My organization collaborates with regulatory institutions, industry associations, NGOs, universities, and others	1.75%	3.64%	6.74%	14.23%	20.82%	33.00%	19.67%
My organization participates in conferences, seminars, workshops, or trade fairs	1.60%	3.30%	6.94%	13.33%	23.36%	31.20%	20.27%

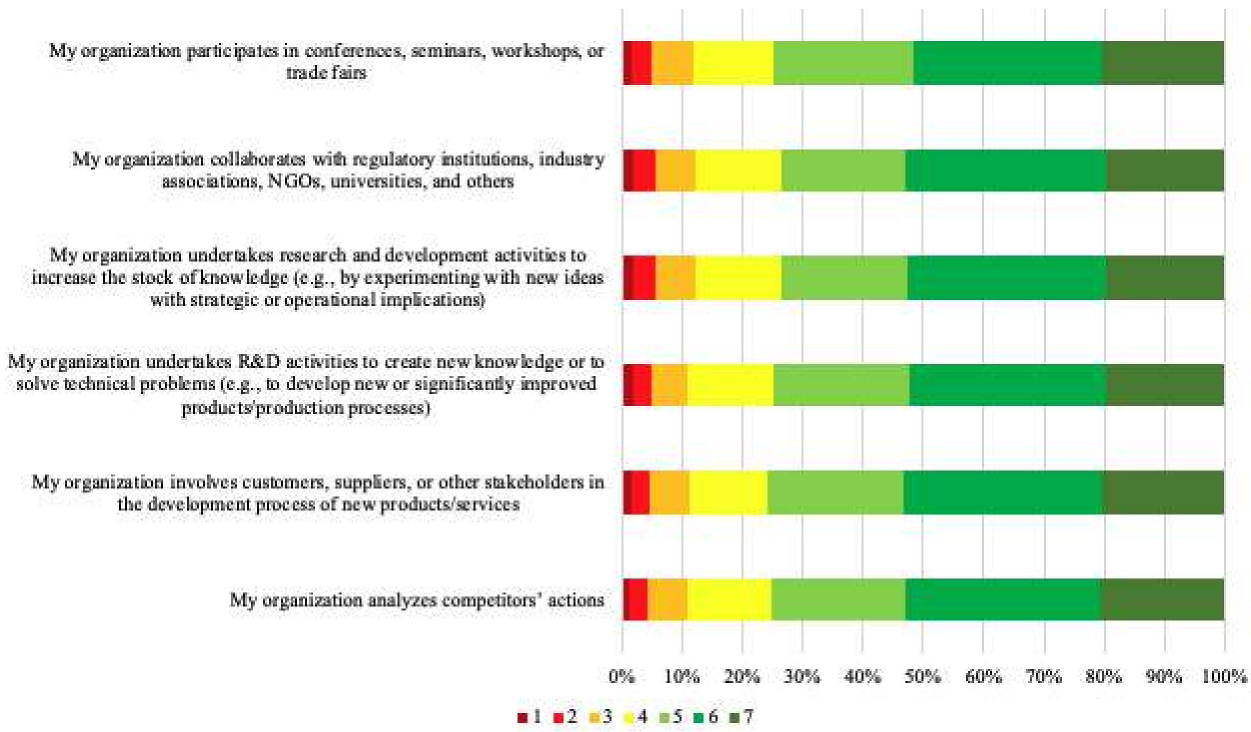


Figure 25 Level of agreement on the organization's ability to identify new opportunities (Italian companies)

The responses provided by German companies are shown in the following table and figure.

Table 34 Level of agreement on the organization's ability to identify new opportunities (German companies)

	1	2	3	4	5	6	7
My organization analyzes competitors' actions	1.80%	3.59%	7.04%	13.73%	23.41%	30.10%	20.32%
My organization involves customers, suppliers, or other stakeholders in the development process of new products/services	2.05%	3.94%	8.14%	14.13%	24.16%	28.31%	19.27%
My organization undertakes R&D activities to create new knowledge or to solve technical problems (e.g., to develop new or significantly improved products/production processes)	2.50%	4.39%	7.79%	14.93%	23.51%	26.91%	19.97%
My organization undertakes research and development activities to increase the stock of knowledge (e.g., by experimenting with new ideas with strategic or operational implications)	2.50%	3.74%	7.44%	15.63%	23.27%	26.96%	20.47%
My organization collaborates with regulatory institutions, industry associations, NGOs, universities, and others	2.55%	3.74%	7.44%	15.63%	23.27%	26.96%	20.47%
My organization participates in conferences, seminars, workshops, or trade fairs	2.05%	4.04%	7.49%	14.68%	23.32%	26.96%	21.47%

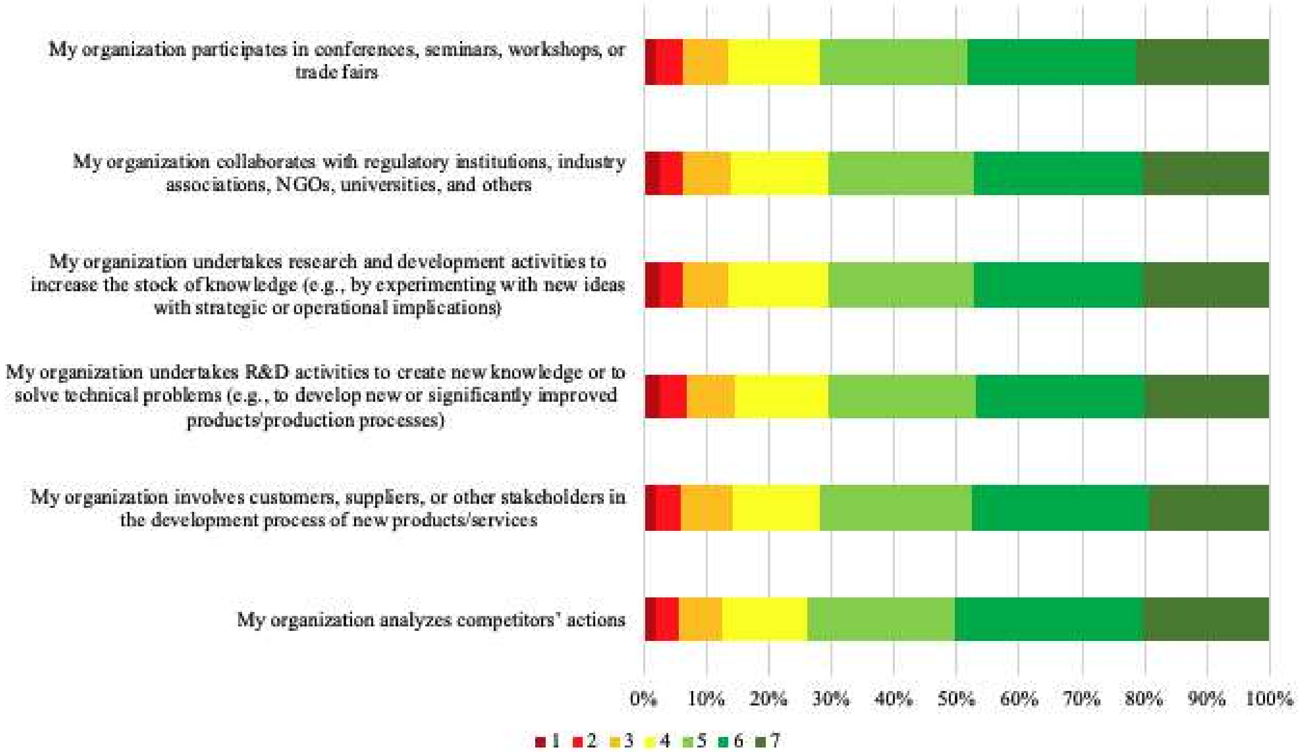


Figure 26 Level of agreement on the organization's ability to identify new opportunities (German companies)

Although the differences are minimal also in this case, Italian companies appear to adopt an information acquisition strategy more based on networking and value chain engagement, while German companies tend to rely more on internal control of processes and research and development.

A second set of questions aimed to investigate the extent to which the organization undertakes certain activities following the identification of a new opportunity. Also in this case, the responses provided by Italian companies are presented in the following table and figure.

Table 35_Level of agreement on the organization's ability to identify new opportunities (Italian companies)

	1	2	3	4	5	6	7
My organization is able to formulate a strategy for the development of new products/services	1.65%	2.55%	6.69%	14.23%	23.36%	31.45%	20.07%
My organization is efficient in planning investments related to R&D activities or collaborations necessary for the development of new products/services	1.50%	3.84%	6.94%	14.13%	21.92%	30.95%	20.72%
My organization is efficient in planning the human resources required for the development of new products/services	1.10%	2.35%	6.74%	12.98%	22.12%	33.65%	21.07%
My organization is competent in redesigning/transforming our existing business models whenever necessary for the development of new products/services	1.35%	2.95%	6.84%	13.63%	22.07%	32.70%	20.47%

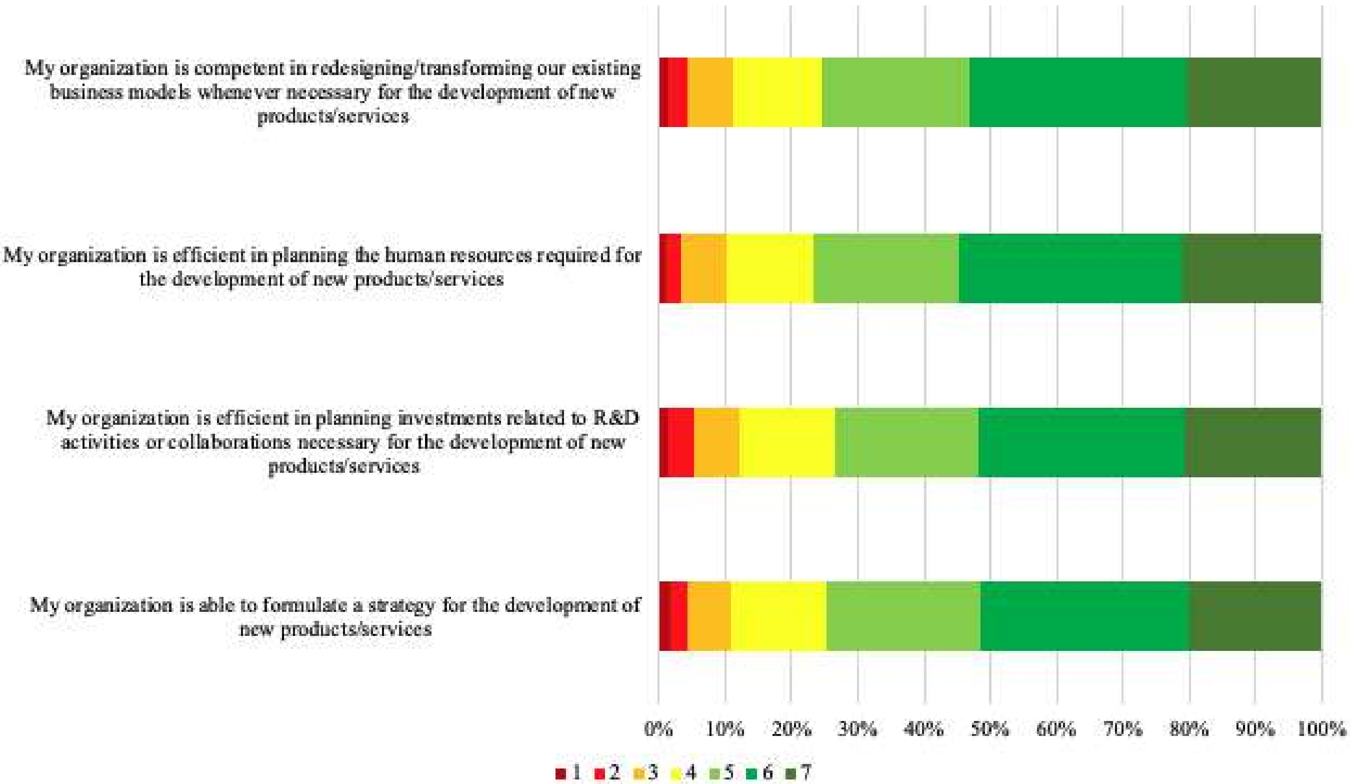


Figure 27 Level of agreement on the organization's ability to identify new opportunities (Italian companies)

The responses provided by German companies are shown in the following table and figure.

Table 36_Level of agreement on the organization's ability to identify new opportunities (German companies)

	1	2	3	4	5	6	7

My organization is able to formulate a strategy for the development of new products/services	1.55%	3.54%	7.69%	13.73%	24.61%	26.96%	21.92%
My organization is efficient in planning investments related to R&D activities or collaborations necessary for the development of new products/services	2.60%	4.04%	8.19%	13.73%	23.41%	28.66%	19.37%
My organization is efficient in planning the human resources required for the development of new products/services	1.95%	4.24%	7.39%	12.88%	23.46%	28.91%	21.17%
My organization is competent in redesigning/transforming our existing business models whenever necessary for the development of new products/services	2.10%	4.59%	7.29%	14.58%	21.27%	30.85%	19.32%

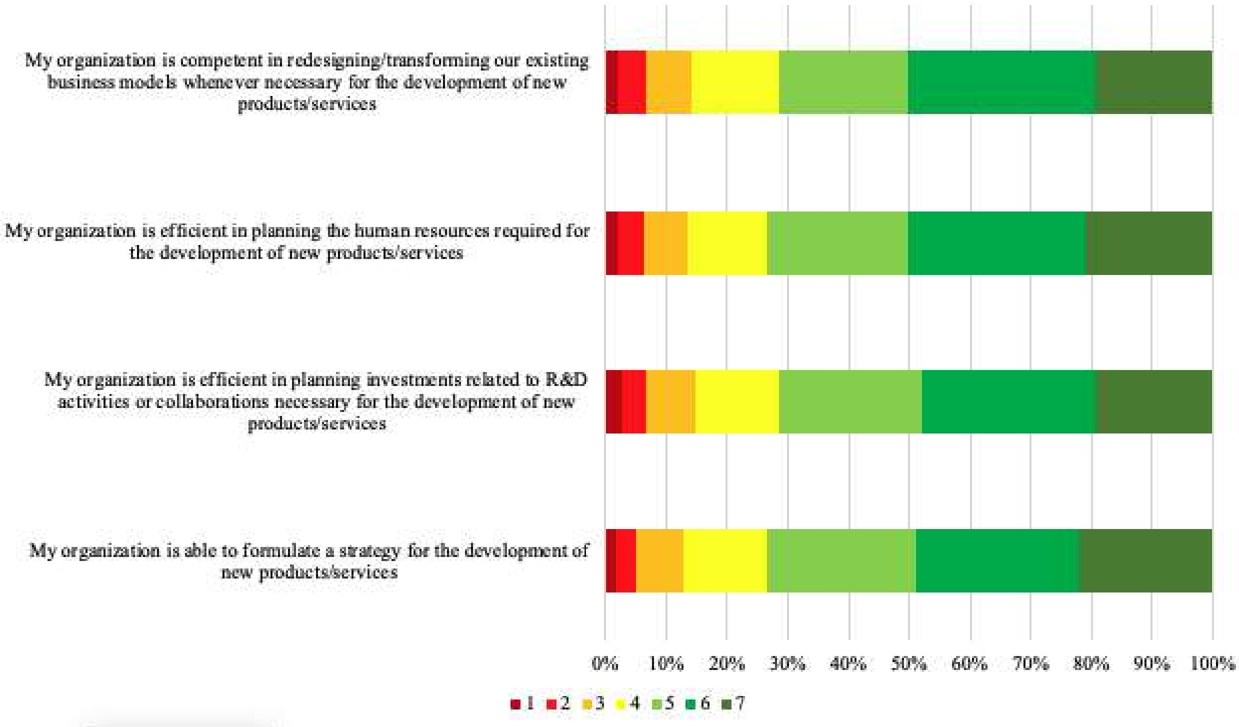


Figure 28 Level of agreement on the organization's ability to identify new opportunities (German companies)

In this case, the responses indicate that German companies perceive themselves as slightly more competent in the strategic planning phase. In contrast, Italian companies show greater confidence in their execution capabilities and their transformational agility.

The last set of questions in this section aimed to investigate the extent to which the organization has been able to introduce significant changes and improvements over the last ten years in order to seize opportunities to produce new products or provide new services. Several options were presented to the companies. The responses provided by the responding Italian companies are shown in the table and figure below.

Table 37 Level of agreement on the organization's ability to introduce significant changes over the last ten years (Italian companies)

	1	2	3	4	5	6	7
New or significantly improved production technologies/processes	0.90%	2.80%	5.69%	12.78%	21.47%	33.95%	22.42%

New methods for organizing work responsibilities and decision-making processes (e.g., teamwork, decentralization, etc.)	1.50%	3.05%	5.54%	13.18%	23.02%	33.50%	20.22%
New or significantly improved logistics, delivery, or distribution methods for inputs/products/services	1.50%	2.85%	5.39%	13.48%	22.12%	34.00%	20.67%
New business practices for organizing procedures (e.g., supply chain management, organizational restructuring, knowledge management, lean production and quality management, etc.)	1.05%	2.80%	6.04%	14.13%	22.12%	33.50%	20.37%
Acquisition of existing sectoral know-how, copyrighted works, patented and non-patented inventions, etc., from other organizations (for the development of new or significantly improved products/production processes)	1.55%	2.80%	6.04%	14.13%	22.12%	33.50%	20.37%

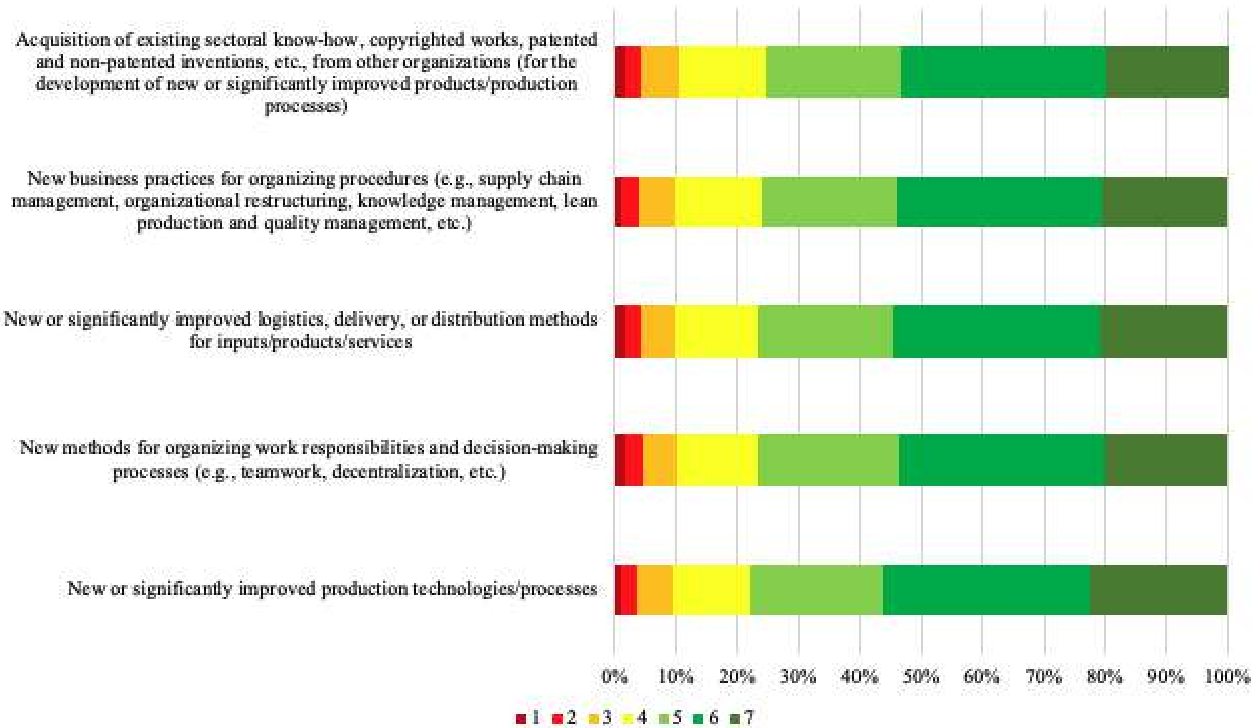


Figure 29 Level of agreement on the organization's ability to introduce significant changes over the last ten years (Italian companies)

The responses provided by German companies are shown in the following table and figure.

Table 38 Level of agreement on the organization's ability to introduce significant changes over the last ten years (German companies)

	1	2	3	4	5	6	7
New or significantly improved production technologies/processes	1,60%	3,49%	7,39%	14,23%	21,97%	28,26%	23,07%
New methods for organizing work responsibilities and decision-making processes (e.g., teamwork, decentralization, etc.)	1,85%	3,34%	6,49%	15,28%	22,62%	29,11%	21,32%

New or significantly improved logistics, delivery, or distribution methods for inputs/products/services	2,00%	4,14%	7,89%	13,73%	22,92%	28,86%	20,47%
New business practices for organizing procedures (e.g., supply chain management, organizational restructuring, knowledge management, lean production and quality management, etc.)	2,15%	4,34%	7,59%	13,53%	23,66%	28,76%	19,97%
Acquisition of existing sectoral know-how, copyrighted works, patented and non-patented inventions, etc., from other organizations (for the development of new or significantly improved products/production processes)	2,30%	4,34%	7,59%	13,53%	23,66%	28,76%	19,97%

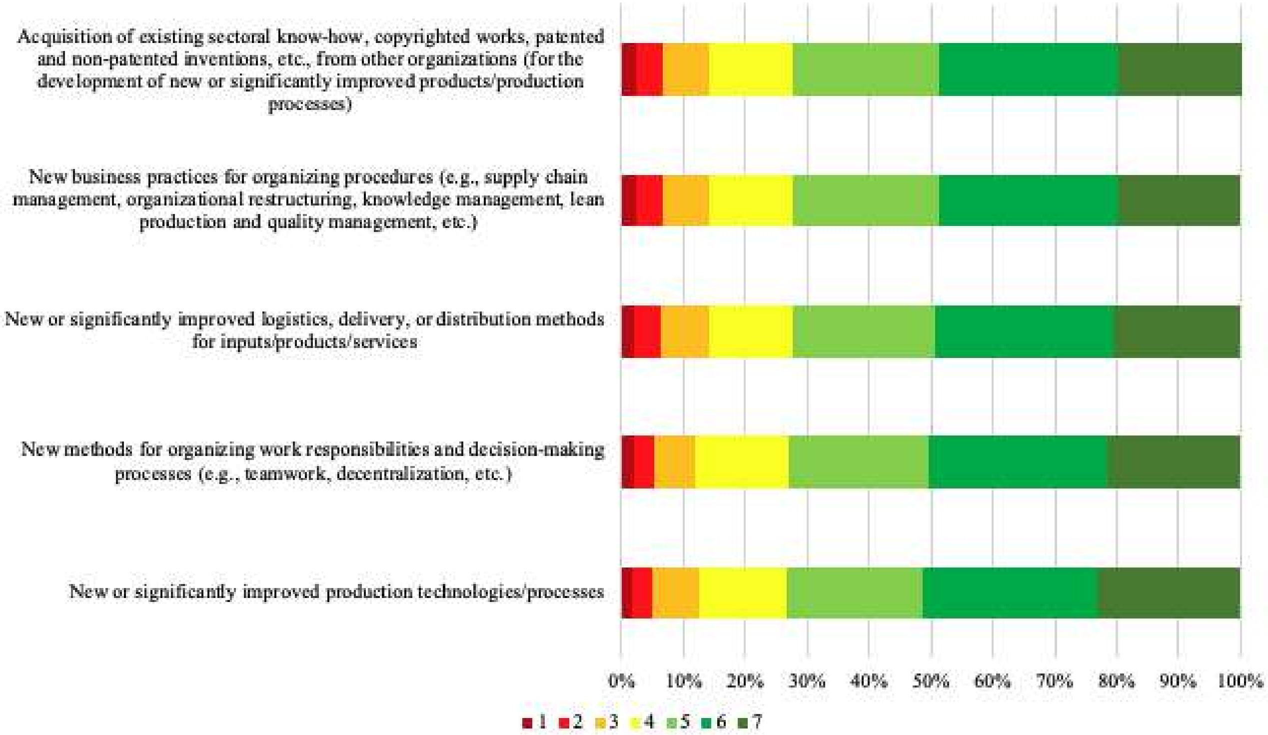


Figure 30 Level of agreement on the organization's ability to introduce significant changes over the last ten years (German companies)

In this final set of questions in the section, Italian companies report higher and more homogeneous scores across all categories, while German companies appear more cautious in their responses. Overall, both Italian and German companies show higher scores on issues related to technologies and production processes.

5.3.6 Use of life cycle assessment tools

In the questionnaire, participants were asked whether their organization had already conducted a Life Cycle Assessment (LCA) or a Carbon Footprint analysis. The question was designed to allow the selection of multiple response options, in order to capture the variety of experiences developed by organizations and the possible coexistence of different tools for measuring environmental impacts.

Table 39 - Modes of use of life cycle assessment tools by Italian companies

Code	Response option	Nr.	%
1	Yes, a Life Cycle Assessment was used to assess the impacts of a product	844	42.14%
2	Yes, a Carbon Footprint was used to assess the impacts of a product	720	35.95%
3	Yes, a Life Cycle Assessment was used to assess the impacts of a process	596	29.76%
4	Yes, a Carbon Footprint was used to assess the impacts of a process	453	22.62%
5	Yes, a Life Cycle Assessment was used to assess the impacts of a service	353	17.62%
6	Yes, a Carbon Footprint was used to assess the impacts of a service	298	14.88%
7	Yes, a Life Cycle Assessment was used to assess the impacts of the organization	335	16.72%
8	Yes, a Carbon Footprint was used to assess the impacts of the organization	265	13.23%
9	Yes, a Life Cycle Assessment was used to assess the impacts of a business model	285	14.23%
10	Yes, a Carbon Footprint was used to assess the impacts of a business model	242	12.08%
11	No, a Life Cycle Assessment or Carbon Footprint has never been used	**167**	8.34%

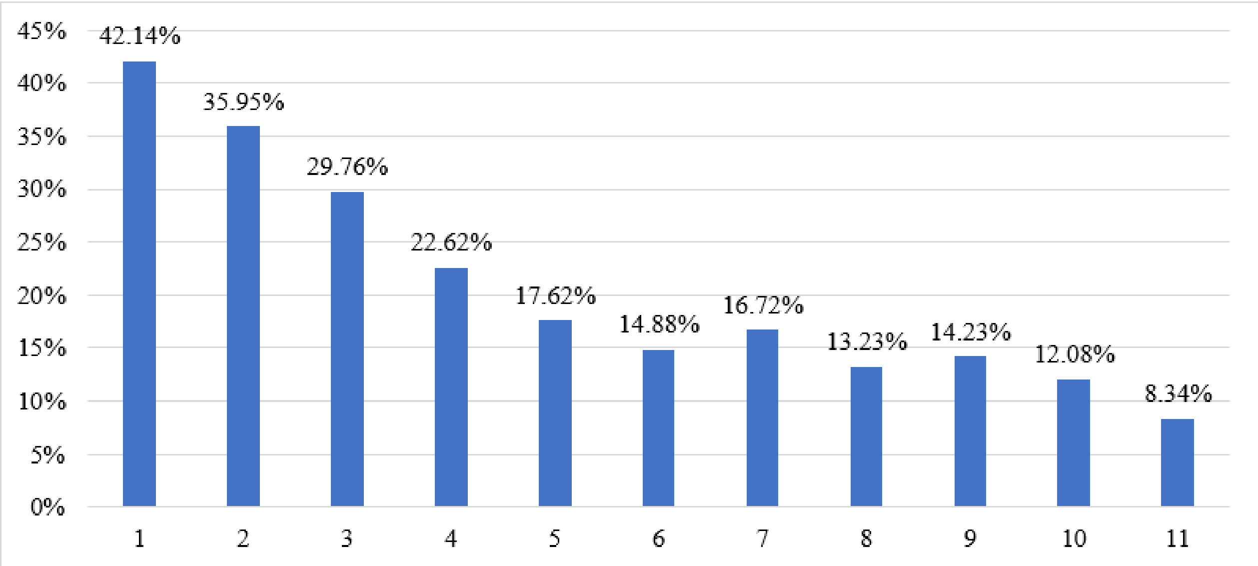


Figure 31 – Modes of use of life cycle assessment tools by Italian companies

Table 40 – Modes of use of life cycle assessment tools by German companies

Code	Response option	Nr.	%
1	Yes, a Life Cycle Assessment was used to assess the impacts of a product	630	31.47%
2	Yes, a Carbon Footprint was used to assess the impacts of a product	508	25.37%
3	Yes, a Life Cycle Assessment was used to assess the impacts of a process	463	23.13%
4	Yes, a Carbon Footprint was used to assess the impacts of a process	352	17.58%
5	Yes, a Life Cycle Assessment was used to assess the impacts of a service	371	18.53%
6	Yes, a Carbon Footprint was used to assess the impacts of a service	277	13.84%

Code	Response option	Nr.	%
7	Yes, a Life Cycle Assessment was used to assess the impacts of the organization	267	13.34%
8	Yes, a Carbon Footprint was used to assess the impacts of the organization	253	12.64%
9	Yes, a Life Cycle Assessment was used to assess the impacts of a business model	280	13.99%
10	Yes, a Carbon Footprint was used to assess the impacts of a business model	210	10.49%
11	No, a Life Cycle Assessment or Carbon Footprint has never been used	**140**	6.99%

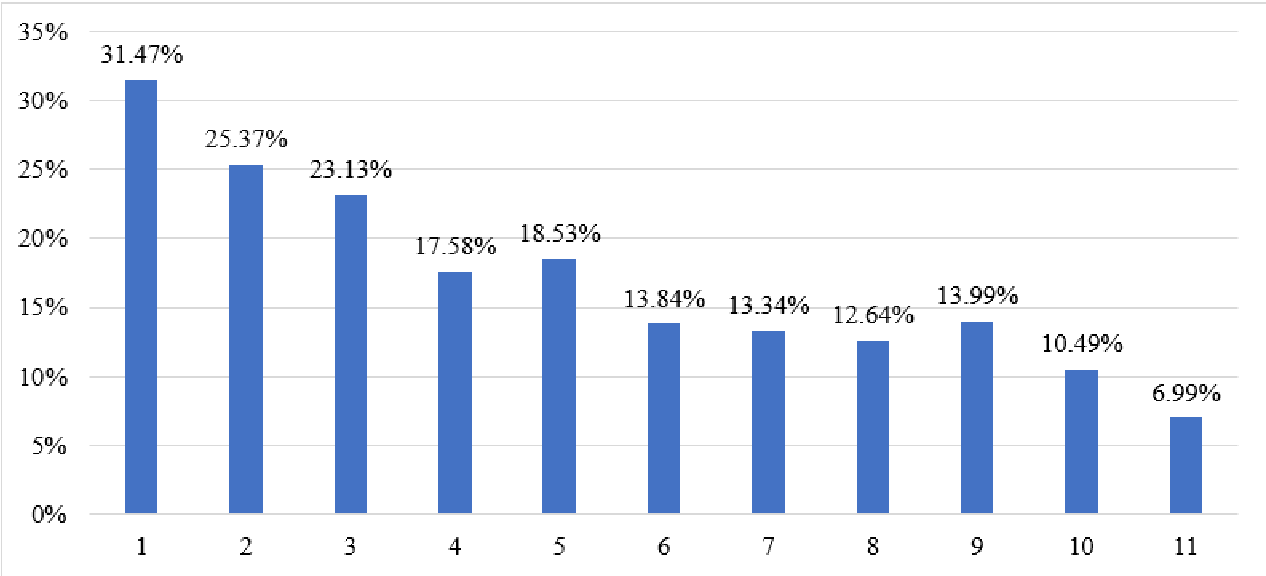


Figure 32 – Modes of use of life cycle assessment tools by German companies

A further question in the questionnaire investigated the perceived benefits for organizations that had carried out an environmental impact assessment using tools such as Life Cycle Assessment (LCA) or Carbon Footprint analysis. Respondents were asked to express the level of advantage derived from these practices on a scale from 1 to 7, where 1 corresponds to "not advantageous at all" and 7 to "extremely advantageous." This approach made it possible to measure in a graded way the perceived effectiveness of these tools across different areas. For this question, respondents who had selected option 11 ("No, a Life Cycle Assessment or Carbon Footprint has never been used") in the previous question were excluded. For this reason, the number of respondents decreased to 1,308 for the Italian questionnaire and to 1,293 for the German questionnaire.

Table 41 – Main benefits for an Italian organization in adopting Life Cycle Assessment

	1	**2**	**3**	**4**	**5**	**6**	**7**
Improvement and optimization of circular economy strategies	1.09%	2.29%	5.23%	13.67%	21.08%	34.10%	22.55%
More comprehensive insights into sustainability performance	0.82%	3.05%	5.83%	13.29%	22.44%	33.44%	21.13%
Support for learning processes and cultural transformation among employees	0.98%	2.40%	6.15%	13.18%	22.11%	34.10%	21.08%

	1	2	3	4	5	6	7
Identification of business perspectives and opportunities	1.14%	2.40%	6.15%	13.18%	22.11%	34.10%	21.08%
Information to benchmark the organization against competitors	0.76%	1.85%	6.43%	13.13%	23.42%	33.06%	21.35%
Greater marketing capabilities and improved reputation	0.93%	2.61%	5.39%	12.75%	22.33%	32.79%	23.20%
Improved communication and reporting towards stakeholders (e.g., employees, suppliers, consumers)	1.09%	2.29%	6.48%	12.69%	22.60%	34.04%	20.81%
Future planning of the company's strategy and vision	1.20%	2.29%	5.56%	12.31%	21.24%	34.86%	22.55%

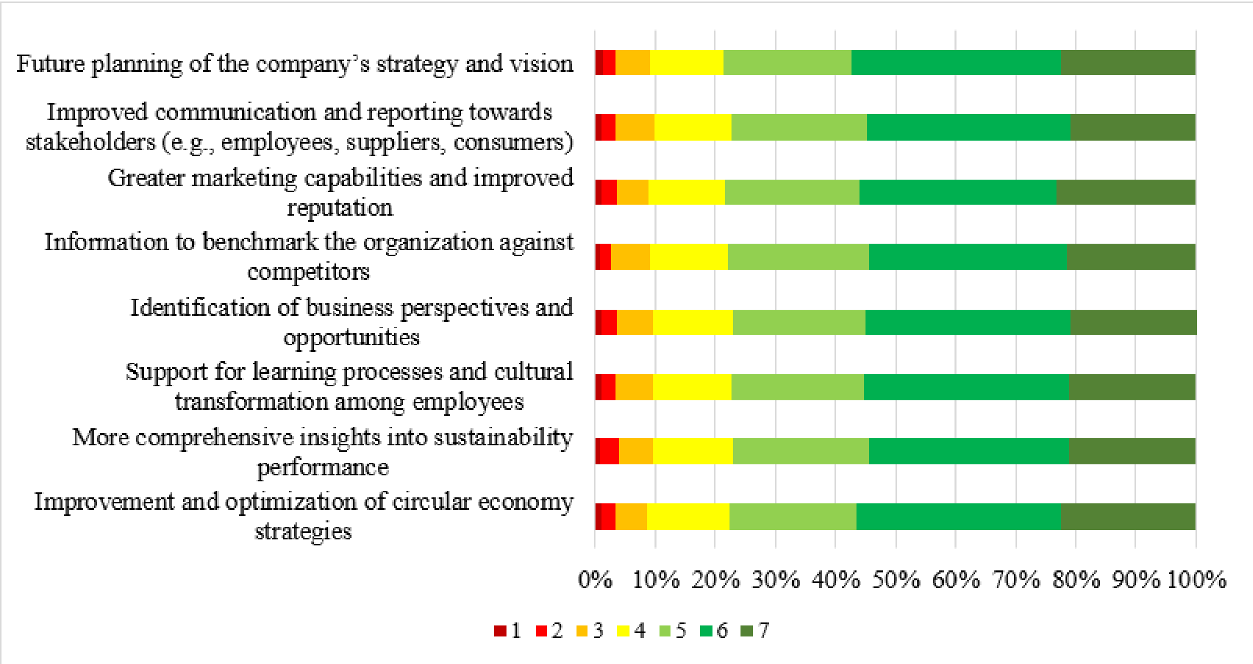


Figure 33 – Main benefits for an Italian organization in adopting Life Cycle Assessment

Table 42 – Main benefits for a German organization in adopting Life Cycle Assessment

	1	2	3	4	5	6	7
Improvement and optimization of circular economy strategies	1.21%	3.91%	6.93%	15.13%	21.67%	30.25%	20.90%
More comprehensive insights into sustainability performance	1.43%	4.29%	6.71%	12.87%	23.54%	29.81%	21.34%
Support for learning processes and cultural transformation among employees	1.60%	4.02%	6.77%	15.07%	22.66%	28.82%	21.07%

	1	2	3	4	5	6	7
Identification of business perspectives and opportunities	2.04%	4.02%	6.77%	15.07%	22.66%	28.82%	21.07%
Information to benchmark the organization against competitors	1.16%	4.35%	7.43%	13.15%	23.76%	29.59%	20.57%
Greater marketing capabilities and improved reputation	1.54%	3.96%	7.26%	13.81%	21.89%	29.48%	22.06%
Improved communication and reporting towards stakeholders (e.g., employees, suppliers, consumers)	2.04%	4.46%	6.60%	14.25%	24.31%	27.61%	20.74%
Future planning of the company's strategy and vision	1.38%	3.19%	7.10%	14.63%	23.38%	28.77%	21.56%

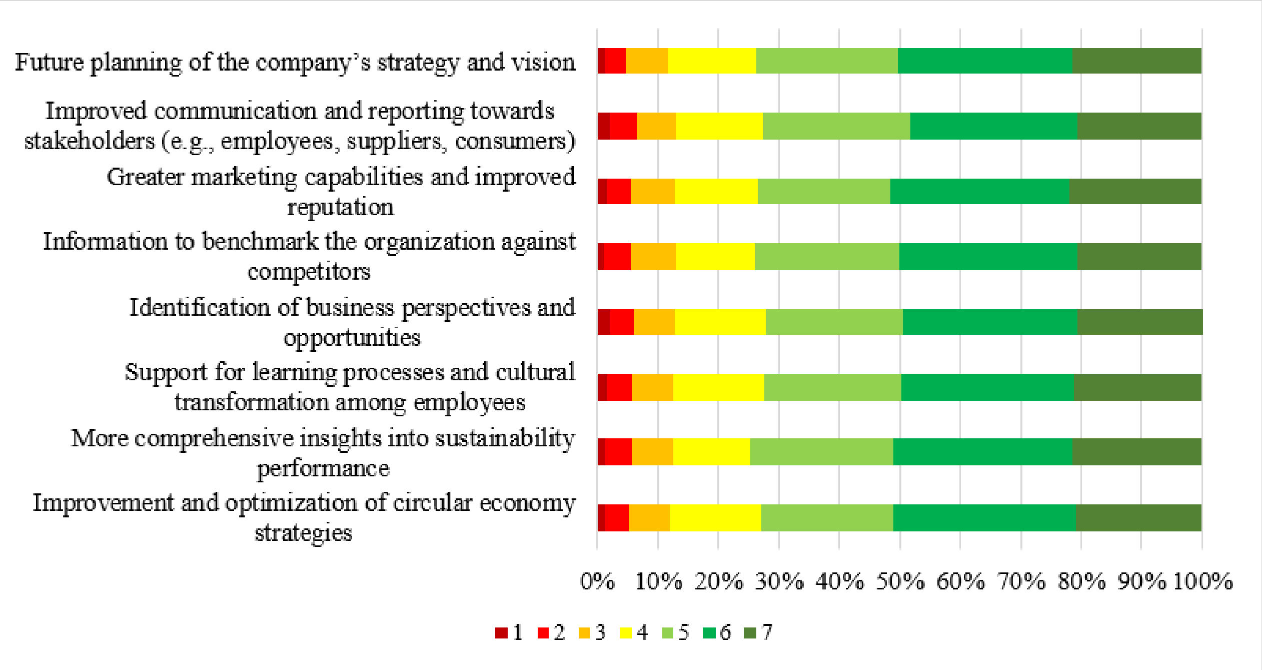


Figure 34 – Main benefits for a German organization in adopting Life Cycle Assessment

To analyze the extent to which companies encounter obstacles in the application of advanced environmental measurement tools, the questionnaire included a section specifically dedicated to the perceived barriers to the adoption of Life Cycle Assessment (LCA) and Carbon Footprint. Respondents were asked to assess the degree to which different factors represented a difficulty for their organization, expressing their level of agreement with each statement on a seven-point scale ranging from "strongly disagree" to "strongly agree."

Table 43 – Main barriers for an Italian organization in adopting Life Cycle Assessment

	1	2	3	4	5	6	7
High initial investments / high costs	3.99%	4.59%	8.49%	15.63%	22.87%	29.11%	15.33%
Lack of financial resources	5.69%	7.24%	10.08%	15.88%	19.27%	27.71%	14.13%
Excessive time requirements	4.19%	6.24%	9.44%	15.63%	22.57%	27.66%	14.28%

	1	2	3	4	5	6	7
Unclear benefits (e.g., economic benefits, tangible benefits, concrete results)	4.94%	6.89%	10.48%	15.13%	21.92%	27.51%	13.13%
Limited specialized knowledge and skills	5.64%	6.89%	10.48%	15.13%	21.92%	27.51%	13.13%
Insufficient or missing data	5.44%	7.44%	11.08%	15.58%	21.07%	25.31%	14.08%
Complexity of the products, services, processes, or circular business models to be assessed	3.94%	5.54%	9.39%	15.03%	22.92%	28.66%	14.53%
Lack of tools that are easily usable by companies	4.69%	6.04%	10.88%	14.33%	22.07%	27.96%	14.03%
Difficulty in collaborating with suppliers and partners to conduct the analysis	5.04%	7.04%	10.03%	15.08%	21.22%	27.46%	14.13%
Reluctant corporate culture or low propensity toward adoption	5.04%	7.04%	10.68%	15.43%	21.62%	26.31%	13.88%
Low priority given to the assessment	5.14%	6.64%	9.64%	16.18%	22.32%	26.56%	13.53%

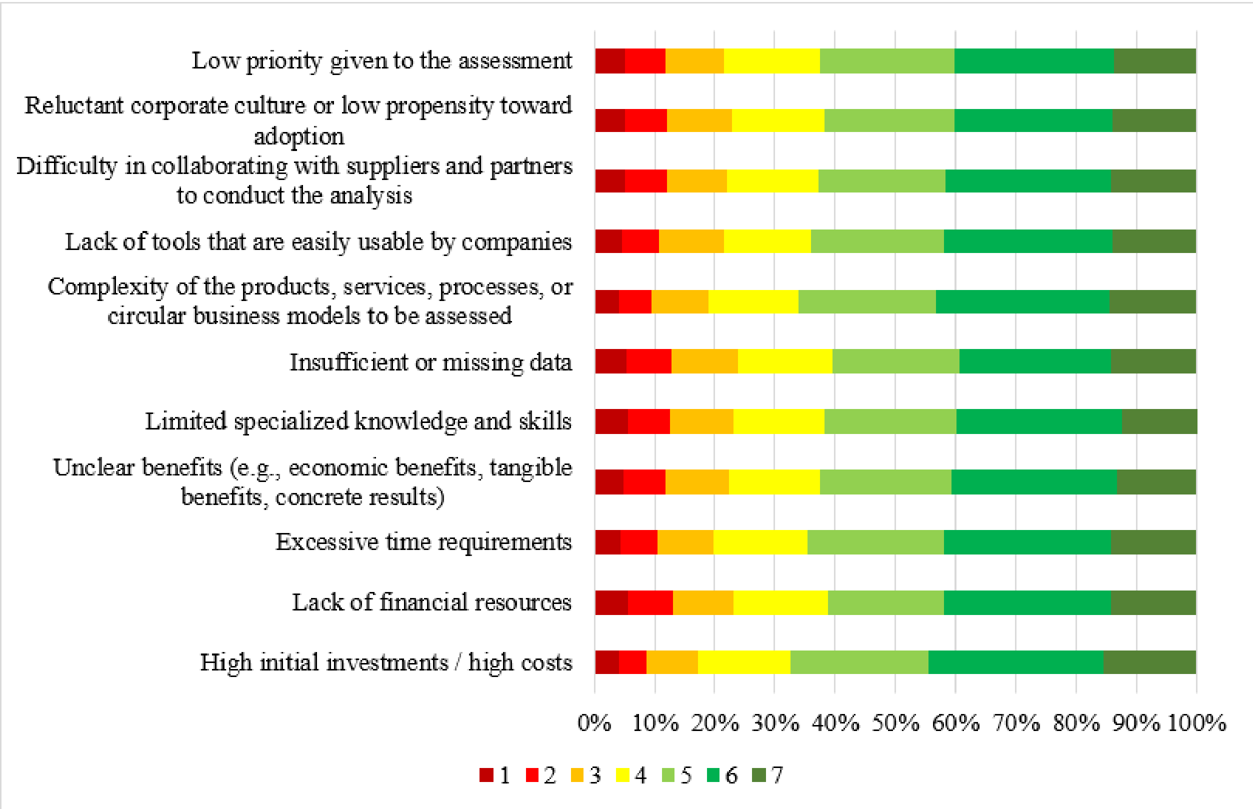


Figure 35 – Main barriers for an Italian organization in adopting Life Cycle Assessment

Table 44 – Main barriers for a German organization in adopting Life Cycle Assessment

	1	2	3	4	5	6	7
High initial investments / high costs	2.90%	6.44%	9.34%	14.99%	22.13%	25.72%	18.48%

	1	2	3	4	5	6	7
Lack of financial resources	5.64%	6.19%	8.24%	15.58%	22.68%	24.78%	16.88%
Excessive time requirements	3.60%	6.84%	10.84%	14.94%	22.38%	24.38%	17.03%
Unclear benefits (e.g., economic benefits, tangible benefits, concrete results)	3.90%	6.64%	10.24%	15.23%	22.78%	24.03%	17.18%
Limited specialized knowledge and skills	4.15%	6.64%	10.24%	15.23%	22.78%	24.03%	17.18%
Insufficient or missing data	4.20%	6.29%	8.94%	16.08%	22.03%	25.37%	17.08%
Complexity of the products, services, processes, or circular business models to be assessed	2.85%	5.74%	9.14%	16.13%	25.02%	25.62%	15.48%
Lack of tools that are easily usable by companies	4.40%	6.39%	9.94%	16.43%	22.58%	24.03%	16.23%
Difficulty in collaborating with suppliers and partners to conduct the analysis	4.05%	6.09%	9.69%	15.58%	21.83%	25.52%	17.23%
Reluctant corporate culture or low propensity toward adoption	4.60%	6.09%	9.29%	15.53%	22.98%	24.78%	16.73%
Low priority given to the assessment	4.40%	6.84%	9.59%	14.99%	21.08%	24.38%	18.73%

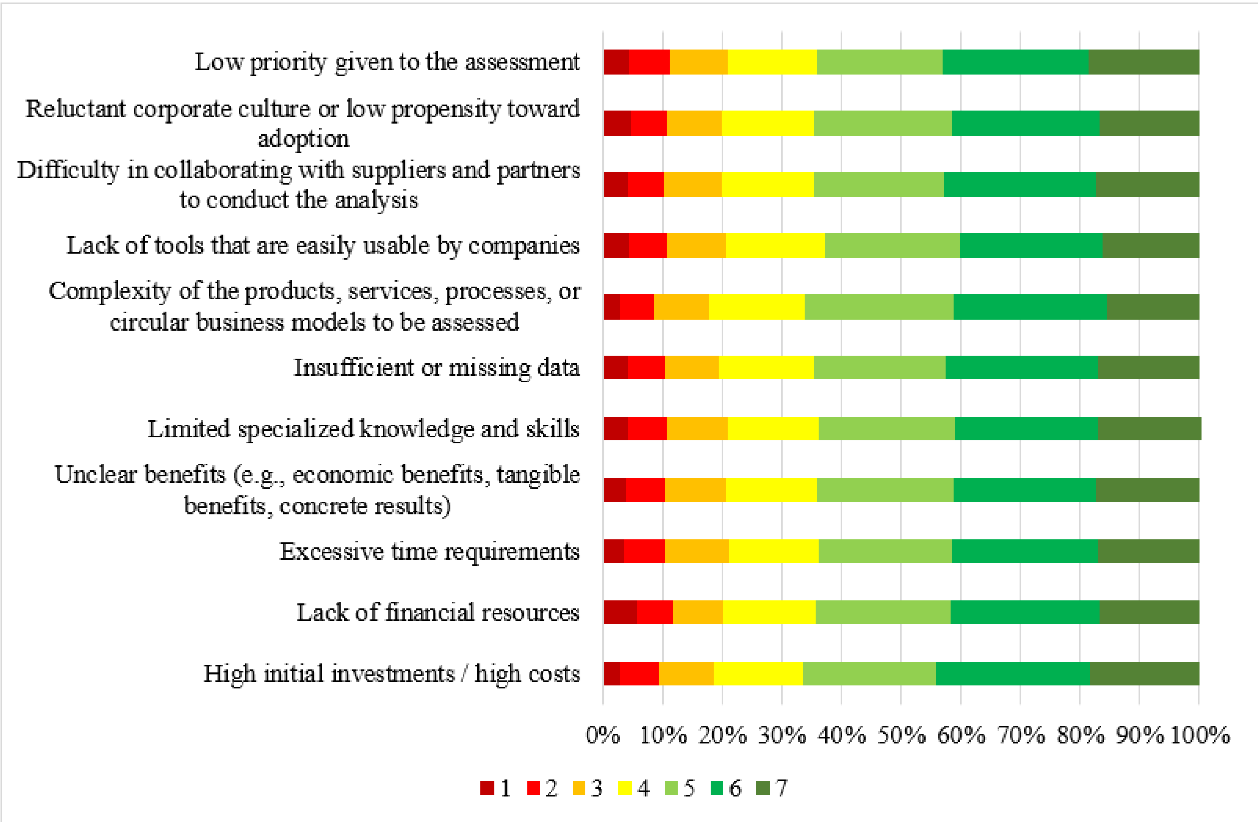


Figure 36 – Main barriers for a German organization in adopting Life Cycle Assessment

5.3.7 Organisational costs

To investigate companies' perceptions regarding the efforts required to integrate environmental practices and services, the questionnaire included a section dedicated to the efforts considered necessary to promote their adoption within organizations. In particular, respondents were asked to indicate their level of agreement with a series of statements concerning these efforts, using a seven-point scale ranging from "strongly disagree" to "strongly agree."

Table 45 – Efforts required to promote environmental practices or services within an Italian organization

	1	**2**	**3**	**4**	**5**	**6**	**7**
Several employees should constantly interact with external suppliers for the adoption of environmental practices or services	1.00%	2.95%	7.24%	13.33%	26.01%	31.15%	18.32%
External suppliers should purchase additional materials/software to achieve the expected objectives	2.05%	3.39%	7.54%	14.28%	25.26%	30.75%	16.72%
External suppliers should have adapted their way of working to support your organization in achieving the expected objectives	1.75%	3.39%	7.54%	14.28%	25.26%	30.75%	16.72%
Employees must learn the specific vocabulary (words, expressions, technical terms, etc.) related to environmental practices or services	2.20%	4.04%	6.84%	15.23%	22.42%	30.95%	18.32%
Employees must learn specific work procedures related to environmental practices or services	1.40%	3.49%	7.19%	14.63%	22.82%	32.50%	17.97%
Employees must learn the particularities (unique characteristics) of environmental practices or services (e.g., proper waste management, energy efficiency practices, ecodesign services, Life Cycle Assessment, etc.)	2.05%	3.15%	6.79%	14.88%	23.46%	32.05%	17.62%
My organization must modify its work procedures in order to collaborate with the supplier	2.10%	5.34%	8.94%	15.03%	22.32%	28.96%	17.32%
My organization provides training to its employees to enable them to work with the supplier	1.80%	3.59%	6.79%	15.63%	21.37%	32.15%	18.67%
My organization provides training to the supplier's employees to enable the supplier to deliver services to the organization	1.90%	3.00%	7.59%	13.88%	21.87%	32.30%	19.47%

Figure 37 – Efforts required to promote environmental practices or services within an Italian organization

Table 46 – Efforts required to promote environmental practices or services within a German organization

	1	2	3	4	5	6	7
Several employees should constantly interact with external suppliers for the adoption of environmental practices or services	2.60%	4.90%	8.49%	14.19%	21.88%	28.77%	19.18%
External suppliers should purchase additional materials/software to achieve the expected objectives	2.30%	4.25%	8.64%	16.93%	24.18%	25.77%	17.93%
External suppliers should have adapted their way of working to support your organization in achieving the expected objectives	2.10%	4.25%	8.64%	16.93%	24.18%	25.77%	17.93%

	1	2	3	4	5	6	7
Employees must learn the specific vocabulary (words, expressions, technical terms, etc.) related to environmental practices or services	1.70%	4.00%	9.09%	15.38%	23.53%	27.87%	18.43%
Employees must learn specific work procedures related to environmental practices or services	2.45%	4.30%	7.89%	14.19%	23.63%	27.37%	20.18%
Employees must learn the particularities (unique characteristics) of environmental practices or services (e.g., proper waste management, energy efficiency practices, ecodesign services, Life Cycle Assessment, etc.)	2.45%	5.00%	8.09%	16.28%	23.98%	26.82%	17.38%
My organization must modify its work procedures in order to collaborate with the supplier	3.40%	5.04%	7.84%	16.03%	23.43%	26.82%	17.43%
My organization provides training to its employees to enable them to work with the supplier	2.30%	4.10%	7.84%	14.79%	24.18%	26.42%	20.38%
My organization provides training to the supplier's employees to enable the supplier to deliver services to the organization	3.10%	4.80%	7.69%	14.94%	23.63%	27.32%	18.53%

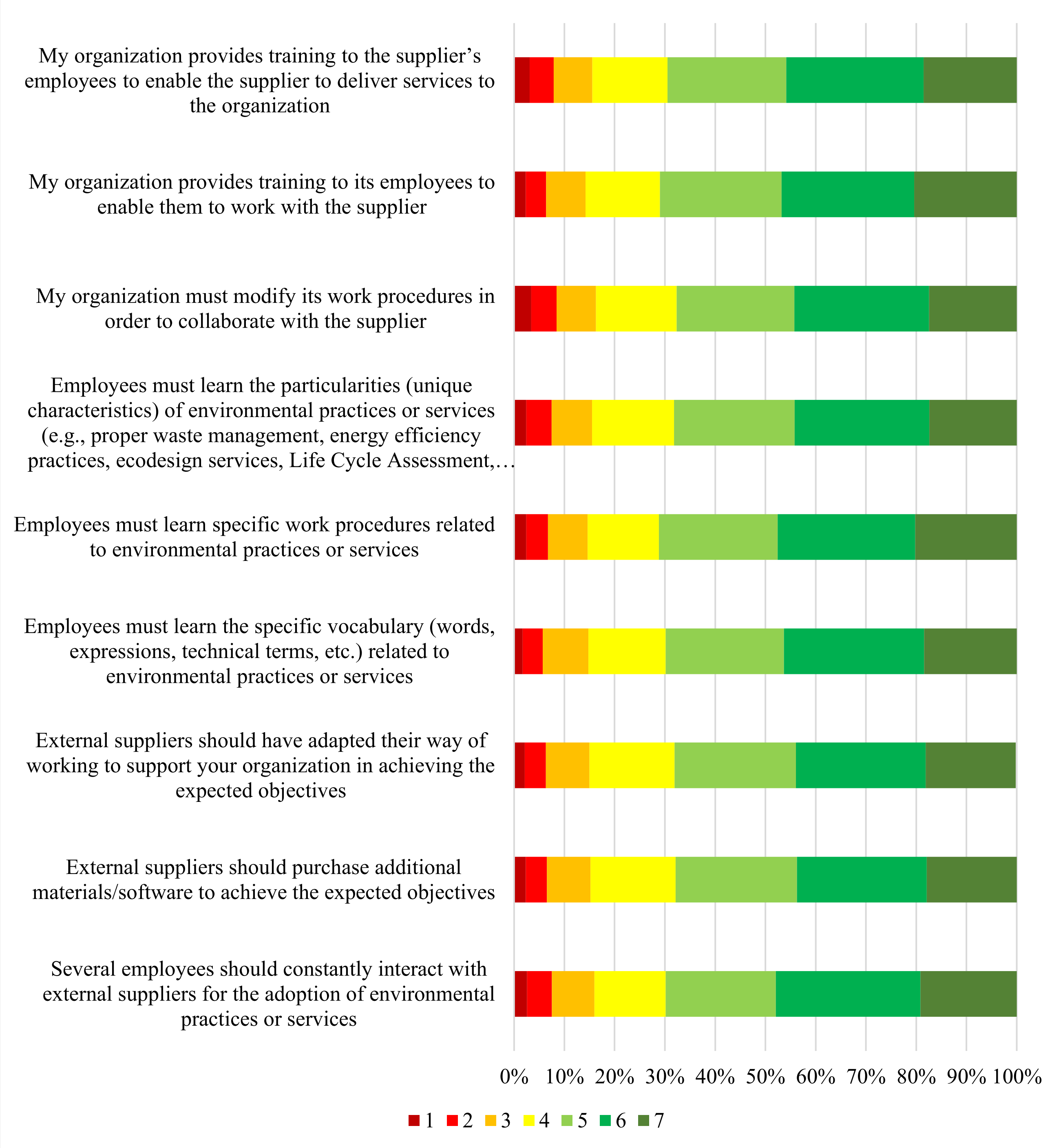


Figure 38 – Efforts required to promote environmental practices or services within a German organization

To further explore the role of the external context in the adoption of sustainability tools, the questionnaire included a section aimed at capturing organizations' perceptions regarding the availability of external suppliers capable of supporting them in the implementation of environmental practices and services, such as Life Cycle Assessment (LCA). Respondents were asked to indicate the extent to which they agreed with a series of statements related to this topic, using a seven-point scale ranging from "strongly disagree" to "strongly agree."

Table 47 – Availability in the market of external suppliers capable of supporting an Italian organization in adopting environmental practices or services

	1	2	3	4	5	6	7
There is not a sufficient number of known external suppliers in my sector that could potentially provide environmental practices and services	3.39%	6.34%	8.79%	16.18%	22.57%	28.16%	14.58%
There is not a sufficient number of reliable external suppliers that could potentially provide environmental practices and services	3.84%	6.09%	9.79%	15.88%	21.22%	27.36%	15.83%
If my organization decided to terminate the current contract with the supplier of environmental practices and services, there would be no other external service providers able to offer the same level of quality in environmental practices and services	3.39%	6.34%	8.79%	16.18%	22.57%	28.16%	14.58%

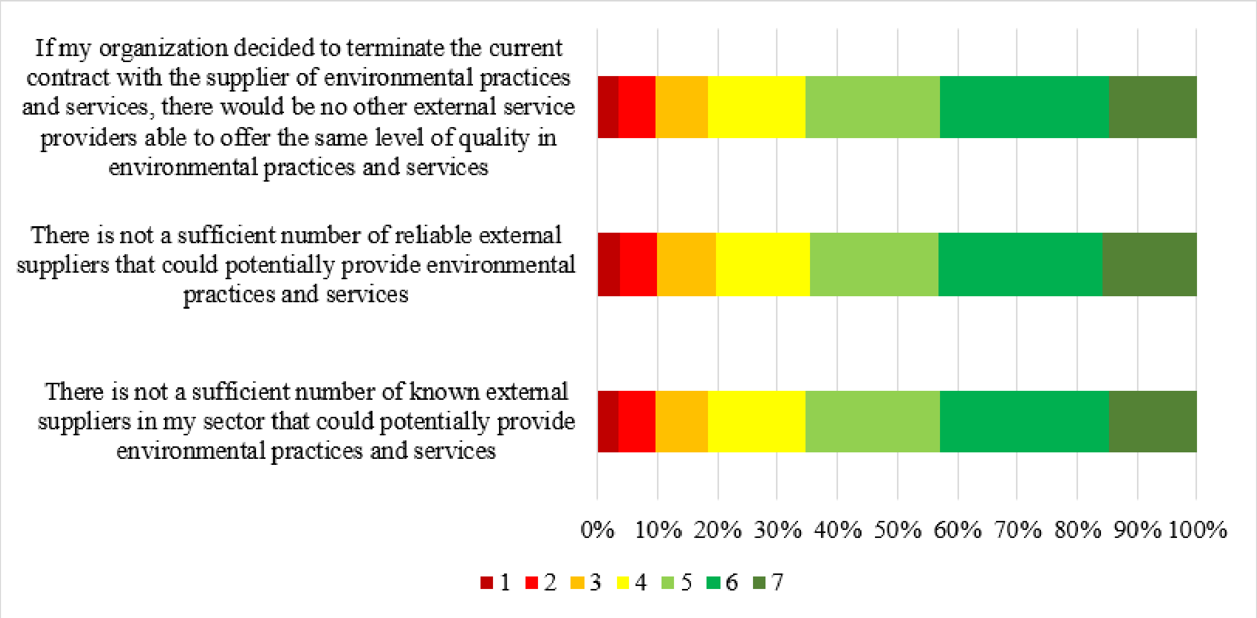


Figure 39 – Availability in the market of external suppliers capable of supporting an Italian organization in adopting environmental practices or services

Table 48 – Availability in the market of external suppliers capable of supporting a German organization in adopting environmental practices or services

	1	**2**	**3**	**4**	**5**	**6**	**7**
There is not a sufficient number of known external suppliers in my sector that could potentially provide environmental practices and services	3.40%	6.24%	9.69%	16.73%	23.33%	24.28%	16.33%

	1	2	3	4	5	6	7
There is not a sufficient number of reliable external suppliers that could potentially provide environmental practices and services	3.70%	5.69%	10.44%	16.93%	21.63%	25.27%	16.33%
If my organization decided to terminate the current contract with the supplier of environmental practices and services, there would be no other external service providers able to offer the same level of quality in environmental practices and services	3.40%	6.24%	9.69%	16.73%	23.33%	24.28%	16.33%

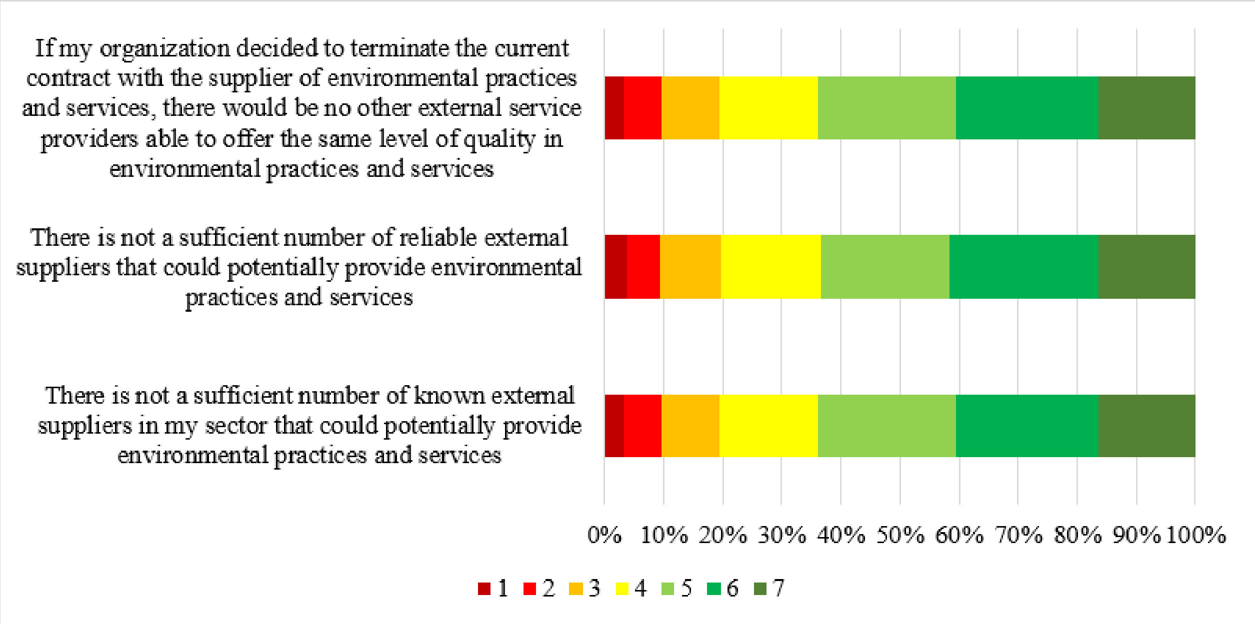


Figure 40 – Availability in the market of external suppliers capable of supporting a German organization in adopting environmental practices or services

To assess how organizations perceive the reliability of results obtained through sustainability tools, the questionnaire investigated the degree of uncertainty associated with the outputs derived from the adoption of environmental practices or services, such as Life Cycle Assessment (LCA), when implemented with the support of external suppliers. Respondents were asked to indicate their level of agreement with a series of statements on this issue using a seven-point scale ranging from "strongly disagree" to "strongly agree."

Table 49 – Level of uncertainty regarding the outputs of environmental practices or services as perceived by Italian organizations

	1	2	3	4	5	6	7
The methodology adopted to carry out the analysis becomes obsolete rather quickly	2.40%	3.89%	8.54%	15.73%	23.27%	30.60%	15.58%
Market demands and the requirements of the adopted service/practice are difficult to predict	3.00%	4.24%	7.44%	14.93%	23.41%	30.85%	16.13%
The technology/methodology of the product/service requires frequent changes	1.45%	4.24%	7.44%	14.93%	23.41%	30.85%	16.13%

	1	2	3	4	5	6	7
Trends in changing environmental requirements are difficult to monitor	2.75%	4.09%	7.29%	16.33%	23.22%	31.15%	15.18%
Environmental changes and requirements are difficult to predict	3.30%	5.09%	8.04%	14.73%	24.71%	28.26%	15.88%
The results of environmental practices or services are essential for the execution of one or more internal operations	1.35%	3.49%	6.89%	14.98%	24.11%	32.00%	17.17%
The results of environmental practices or services are essential for the execution of one or more outsourced operations	1.60%	2.95%	7.79%	13.43%	23.96%	32.70%	17.57%
My organization considers the results of environmental practices or services when undertaking actions for improvement	1.40%	3.15%	7.14%	14.83%	23.51%	32.60%	17.37%
My organization ensures the integration of practices or services into its business processes	1.00%	3.25%	7.69%	13.53%	24.46%	31.50%	18.57%

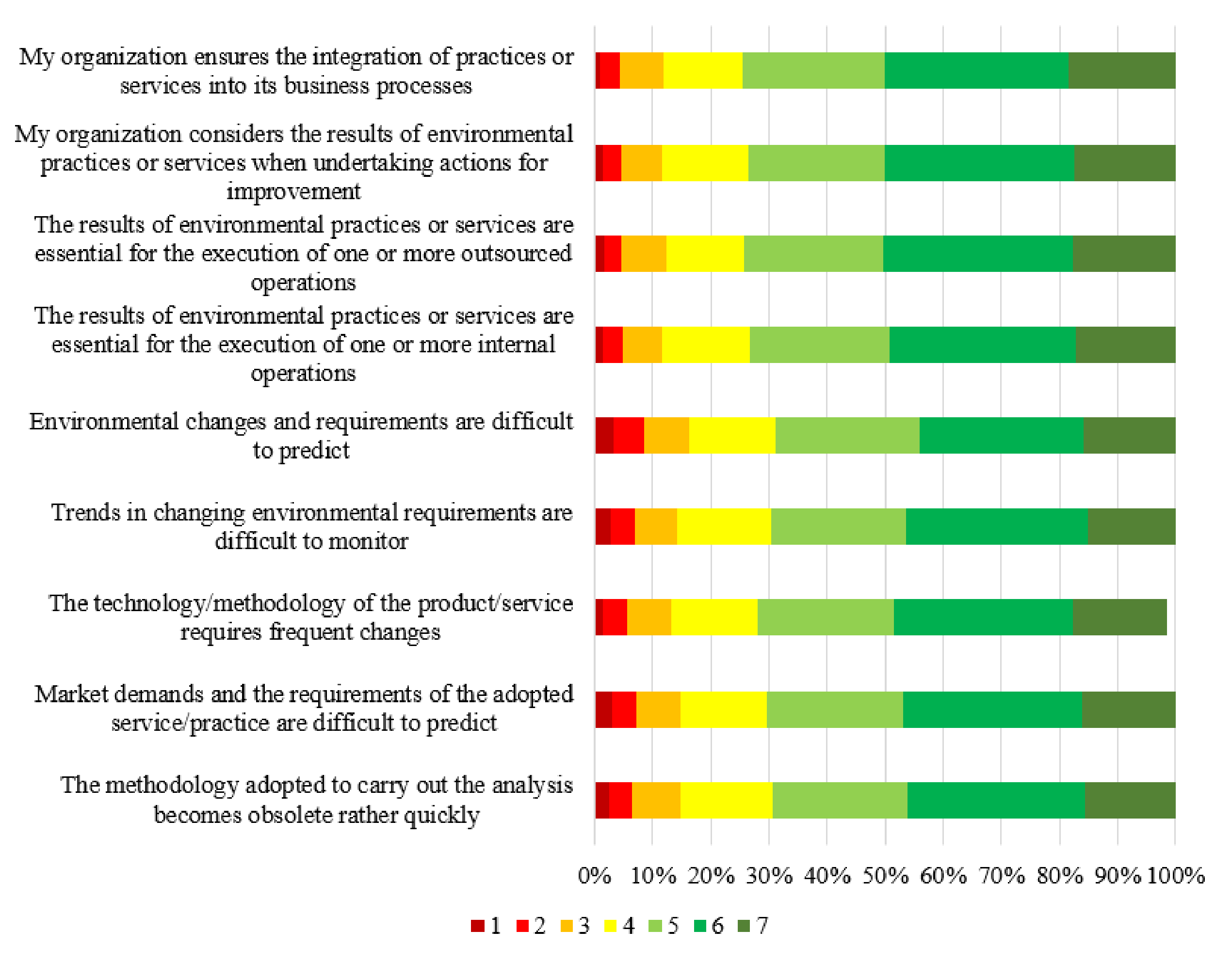


Figure 41 – Level of uncertainty regarding the outputs of environmental practices or services as perceived by Italian organizations

Table 50 – Level of uncertainty regarding the outputs of environmental practices or services as perceived by German organizations

	1	2	3	4	5	6	7
The methodology adopted to carry out the analysis becomes obsolete rather quickly	3.20%	5.54%	8.94%	15.98%	23.08%	26.12%	17.13%
Market demands and the requirements of the adopted service/practice are difficult to predict	2.45%	5.04%	8.64%	16.13%	22.58%	27.37%	17.78%
The technology/methodology of the product/service requires frequent changes	2.60%	5.04%	8.64%	16.13%	22.58%	27.37%	17.78%
Trends in changing environmental requirements are difficult to monitor	3.20%	5.04%	9.39%	15.38%	22.08%	26.87%	18.03%
Environmental changes and requirements are difficult to predict	2.90%	5.19%	9.69%	16.23%	22.88%	24.98%	18.13%
The results of environmental practices or services are essential for the execution of one or more internal operations	2.10%	5.24%	9.14%	14.54%	23.58%	26.67%	18.73%
The results of environmental practices or services are essential for the execution of one or more outsourced operations	2.05%	4.90%	8.14%	15.83%	24.98%	26.72%	17.38%
My organization considers the results of environmental practices or services when undertaking actions for improvement	2.40%	4.80%	8.84%	15.73%	23.38%	25.77%	19.08%
My organization ensures the integration of practices or services into its business processes	1.80%	3.85%	7.84%	14.99%	23.98%	26.32%	21.23%

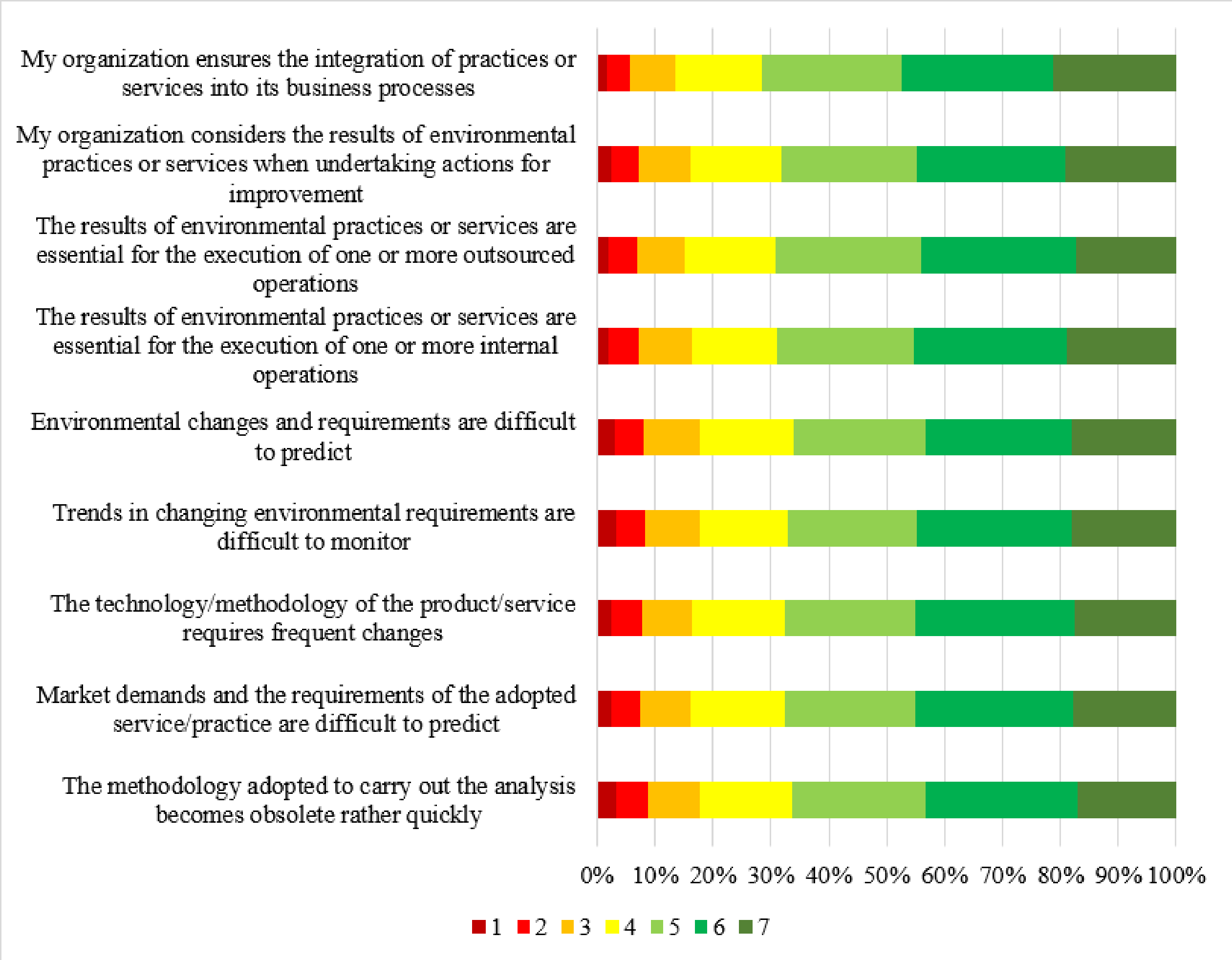


Figure 42 – Level of uncertainty regarding the outputs of environmental practices or services as perceived by German organizations

In order to gain a better understanding of how sustainability practices are implemented, the questionnaire included a section dedicated to the management of environmental activities carried out with the support of external suppliers, such as life cycle assessment (LCA). Participants were asked to indicate their level of agreement with a series of statements regarding such management, using a seven-point scale ranging from 'strongly disagree' to 'strongly agree'.

Table 51 – Management of environmental practices or services implemented with the support of an external supplier by Italian organizations

	1	2	3	4	5	6	7
My organization clearly indicates to the external supplier the performance standards it expects	1.20%	3.00%	6.39%	14.48%	24.71%	31.05%	19.17%
In terms of quantity, quality, and timeliness of results, the external supplier clearly knows what level of work performance my organization expects	1.20%	3.89%	7.94%	14.58%	23.66%	31.80%	16.92%
The external supplier has provided written or unwritten procedures for managing environmental practices or services	1.80%	3.54%	7.49%	15.48%	23.32%	31.00%	17.37%

	1	2	3	4	5	6	7
The rules and procedures provided by external suppliers precisely establish how to manage the main tasks related to environmental practices or services	1.95%	4.24%	7.44%	13.23%	24.61%	32.05%	16.48%
To support my organization in adopting environmental practices or services, the external supplier has used various written procedures, rules, or requirements	1.60%	4.24%	7.44%	13.23%	24.61%	32.05%	16.48%
It was easy to identify the sequence of steps required to successfully carry out environmental practices or services	1.55%	3.15%	6.69%	15.43%	24.56%	31.40%	17.22%
The consequences of environmental practices or services were easy to predict	1.10%	2.95%	7.74%	14.88%	25.06%	31.55%	16.72%
The rules and procedures related to environmental practices or services are rarely subject to change	1.35%	3.99%	8.34%	14.68%	24.86%	30.50%	16.28%
The tasks and procedures involved in carrying out environmental practices or services are always the same	1.50%	3.59%	8.64%	14.73%	24.41%	31.35%	15.78%
When carrying out environmental practices or services, problems that cannot be immediately resolved rarely arise	1.30%	3.94%	8.34%	13.98%	24.76%	30.05%	17.62%
In general, it is possible to immediately determine whether outsourced operations have been successfully performed or not	1.50%	3.34%	7.64%	14.93%	22.97%	31.80%	17.82%

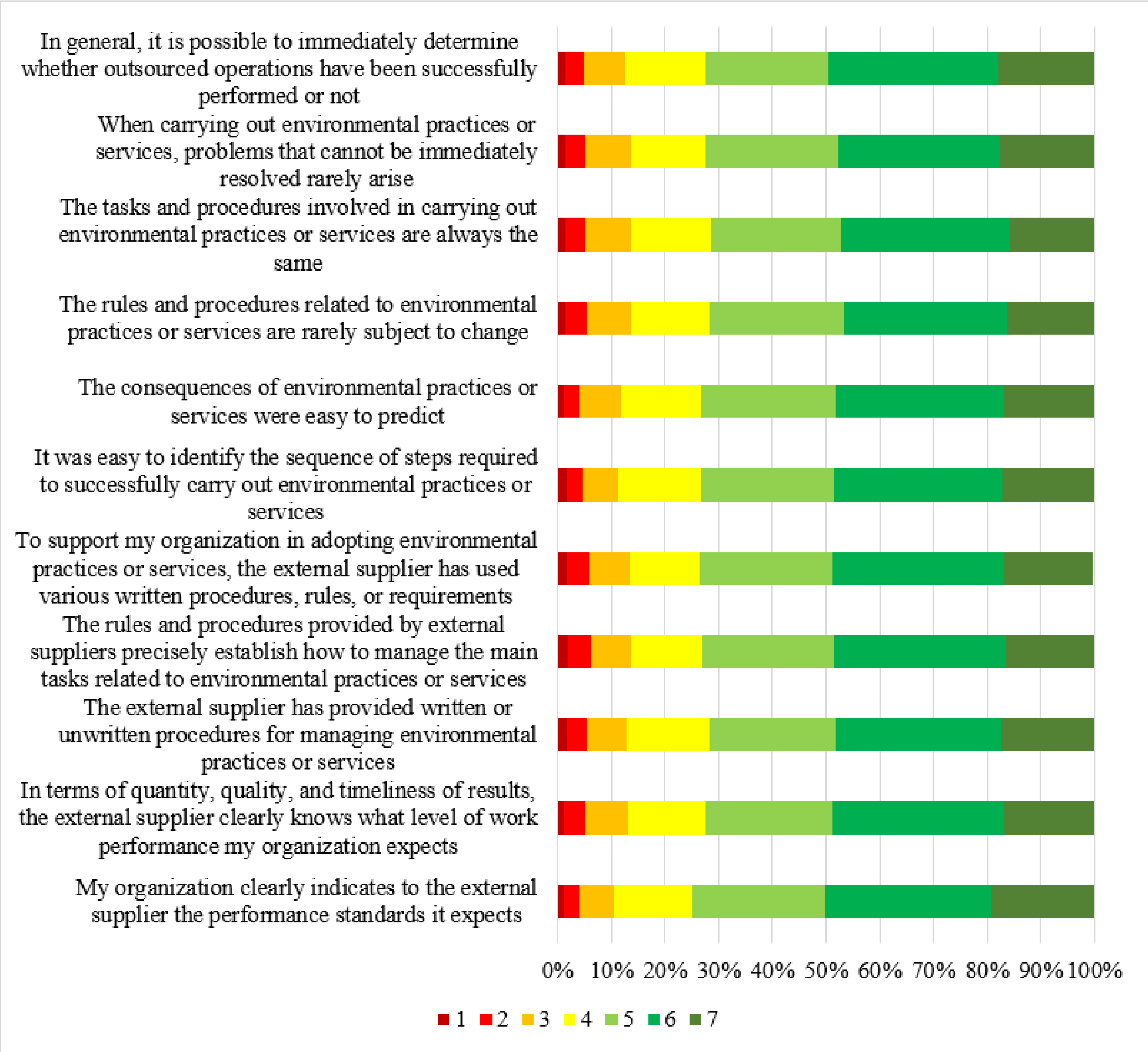


Figure 43 – Management of environmental practices or services implemented with the support of an external supplier by Italian organizations

Table 52 – Management of environmental practices or services implemented with the support of an external supplier by German organizations

	1	2	3	4	5	6	7
My organization clearly indicates to the external supplier the performance standards it expects	1.40%	4.35%	8.09%	15.93%	22.18%	27.07%	20.98%
In terms of quantity, quality, and timeliness of results, the external supplier clearly knows what level of work performance my organization expects	2.00%	4.85%	9.29%	15.18%	23.88%	26.17%	18.63%
The external supplier has provided written or unwritten procedures for managing environmental practices or services	1.50%	4.65%	8.74%	15.48%	24.43%	25.67%	19.53%

	1	**2**	**3**	**4**	**5**	**6**	**7**
The rules and procedures provided by external suppliers precisely establish how to manage the main tasks related to environmental practices or services	1.80%	3.90%	8.19%	16.13%	24.23%	26.77%	18.98%
To support my organization in adopting environmental practices or services, the external supplier has used various written procedures, rules, or requirements	2.10%	3.90%	8.19%	16.13%	24.23%	26.77%	18.98%
It was easy to identify the sequence of steps required to successfully carry out environmental practices or services	1.95%	4.65%	8.09%	14.94%	23.73%	27.92%	18.73%
The consequences of environmental practices or services were easy to predict	1.80%	4.05%	9.09%	16.28%	23.58%	27.22%	17.98%
The rules and procedures related to environmental practices or services are rarely subject to change	1.75%	4.25%	8.84%	15.68%	24.03%	26.17%	19.28%
The tasks and procedures involved in carrying out environmental practices or services are always the same	2.60%	4.40%	8.29%	15.13%	24.13%	26.77%	18.68%
When carrying out environmental practices or services, problems that cannot be immediately resolved rarely arise	2.15%	4.65%	8.29%	15.43%	24.38%	27.62%	17.48%
In general, it is possible to immediately determine whether outsourced operations have been successfully performed or not	1.55%	3.70%	8.29%	16.38%	22.63%	27.87%	19.58%

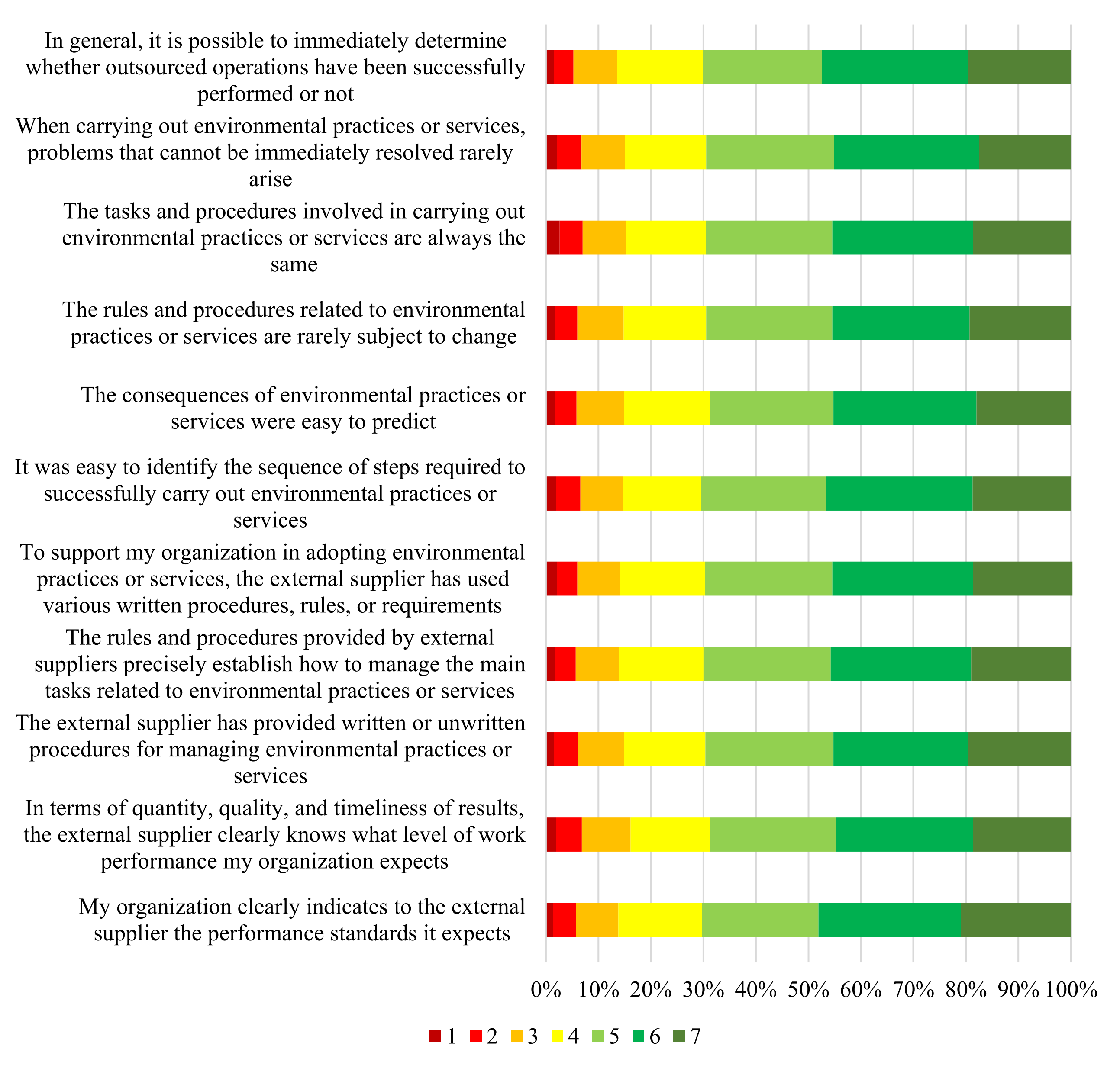


Figure 44 – Management of environmental practices or services implemented with the support of an external supplier by German organizations

5.3.8 Employees' green skills

To explore the topic of sustainability-related professional roles, the questionnaire included a dedicated section on "green" job positions, namely roles specifically oriented toward environmental management or the promotion of sustainable practices. Respondents were asked to indicate their level of agreement with a series of statements on this topic using a seven-point Likert scale ranging from "strongly disagree" to "strongly agree."

Table 53 – "Green" job positions in Italian organizations

	1	2	3	4	5	6	7
My organization has integrated environmental protection responsibilities into every job position related to environmental aspects	1.95%	3.79%	7.14%	14.28%	23.61%	31.70%	17.52%
My organization has included its environmental and social requirements in job descriptions	1.55%	3.99%	7.74%	13.08%	22.32%	32.00%	19.32%
My organization has incorporated environmental aspects as tasks within job descriptions	1.80%	3.34%	7.79%	13.18%	22.02%	33.00%	18.87%
My organization has incorporated environmental competencies as a distinguishing element in job specifications	1.35%	2.45%	6.99%	13.98%	20.77%	28.36%	26.11%
My organization has introduced specific job positions related to environmental aspects to emphasize environmental protection	1.80%	3.25%	7.74%	15.38%	21.07%	31.65%	19.12%
My organization has incorporated "environmental awareness" criteria into its human resources personnel policies	1.70%	3.94%	7.44%	14.78%	21.87%	31.60%	18.67%
In my organization, candidates are evaluated based on their environmental competencies and awareness during job interviews	2.15%	4.04%	7.89%	13.88%	21.87%	31.30%	18.87%
My organization considers candidates' environmental awareness, motivation, and interest as selection criteria	1.80%	3.59%	7.79%	14.18%	22.67%	31.10%	18.87%

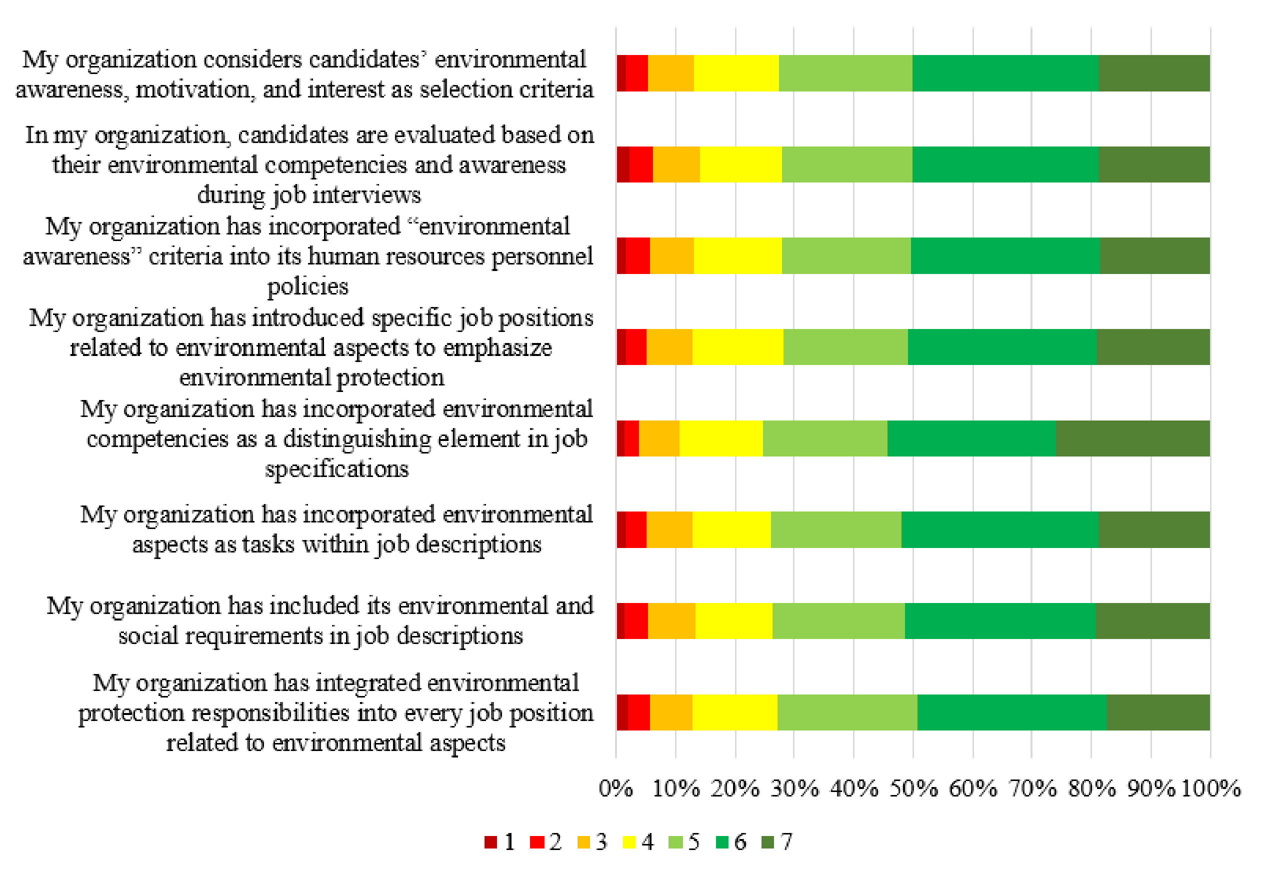


Figure 45 – "Green" job positions in Italian organizations

Table 54 – "Green" job positions in German organizations

	1	2	3	4	5	6	7
My organization has integrated environmental protection responsibilities into every job position related to environmental aspects	2.65%	4.80%	8.34%	14.24%	22.98%	27.17%	19.83%
My organization has included its environmental and social requirements in job descriptions	2.95%	4.90%	7.89%	15.08%	22.43%	27.72%	19.03%
My organization has incorporated environmental aspects as tasks within job descriptions	3.45%	4.60%	7.99%	14.54%	22.78%	26.72%	19.93%
My organization has incorporated environmental competencies as a distinguishing element in job specifications	3.30%	5.34%	7.89%	15.78%	22.63%	26.72%	18.33%
My organization has introduced specific job positions related to environmental aspects to emphasize environmental protection	2.85%	4.75%	8.89%	14.39%	22.88%	26.42%	19.83%

	1	2	3	4	5	6	7
My organization has incorporated “environmental awareness” criteria into its human resources personnel policies	2.45%	5.00%	8.19%	14.19%	22.78%	26.12%	21.28%
In my organization, candidates are evaluated based on their environmental competencies and awareness during job interviews	3.30%	5.09%	9.44%	13.64%	23.23%	27.07%	18.23%
My organization considers candidates’ environmental awareness, motivation, and interest as selection criteria	2.65%	4.95%	7.99%	15.18%	23.78%	26.97%	18.48%

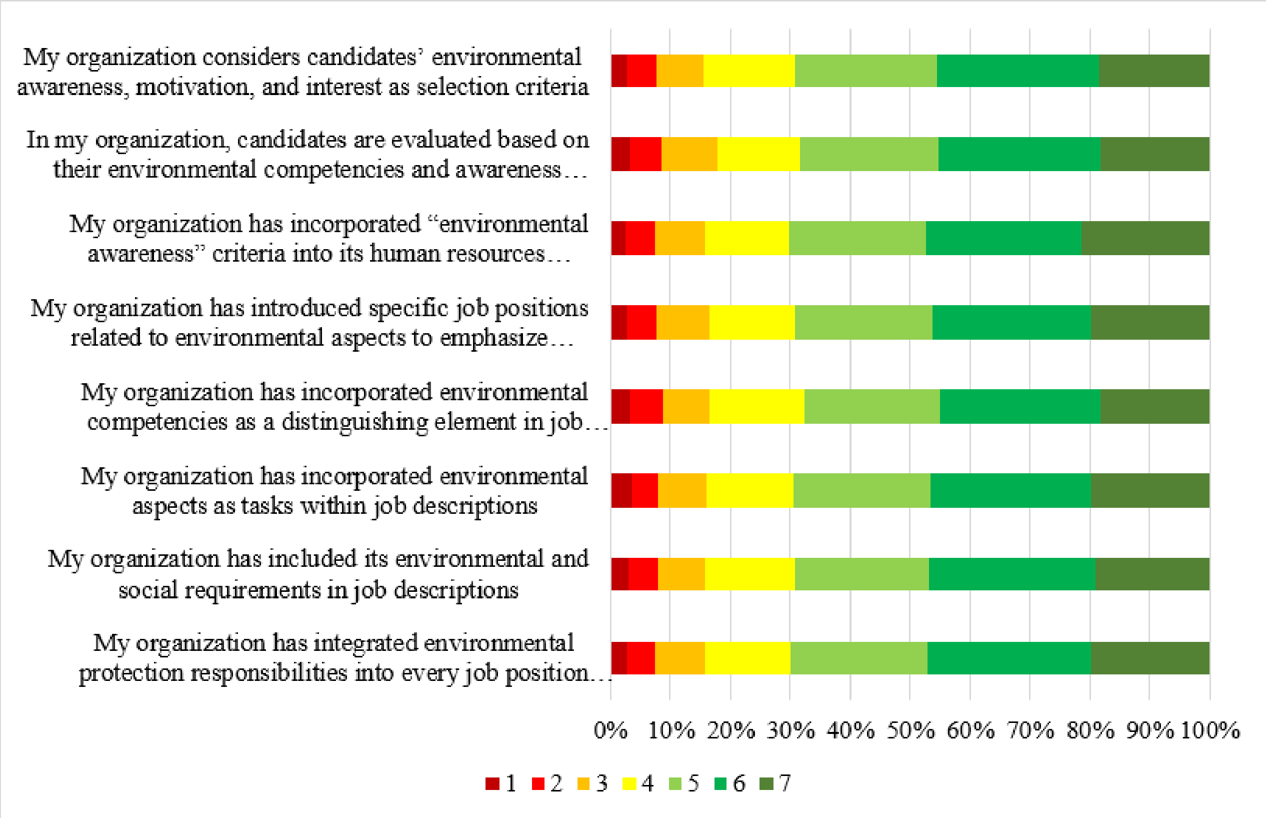


Figure 46 – “Green” job positions in German organizations

To examine organizations’ commitment to the development of internal competencies, the questionnaire included a section dedicated to the environmental training provided to their members. Participants were asked to indicate their level of agreement with a series of statements regarding this training, using a seven-point Likert scale ranging from “strongly disagree” to “strongly agree.”

Table 55 – Environmental training in Italian organizations

	1	2	3	4	5	6	7
In my organization, environmental training is offered to all employees (including outsourced staff) at all hierarchical levels	1.70%	4.04%	6.94%	13.93%	20.42%	32.70%	20.27%

	1	2	3	4	5	6	7
In my organization, employees are generally satisfied with the environmental training provided	1.65%	3.15%	7.89%	12.83%	22.47%	32.65%	19.37%
In my organization, the topics covered in environmental training sessions are appropriate and up to date for the organization's activities	1.15%	2.95%	8.54%	12.78%	22.57%	31.80%	20.22%
My organization assesses in which environmental aspects employees require training	1.75%	3.00%	6.54%	13.33%	22.77%	33.15%	19.47%
My organization assesses who needs training in managing environmental issues	1.55%	3.25%	6.54%	13.18%	23.12%	32.30%	20.07%
My organization provides training on environmental management to improve employees' awareness, skills, and know-how	1.60%	2.95%	6.39%	15.23%	21.12%	33.70%	19.02%

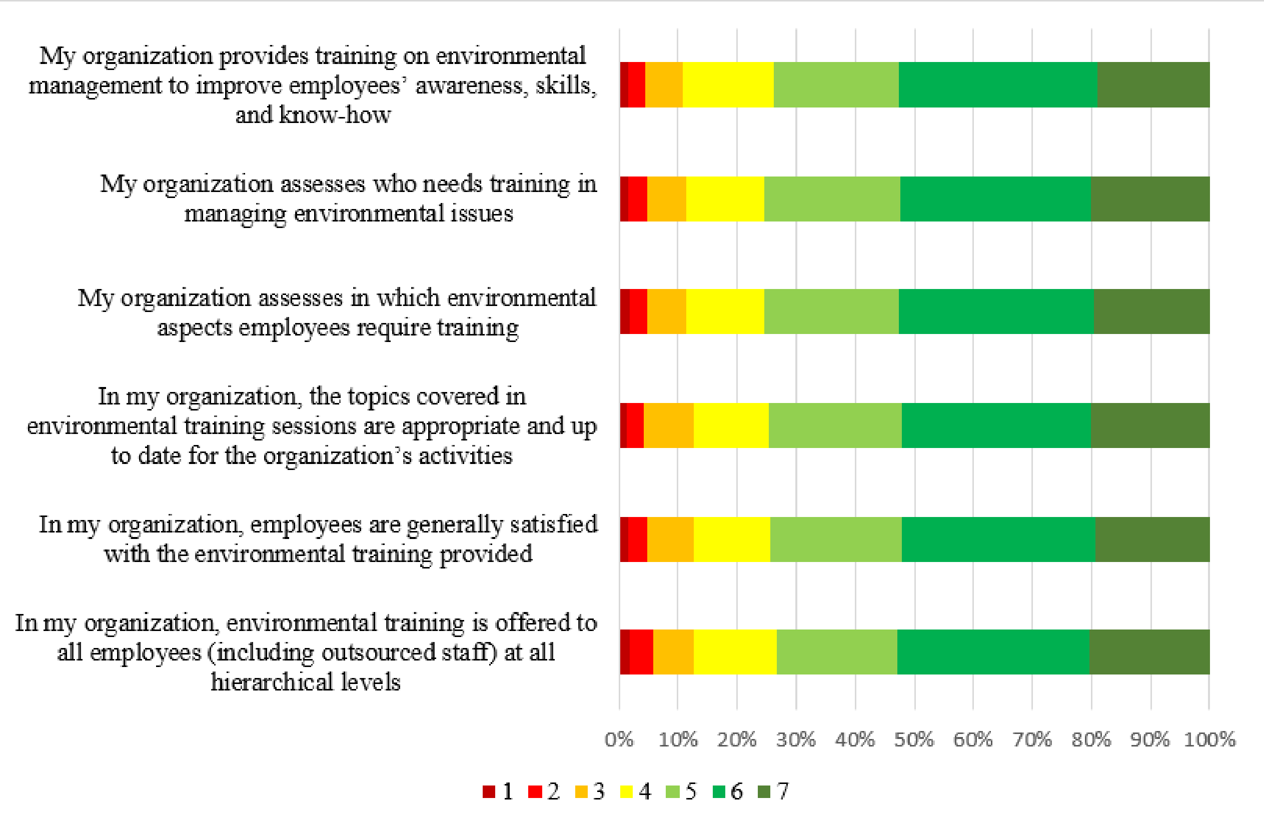


Figure 47 – Environmental training in Italian organizations

Table 56 – Environmental training in German organizations

	1	2	3	4	5	6	7
In my organization, environmental training is offered to all employees (including outsourced staff) at all hierarchical levels	2.35%	5.14%	7.69%	15.83%	22.83%	26.42%	19.73%
In my organization, employees are generally satisfied with the environmental training provided	1.65%	4.50%	7.24%	15.23%	22.28%	27.97%	21.13%
In my organization, the topics covered in environmental training sessions are appropriate and up to date for the organization's activities	2.45%	5.19%	8.64%	14.54%	23.18%	25.82%	20.18%
My organization assesses in which environmental aspects employees require training	2.90%	4.55%	8.64%	13.94%	24.08%	27.62%	18.28%
My organization assesses who needs training in managing environmental issues	1.75%	4.65%	6.79%	15.48%	23.08%	29.52%	18.73%
My organization provides training on environmental management to improve employees' awareness, skills, and know-how	3.05%	4.90%	8.19%	15.28%	23.18%	25.97%	19.43%

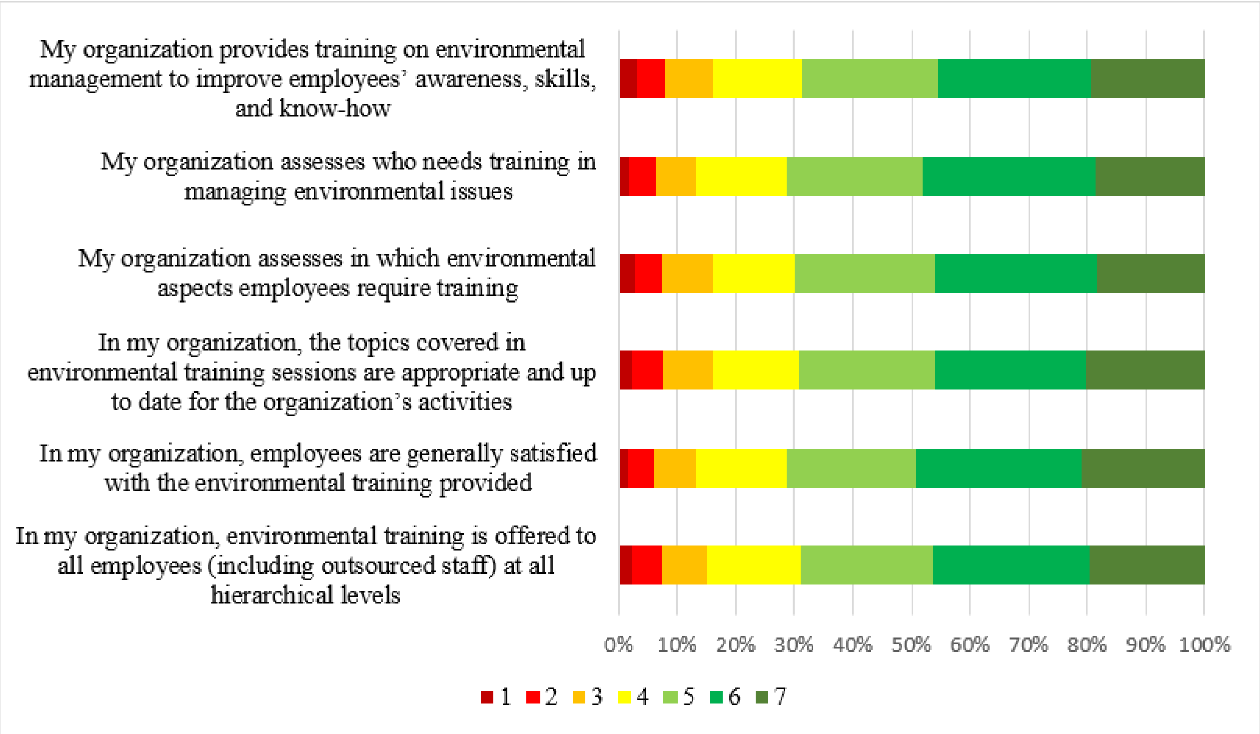


Figure 48 – Environmental training in German organizations

To further investigate the role of human resources in sustainability processes, the questionnaire included a section aimed at assessing the level of employees' commitment and involvement with regard to the environmental issues addressed by the organization. Respondents were asked to indicate their level of agreement with a series of statements on this topic using a seven-point Likert scale ranging from "strongly disagree" to "strongly agree."

Table 57 – Level of employee commitment and involvement in environmental issues in Italian organizations

	1	2	3	4	5	6	7
My organization uses various formal and informal communication methods to foster environmental awareness	1.40%	3.30%	7.29%	12.98%	23.07%	32.80%	19.17%
My organization offers seminars, forums, or joint sessions for staff members to improve environmental behavior and exchange knowledge	2.15%	3.44%	5.69%	13.68%	23.36%	32.30%	19.37%
In my organization, teamwork is promoted and encouraged to effectively manage and raise awareness of environmental issues	1.80%	3.20%	7.24%	14.08%	21.07%	32.25%	20.37%
My organization promotes a culture of environmental protection by emphasizing environmental values and adopting sustainable practices	1.35%	3.25%	7.64%	12.53%	22.87%	32.55%	19.82%
Within my organization, helplines and anonymous reporting procedures on environmental issues (green whistleblowing) are regularly used as opportunities for improvement	2.15%	3.99%	6.49%	14.28%	21.87%	31.95%	19.27%

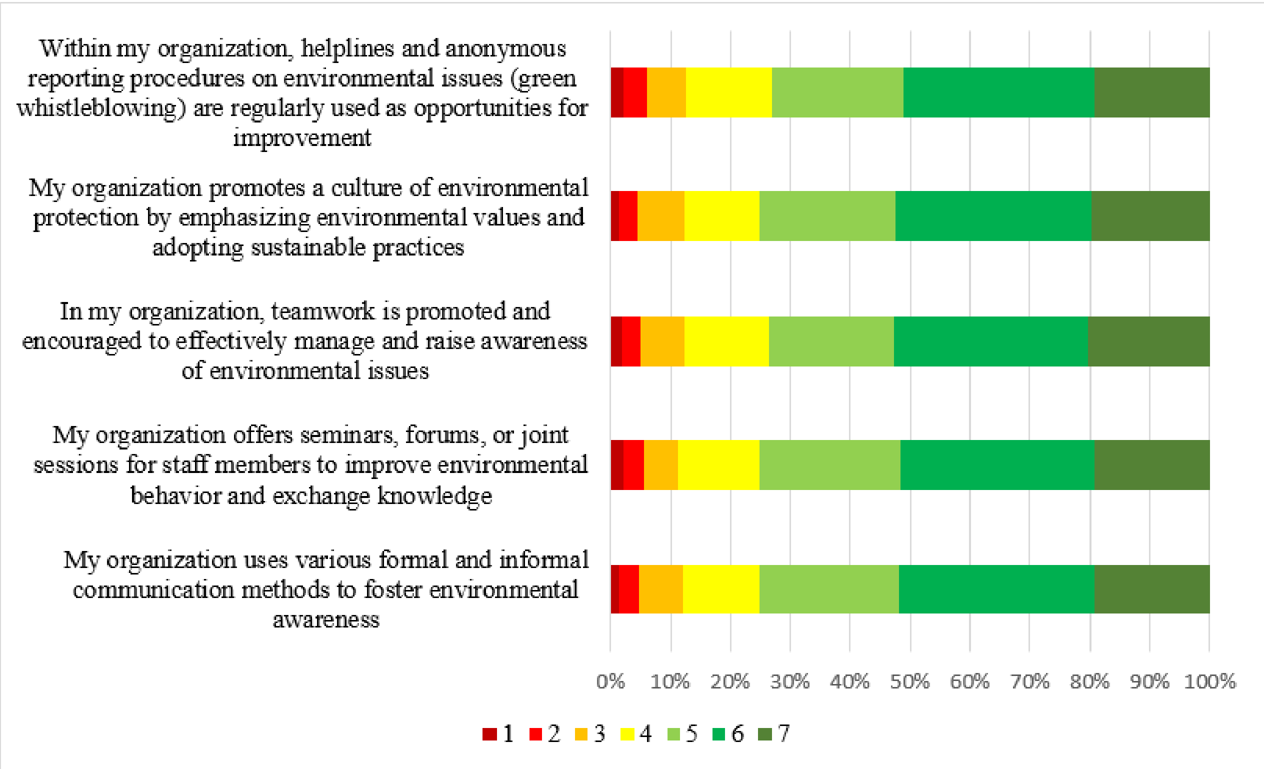


Figure 49 – Level of employee commitment and involvement in environmental issues in Italian organizations

Table 58 – Level of employee commitment and involvement in environmental issues in German organizations

	1	2	3	4	5	6	7
My organization uses various formal and informal communication methods to foster environmental awareness	2.45%	4.75%	7.54%	15.13%	21.88%	27.97%	20.28%
My organization offers seminars, forums, or joint sessions for staff members to improve environmental behavior and exchange knowledge	2.45%	4.60%	7.79%	16.18%	23.48%	25.67%	19.83%
In my organization, teamwork is promoted and encouraged to effectively manage and raise awareness of environmental issues	2.35%	5.04%	7.74%	14.29%	22.98%	27.22%	20.38%
My organization promotes a culture of environmental protection by emphasizing environmental values and adopting sustainable practices	2.10%	3.70%	8.34%	15.18%	23.03%	27.52%	20.13%
Within my organization, helplines and anonymous reporting procedures on environmental issues (green whistleblowing) are regularly used as opportunities for improvement	3.40%	4.60%	8.19%	15.88%	22.03%	27.72%	18.18%

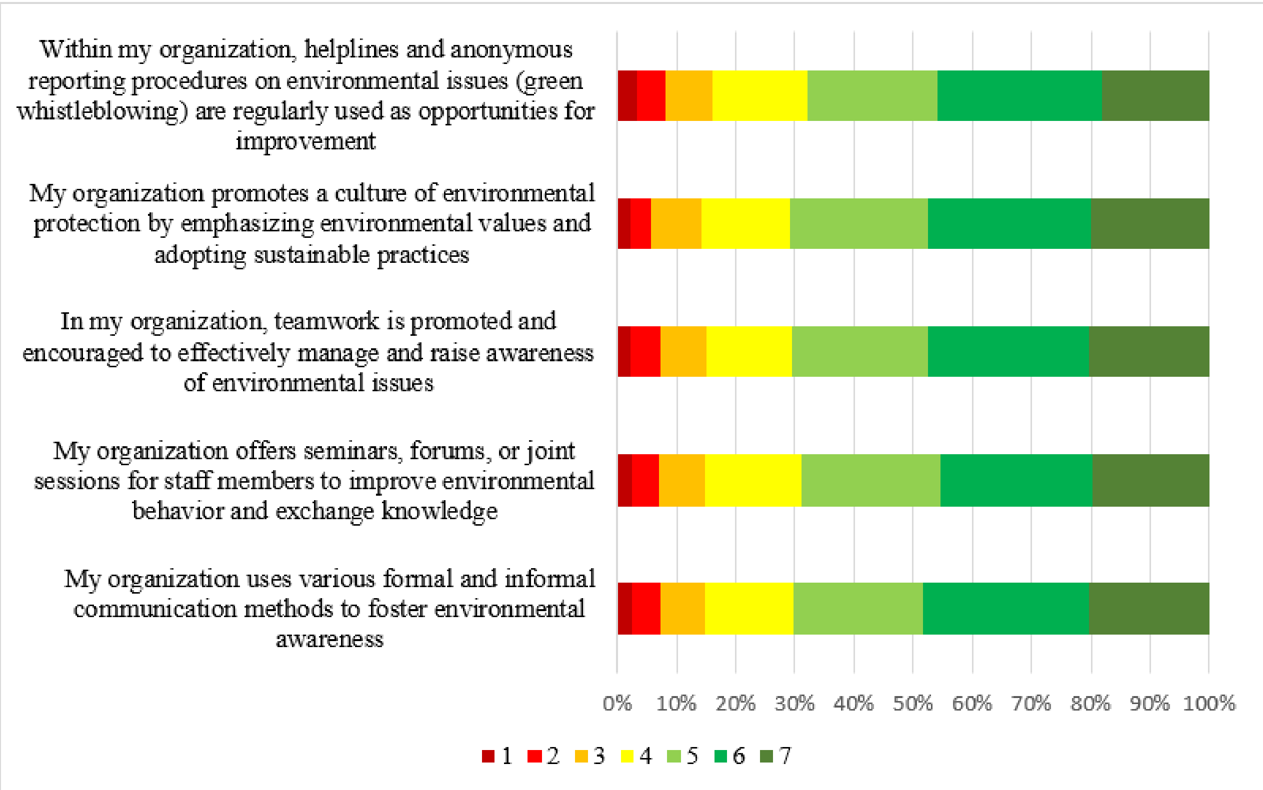


Figure 50 – Level of employee commitment and involvement in environmental issues in German organizations

To analyze how internal policies can encourage sustainable behaviors, the questionnaire included a section dedicated to the employee performance management and reward system adopted by the organizations. Participants were asked to indicate their level of agreement with a series of statements related to this topic using a seven-point Likert scale ranging from "strongly disagree" to "strongly agree."

Table 59 – Employee performance management and reward system adopted by Italian organizations

	1	2	3	4	5	6	7
My organization regularly provides feedback to employees or teams to achieve environmental goals or improve their environmental performance	2.05%	3.94%	7.69%	13.28%	21.62%	31.55%	19.87%
My organization integrates corporate environmental management goals and targets into the employee performance appraisal system	1.85%	3.84%	7.44%	14.73%	21.77%	31.55%	18.82%
My organization sets environmental objectives, expected outcomes, and responsibilities for each employee	2.20%	3.44%	6.19%	14.98%	22.52%	31.10%	19.57%
In my organization, managers have established environmental performance targets that are incorporated into periodic evaluations	1.40%	3.44%	6.19%	14.98%	22.52%	31.10%	19.57%
My organization focuses on communicating environmental goals	1.65%	3.64%	7.84%	13.23%	22.07%	32.70%	18.87%
In my organization, environmental incidents are consistently evaluated and recorded	1.85%	3.20%	6.89%	14.93%	21.87%	32.40%	18.87%
My organization offers non-monetary or monetary rewards based on environmental results achieved (e.g., sabbaticals, leave, gifts, benefits, financial bonuses, promotions, etc.)	2.85%	3.69%	7.34%	14.13%	23.61%	30.00%	18.37%
In my organization, employees' environmental performance is made public	2.30%	3.89%	7.14%	12.68%	23.46%	31.05%	19.47%
My organization provides incentives to encourage environmentally responsible activities and behaviors (e.g., car-sharing, etc.)	2.50%	3.64%	6.89%	14.63%	22.27%	31.65%	18.42%
My organization offers and organizes environmentally friendly activities for employees	1.55%	3.49%	6.94%	13.33%	22.52%	31.45%	20.72%

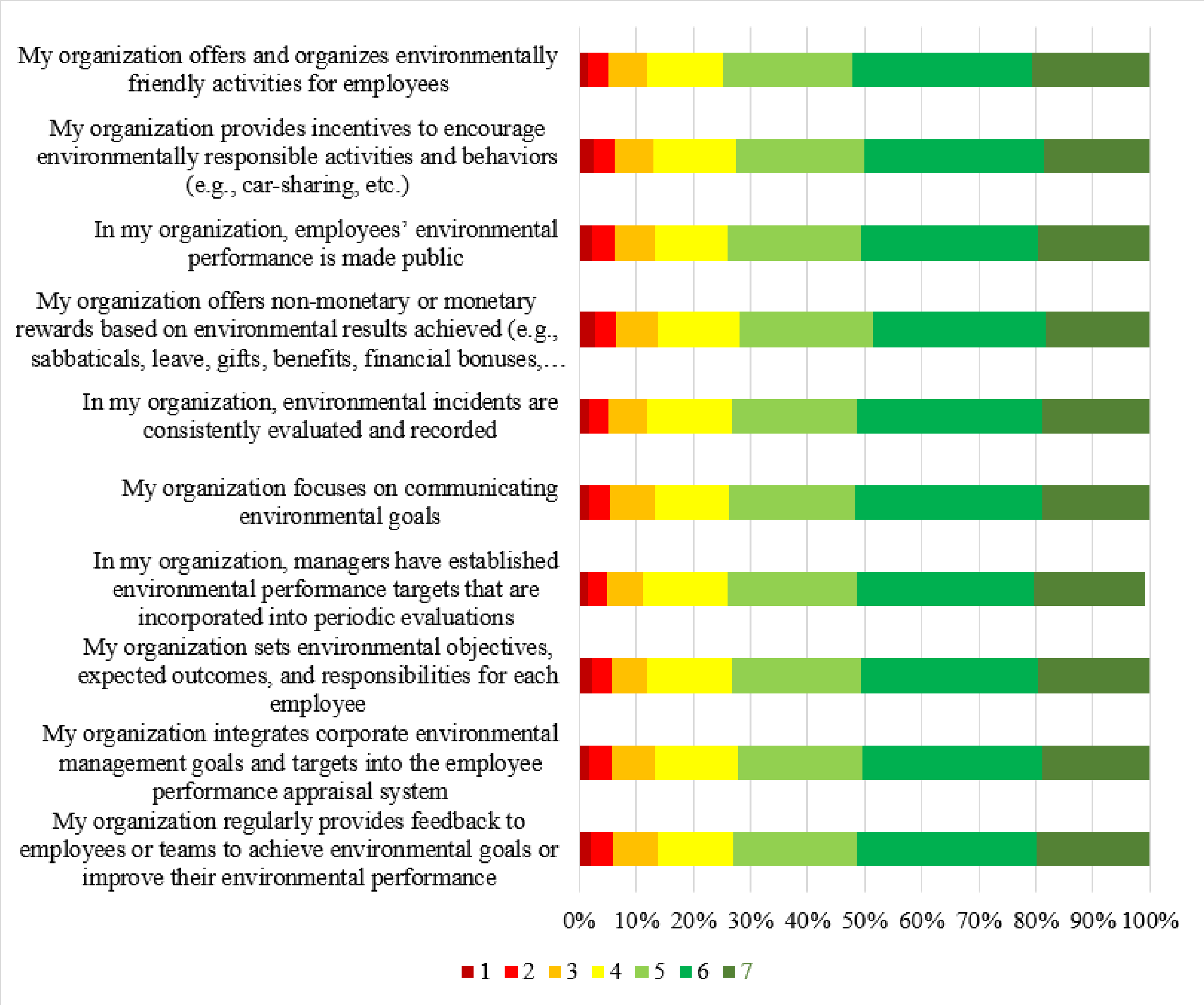


Figure 51 – Employee performance management and reward system adopted by Italian organizations

Table 60 – Employee performance management and reward system adopted by German organizations

	1	2	3	4	5	6	7
My organization regularly provides feedback to employees or teams to achieve environmental goals or improve their environmental performance	2.65%	5.24%	8.59%	14.79%	23.38%	26.42%	18.93%
My organization integrates corporate environmental management goals and targets into the employee performance appraisal system	2.90%	5.00%	8.04%	15.08%	24.33%	25.42%	19.23%
My organization sets environmental objectives, expected outcomes, and responsibilities for each employee	3.10%	4.70%	7.39%	14.29%	22.58%	28.67%	19.28%
In my organization, managers have established environmental performance	2.55%	4.70%	7.39%	14.29%	22.58%	28.67%	19.28%

	1	2	3	4	5	6	7
targets that are incorporated into periodic evaluations							
My organization focuses on communicating environmental goals	2.35%	5.14%	8.29%	14.04%	22.93%	27.17%	20.08%
In my organization, environmental incidents are consistently evaluated and recorded	2.70%	4.55%	7.84%	14.74%	22.78%	27.27%	20.13%
My organization offers non-monetary or monetary rewards based on environmental results achieved (e.g., sabbaticals, leave, gifts, benefits, financial bonuses, promotions, etc.)	3.60%	4.65%	7.49%	14.89%	23.18%	27.57%	18.63%
In my organization, employees' environmental performance is made public	4.50%	5.14%	8.04%	14.19%	22.28%	26.07%	19.78%
My organization provides incentives to encourage environmentally responsible activities and behaviors (e.g., car-sharing, etc.)	3.05%	4.30%	7.44%	14.84%	23.48%	27.67%	19.23%
My organization offers and organizes environmentally friendly activities for employees	2.45%	4.55%	7.14%	14.44%	23.58%	27.32%	20.53%

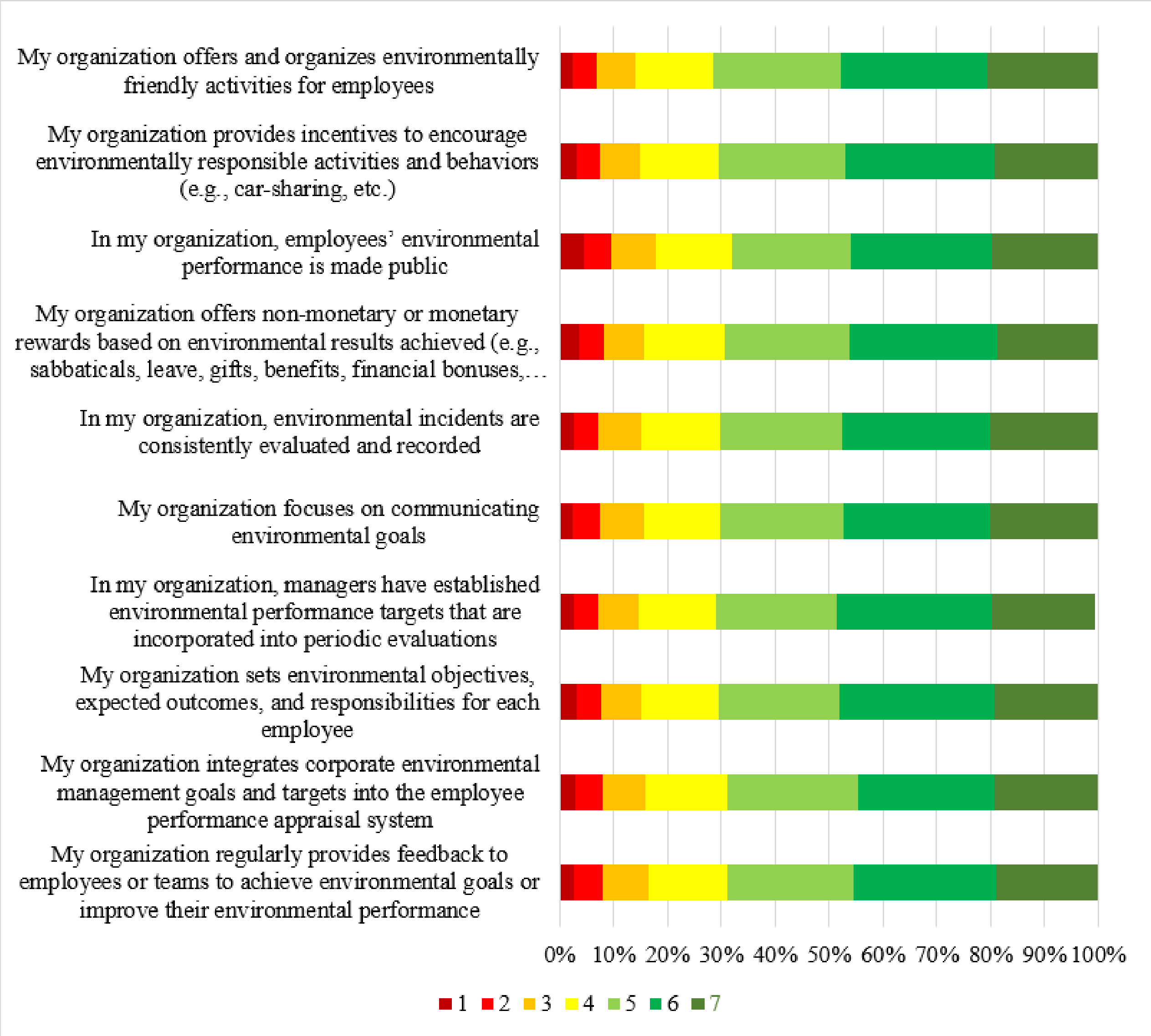


Figure 52 – Employee performance management and reward system adopted by German organizations

5.3.9 Drivers of the adoption of sustainability or circular economy initiatives

To examine the influence of the external context on firms' decision-making processes, the questionnaire included a section dedicated to the perceived and/or experienced pressures encouraging the adoption of sustainability and circular economy practices. Respondents were asked to indicate their level of agreement with a series of statements related to these dynamics using a seven-point Likert scale ranging from "strongly disagree" to "strongly agree."

Table 61 – Perceived and/or received external pressures for the adoption of sustainability/circular economy practices by Italian organizations

	1	2	3	4	5	6	7
The organization's main customers believe that we should adopt sustainability/circular economy practices	2.15%	3.44%	7.54%	14.43%	22.72%	31.05%	18.67%

	1	2	3	4	5	6	7
The organization’s main suppliers believe that we should adopt sustainability/circular economy practices	2.30%	3.94%	7.49%	14.28%	22.17%	31.05%	18.77%
Suppliers that are crucial to the organization strongly expect the adoption of sustainability/circular economy practices	2.05%	3.84%	6.94%	15.18%	22.87%	30.75%	18.37%
The local community believes that we should adopt sustainability/circular economy practices	2.05%	3.84%	6.94%	15.18%	22.87%	30.75%	18.37%
Major competitors that have adopted sustainability/circular economy practices have benefited significantly from them	1.60%	3.34%	8.49%	14.58%	22.22%	30.50%	19.27%
Major competitors that have adopted environmental practices or services are more competitive	1.90%	3.34%	8.74%	14.78%	22.47%	31.00%	17.77%
Major competitors that have adopted environmental practices or services are perceived favorably by customers	1.75%	3.89%	8.44%	15.43%	21.67%	30.35%	18.47%
My organization has adopted sustainability/circular economy practices to ensure better management and compliance with legal requirements	1.60%	3.84%	7.19%	14.43%	22.82%	31.50%	18.62%
My organization has adopted sustainability/circular economy practices to avoid the risk of environmental damage and legal penalties	1.40%	3.69%	8.54%	14.33%	21.67%	31.45%	18.92%
Professional standards, professional networks, and/or employee movements believe that we should adopt sustainability/circular economy practices	2.35%	3.54%	7.94%	14.13%	24.36%	29.66%	18.02%

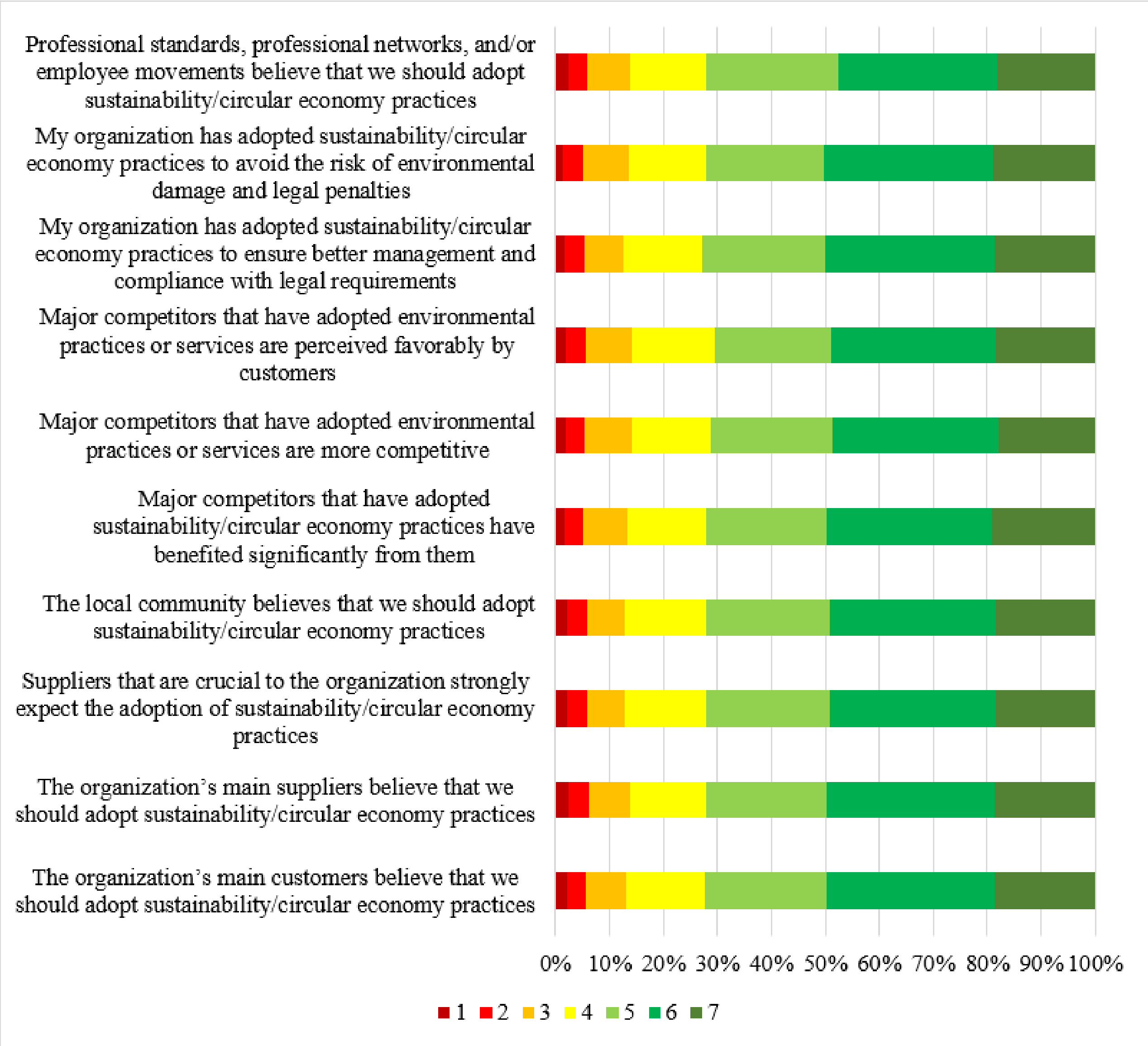


Figure 53 – Perceived and/or received external pressures for the adoption of sustainability/circular economy practices by Italian organizations

Table 62 – Perceived and/or received external pressures for the adoption of sustainability/circular economy practices by German organizations

	1	2	3	4	5	6	7
The organization's main customers believe that we should adopt sustainability/circular economy practices	2.60%	4.15%	9.09%	15.43%	23.43%	26.77%	18.53%
The organization's main suppliers believe that we should adopt sustainability/circular economy practices	2.70%	4.95%	8.24%	16.88%	22.98%	27.17%	17.08%
Suppliers that are crucial to the organization strongly expect the adoption of sustainability/circular economy practices	3.30%	4.95%	8.84%	16.13%	24.18%	24.83%	17.78%

	1	2	3	4	5	6	7
The local community believes that we should adopt sustainability/circular economy practices	2.55%	4.95%	8.84%	16.13%	24.18%	24.83%	17.78%
Major competitors that have adopted sustainability/circular economy practices have benefited significantly from them	2.90%	4.75%	8.64%	15.23%	23.63%	27.32%	17.53%
Major competitors that have adopted environmental practices or services are more competitive	3.10%	4.35%	8.24%	14.74%	23.43%	27.07%	19.08%
Major competitors that have adopted environmental practices or services are perceived favorably by customers	2.40%	4.55%	7.84%	15.43%	24.18%	25.57%	20.03%
My organization has adopted sustainability/circular economy practices to ensure better management and compliance with legal requirements	1.70%	4.80%	8.49%	15.48%	24.08%	26.32%	19.13%
My organization has adopted sustainability/circular economy practices to avoid the risk of environmental damage and legal penalties	1.85%	4.55%	9.09%	15.53%	24.33%	26.87%	17.78%
Professional standards, professional networks, and/or employee movements believe that we should adopt sustainability/circular economy practices	2.20%	5.04%	9.09%	16.23%	23.63%	25.67%	18.13%

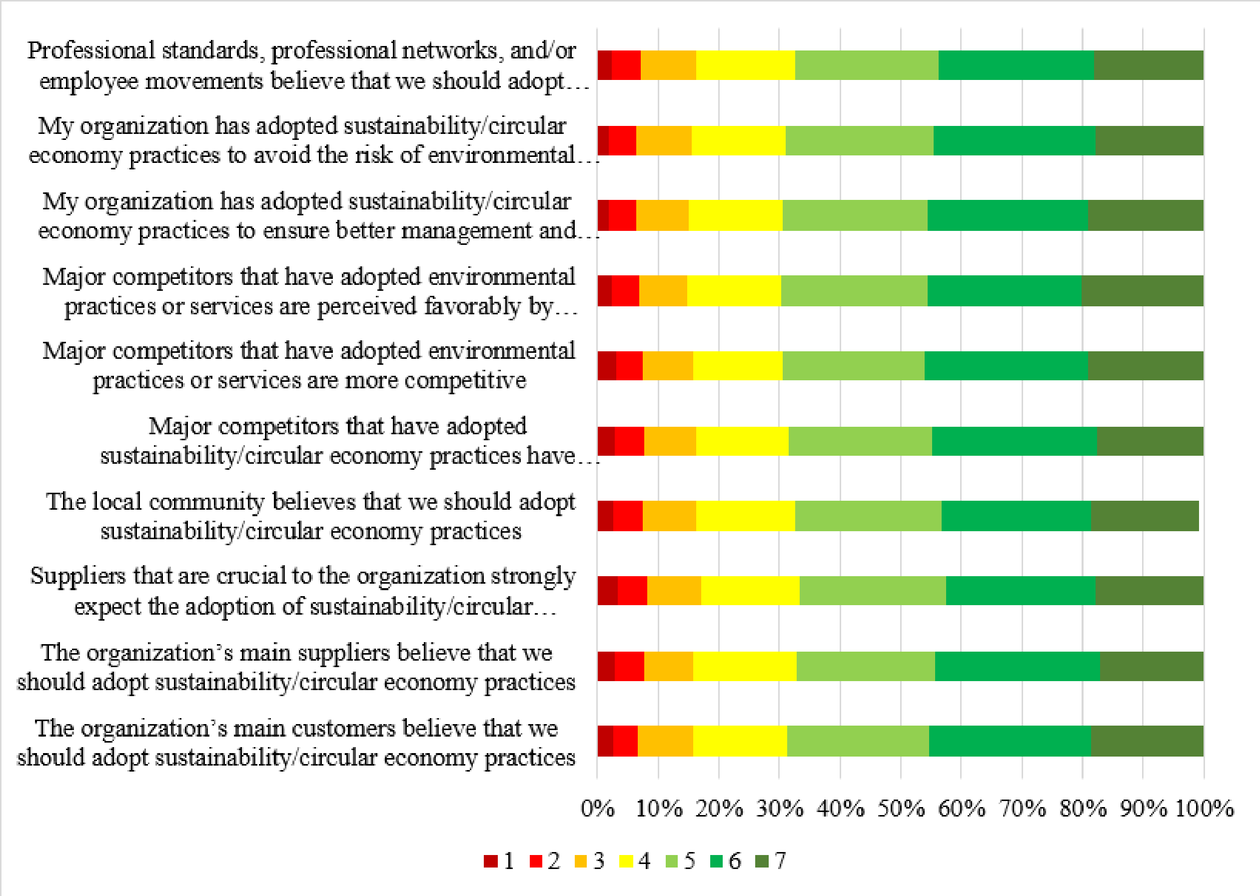


Figure 54 – Perceived and/or received external pressures for the adoption of sustainability/circular economy practices by German organizations

5.3.10 Organizational learning

To further explore the role of knowledge as a strategic lever in the sustainable transition, the questionnaire included a section aimed at assessing organizations' ability to acquire and disseminate information, including information related to circular economy issues. Participants were asked to indicate their level of agreement with a series of statements on this topic using a seven-point Likert scale ranging from "strongly disagree" to "strongly agree."

Table 63 – Capacity of Italian organizations to acquire and disseminate knowledge related to circular economy issues

	1	2	3	4	5	6	7
My organization learns from its customers, suppliers, and/or other business partners	0.95%	3.20%	7.19%	13.73%	22.37%	32.40%	20.17%
My organization constantly benchmarks itself against its competitors	1.45%	3.20%	7.19%	13.73%	22.37%	32.40%	20.17%
My organization has processes in place to acquire relevant information from external sources	1.10%	3.34%	6.94%	14.38%	22.22%	32.15%	19.87%
My organization develops new knowledge from existing knowledge	0.85%	2.80%	6.14%	13.78%	23.61%	32.70%	20.12%

	1	2	3	4	5	6	7
Employees from different areas share experiences and/or knowledge	1.20%	2.80%	7.24%	12.63%	24.06%	31.60%	20.47%
In my organization, lessons learned by one group are actively shared with others	1.50%	3.49%	7.19%	12.98%	21.77%	33.25%	19.82%
My organization has processes in place for knowledge sharing among individuals	1.45%	2.85%	6.44%	15.23%	21.42%	31.25%	21.37%

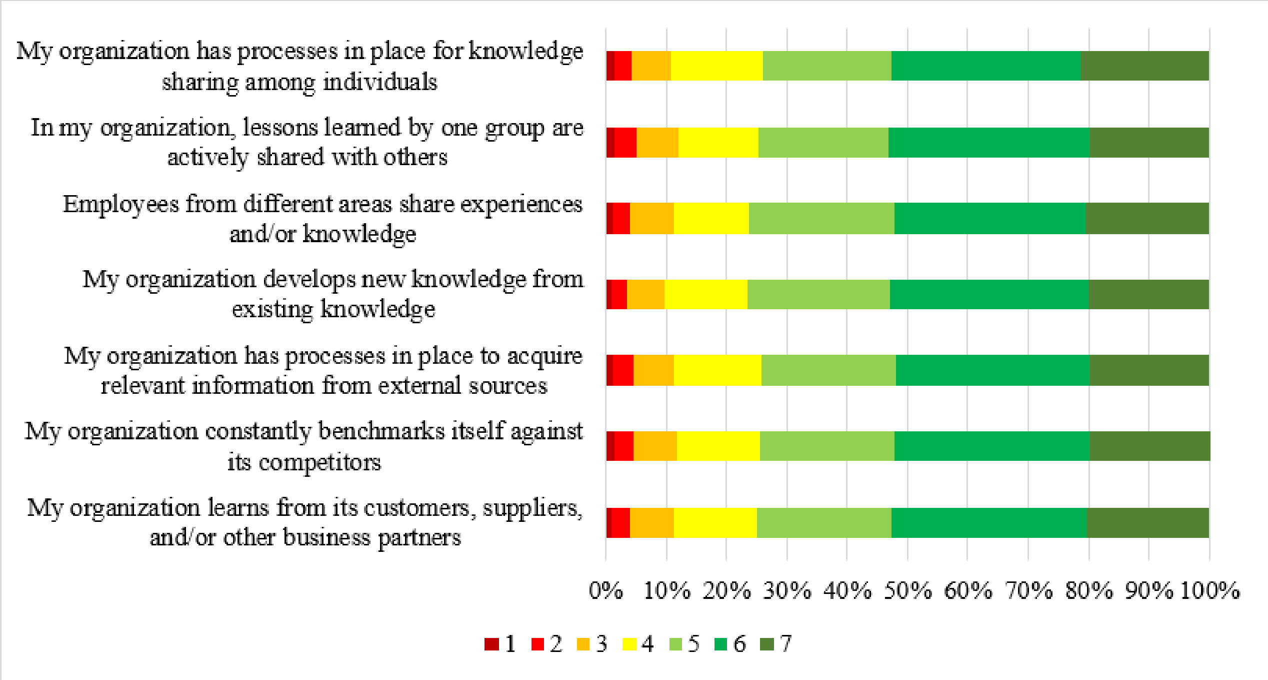


Figure 55 – Capacity of Italian organizations to acquire and disseminate knowledge related to circular economy issues

Table 64 – Capacity of German organizations to acquire and disseminate knowledge related to circular economy issues

	1	2	3	4	5	6	7
My organization learns from its customers, suppliers, and/or other business partners	1.60%	3.95%	7.54%	14.49%	22.78%	28.67%	20.98%
My organization constantly benchmarks itself against its competitors	1.55%	3.95%	7.54%	14.49%	22.78%	28.67%	20.98%
My organization has processes in place to acquire relevant information from external sources	2.70%	4.35%	8.84%	14.29%	23.53%	26.62%	19.68%
My organization develops new knowledge from existing knowledge	1.85%	3.95%	7.19%	13.54%	22.33%	28.97%	22.18%
Employees from different areas share experiences and/or knowledge	1.15%	3.20%	7.29%	13.79%	24.43%	28.67%	21.48%
In my organization, lessons learned by one group are actively shared with others	1.90%	4.65%	7.24%	16.43%	22.48%	27.12%	20.18%

	1	2	3	4	5	6	7
My organization has processes in place for knowledge sharing among individuals	2.10%	4.05%	9.04%	14.09%	22.38%	27.77%	20.58%

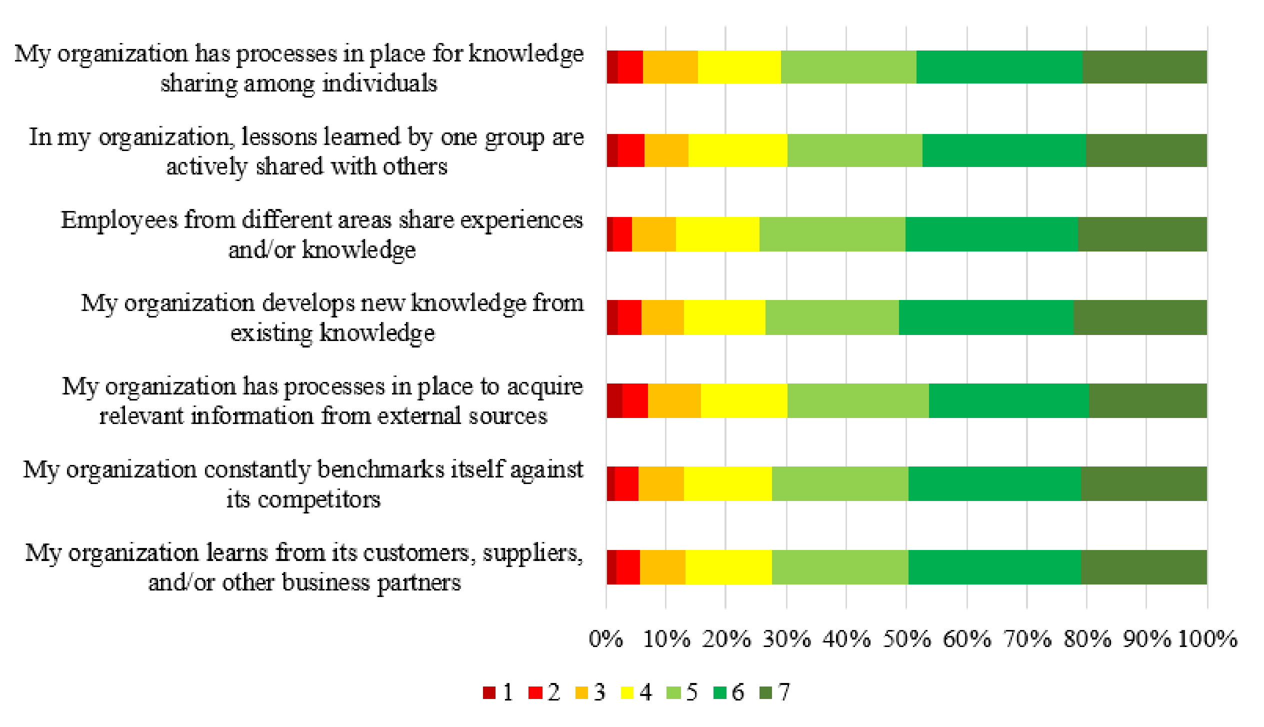


Figure 56 – Capacity of German organizations to acquire and disseminate knowledge related to circular economy issues

To investigate how internal competencies influence the actual adoption of sustainable practices, the questionnaire included a section dedicated to employees' ability to interpret knowledge and information, with particular attention to circular economy issues. Respondents were asked to indicate their level of agreement with a series of statements on this topic using a seven-point Likert scale ranging from "strongly disagree" to "strongly agree."

Table 65 – Italian employees' ability to interpret knowledge and information, including in relation to circular economy issues

	1	2	3	4	5	6	7
Employees are willing to reconsider decisions when they are presented with new and relevant information	0.90%	3.64%	7.44%	12.93%	22.82%	31.90%	20.37%
Employees seek to deeply understand issues and concepts	1.60%	3.15%	6.44%	13.28%	23.36%	33.00%	19.17%
Employees raise concerns and ask for clarification when they encounter unclear aspects or decisions	1.40%	3.49%	6.44%	14.18%	23.12%	31.95%	19.42%
Employees are interested in knowing not only what to do but also why it is done	1.20%	3.94%	7.44%	13.18%	21.17%	32.10%	20.97%

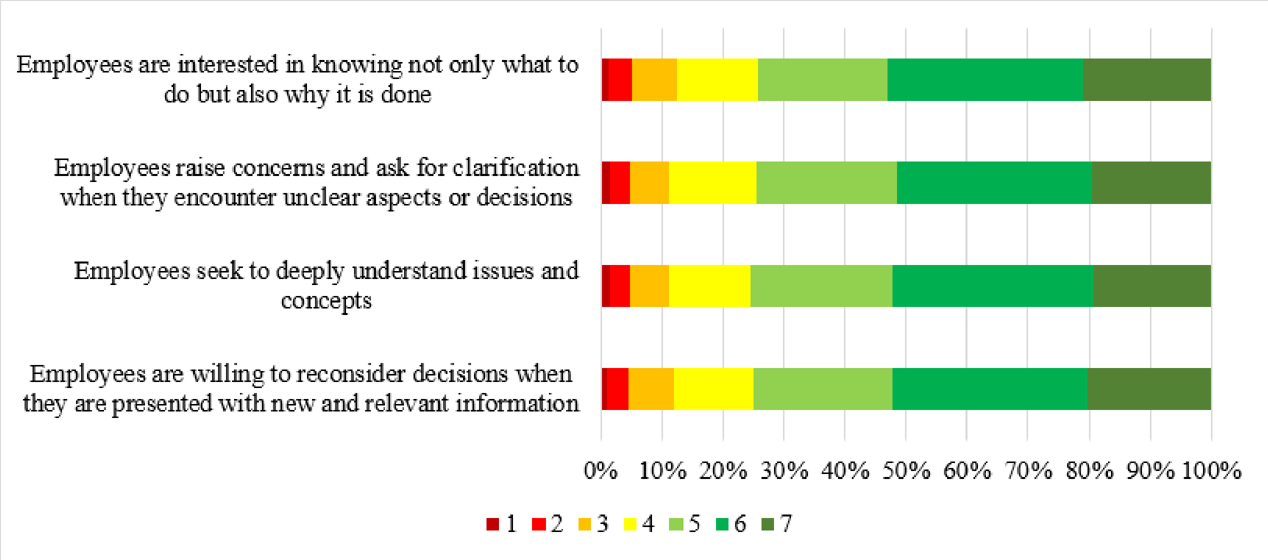


Figure 57 – Italian employees' ability to interpret knowledge and information, including in relation to circular economy issues

Table 66 – German employees' ability to interpret knowledge and information, including in relation to circular economy issues

	1	2	3	4	5	6	7
Employees are willing to reconsider decisions when they are presented with new and relevant information	1.35%	3.85%	7.64%	14.74%	23.53%	28.22%	20.68%
Employees seek to deeply understand issues and concepts	1.25%	2.70%	7.69%	15.23%	23.23%	28.52%	21.38%
Employees raise concerns and ask for clarification when they encounter unclear aspects or decisions	2.00%	3.80%	6.94%	14.09%	24.43%	27.17%	21.58%
Employees are interested in knowing not only what to do but also why it is done	2.05%	4.05%	7.94%	13.79%	22.68%	29.02%	20.48%

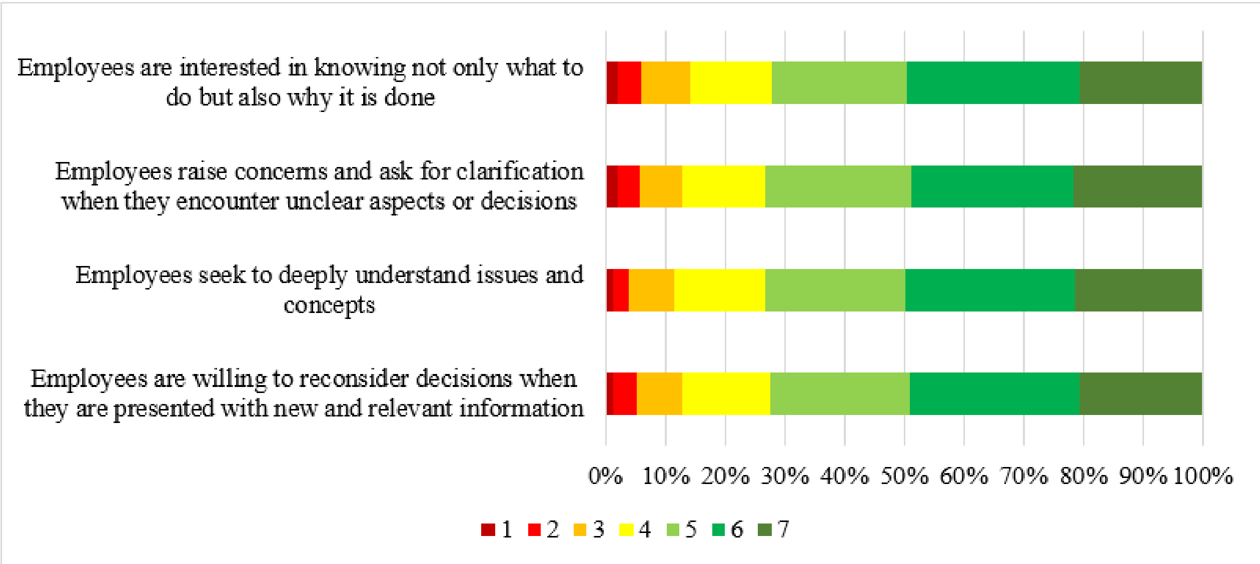


Figure 58 – German employees' ability to interpret knowledge and information, including in relation to circular economy issues

To assess the contribution of human resources to sustainable innovation processes, the questionnaire included a section dedicated to employees' ability to integrate knowledge and information, particularly with regard to circular economy issues. Participants were asked to indicate their level of agreement with a series of statements on this topic using a seven-point Likert scale ranging from "strongly disagree" to "strongly agree."

Table 67 – Italian employees' ability to integrate knowledge and information, including in relation to circular economy issues

	1	2	3	4	5	6	7
In my organization, we discuss problems until we reach a shared understanding	1.45%	4.34%	5.74%	11.78%	22.52%	32.15%	22.02%
In my organization, top management integrates information coming from different organizational areas	1.35%	3.30%	6.94%	13.48%	21.87%	31.00%	22.07%
In my organization, employees regularly meet to address problems and concerns	1.50%	3.89%	6.24%	11.23%	22.22%	33.60%	21.32%
In my organization, we seek to reach consensus through dialogue and reasoning	1.55%	3.59%	6.69%	12.93%	21.87%	32.00%	21.37%
My organization emphasizes sharing and understanding the managerial vision through communication with colleagues	1.30%	3.79%	6.24%	13.38%	21.82%	32.80%	20.67%

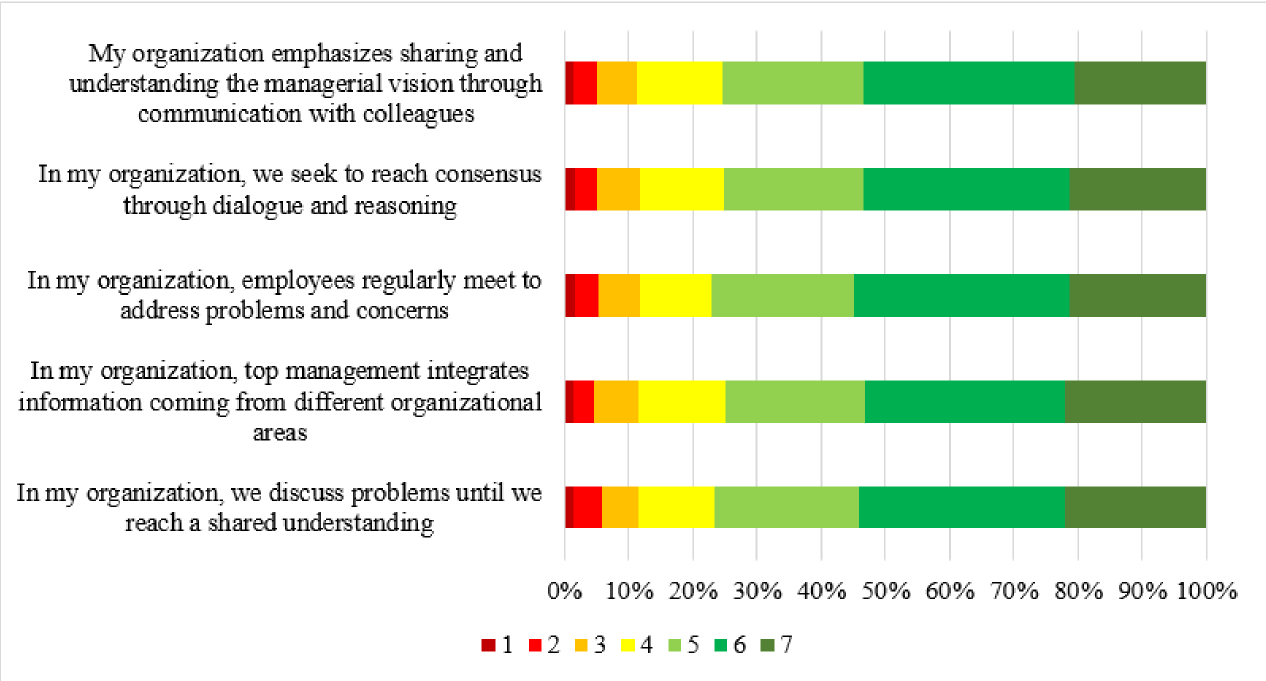


Figure 59 – Italian employees' ability to integrate knowledge and information, including in relation to circular economy issues

Table 68 – German employees' ability to integrate knowledge and information, including in relation to circular economy issues

	1	2	3	4	5	6	7
In my organization, we discuss problems until we reach a shared understanding	1.60%	4.35%	8.39%	16.08%	23.13%	27.32%	19.13%
In my organization, top management integrates information coming from different organizational areas	1.90%	3.70%	8.74%	13.74%	24.03%	27.92%	19.98%
In my organization, employees regularly meet to address problems and concerns	1.45%	3.85%	7.64%	14.19%	23.38%	28.32%	21.18%
In my organization, we seek to reach consensus through dialogue and reasoning	1.40%	3.20%	6.99%	15.58%	24.58%	28.12%	20.13%
My organization emphasizes sharing and understanding the managerial vision through communication with colleagues	1.25%	3.80%	7.74%	14.19%	25.12%	28.57%	19.33%

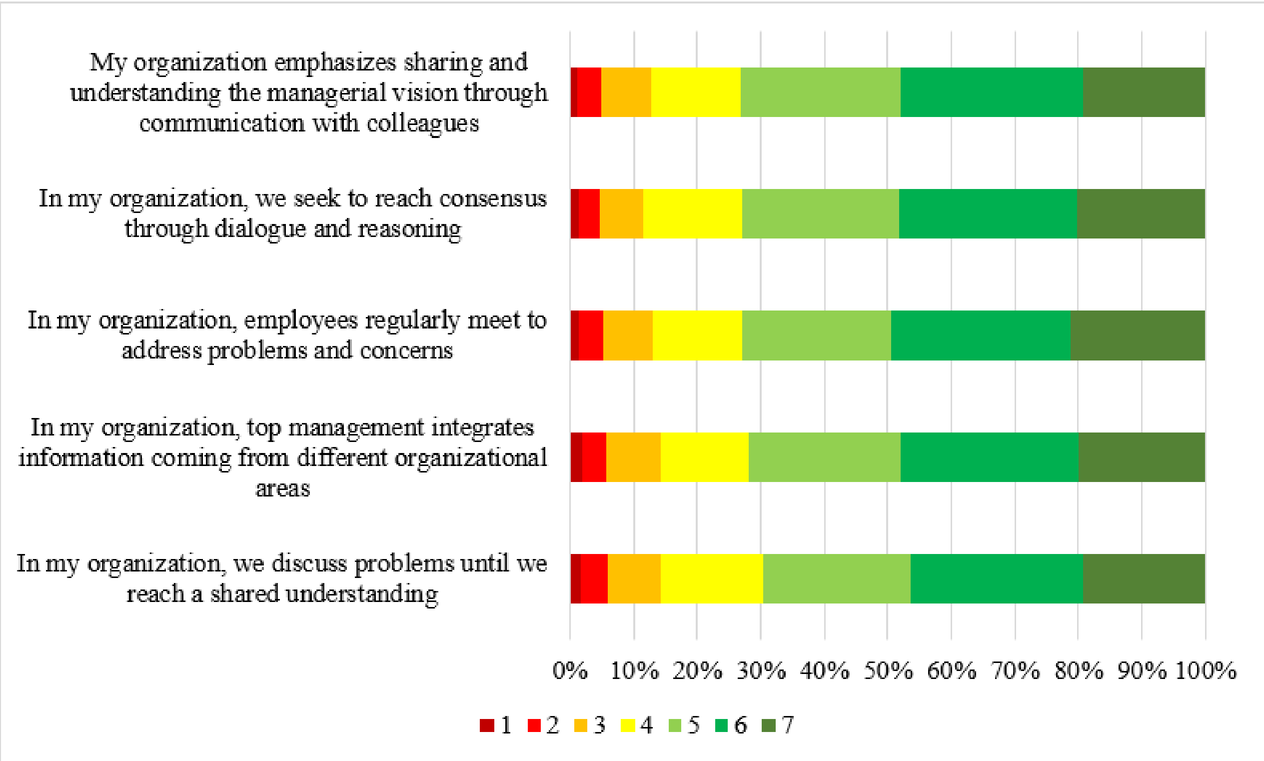


Figure 60 – German employees' ability to integrate knowledge and information, including in relation to circular economy issues

To examine the robustness of organizational processes related to knowledge management, the questionnaire included a section dedicated to employees' ability to retain knowledge and information, with particular reference to circular economy issues. Respondents were asked to indicate their level of agreement with a series of statements on this topic using a seven-point Likert scale ranging from "strongly disagree" to "strongly agree."

Table 69 – Italian employees' ability to retain knowledge and information, including in relation to circular economy issues

	1	2	3	4	5	6	7
In my organization, we make significant efforts to preserve information	0.95%	3.44%	6.19%	12.88%	22.07%	33.30%	21.17%
In my organization, we have an effective mechanism for storing information	1.25%	2.80%	6.49%	12.58%	21.72%	34.05%	21.12%
In my organization, there is a formal data management function	1.20%	3.00%	5.74%	12.48%	24.21%	32.80%	20.57%
My organization stores detailed information to guide operations	1.00%	2.50%	7.19%	13.88%	22.47%	32.55%	20.42%
In my organization, when employees need specific information, they know who has it and how to access it	1.15%	2.75%	6.64%	12.88%	23.61%	32.80%	20.17%
In my organization, company files and databases are available to provide the information needed to perform our work	1.55%	3.39%	6.94%	12.43%	23.07%	32.65%	19.97%

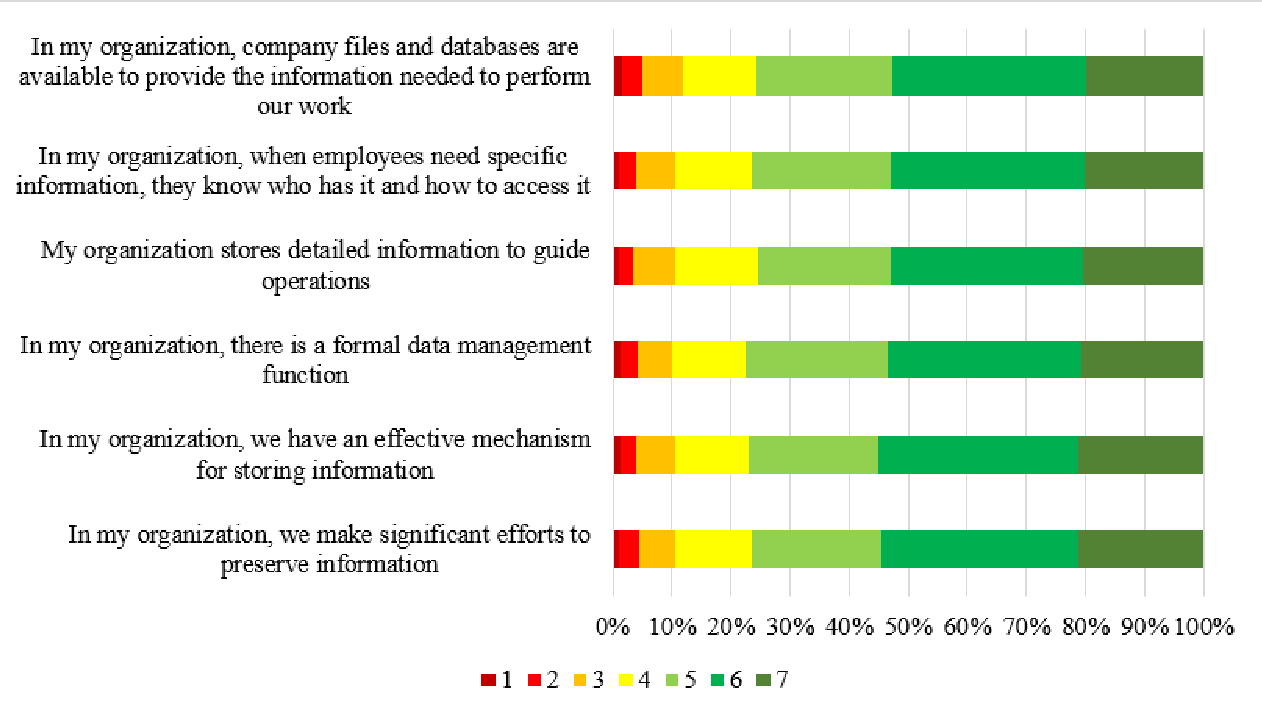


Figure 61 – Italian employees' ability to retain knowledge and information, including in relation to circular economy issues

Table 70 – German employees' ability to retain knowledge and information, including in relation to circular economy issues

	1	2	3	4	5	6	7
In my organization, we make significant efforts to preserve information	1.50%	3.70%	7.64%	14.64%	24.23%	29.42%	18.88%

	1	2	3	4	5	6	7
In my organization, we have an effective mechanism for storing information	1.80%	3.20%	8.54%	14.99%	23.33%	27.02%	21.13%
In my organization, there is a formal data management function	0.90%	4.20%	7.69%	14.09%	22.53%	28.97%	21.63%
My organization stores detailed information to guide operations	1.95%	3.80%	6.89%	14.94%	23.18%	30.22%	19.03%
In my organization, when employees need specific information, they know who has it and how to access it	1.40%	4.35%	7.29%	14.39%	23.88%	28.17%	20.53%
In my organization, company files and databases are available to provide the information needed to perform our work	1.30%	3.75%	8.34%	15.88%	23.78%	26.02%	20.93%

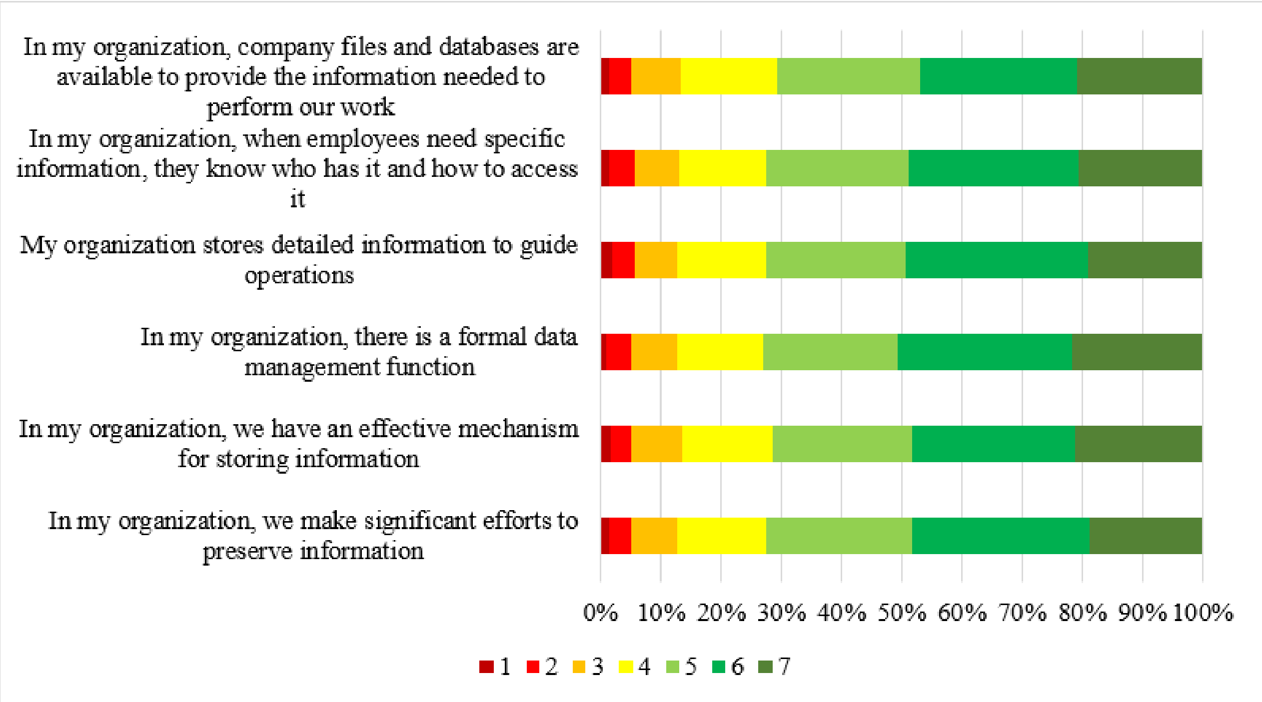


Figure 62 – German employees' ability to retain knowledge and information, including in relation to circular economy issues

5.3.11 Organisational agility

To analyse companies' competitive positioning in relation to sustainability, the questionnaire included a section dedicated to comparison with competitors. In particular, respondents were asked to assess how effectively their organisation performs, or is able to perform, specific activities, also in relation to environmental and circularity-related issues. The evaluation was expressed using a seven-point scale ranging from "much worse" to "much better."

Table 71 – Effectiveness of Italian organisations in carrying out activities related to environmental and circularity issues

	1	2	3	4	5	6	7
My organisation meets our customers' requests for rapid and special responses whenever such requests arise	1.10%	2.60%	6.34%	12.73%	23.41%	33.25%	20.57%
Customers trust my organisation's capabilities	1.50%	2.80%	5.49%	11.73%	21.92%	33.60%	22.97%
My organisation can rapidly increase or decrease production/service levels to support fluctuations in market demand	1.20%	3.05%	6.79%	14.78%	24.16%	31.30%	18.72%
Whenever supply disruptions from suppliers occur, my organisation can quickly adopt the necessary alternative solutions and internal adjustments	1.00%	3.49%	7.94%	13.28%	21.57%	33.15%	19.57%
My organisation is ready to make and implement appropriate decisions in response to market/customer changes	1.60%	3.15%	7.49%	13.33%	20.02%	33.10%	21.32%
My organisation is constantly seeking ways to reinvent/redesign itself in order to better serve our market	1.40%	3.79%	6.89%	13.23%	22.82%	30.65%	21.22%
My organisation views market-related changes as opportunities to capitalise on quickly	1.65%	3.00%	6.89%	14.03%	22.07%	32.90%	19.47%
My organisation gathers detailed information about its suppliers and service providers	1.50%	3.30%	6.24%	13.08%	22.22%	33.15%	20.52%
My organisation is able to leverage suppliers' resources and capabilities to improve the quality and quantity of products and services	1.15%	2.80%	6.74%	13.83%	23.32%	32.50%	19.67%
My organisation collaborates with external suppliers to create high-value products and services	0.80%	3.15%	7.29%	14.23%	22.42%	30.85%	21.27%
My organisation is able to manage relationships with outsourcing partners	1.15%	2.35%	6.74%	12.38%	23.76%	32.50%	21.12%
My organisation can switch suppliers to benefit from lower costs, better quality, or improved delivery times	1.30%	3.94%	6.79%	13.48%	22.02%	32.10%	20.37%

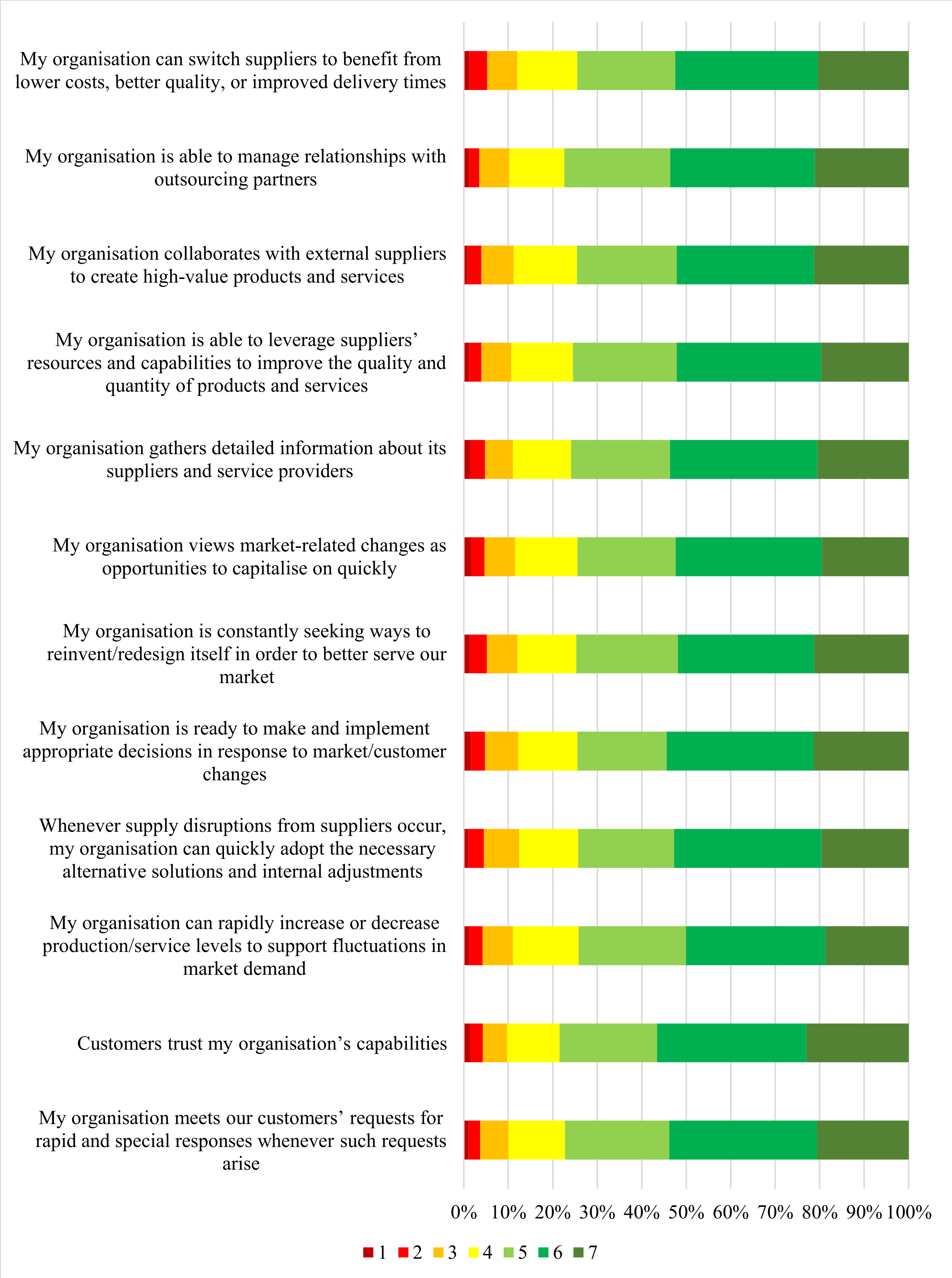


Figure 63 – Effectiveness of Italian organisations in carrying out activities related to environmental and circularity issues

Table 72 – Effectiveness of German organisations in carrying out activities related to environmental and circularity issues

	1	**2**	**3**	**4**	**5**	**6**	**7**
My organisation meets our customers' requests for rapid and special responses whenever such requests arise	1.35%	3.30%	7.59%	14.49%	23.73%	29.17%	20.38%
Customers trust my organisation's capabilities	1.45%	3.45%	8.14%	12.94%	22.73%	28.67%	22.63%
My organisation can rapidly increase or decrease production/service levels to support fluctuations in market demand	1.45%	3.60%	7.94%	15.93%	23.63%	27.37%	20.08%
Whenever supply disruptions from suppliers occur, my organisation can quickly adopt the necessary alternative solutions and internal adjustments	2.10%	3.95%	7.99%	14.64%	24.53%	28.72%	18.08%
My organisation is ready to make and implement appropriate decisions in response to market/customer changes	1.85%	3.85%	8.29%	13.24%	23.73%	27.57%	21.48%
My organisation is constantly seeking ways to reinvent/redesign itself in order to better serve our market	1.55%	3.50%	7.64%	13.94%	23.03%	28.72%	21.63%
My organisation views market-related changes as opportunities to capitalise on quickly	1.35%	3.50%	8.14%	14.24%	23.58%	28.62%	20.58%
My organisation gathers detailed information about its suppliers and service providers	2.00%	3.95%	7.89%	15.08%	23.33%	28.22%	19.53%
My organisation is able to leverage suppliers' resources and capabilities to improve the quality and quantity of products and services	1.40%	3.95%	8.04%	14.64%	24.68%	27.17%	20.13%
My organisation collaborates with external suppliers to create high-value products and services	1.50%	3.80%	8.74%	13.64%	23.83%	28.37%	20.13%
My organisation is able to manage relationships with outsourcing partners	1.65%	3.35%	7.34%	14.99%	23.58%	28.22%	20.88%
My organisation can switch suppliers to benefit from lower costs, better quality, or improved delivery times	1.60%	4.55%	7.84%	15.53%	23.18%	28.52%	18.78%

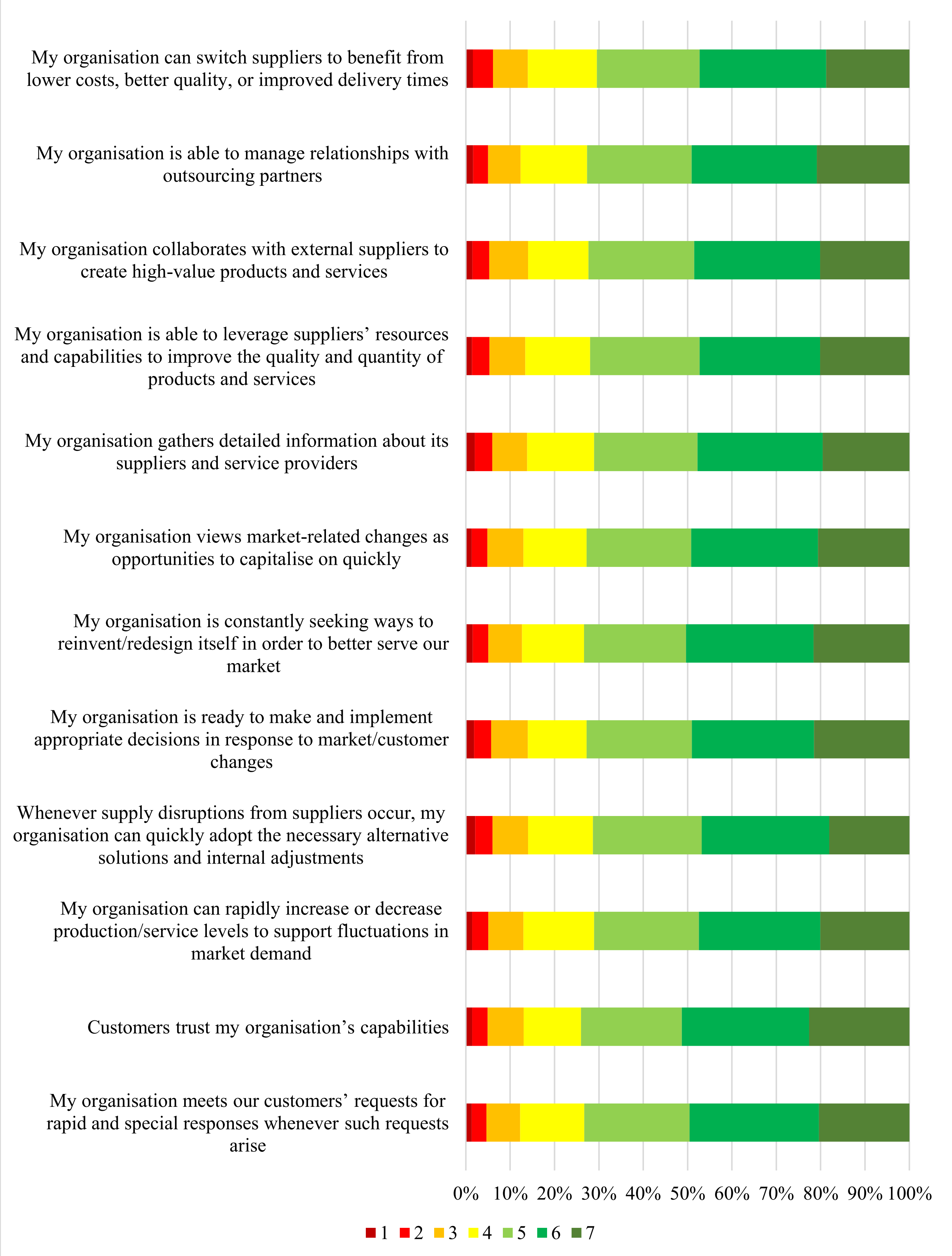


Figure 64 – Effectiveness of German organisations in carrying out activities related to environmental and circularity issues

5.3.12 L Information System Capabilities

To capture perceptions of organisational competitiveness, the questionnaire included a section in which participants were asked to indicate how effectively their organisation performs, or is able to perform, specific activities compared with its competitors. The assessment was expressed using a seven-point scale ranging from “much worse” to “much better.”

Table 73 – Effectiveness of Italian organisations in managing information related to the implementation of activities concerning environmental and circularity issues

	1	2	3	4	5	6	7
Manage effectively the linkages between the information systems function and stakeholders external to the organisation	1.15%	3.20%	6.84%	15.83%	22.67%	31.45%	18.87%
Collect information from external sources and disseminate it appropriately across different departments to ensure a timely and positive response to market information	1.90%	3.30%	6.74%	12.93%	23.81%	31.30%	20.02%
Establish effective collaborations with external partners (e.g., suppliers, consultants, or institutions) to innovate information systems and improve organisational competitiveness	1.55%	3.20%	6.49%	13.23%	23.07%	32.20%	20.27%
Integrate and effectively align the information systems function with other areas or departments within the organisation	1.50%	2.55%	7.34%	13.38%	22.42%	32.85%	19.97%
Anticipate future conditions and appropriately develop or acquire hardware, software, personnel, and capabilities to respond to evolving circumstances	1.35%	3.15%	6.29%	12.98%	23.02%	33.20%	20.02%
Consistently involve managers from different departments in defining IT strategies in order to integrate cross-functional perspectives and needs for the optimal use of technological resources	1.30%	3.15%	6.99%	14.18%	23.02%	31.90%	19.47%
Establish an appropriate portfolio of information and communication technologies capable of accommodating and integrating different specific applications	1.55%	3.30%	6.14%	12.63%	23.66%	32.30%	20.42%
Acquire, use, and manage up-to-date knowledge about the organisation’s information systems and technologies to ensure their appropriate use and functioning	1.05%	3.30%	6.99%	13.53%	22.97%	31.85%	20.32%

	1	2	3	4	5	6	7
Rapidly provide and implement information systems applications that enable agile responses to changing market conditions	0.90%	2.80%	7.24%	14.18%	22.27%	31.20%	21.42%
Support and manage information systems operations continuously and in a cost-efficient manner	1.30%	3.10%	5.89%	12.63%	23.66%	33.25%	20.17%

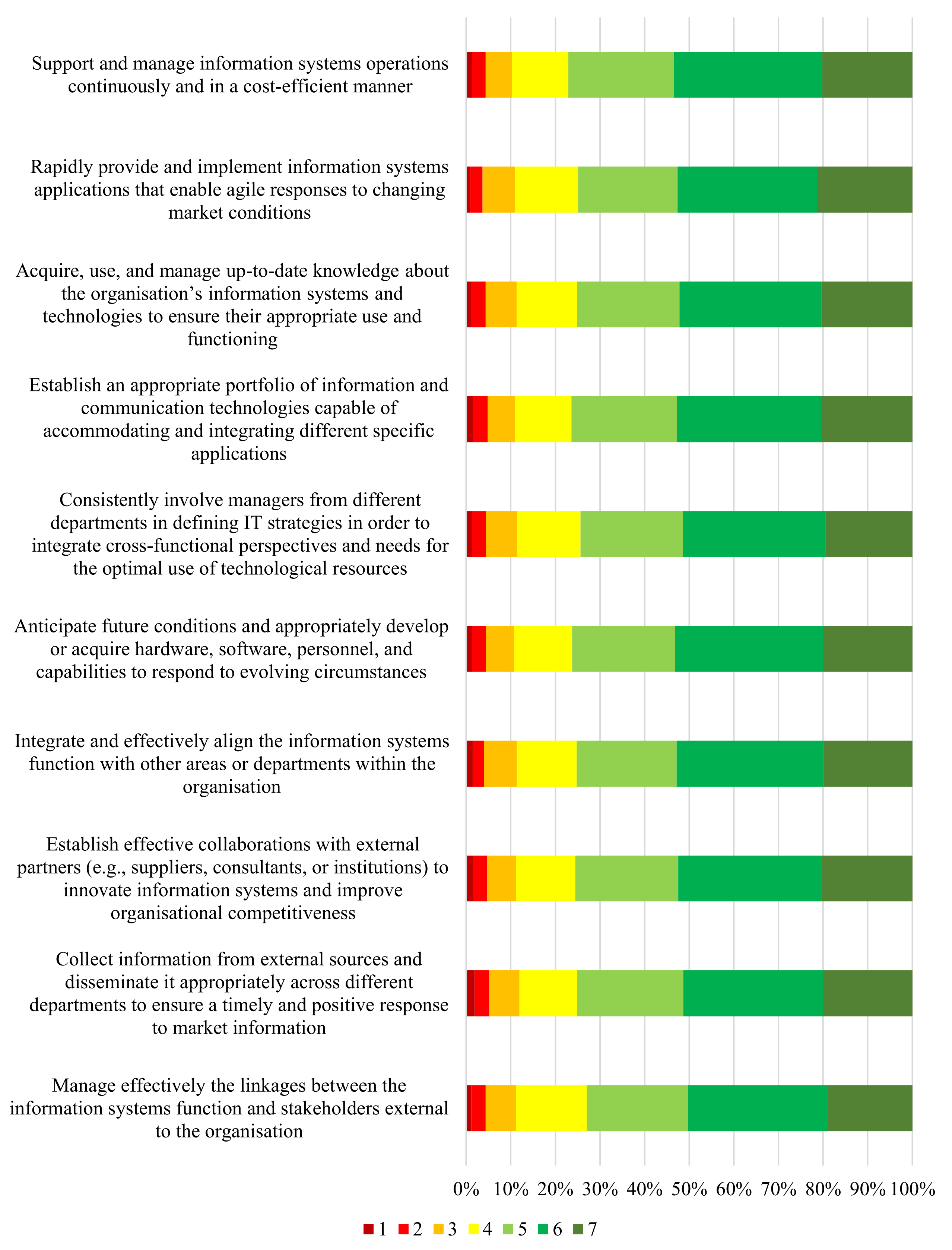


Figure 65 – Effectiveness of Italian organisations in managing information related to the implementation of activities concerning environmental and circularity issues

	1	2	3	4	5	6	7
Manage effectively the linkages between the information systems function and stakeholders external to the organisation	1.55%	4.10%	7.54%	16.03%	24.18%	26.52%	20.08%
Collect information from external sources and disseminate it appropriately across different departments to ensure a timely and positive response to market information	2.15%	3.45%	7.49%	14.34%	23.38%	28.97%	20.23%
Establish effective collaborations with external partners (e.g., suppliers, consultants, or institutions) to innovate information systems and improve organisational competitiveness	1.80%	4.30%	7.74%	14.99%	25.32%	27.02%	18.83%
Integrate and effectively align the information systems function with other areas or departments within the organisation	1.25%	2.90%	7.14%	14.39%	24.13%	28.77%	21.43%
Anticipate future conditions and appropriately develop or acquire hardware, software, personnel, and capabilities to respond to evolving circumstances	1.70%	3.45%	7.24%	15.58%	23.18%	30.02%	18.83%
Consistently involve managers from different departments in defining IT strategies in order to integrate cross-functional perspectives and needs for the optimal use of technological resources	1.95%	4.10%	8.49%	14.99%	22.08%	29.12%	19.28%
Establish an appropriate portfolio of information and communication technologies capable of accommodating and integrating different specific applications	1.70%	3.50%	7.69%	14.59%	25.32%	27.72%	19.48%
Acquire, use, and manage up-to-date knowledge about the organisation's information systems and technologies to ensure their appropriate use and functioning	1.60%	4.00%	7.79%	13.74%	24.33%	29.42%	19.13%
Rapidly provide and implement information systems applications that enable agile responses to changing market conditions	1.40%	3.50%	7.69%	15.38%	23.78%	28.07%	20.18%
Support and manage information systems operations continuously and in a cost-efficient manner	1.70%	3.50%	7.69%	14.59%	25.32%	27.72%	19.48%

Table 74 – Effectiveness of German organisations in managing information related to the implementation of activities concerning environmental and circularity issues

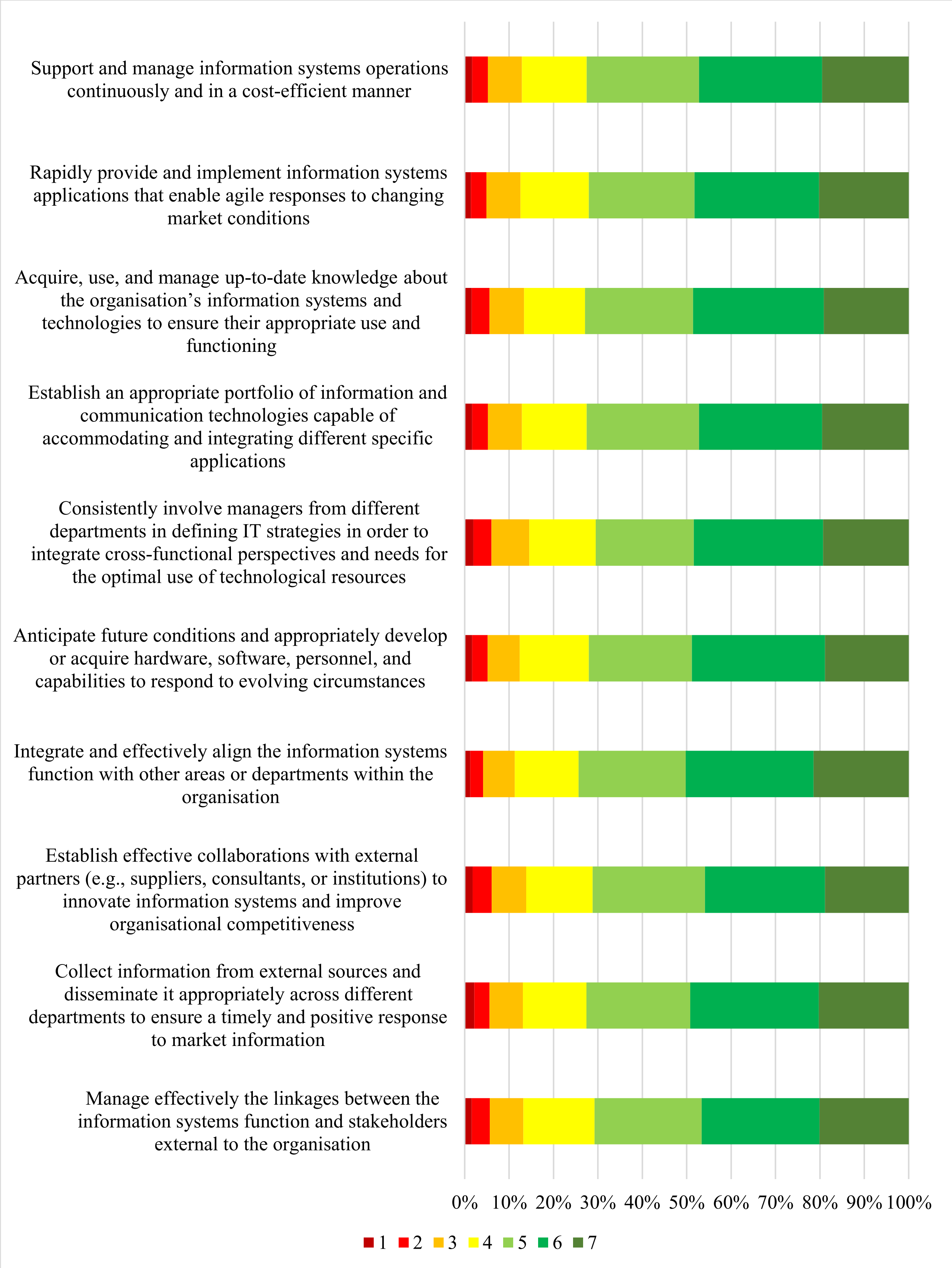


Figure 66 – Effectiveness of German organisations in managing information related to the implementation of activities concerning environmental and circularity issues

5.3.13 Adoption of artificial intelligence for sustainability or the circular economy

To investigate the degree of implementation of innovative solutions, the questionnaire included a section dedicated to the adoption of initiatives based on artificial intelligence (AI) in support of sustainability and the circular economy. Respondents were asked to indicate the extent to which their organisation is effectively implementing a series of statements related to this area, using a seven-point scale, where the minimum value corresponds to "not at all" and the maximum to "to an excellent extent".

Table 75 – Adoption of AI practices by Italian organisations – Part 1

	1	2	3	4	5	6	7
My organisation collects post-sale feedback and uses AI to personalise the customer experience, supporting solutions that extend product lifespan or promote reuse	2.50%	3.69%	7.59%	14.43%	22.67%	30.60%	18.52%
My organisation uses advanced tools to calculate the optimal cost and duration of warranties, supporting refurbishment initiatives and extended maintenance services for customers	1.80%	4.14%	7.19%	14.78%	22.72%	29.71%	19.67%
My organisation employs machine learning models to optimise pricing processes and offer formulation, with the aim of reducing waste and promoting circular solutions (e.g. leasing, pay-per-use)	3.30%	3.74%	6.09%	13.23%	22.47%	31.65%	19.52%
My organisation collects and analyses data from integrated sensors to provide predictive maintenance and operational optimisation services, contributing to the extension of product life cycles	2.25%	3.54%	5.79%	13.18%	24.01%	31.00%	20.22%

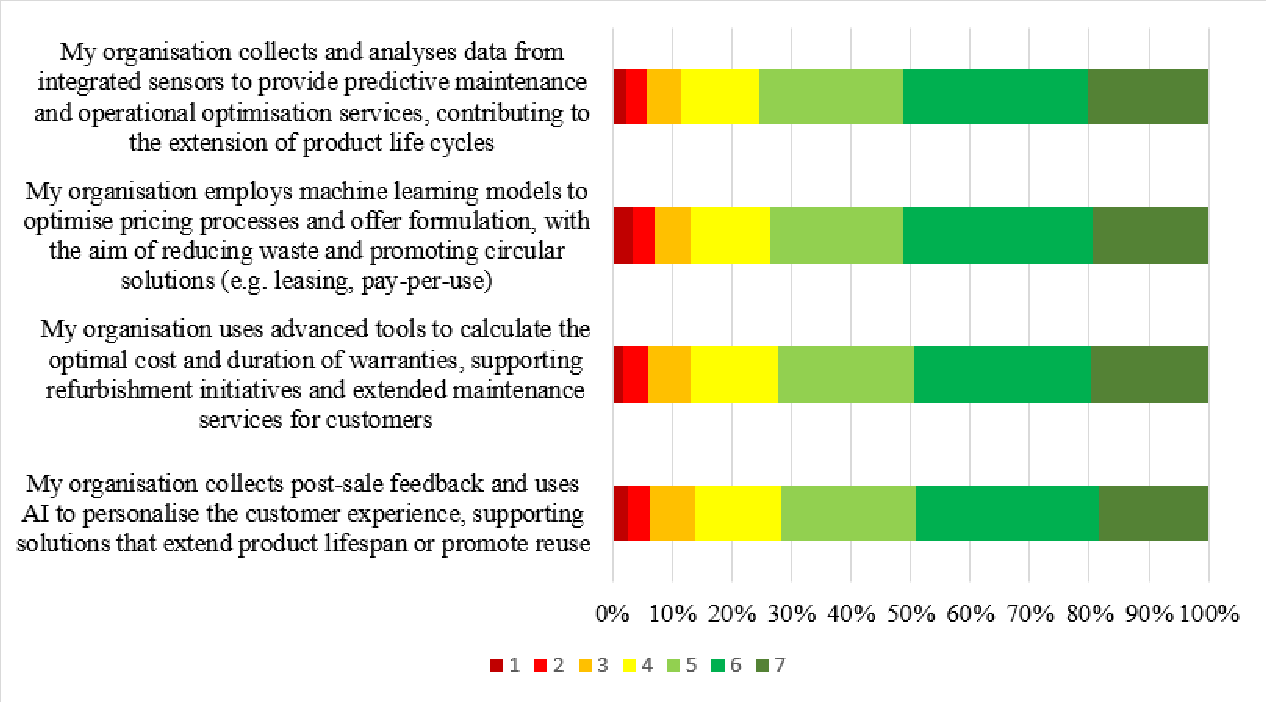


Figure 67 – Adoption of AI practices by Italian organisations – Part 1

Table 76 – Adoption of AI practices by German organisations – Part 1

	1	**2**	**3**	**4**	**5**	**6**	**7**
My organisation collects post-sale feedback and uses AI to personalise the customer experience, supporting solutions that extend product lifespan or promote reuse	2.40%	4.45%	8.39%	14.64%	23.73%	25.82%	20.58%
My organisation uses advanced tools to calculate the optimal cost and duration of warranties, supporting refurbishment initiatives and extended maintenance services for customers	1.65%	4.10%	7.69%	15.23%	24.23%	28.27%	18.83%
My organisation employs machine learning models to optimise pricing processes and offer formulation, with the aim of reducing waste and promoting circular solutions (e.g. leasing, pay-per-use)	3.45%	4.85%	8.29%	13.19%	22.03%	29.32%	18.88%
My organisation collects and analyses data from integrated sensors to provide predictive maintenance and operational optimisation services, contributing to the extension of product life cycles	2.10%	4.25%	7.24%	14.64%	23.03%	28.37%	20.38%

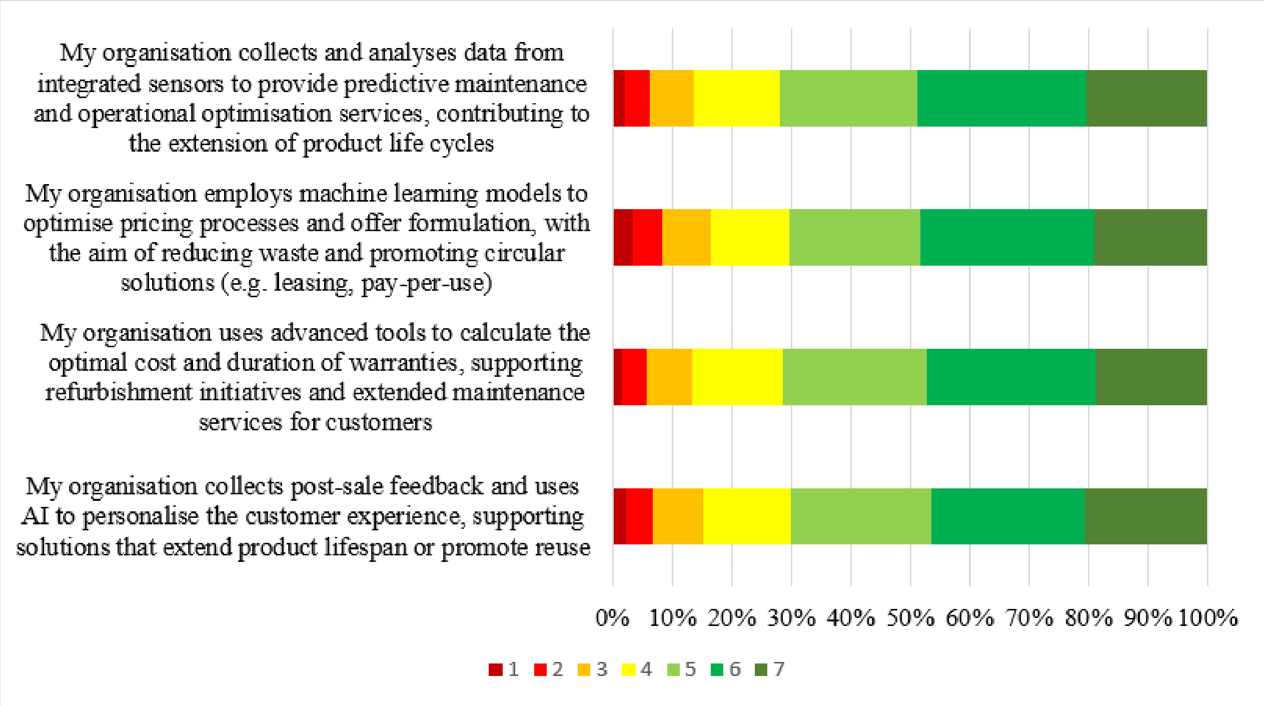


Figure 68 – Adoption of AI practices by German organisations – Part 1

Table 77 – Adoption of AI practices by Italian organisations – Part 2

	1	2	3	4	5	6	7
My organisation uses advanced data science techniques for demand forecasting and inventory management, limiting overproduction and resource waste	2.55%	4.04%	6.89%	12.98%	22.87%	32.25%	18.42%
My organisation strategically acquires and analyses data to meet customer orders in a timely manner, integrating considerations of material reuse and recovery wherever possible	2.50%	3.54%	6.54%	12.53%	23.12%	31.25%	20.52%
My organisation employs advanced robotics and predictive maintenance, helping to reduce failures, waste, and scrap materials	3.30%	4.44%	6.39%	12.03%	21.92%	33.60%	18.32%
My organisation leverages AI capabilities such as machine vision and edge analytics to optimise yields, supporting more sustainable and circular production processes (e.g. by reducing defects and enabling component recovery)	2.85%	4.34%	6.79%	13.18%	23.12%	30.20%	19.52%
Through data mining and big data techniques, my organisation improves product innovation processes by designing solutions that facilitate repair, disassembly, and/or modular upgrades	3.15%	4.09%	7.39%	12.93%	22.17%	31.35%	18.92%

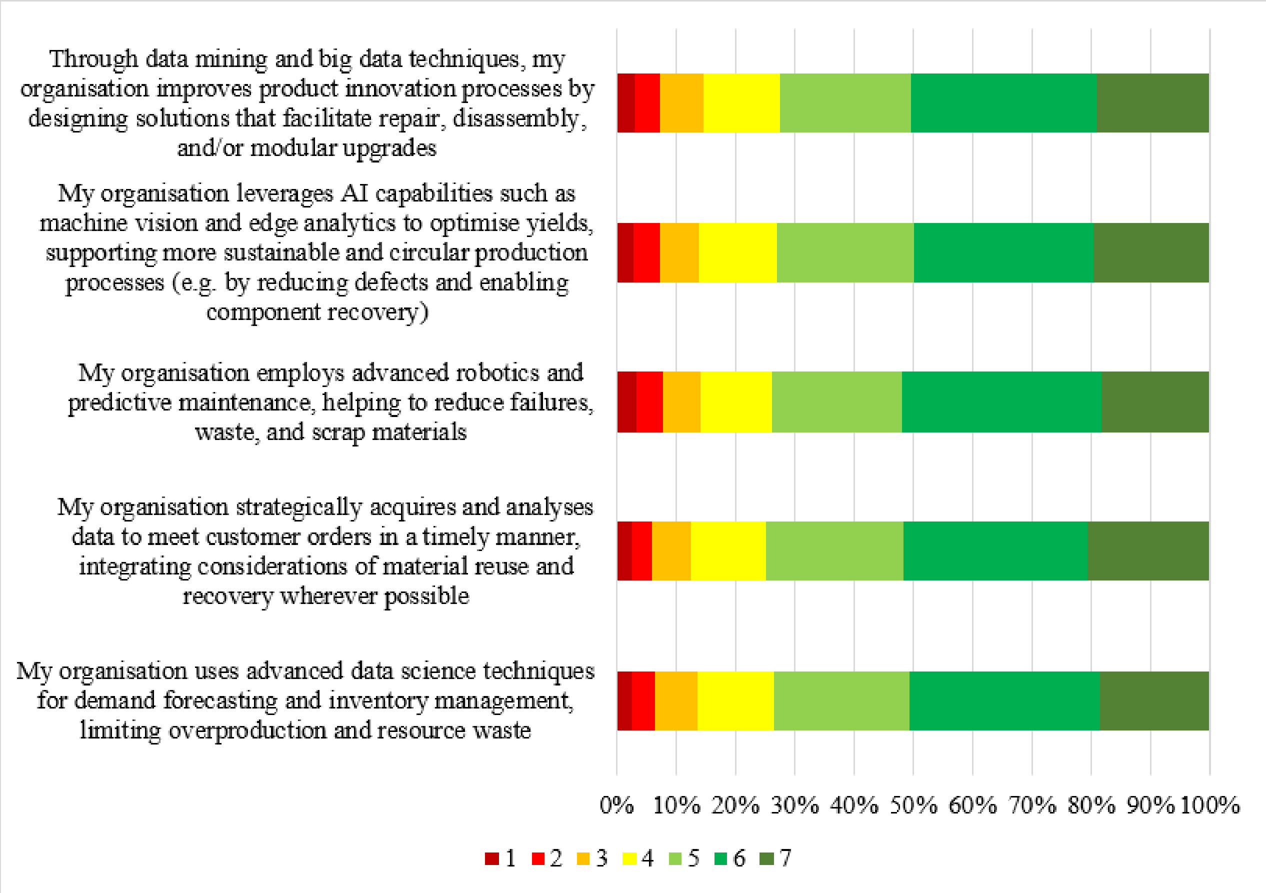


Figure 69 – Adoption of AI practices by Italian organisations – Part 2

Table 78 – Adoption of AI practices by German organisations - Part 2

	1	**2**	**3**	**4**	**5**	**6**	**7**
My organisation uses advanced data science techniques for demand forecasting and inventory management, limiting overproduction and resource waste	2.40%	4.25%	7.69%	14.49%	22.63%	28.07%	20.48%
My organisation strategically acquires and analyses data to meet customer orders in a timely manner, integrating considerations of material reuse and recovery wherever possible	2.90%	4.65%	7.89%	14.19%	23.48%	27.07%	19.83%
My organisation employs advanced robotics and predictive maintenance, helping to reduce failures, waste, and scrap materials	3.05%	4.30%	6.59%	14.04%	23.63%	28.12%	20.28%
My organisation leverages AI capabilities such as machine vision and edge analytics to optimise yields, supporting more sustainable and circular production processes (e.g. by reducing defects and enabling component recovery)	3.15%	4.85%	8.34%	15.28%	21.53%	26.67%	20.18%

	1	2	3	4	5	6	7
Through data mining and big data techniques, my organisation improves product innovation processes by designing solutions that facilitate repair, disassembly, and/or modular upgrades	2.70%	4.40%	7.74%	13.74%	23.43%	28.32%	19.68%

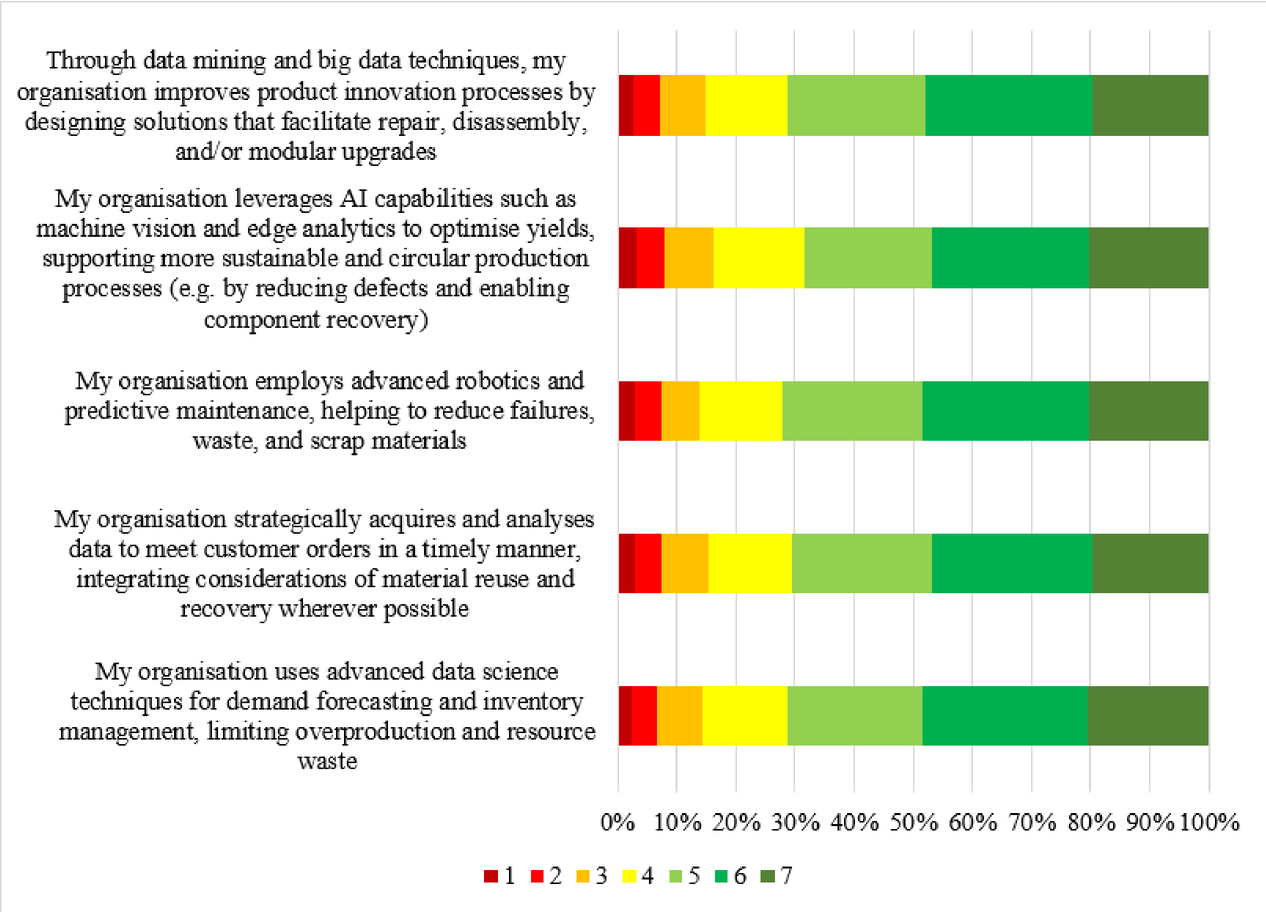


Figure 70 – Adoption of AI practices by German organisations – Part 2

Table 79 – Adoption of AI practices by Italian organisations – Part 3

	1	2	3	4	5	6	7
My organisation applies analytical techniques to integrated data warehouses to optimise the supplier network, aiming at solutions that support closed-loop systems and material recovery	2.65%	3.39%	6.39%	13.08%	23.66%	31.85%	18.97%
My organisation uses advanced analytics to maximise the efficiency of the entire resource network, including opportunities for reuse, recycling, or remanufacturing	2.55%	3.79%	7.19%	12.38%	22.02%	32.50%	19.57%
My organisation adopts artificial intelligence solutions to map the entire life cycle of materials and components, enabling their	2.85%	3.89%	6.59%	13.18%	22.17%	32.45%	18.87%

	1	2	3	4	5	6	7
recovery and reintegration into production processes, thereby reducing the use of virgin resources							
My organisation uses applied AI (e.g. deep learning) to reduce energy consumption, emissions, and waste in our processes, while also promoting product life extension and resource regeneration	3.34%	4.74%	7.69%	13.58%	21.87%	30.65%	18.12%
My organisation uses AI solutions to enhance transparency and traceability of material flows	2.90%	4.84%	6.49%	13.33%	22.52%	30.55%	19.37%

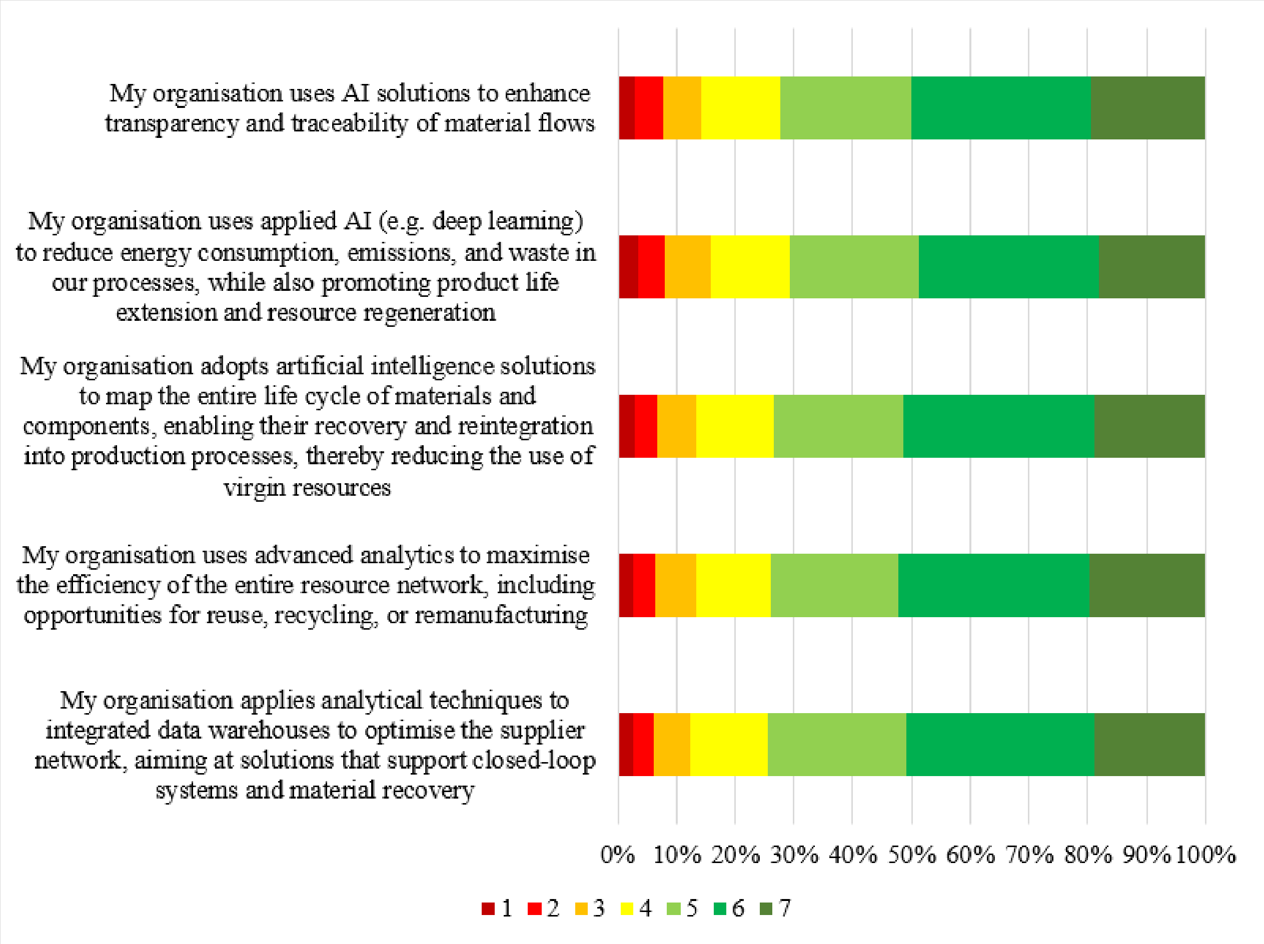


Figure 71 – Adoption of AI practices by Italian organisations – Part 3

Table 80 – Adoption of AI practices by German organisations - Part 3

	1	2	3	4	5	6	7
My organisation applies analytical techniques to integrated data warehouses to optimise the supplier network, aiming at solutions that support closed-loop systems and material recovery	3.10%	4.85%	7.74%	13.69%	22.83%	29.17%	18.63%

	1	2	3	4	5	6	7
My organisation uses advanced analytics to maximise the efficiency of the entire resource network, including opportunities for reuse, recycling, or remanufacturing	2.10%	4.85%	7.84%	15.13%	22.03%	28.22%	19.83%
My organisation adopts artificial intelligence solutions to map the entire life cycle of materials and components, enabling their recovery and reintegration into production processes, thereby reducing the use of virgin resources	2.80%	4.95%	7.89%	14.14%	23.33%	26.87%	20.03%
My organisation uses applied AI (e.g. deep learning) to reduce energy consumption, emissions, and waste in our processes, while also promoting product life extension and resource regeneration	3.35%	5.19%	7.74%	14.44%	22.23%	27.22%	19.83%
My organisation uses AI solutions to enhance transparency and traceability of material flows	3.03%	4.30%	6.98%	14.88%	23.41%	26.73%	20.66%

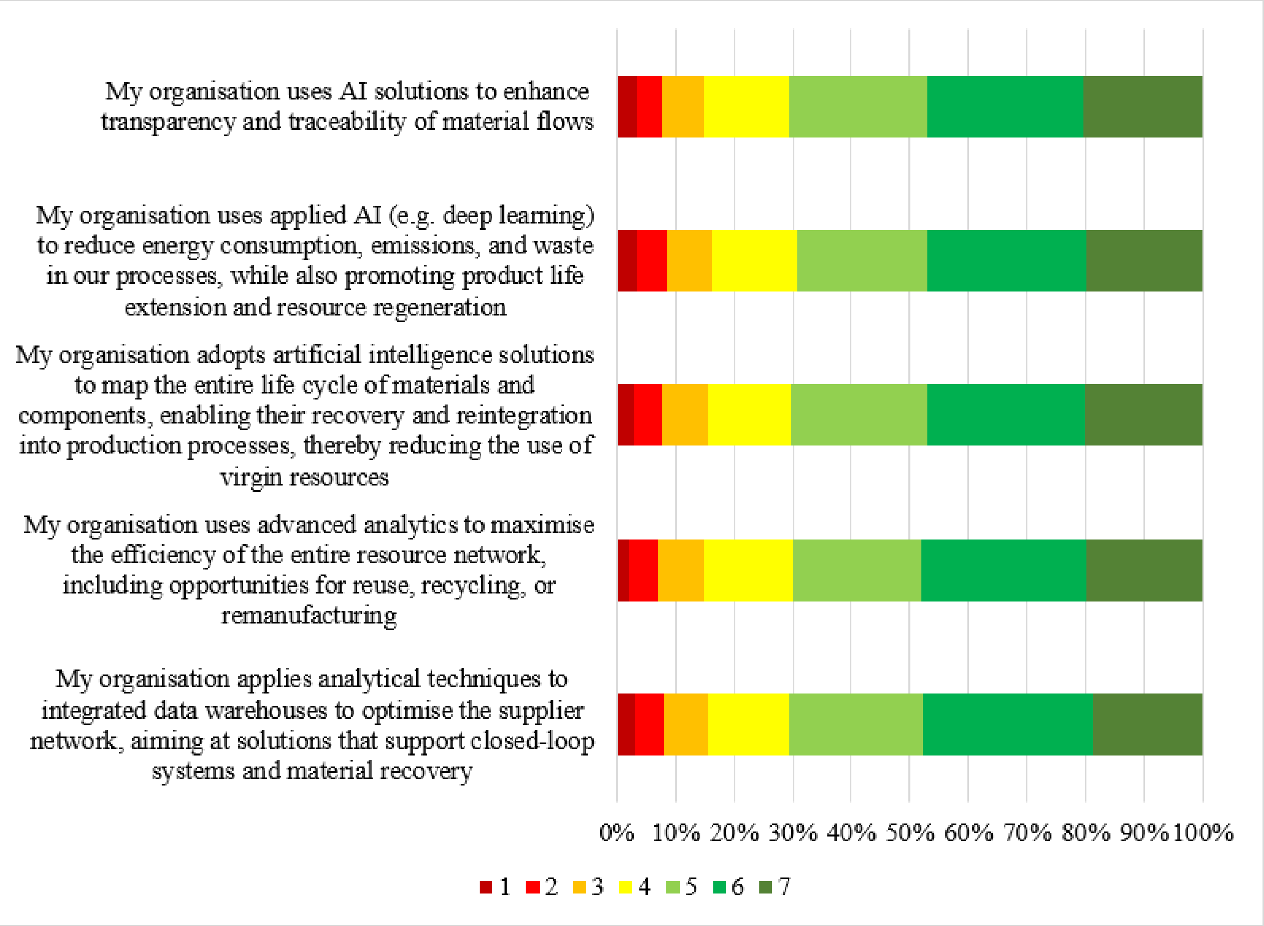


Figure 72 – Adoption of AI practices by German organisations – Part 3

5.4 Conclusions

The survey conducted within the GRINS project provides a broad and comparative overview of the maturity level of Italian and German companies with respect to the adoption of sustainability and circular economy practices. The results obtained from more than four thousand companies, evenly distributed between the two countries, outline an overall positive picture, although differentiated in terms of approaches, priorities, and implementation methods.

With regard to the presence and degree of integration of sustainability strategies within organisations, the analysis highlights a mature yet differentiated picture of how Italian and German companies approach sustainability and the integration of environmental tools into corporate strategies.

The results show a widespread awareness in both contexts of the importance of sustainability as a structural component of business management. However, subtle differences emerge in the way this awareness translates into concrete actions and organisational processes.

Italian companies tend to report a higher level of commitment to integrating sustainability into their strategic objectives and decision-making processes. Attention to environmental issues appears not only consolidated but also linked to a value-based and identity dimension: many organisations seem to orient their mission toward creating a positive impact and maintaining coherence with ethical and social principles. This orientation is reflected in the role attributed to top management, which is perceived as directly involved in defining and monitoring environmental strategies, evaluating performance, and communicating with stakeholders. In the Italian case, sustainability therefore appears as both a managerial and reputational lever, strongly linked to vision, continuous improvement, and the consolidation of the company's image in the long term.

German companies demonstrate an equally conscious but more cautious approach in their self-assessments. Sustainability appears less emphasised as a value and more integrated into the normality of planning and control processes. German companies demonstrate greater systematic alignment between objectives, monitoring, and strategy updates, highlighting an organisational culture oriented toward precision and operational consistency. Rather than focusing on external communication, attention appears to be directed toward internal efficiency and the solidity of procedures, with a perspective that tends to treat sustainability as a technical component of management rather than as an identity-defining element.

A common aspect in both contexts is the still-evolving but increasing use of scientific tools such as Life Cycle Assessment (LCA) and Carbon Footprint (CF). Italian companies attribute to these tools a strategic support role, useful for guiding decisions and periodically revising the business model; German companies, by contrast, emphasise their operational value and their function in the systematic updating of decision-making processes. In Italy, these tools appear to act as catalysts for learning and innovation; in Germany, they represent a consolidated mechanism for control and continuous improvement.

The comparison between the two countries does not suggest a difference in maturity but rather two different ways of understanding sustainability: a more relational Italian model, oriented toward adaptation and the construction of internal and external consensus, and a more structured German model, aimed at standardisation and efficiency. Both move in the same direction, but with languages and tools that reflect their respective industrial and organisational cultures. In both cases, the transition toward the circular economy and decarbonisation is underway and increasingly embedded, supported by the progressive strengthening of governance and the growing integration of quantitative methods for measuring environmental impacts.

Overall, both economies show a growing awareness of the need to integrate environmental sustainability into corporate strategy, although with different nuances.

Italian companies tend to report higher average levels of agreement regarding the integration of sustainability principles and objectives within governance structures and strategic decisions. In particular, the responses highlight a stronger direct involvement of top management in environmental decisions and a greater propensity to integrate the results of LCA and Carbon Footprint assessments into the definition of corporate objectives and the revision of business models. This evidence suggests that in Italy sustainability is increasingly perceived as both a managerial and reputational lever, linked to long-term vision and the improvement of corporate image toward external stakeholders.

German companies, while showing a similar level of awareness, appear slightly more cautious in their self-assessments regarding strategic commitment, but more systematic in the use of monitoring tools and procedures. German responses reveal a more methodical tendency to link the revision of corporate objectives to updates of LCA/CF assessments and to maintain consistency between planning and control. This suggests a more technical and operational approach, based on consolidated processes and a culture of measurement and efficiency rather than on value-based or communicative emphasis.

With regard to proactive environmental capabilities, the two corporate populations show very similar values, though with qualitative differences: Italian companies stand out for their ability to rapidly assimilate new technologies, recognise market opportunities, and activate collaborations with other companies and research centres; German companies instead show greater structuring of learning processes and a more homogeneous distribution of competencies across departments. Also in terms of internal communication, Italian companies appear more oriented toward creating interdepartmental information flows and periodic exchange moments, indicating a growing attention to collaborative dimensions and organisational innovation.

The most marked differences emerge in the area of environmental and circular performance. Italian companies report slightly higher performance in terms of energy efficiency, material use, and the adoption of decarbonisation strategies. There appears to be greater dynamism in the intention to "become circular organisations", fostering supply-chain collaborations, co-creation of solutions, and adaptation of product portfolios. German companies, on the other hand, show a lower declared propensity to transform their business models, but a stronger focus on product innovation and the availability of data along the value chain, consistent with a more structured industrial tradition.

In terms of social responsibility and stakeholder relations, Italian companies again show slightly higher average scores, indicating greater attention to communicating social commitments and managing relationships with local communities. German companies, while at similar levels, appear less explicit in their statements regarding social impact, suggesting a corporate culture more oriented toward compliance and less toward value-based communication.

The comparison between the two countries reveals a balance between different models of corporate sustainability: in Italy a "relational and adaptive sustainability" prevails, based on participation, learning, and inter-organisational cooperation; in Germany a "structural and operational sustainability" emerges, anchored in planning, standardisation, and process efficiency. These differences do not represent a gap in maturity, but rather two distinct pathways toward the same objective: integrating environmental and circular sustainability into production and decision-making processes.

Finally, the analysis suggests that the full potential of Life Cycle Thinking tools such as LCA and Carbon Footprint will only be realised through the strengthening of organisational capabilities and digital capabilities that allow the systemic linking of impact measurement with strategic planning. From this perspective, the creation of open-source platforms and data-driven tools, as envisaged by the GRINS project, represents a fundamental step in supporting companies' transition toward truly circular and decarbonised models based on shared knowledge, transparency, and continuous learning.

6 Best practices of CE implementation in the tissue paper sector

6.1 Results from the literature review

Tissue paper is a lightweight paper type that is characterized by being thin, soft, absorbent, and with a high specific volume. It includes products such as toilet paper, paper towels, handkerchiefs, and napkins (or facial tissues). Manufacturing tissue paper products has several key differences compared to production of other paper types like writing paper or cardboard. These may relate to input of materials, use of resources and energy, or generated waste streams, and derive from the distinctive desired properties and end uses of tissue paper. As a result, the environmental performance may differ from that of other paper types. Tissue paper is often made using a higher proportion of virgin pulp to achieve the desired softness and quality, potentially causing higher pressure on forest resources (BIR, 2021; Simamora et al., 2023). Further processing required for softer and whiter tissue paper might increase water and energy consumption (Man et al., 2019, 2018). Contamination issues in the end-of-life combined with the predominant single-use and the short nature of the fibers make tissue products mostly unsuitable for recycling, limiting the possibility for materials and resources recovery. Therefore, circular economy (CE) strategies for tissue paper should be examined separately from the rest of the paper industry.

The literature review conducted in the context of the tissue paper sector investigated the application of Life Cycle Assessment (LCA) in the sector and the most important CE strategies that are relevant for tissue products. The identified strategies could be classified based on the four CE principles proposed by Konietzko et al., 2020, namely 1) *closing* resource loops through the use of recycled fibers for tissue paper production, 2) *narrowing* resource use with strategies to control energy and water consumption, 3) *slowing* resource loops for decreasing tissue paper consumption by consumers and 4) *regenerating* energy resource flows with the integration of renewable energy within production. No strategies, such as recycling, could be identified for the end-of-life stage of tissue paper because the typical fate is incineration, landfilling and more rarely composting, except for toilet paper which typically ends up in the sewage system. Figure 73 summarizes the CE strategies emerged from the literature and illustrates the relevant stage of application in the life cycle of tissue paper products. Each strategy is discussed in more detail in the following sections, considering the four areas of application: choice of fiber, energy consumption, water consumption and tissue paper consumption.

1) *Closing resource loops: input fiber*

Material circularity in tissue production is mainly achieved by using recycled paper in an open-loop system that ends with tissue disposal. Recycled wastepaper is generally preferable to virgin pulp, as it lowers GHG emissions and reduces impacts on health, ecosystems, and resources (Gemechu et al., 2013; Masternak-Janus and Rybaczewska-Błazejowska, 2015; Thi and Thi Anh, 2020). Although recycling requires extra steps (e.g., deinking, washing, pressing), chemicals, and higher electricity use, these impacts are outweighed by the larger material and energy demand of producing virgin pulp. Since tissue represents the final fiber use and cannot be recycled further, employing wastepaper as feedstock is a more effective way to improve the circularity of virgin resources.

Despite the environmental benefits of using recycled fibers, their use in tissue production could be challenging. Strict sanitary and quality requirements, along with consumer expectations, limit substitution of virgin pulp (Or-Chen et al., 2024). At the same time, the decline of high-quality graphic paper waste due to media digitalization has reduced the supply of suitable recycled feedstock, pushing manufacturers toward virgin pulp (Charles et al., 2024; Furszyfer Del Rio et al., 2022). As a result, a substantial share of tissue will continue to rely on virgin materials. Addressing this requires technological innovations to recycle lower-grade fibers more effectively, allowing larger utilization of the available fraction of recyclable materials, and exploration of alternative raw materials. Bamboo is particularly promising given its high cellulose content, rapid growth, and potential to lower GHG emissions and water use (Duan et al., 2025; Guan et al., 2019; Man et al., 2018).

2) *Narrowing, closing and regenerating energy resource flows*

Energy consumption is a major environmental hotspot in tissue production, with some evidence suggesting that tissue requires more energy than other paper products such as cardboard or writing paper, resulting in higher impacts (Man et al., 2020, 2019).

As emerged from the literature, the key actions are reducing dependency on fossil fuels, especially coal, and increasing the use of renewable energy sources. Biomass is suggested as a suitable renewable alternative, provided that it is sourced from sustainably managed forests or is residual biomass that does not cause deforestation or other land use change impacts (Dias et al., 2024; Ingwersen et al., 2016). Other recommended energy sources are dewatered sludge, generated during the paper making process, and black liquor, a by-product of the Kraft process for pulp making, which can be used for on-site power generation (Gemechu et al., 2013; Thi and Thi Anh, 2020). The utilization of waste streams as sources of energy contributes both to decreasing dependency on fossil fuels and to *closing* the loop of resources used as input materials.

For *narrowing* the consumption of energy and reducing tissue's environmental footprint, increasing efficiency of energy generation is needed. On-site cogeneration of heat and power, process integration between pulp and tissue mills, and upgrades to existing machinery (e.g., inverters, improved boilers, energy recovery systems) can significantly cut energy demand (Dias et al., 2024; Gemechu et al., 2013; Thi and Thi Anh, 2020). The choice of drying technology is also critical: conventional Light Dry Creped (LDC) processes are less energy intensive than Through Air Drying (TAD), which, while producing higher-quality tissue, carries greater carbon impacts (Brito et al., 2023).

3) Narrowing water resource flows

The literature review revealed that the issue of reducing water consumption in tissue paper mills is not well addressed. In general terms, measures for water reduction and recycling strategies should be implemented primarily during the pulp making and the paper making stages. In certain contexts, such as China, selecting non-irrigated fiber sources like forest wood or bamboo, or avoiding pulp bleaching could also play a significant role in reducing pressure on water resources (Man et al., 2018).

4) Slowing tissue paper consumption

Tissue paper is typically a single-use type of paper, therefore reducing its consumption at consumer level is as important as challenging. Also in this case, a comprehensive overview of potential strategies to reduce tissue consumption was missing in the literature. Emerged considerations indicate that specific product design enhancements for paper dispensers, such as auto-cut, single extraction dispensers or implementation of LCD screens informing users when overconsuming paper, could be effective strategies to reduce consumption and overall impacts (Serna-Mansoux et al., 2014; Strazza et al., 2015).

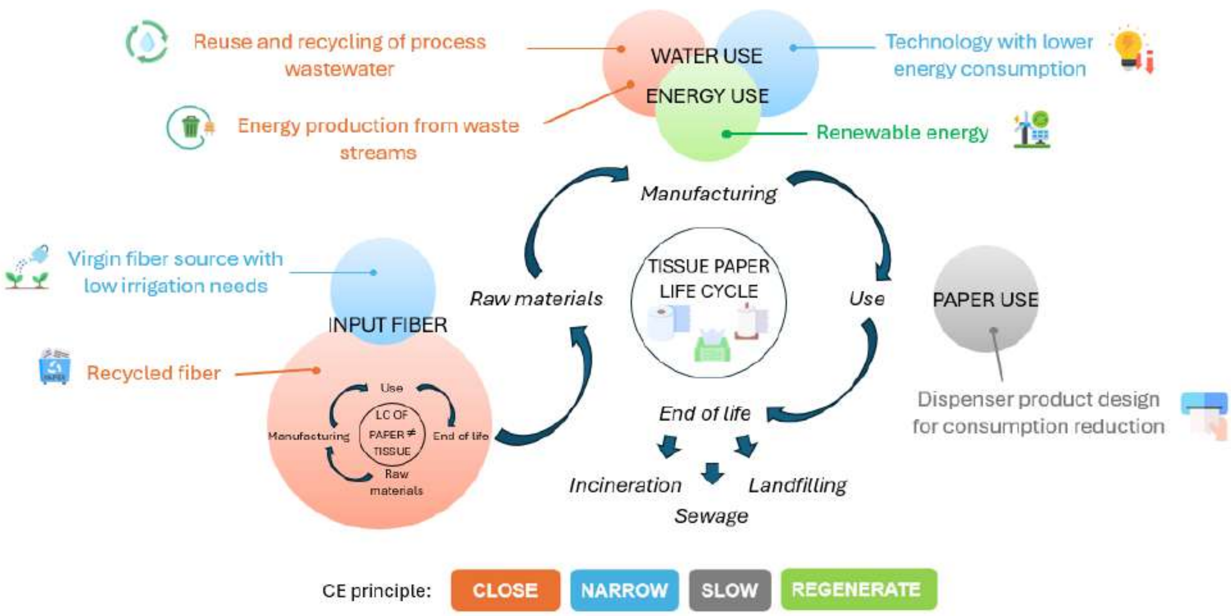


Figure 73: Overview of CE strategies and corresponding life cycle stage of application relevant for tissue paper products, as emerged from the literature review.

6.2 Practical examples from the industry sector

To complement the set of CE strategies identified through the literature review and provide a broader overview of best practices for CE implementation within the tissue paper sector, this section presents real examples of initiatives that have been adopted in the industry to increase circularity.

6.2.1 Lucart

Lucart is one of the incumbent firms that constitute the tissue paper industrial cluster of Lucca in Italy. The company has launched several initiatives to integrate CE into its business model over the past few years. These can be grouped into three main areas of action: reducing consumption of natural resources and energy, recovering and reusing paper waste and scraps and developing effective sustainable innovations in SC practices (Gandolfo and Lupi, 2021).

Most of the initiatives adopted by Lucart are in line with the CE strategies emerged from the literature review and include:

Increasing efficiency of energy generation systems and modernization of machinery (e.g. installation of co-generation plants, inverters or recovery of process vapour)

- Use of renewable energy sources
- Recovery and reuse of wastewater
- Use of recycled fibers for tissue paper production
- Recovery and reuse of waste streams from pulp and paper mills operations

A remarkable example of utilization of recycled fibers is the recovery of cellulose fibers from beverage cartons. These fibers are separated from the layers of aluminum and polyethylene composing the cartons and recycled to produce new tissue paper, particularly paper towels. In parallel, the aluminum and polyethylene fractions are also recovered and recycled to manufacture several items, such as tissue dispensers or wastepaper bins. This practice allows to reduce the use of virgin materials for manufacturing and at the same time reduce the quantity of waste that is sent to landfilling, as typically happens for beverage cartons (Gandolfo and Lupi, 2021; Lucart, 2024).

Other examples of initiatives adopted by Lucart relate to waste reduction and recovery. By increasing the efficiency of plants, the company improved the recovery and treatment of paper mill sludge, thus reducing the generation of non-treatable waste. Moreover, the residues from sludge treatment, together with the sludge from cellulose mechanical separation and the pulper scrap are reutilized in environmental reclamation activities, such as public gardens reclamation (Gandolfo and Lupi, 2021). This enables the recirculation of materials in addition to waste minimization.

Packaging is another area where the company introduced practices for reducing the use of resources and increasing circularity, with higher fractions of recycled materials as production input and the commitment to ensure that all packaging is either reusable, recyclable or compostable (Lucart, 2024).

To implement effective CE strategies without affecting business efficiency and financial performance, two aspects emerge as crucial: 1) technological innovation and 2) the creation of strong collaboration patterns gathering industrial players, policy makers and customers (Gandolfo and Lupi, 2021). This requires companies to develop adequate coordination of both the upstream and the downstream sides of the supply chain, i.e. the supply and the demand side. At the supply side, collaboration is important to ensure collection, sorting and treatment of recoverable paper materials. An example from Lucart experience derives from the program of utilizing cellulose fibers from beverage cartons. The company managed to engage with local communities and specialized firms to selectively collect beverage cartons from public places and sending them to pre-treatment. Subsequently the material reaches Lucart for recycling into new tissue products that are then intended for use in the same public places that provided the first cartons to recycle (Figure 74).

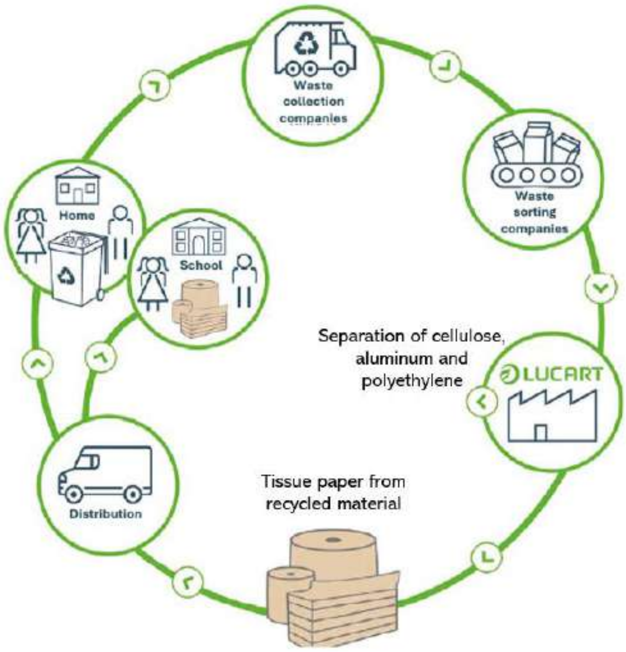


Figure 74: System for recovery and recycling of beverage cartons into new tissue products (adapted from (Lucart, 2024).

On the demand side, it is imperative that products reach the market and are accepted by distributors and end users. For instance, customers should be informed that tissue products made from recycled materials can also be of high quality, and that quality is not determined solely by the white color typical of virgin fiber products. Therefore, trained salesforce, communication sharing and relationship building during marketing are key strategies to achieve circular supply chains (Gandolfo and Lupi, 2021).

Other important players of the tissue paper industrial district of Lucca, such as Sofidel, report practices targeting resources and material circularity that are analogous to those of Lucart. Companies relying more on virgin fibers for tissue production declare committed in ensuring that the raw material originates from certified sustainably managed forests where deforestation and depletion of natural resources are kept under control (Sofidel, 2024).

A final example of CE initiative tested in the industry is represented by the possibility of closing the loop in tissue paper life cycle. Recycling tissue paper after use is typically not possible due to contamination issues and the shortness of the fibers, which prevents the formation of robust fibers bonding. However, collecting and recycling paper towels is emerging as a new practice for closing the loop. Since the 2020s, several initiatives have been launched to selectively collect paper towels for drying hands in public spaces and recycle them into new tissue paper (UNECE, 2024). The Swedish multinational Essity was the first to launch such a recycling service for paper hand towels used in companies and public places like schools and municipalities (Essity, 2024).

Table 81 summarizes all CE best practices relevant for the tissue paper sector gathered from both the literature study and from industry real cases. Classification of each practice according to the CE principles of Konietzko et al., 2020 is also shown.

Table 81: Summary of best practices for CE application in the tissue paper sector.

Practice	Macro area	CE principle
Use of recycled fiber (from wastepaper)	Input fiber	Close
Use of recycled fiber from beverage cartons	Input fiber	Close
Responsible sourcing of virgin fibers	Input fiber	Close
Process wastewater recovery and reuse	Water use	Close
Selection of virgin fiber sources with low irrigation needs	Water use	Narrow
Avoid pulp bleaching	Water use	Narrow
Recover process vapors	Energy use	Narrow
Methane co-generation plants	Energy use	Narrow
Photovoltaic and other renewable energy sources	Energy use	Regenerate
Modernization with high energy efficiency and low consumption motors	Energy use	Narrow
Installation of inverters	Energy use	Narrow
Replacement of traditional bulbs with LED bulbs	Energy use	Narrow
Pulp and paper mills process integration	Resource use	Close - Narrow
Improving convection systems	Energy use	Narrow
Recovery of aluminum and polyethylene from beverage cartons for tissue dispensers' production	Waste (from society) recovery and recycling	Close
Recovery and reuse of mechanical separation sludge and pulper scrap (black liquor) for environmental reclamation or for energy generation	Waste recovery and reuse	Close
Improved recovery and treatment of paper mill sludge with more efficient plants	Non-treatable waste reduction	Close

Use sludge treatment residues in garden reclamation	Waste recovery and reuse	Close
Collection and recycling of wastepaper towels	Waste recovery and recycling	Close
Packaging made of recycled material	Packaging	Close
Ensure reuse, recyclability or compostability of packaging	Packaging	Close
Product design enhancements	Paper use	Slow
Tissue paper hand towels recycling	Waste recovery and recycling	Close

6.2.2 Cartiere Carrara

Among industrial best practices, Cartiere Carrara stands out for the complexity of its efforts to achieve ever-better environmental performance, including various actions inspired by the principles of the circular economy.

Cartiere Carrara, founded by the Carrara family in 1873, is one of the leading Italian and European companies operating in the integrated production of tissue paper.

The Group's companies oversee the entire production process, from the selection of pulp to tissue manufacturing, from converting operations to the distribution of the finished product.

The Company operates 7 production sites, all located in Italy, employs approximately 730 people, and runs 60 converting lines, with an annual production of about 300,000 tonnes of tissue paper made from both virgin pulp and recycled paper. Through its integrated production process, Cartiere Carrara manufactures semi-finished products starting from raw materials and converts them into a wide range of finished products intended for the professional market (the "Away-From-Home" / "Professional" Division) as well as for personal and household consumption (the "Consumer" Division).

Through the production of folded and rolled paper towels, kitchen rolls, toilet paper, facial tissues and paper handkerchiefs, napkins, and placemats, the Company has established a significant presence across multiple geographic areas, serving customers in 50 European and non-European countries.

Cartiere Carrara stands out for its strong commitment to environmental sustainability, directing its activities toward more efficient choices aimed at safeguarding the environment and human health through an effective environmental management system. Over the years, sustainability has become an integral part of Cartiere Carrara's development strategy, leading to significant achievements in the following areas:

- optimization of water resource use, through the recycling and reuse of process water;
- reduction of energy consumption, also supported by the presence of high-efficiency cogeneration plants;
- responsible sourcing, through the selection of renewable and certified raw materials;
- reduction of waste generation.

In confirmation of its commitment to sustainability, Cartiere Carrara has joined several voluntary certification schemes with the aim of continuously improving its performance. Among these, it is worth mentioning:

- ISO 14001: internationally recognized standard for environmental management systems (EMS).

- ECOLABEL EU: the EU official, world-renowned, voluntary label for environmental excellence, promoting goods and services that clearly demonstrate environmental high performance, based on standardised processes and scientific evidence.
- NORDIC SWAN ECOLABEL: the sustainability ecolabel adopted for products marketed in the Nordic European countries.
- BLAUE ANGEL**:** the Germany's environmental quality label, which establishes high standards for the design and production of environmentally friendly products.

The company markets its products under the brands 'Bulkysoft', 'Carind', "Tuscany" and 'Maxi', as well as producing for large-scale retail customers in the private label market (Cartiere Carrara, 2024a)

In 2024 driven by both the initiative of the current Director of Quality and Sustainability together with the other internal stakeholders, demanding a higher consciousness about the sustainability implications of the company industrial processes, and the pressure of the clients, asking for a certified and science-based assessment of purchased products environmental footprint, the company decided to develop a strong internal competence on LCA.

Thanks to the help of a consultant, they designed an Excel-based tool enabling the assessment of the environmental profile of their products in compliance with ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b) methodology on LCA .

The methodological steps followed are schematically represented in Figure 75.

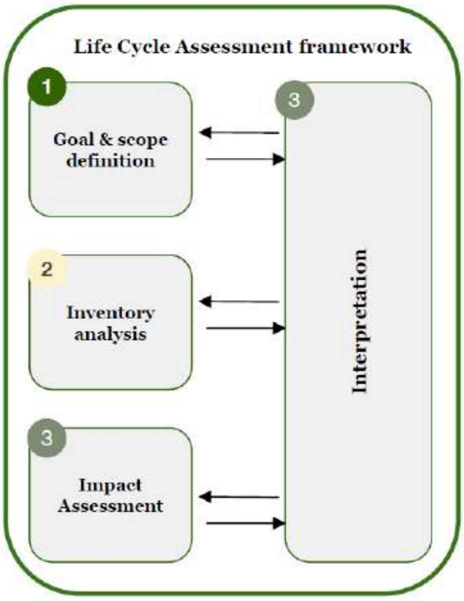


Figure 75: LCA steps followed by Cartiere Carrara (Cartiere Carrara, 2024b)

They investigated 21 commercial articles, each representing a different product family manufactured at Cartiere Carrara and differentiated by product type, target market (Professional or Consumer), paper composition, production sites and packaging. Their first focus was on global warming potential impact, perceived as a priority for both internal and external stakeholders.

In order to assess the environmental impact, in terms of kgCO2eq, of the 21 products, they carried out the activities identified in Figure 76.

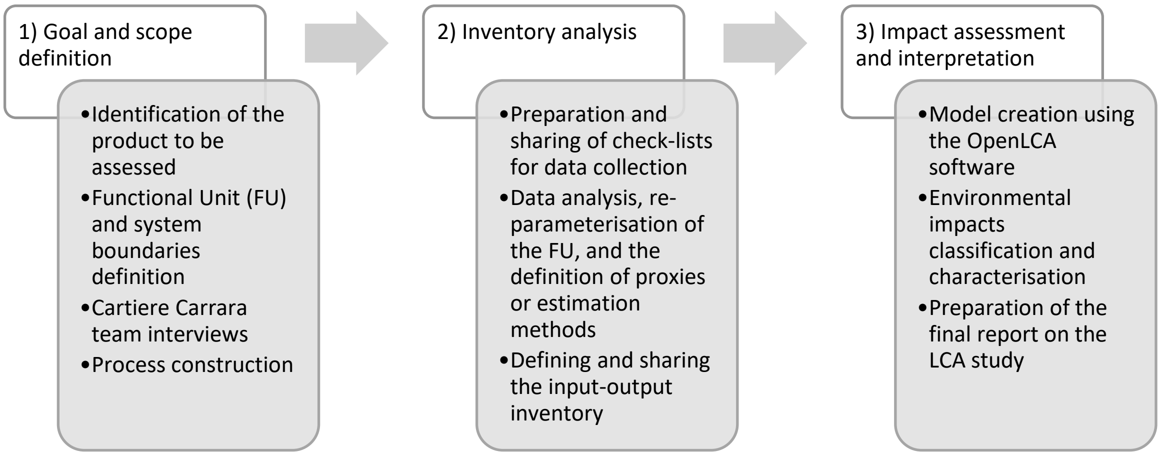


Figure 76: Activities carried out by Cartiere Carrara for each LCA step, for all 21 products

The functional unit is defined as 1 kg of paper delivered to the end user, including packaging.

The System boundaries of the tissue paper product is represented in the following diagram (Figure 77).

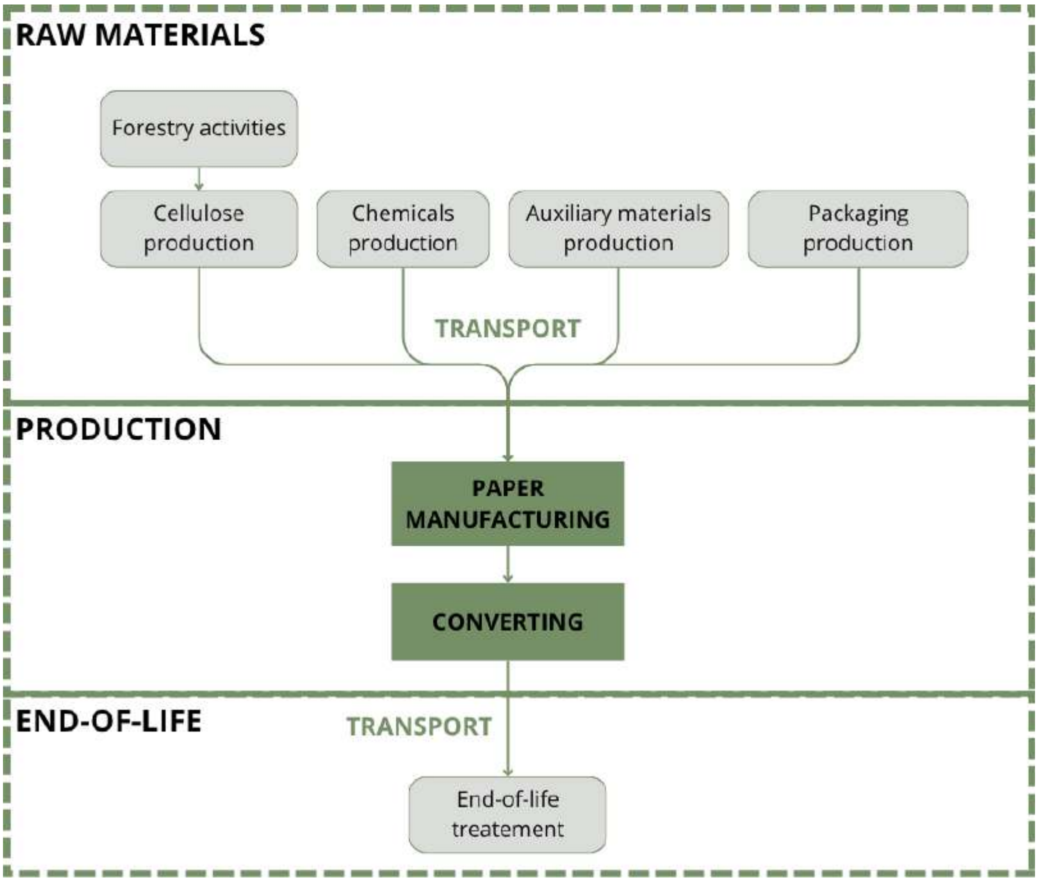


Figure 77: System boundaries of the general tissue paper product

Among the 21 products, they first identified the worst-case scenario in order to understand which areas needed to be improved as a priority. The aggregated results, as shown in Figure 78, indicate that the contribution to total life cycle emissions is evenly distributed across the main process stages: upstream (including all processes related to raw material production), core (covering inbound transport and manufacturing processes), and downstream (encompassing all post-production activities, including distribution and product end-of-life).

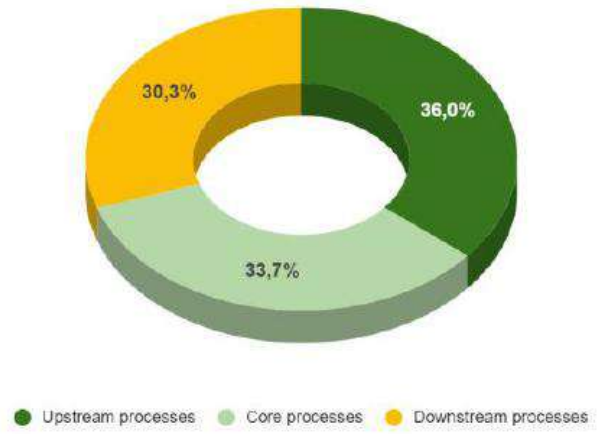
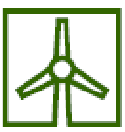
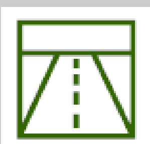


Figure 78: distribution of emissions by process stage of the worst-case scenario

Results obtained for the 21 reference products allow Cartiere Carrara to identify among upstream, core and downstream activities, the most relevant processes in order to prioritize the emissions reduction efforts consistently.

Table 82: Most relevant processes and decarbonisation strategies

	Step	Process	Decarbonisation strategies
	**Upstream**	• Production and origin of raw materials/secondary raw materials (e.g. SBS, cellulose, forest management) • Weight of packaging per kg of paper (e.g. envelopes + bags for lightweight toilet paper, tissue boxes and boxes).	• Selection of suppliers that have a sustainability plan, which includes specific strategies aimed at reducing Scope 1 and 2 emissions • Selection of local suppliers to reduce transport distances and the use of biofuels • Selection of more sustainable packaging for lightweight products during the product design phase
	**Core**	• The paper mill's electricity and heat consumption (e.g. Pietrabuona is the most energy-intensive paper mill, whilst PM6 is the most sustainable machine)	• Selection of the most sustainable continuous production machine from among those that are technically suitable. • Purchase of renewable electricity and natural gas certified with a guarantee of origin (GOs).
	**Downstream**	• Method of disposal for the products and their packaging (e.g. sanitary waste as opposed to other items) • Disposal procedures in the product's country of destination. • Transport by lorry > 32 tonnes	• Select local suppliers to reduce transport distances and use biofuels as a substitute for diesel where it is used by vehicles in the supply chain.

Evidences emerged from the LCA assessment are aligned with those identified by literature review conducted in the context of the tissue paper sector and presented in paragraph 6.1. Raw materials origin and production, electric and thermal energy consumption as well as end-of-life tissue paper waste treatment are the main sources of impacts and priority areas of decarbonization intervention. Potential decarbonization strategies include, but are not limited to, the selection of exemplary suppliers, who demonstrate a measurable commitment to reducing direct emissions (Scope 1) and indirect emissions associated with purchased energy (Scope 2 prioritisation of local sourcing to minimise transport distances and related emissions; procurement of electric and thermal energy from renewable sources; the adoption of biofuel for the transport vehicles across the supply chain (Table 82).

7 Development of PEFCR in the plasterboard sector

7.1 What are PEFCR

The Product Environmental Footprint Category Rules (PEFCR) represent a key component of the Product Environmental Footprint (PEF) method. PEF is a Life Cycle Assessment (LCA)-based approach used to quantify the relevant environmental impacts of products (goods or services), building on existing approaches and international standards. Within this framework, PEFCRs provide consistent and specific set of rules to calculate the relevant environmental information of products belonging to the product category in scope. By establishing these common rules, PEFCRs improve the reproducibility of LCA studies and enable the credibility and comparability of results, reducing market fragmentation. They are part of the European Commission's Environmental Footprint (EF) initiative, which aims to harmonize LCA methods and provide reliable, comparable and verifiable environmental information (European Commission [EC], 2021).

PEFCRs are structured to provide a clear and comprehensive framework for assessing the environmental impacts of products. They are organized into several sections, each addressing a specific aspect of the assessment process and providing methodological guidance. The main sections of the PEFCRs include the definition of the scope, containing the life cycle stages to be considered; the data quality requirements; the most relevant impact categories, life cycle stages and processes and the results, including the benchmark values. Each section sets out detailed methodological instructions for conducting the assessment, thereby supporting the robustness, consistency and comparability of the results. An important aspect detailed in each PEFCR is the minimum list of processes, called mandatory processes, that shall always be covered by company-specific (primary) data based on their relevance and availability, in order to avoid the use of default (secondary) data.

PEFCRs are applied in a wide range of sectors, from food and drink to textiles and electronics. The complete list of PEFCRs in revision, in development and the new published ones can be found at: https://green-forum.ec.europa.eu/green-business/environmental-footprint-methods/pef-method_en.

7.1.1 PCR in the context of the MGI scheme

The "Made Green in Italy" scheme adopt the PEF methodology to determine the environmental footprint of goods and services aiming at promoting those products with good or excellent environmental performance in the context of the Italian market.

As with the PEF method, the first step in making the framework effectively applicable to products on the market is the existence of Product Category Rules (PCR), i.e. documents containing methodological guidelines that define the mandatory and optional rules and requirements necessary for conducting environmental footprint studies for a specific product category, developed following the same procedural steps.

Some of the MGI scheme currently valid PCRs, available at https://www.mase.gov.it/portale/web/guest/rcp-in-corso-di-validit%C3%A0, are:

- Pig meat, fresh or chilled;
- Vinegar;
- Gran Padano DOP cheese;

- Wooden packaging;
- PE multipurpose bags;
- Fabrics made of carded wool or carded fine hair;
- Geotextiles and related products.

7.2 MGI Product Category Rules definition steps

The procedural steps leading to the publication of a new PCR can be summarized in two main stages:

1. **Proposal and approval of PCRs**: PCRs may be proposed by entities (public or private) composed of at least three companies, of which at least one must be a small or medium-sized enterprise (SME), according to the definition provided by DM 18.04.2005 (Minister of Productive Activities, 2005), that represent the majority share of the sector of the specific product category for which the development of PCRs is proposed. A majority share is defined as more than 50% of the sector's turnover, referring to the calendar year preceding the PCR proposal.

   The scheme follows the PEF methodology, therefore, if a PEFCR exists at the European level, it must be adopted and integrated into the PCR under development, including the mandatory and optional additional requirements; otherwise, a new PCR is developed at the national level.

2. **Application for participation**: once the process has been completed and a PCR for a given sector has been approved, interested companies may apply to join the MGI scheme, carry out a PEF study and, upon submission of the required documentation, may obtain the "Made Green in Italy" logo for their product (Ministry of the Environment and Energy Security [MASE], 2024).

The individual sub-activities, detailed step by step and including an indication of the estimated number of days required for their completion, are specified in the tables below.

Table 83: stages in the process of developing a PCR for the MGI scheme. The figures shown in the table are subject to change depending on the specific circumstances of the case under consideration.

Step	PCR drafting	Days
1.1	Technical staff and company representatives have met to outline the project's objectives, operational phases, and the roles of those involved.	1
1.2	Site visits by technical staff to draw on the knowledge and expertise of various sector specialists.	2
1.3	Elaboration of the initial draft of data collection checklist, designed to facilitate completion by staff whilst ensuring completeness and quality.	4
1.4	Validation of the draft checklist with individual companies to ensure effective and efficient data collection.	1
1.5	Drafting of the final version of the checklist, amended following the incorporation of comments received during the validation phase.	2
1.6	Distribution and completion of the checklist by the companies.	60
1.7	Interpretation of the data and life cycle analysis of the representative average product to define environmental performance.	60
1.8	Presentation of the results to the companies and discussion of the impact of the methodological choices and assumptions adopted on the results.	30
1.9	Drafting of the screening study report and the PCR	30
Total		***190***

Table 84: Stages in the process of publishing a PCR for the MGI scheme. The figures shown in the table are subject to change depending on the specific circumstances of the case in question.

Step	PCR publication	Days
2.1	Completion of the forms for the request to draw up a draft PCR using "Form A", which contains the details of the lead applicant and the proposing parties.	10

2.2	MASE manages the request for the preparation of a new PCR	30
2.3	Deadlines for the submission of the PCR using "Form B" and attaching the screening study and the PCR	180
2.4	Public consultation on the PCR	30
2.5	Post-consultation amendments	30
Total		***280***

Table 85: Stages in the process of applying a PCR for the MGI scheme. The values shown in the table are subject to variation depending on the specific circumstances of the case in question.

Step	**PCR application**	**Days**
3.1	Collection and processing of data by the company seeking to certify its MGI product, and submission to any consultant with technical responsibility for conducting the life cycle assessment.	15
3.2	LCA of the product for its classification into environmental performance classes. Compilation of the documentation required to obtain the logo (environmental footprint analysis, environmental product declaration, supplementary forms).	45
3.3	Critical review by an Accredia-accredited verification body, with a site visit if required.	5
3.4	Incorporation of revisions by the consultant.	5
3.5	Final review by MASE and implementation of any changes	10
Total		***80***

Table 86: stages in the process of developing, publishing and implementing a PCR for the MGI scheme. The figures shown in the table are subject to variation depending on the specific circumstances of the case in question.

Step	**Development, Publication and Implementation of the RCP**	**Days**
1	Development of the PCR	190
2	Publication of the PCR	280
3	Implementation of the PCR	80
Total		***550***

7.3 Plasterboard sector case

7.3.1 The Italian plasterboard sector

Gypsum plasterboard is a building material consisting of a gypsum (calcium sulfate dihydrate) core enclosed between two layers of paper facing, manufactured in panel form and primarily used for the construction of interior walls, partitions, and ceiling systems in building applications.

In Italy, manufacturers of gypsum and related products have long been part of the Confindustria system, initially within Assocemento, subsequently, since 1994, within CAGEMA, and, most recently, since 2022, within Assogesso.

Assogesso – the Italian Association of Gypsum and Gypsum Products Manufacturers – is a non-profit industry association, established in response to the need of companies in the sector to create a representative body to engage with institutions and public administrations and to carry out activities specifically dedicated to the gypsum industry. The association aims to engage with institutional and political stakeholders and to promote the contribution that this industry provides to society in terms of economic value, technological and design innovation, safety in construction, and, in particular, environmental sustainability and the reduction of energy consumption (Assogesso, 2023).

The member companies of Assogesso are:

- ETEX BUILDING PERFORMANCE
- FASSA BORTOLO
- FIBRAN
- GIPSOS
- KNAUF
- SAINT-GOBAIN ITALIA
- SICILGESSO

Assogesso is a member of Eurogypsum, the European federation of national associations of gypsum product manufacturers, headquartered in Brussels, aiming at zero emissions of the sector by 2050.

7.3.2 Assogesso's initiative for the development of PCR

As part of the sector's sustainability initiatives, Assogesso has expressed its commitment to initiating the process for the development of PCRs within the framework of the MGI certification scheme.

Companies involved in this initiative are: Etex, Fassa Bortolo, Fibran, Knauf and Saint-Gobain, representing together more than 50% of the sector's turnover.

During the first meeting, companies were briefed on the characteristics and objectives of the MGI certification scheme, as illustrated in Figure 79. The focus is on the dual purpose of the certification scheme: on the one hand, it provides a standardised procedure to communicate products environmental footprints, in accordance with the typical requirements of Type 3 environmental labelling, as defined by ISO 14025:2006 (International Organization for Standardization [ISO], 2006); on the other hand, the MGI incorporates the typical requirements of excellence labels awarded to products capable of exceeding certain performance standards, outperforming an average category benchmark, as in the case with Type 1 environmental labelling, regulated by ISO 14024:2018 (ISO, 2018).

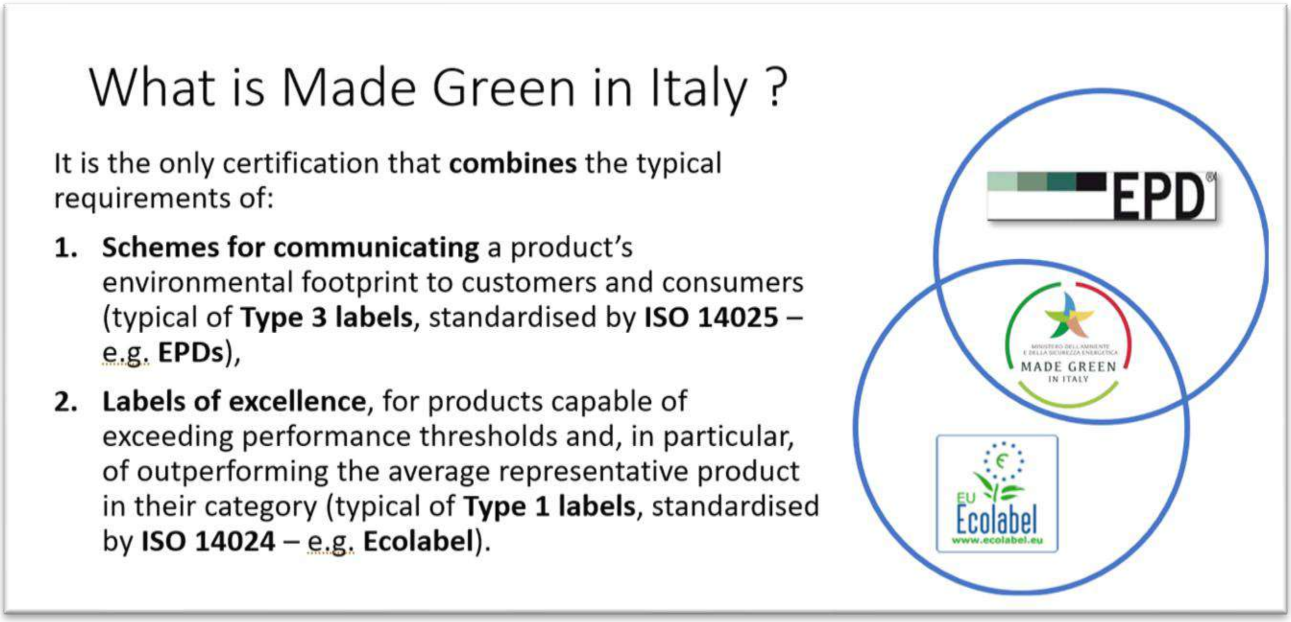


Figure 79: What is Made Green in Italy? Purpose and features of MGI

They were informed of the different activities and the timelines necessary for the development of a new PCR (Table 87).

Table 87: Plasterboard PCR publication activities timeline

	M1	M2	M3	M4	M5	M6	M7	M8
PCR of plasterboard definition	**Check list**	**Data collection**	**Data collection**	**Data collection**	**Model definition and LCA analysis**	**Model definition and LCA analysis**	**PCR drafting**	**PCR drafting**

The activities are described in detail as follows:

1. Checklist development: This phase involves the definition and structuring of a comprehensive checklist covering all relevant processes and activities associated with the life cycle of the Representative Product (RP) (i.e., a plasterboard panel). The checklist is designed to support the application of the LCA methodology in accordance with ISO standards (ISO, 2006a; 2006b).
2. Data collection: In this step, both primary and secondary data related to the Life Cycle Inventory (LCI) of the RP are systematically gathered. Data acquisition is carried out through the distribution of a structured Excel-based questionnaire, which participating companies are requested to complete.
3. LCA model development: This activity consists of modelling the RP within the SimaPro software environment (PRé Sustainability, 2026). The model is developed using a weighted average approach based on the life cycle inventory data collected from the five participating companies, ensuring representativeness and consistency.
4. Life Cycle Impact Assessment (LCIA): The developed LCA model is subsequently analyzed by applying the Environmental Footprint (EF) method established by the European Commission. This step enables the evaluation of potential environmental impacts associated with the product system (Bassi et al., 2023).
5. PCR drafting: The final phase involves the preparation of the Product Category Rules (PCR) document for plasterboard. This includes the definition of calculation criteria and environmental performance metrics, as well as the identification of an appropriate benchmark for comparative purposes.

7.3.3Activities undertaken

Following an initial phase in which the rationale behind the MGI certification scheme was explained to each involved Assogesso member company, we identified the Functional Unit (FU), defined the system boundaries and discussed about the data needs for the LCA.

The FU of the study is defined as 1 m^2 of gypsum-based plasterboard installed to the highest standards, included its packaging.

The system boundaries of the product are described in Figure 80.

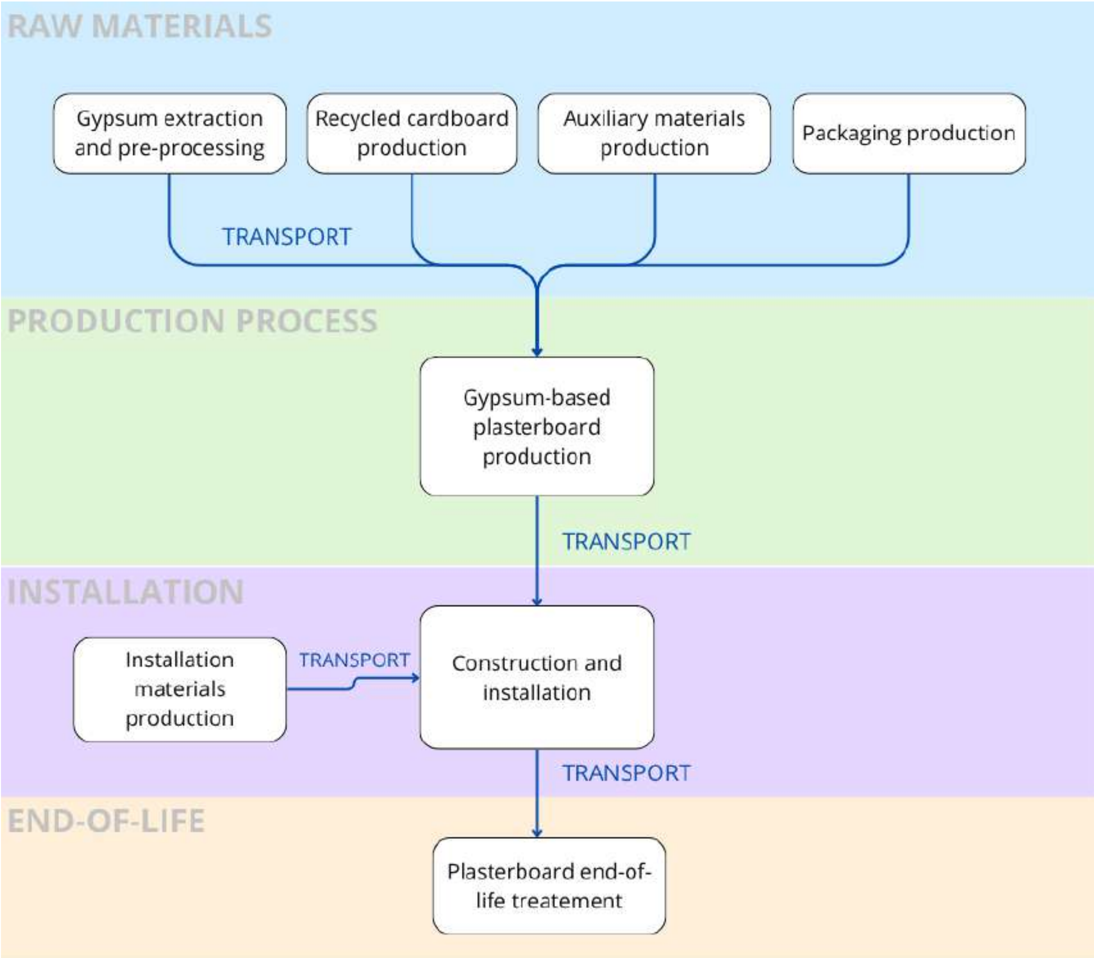


Figure 80: System boundaries of plasterboard LCA

The discussion on data needs lead to the definition of the checklists for Life Cycle Inventory (LCI) activity. These Excel-based documents were finalised and shared between October and November 2025 (Figure 81).

"CHECKLIST RACCOLTA DATI PER ANALISI LCA"				
Indirizzo stabilimento	*via....*			
PRODOTTI STABILIMENTO	**m2/anno 2024 (lastre)**	**kg/anno 2024 (altri prodotti a base gesso)**	**Responsabile raccolta dato**	**Fonte dato**
LASTRE TOTALI				
MALTE E INTONACI A BASE GESSO				
BLOCCHI IN GESSO/ALTRI PRODOTTI A BASE GESSO				
CONSUMI Energia Elettrica	**ANNO 2024**	**Commenti**	**Responsabile raccolta dato**	**Fonte dato**
Prelevata da rete nazionale (kWh)				
di cui da fornitore certificato green (%)				
di cui con Certificati di garanzia d'origine (%)				
Autoprodotta da pannelli fotovoltaici (kWh)				
Autoprodotta da altre fonti rinnovabili -specificare fonte nei commenti- (kWh)				
Autoprodotta da cogenerazione (kWh)				
PRODUZIONE COGENERATORE	**ANNO 2024**	**Commenti**	**Responsabile raccolta dato**	**Fonte dato**
Potenza (kW)				
Consumo di gas naturale per congeneratore (Sm3)				
Energia elettrica totale prodotta (kWh)				
Energia termica totale prodotta (kWh)				
Totale energia prodotta(kWh)				
CONSUMO Idrico	**ANNO 2024**	**Commenti**	**Responsabile raccolta dato**	**Fonte dato**
Acqua prelevata (m3)				
di cui da acquedotto (%)				
di cui da pozzo/corso d'acqua/natura (%)				
SPECIFICHE TECNICHE DELLE LASTRE 2024				
	Intervallo (da-a)	**Valore medio ponderato in base alle % di produzione, calcolata in mq, delle diverse lastre**	**Commenti**	**DISCLAIMER: in alternativa potremmo chiedere le INFO DI CIASCUNA SINGOLA LASTRA e provvederemmo noi al calcolo delle medie ponderate**
Densità o peso specifico (kg/m3)				
Lunghezza (mm)				
Larghezza (mm)				
Spessore (mm)				

Figure 81:LCA data collection checklist extract

Since December, the participating companies have been collecting primary activity data. The collection is almost complete, apart from a few details regarding a specific group of raw materials, which have required further discussions between the companies to agree on the level of detail to be reported.

7.3.4 Future developments

Once data collection has been completed, the LCA model of the RP for the Italian plasterboard sector will be developed. The modelling approach will be based on a weighted aggregation of company-specific data, where weights are assigned according to each company's market share. Market share will be determined on the basis of production volumes or, alternatively, the contribution to the overall sector turnover, ensuring that the resulting model accurately reflects the structure of the national market.

Subsequently, a screening LCA of the averaged RP model will be carried out in accordance with the PEF framework. The calculation will apply the most recent version of the EF impact assessment method, enabling the quantification of characterized, normalized, and weighted indicators of potential environmental impacts.

The LCA Interpretation phase will focus on the identification of the most relevant impact categories, defined as those contributing cumulatively to at least 80% of the total weighted environmental footprint. In parallel, the analysis will identify environmental hotspots within the product system. Hotspots are defined as the most significant life cycle stages, processes, and elementary flows, namely those responsible for at least 80% of the impacts within the previously identified most relevant impact categories.

This activity represents the starting point of the benchmark value identification and subsequent performance classes definition. The benchmark value (BM) is defined as a single aggregated score, calculated as the sum of the three most relevant impact categories indicators' results, obtained after the application of normalization and weighting procedures (Ministry Of The Environment, Land And Marine Conservation [MATTM], 2018) to the RP characterised impact results. The characterization, normalization, and weighting factors applied are those of the EF method, as specified in Annex A of the PEFCR Guidance (EC, 2018).

Building on the example provided in the PEF methodology (European Commission, 2021), which describes a possible procedure for defining five performance classes - ranging from category A, representing the best performance with the lowest environmental impact, to category E, representing the worst performance with the highest impact (Figure 82) - the MGI scheme establishes, as part of its mandatory additional requirements, three environmental performance classes (A, B, and C).

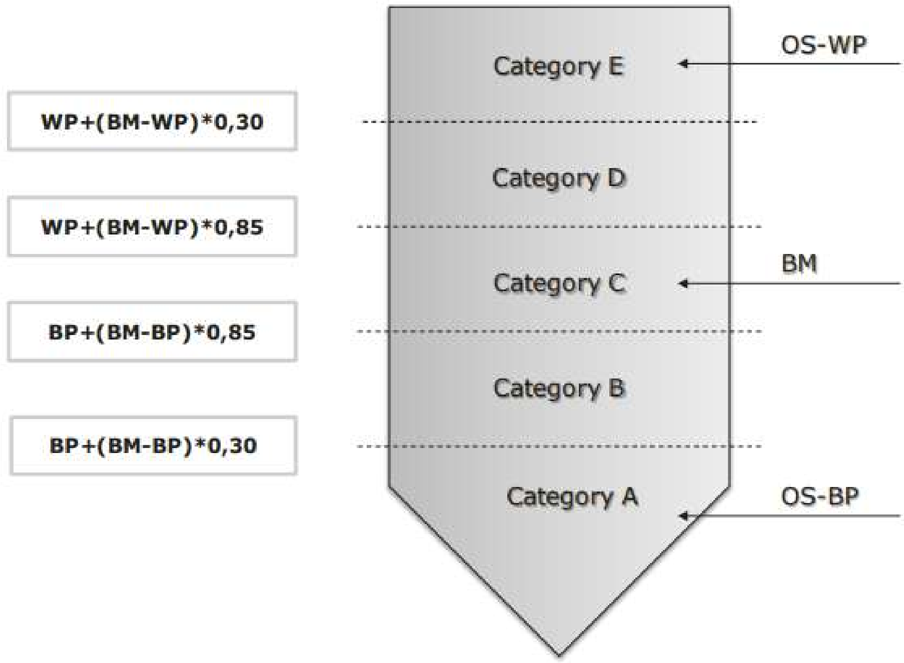


Figure 82: PEF Classes of performance (European Commission, 2021)

where OS-BP is the single overall score of the best product, OS-WP is the single overall score of the worst product, BM is the single overall score of the representative product (benchmark value), OS is the single overall score of a specific product calculated based on a PEF study carried out in compliance with the PEFCR.

These classes are defined relative to a benchmark value, representing the midpoint of class B, and are delineated by two threshold levels: one above and one below the benchmark, after having calculated the Best Performer (BP) and Worst Performer (WP) and applying the formula described in Table 88.

Table 88: MGI classes of performance proposal

Upper class	**A** <= *Best Performer +(benchmark- Best Performer)*0,58*
Intermediate class	*Best Performer +(benchmark- Best Performer)* 0,58* < **B** < *Worst Performer+(benchmark- Worst Performer)* 0,58*
Lower class	**C** >= *Worst Performer +(benchmark- Worst Performer)* 0,58*

BP and WP are theoretical virtual products modelled assigning to the most relevant parameters, identified through a sensitivity analysis of the RP model, the values contributing, respectively, the least and the most to the single score The single score is calculated as the sum of the weighted results across the three most relevant impact categories.

The intermediate class (Class B) corresponds to products exhibiting average environmental performance, as represented by the benchmark. Products achieving performance above the benchmark are assigned to the highest class (class A), whereas those with comparatively lower environmental performance are allocated to the lowest class (class C).

The screening LCA study of the RP for the Italian plasterboard sector, from the goal and scope definition up to the interpretation phase, including the identification of the three classes of performance, will be described in a report (*PEF Screening Report*). This Report will represent the supporting document for the *Italian Plasterboard PCR* drafting, developed following the European Commission Recommendation 2013/179/EU (EC, 2013) and the PEF guidelines (EC, 2018) supplemented by the additional mandatory and optional requirements referred to in Article 2 of D.M. 21 March 2018, n.56 (MATTM, 2018).

8 CE implementation in the agrifood sector exploiting GIS and survey

8.1 Fruits and legumes

The research unit of Bari proposed a method for applying the Circular Economy (CE) perspectives in agriculture, considering the reuse of the relative residues of the investigated crops, such as peaches, nectarines, apples, grapes, chickpeas, lentils, fava beans and peas. Particularly, they applied the theorized method for the quantification of these residues by Paiano & Lagioia (2016) and employed the Geographic Information System (GIS)-based approach to assess the spatial distribution of these biomasses. Thus, through this methodology they provided a replicable approach for energy valorization from a Circular Economy perspective.

Mainly, the output of this application, that addresses the Deliverable 1.3.2, titled "Open-source data platform/s based on multiple data and sources to support companies of different production sectors in the transition processes toward a more decarbonized and circular economy" in the context of PNRR GRINS project, is based on a combination of several materials and methods:

- quantification of the production of the selected crops through the use of statistical data;
- assessment of the agricultural residues, following the methodology of Paiano & Lagioia (2016);
- application of spatial representation, using GIS approach, for the visualization of this assessment at local scale (for the Italian provinces). Furthermore, the GIS tool allowed to provide the geo-referenced maps and data visualization of spatially explicit indicators that support several strategies by monitoring biomass regeneration, water efficiency, land restoration, and urban material stocks. For example, the NDVI (Normalized Difference Vegetation Index), the NDMI (Normalized Difference Moisture Index), and the NDWI (Normalized Difference Water Index).

As regards the first outcome of this derivable, the assessment of agricultural residues provides best practices to be implemented by stakeholders in the context of the Circular Economy.

Agriculture produces a large amount of residual biomass, distributed in a diverse manner and sometimes difficult to harvest. This includes crop residues, pruning waste, and other by-products. These materials can be converted into valuable organic products, animal feed, or a renewable energy source, thus reducing environmental impact and improving resource efficiency. In particular, the opportunity to bioenergy-use residues represents an alternative to the use of fossil fuels, improving environmental performance and reducing Greenhouse gas emissions (Kanianska et al., 2011; Felten et al., 2013; Paiano & Lagioia, 2016).

Consequently, using the residues quantification and the energy potential of residual biomass assessed, their spatial distribution by Italian provinces was presented using a GIS approach, accordingly to Lovrak et al. (2020) and Paiano & Lagioia (2016).

Methodologically, this outcome emphasized the use of GIS tools that have been applied very frequently in agriculture for several years for the mapping of biomass potential, providing valuable information on spatial distribution and thus allowing the optimization of the use of bioenergy production facilities within the framework of the principles of the Circular Economy (Van Meerbeek et al., 2015; Lourinho & Brito, 2015; Haase et al., 2016).

8.1.1 GIS-based spatial framework

In order to support a comprehensive spatial analysis and data visualization for agricultural applications the research group developed a GIS-based spatial framework. The framework enables a complete, step-by-step approach to activities carried out using GIS, including data acquisition, processing, analysis, and visualization of geospatial information.

In the context of IoT (Internet of Things), GIS represents a computer-based system used to capture, store, manage, analyze, and visualize spatial or geographic data. According to Longley et al. (2015), GIS is defined as: "A system for capturing, storing, checking, integrating, manipulating, analyzing, and displaying data which are spatially referenced to the Earth."

Hence, GIS is "the mapping and data analysis technology that's powering business decisions, supporting government operations, and transforming decision-making processes worldwide" (ESRI, 2022). Moreover, GIS links location data with descriptive information, enabling mapping and analysis to understand spatial patterns, relationships, and context. It supports better communication, efficiency, management, and decision-making across science and various industrial fields (ESRI, 2022).

Currently, there are several kinds of GIS software programs available for practitioners, from paid to free software. Some examples are:

1) **Paid Software**: practitioners can use ArcGIS (used for mapping, spatial analysis, and geodatabases), ERDAS IMAGINE (based on remote sensing and raster analysis), MapInfo Professional (prevalent for business mapping and spatial analytics);
2) **Open-Source Software**: such as QGIS (free for analysis and mapping), gvSIG (Geographic data management and analysis platform), GRASS GIS (Advanced spatial modelling, geostatistics, and environmental applications);
3) **Web-Based / Cloud GIS**: the well-known Google Earth (for visualization and exploration of spatial data globally) and ArcGIS Online (Cloud-based GIS for mapping, collaboration, and dashboards).

For the objectives included in DW 1.3.2, the research group used QGIS, a free platform with extensive plugins for analysis and mapping, specifically tailored to the agricultural context considered.

8.1.2 Sustainable exploitation of biomass in agriculture

The sustainable exploitation of biomass in agriculture is extremely essential for several reasons:

- allows the recovery of large quantities of waste that otherwise should be disposed,
- transforms residues into new resources,
- can be used to produce biogas, bioethanol, biodiesel, electricity, and thermal energy,
- promotes the energy transition by reducing dependence on fossil fuels and carbon dioxide emissions,
- reduces the risk of soil and water pollution associated with the uncontrolled decomposition of agricultural waste and residues,
- it can be a source of income for farmers,
- improves soil fertility,
- closes the agricultural production cycle in accordance with the principles of the Circular Economy.

For the reasons above mentioned, this approach represents an important opportunity to implement on a large scale the experimental principles and methodologies proposed by Paiano & Lagioia (2016).

From a regulatory point of view, the European Union developed several key policies to promotes the sustainable use of biomass in agriculture and the relative energy production:

- The Renewable Energy Directive EU 2018/2001,
- The Common Agricultural Policy (CAP),
- The Waste framework Directive 2008/98/EC,
- The Land Use, Land-Use Change and Forestry (LULUCF) Regulation EU 2018/841.

Italy implemented EU directives above mentioned through national laws, such as the Legislative Decree 199/2021, which transposes the Directive EU 2018/2001, defining sustainability requirements for biogas and biomass plants.

For the motivations above mentioned, to effectively quantify and manage the spatial distribution of biomass resources, the integration of GIS becomes essential.

Specifically, the GIS consists in a versatile tool that supports technical approaches to various renewable energy sources, including solar, small hydro, wind, and bioenergy, as well as Life Cycle Assessment methods (Guido et al., 2024).

Particularly, the integration of biomass resource assessment with GIS constitutes a robust analytical framework for the spatial quantification and optimization of bioenergy potential. Effectively, GIS-based methodologies enable the collection, processing, and spatial correlation of heterogeneous datasets, such as land use, crop distribution, forest cover, topography, and transport infrastructure, to estimate the availability and accessibility of biomass feedstocks. These advanced spatial modeling techniques allow the identification of high-potential zones for biomass exploitation. For this reason, it is recommended this geospatial approach use since it enhances the accuracy of resource mapping, supports strategic planning for bioenergy facility siting, and contributes to the implementation of Circular Economy principles through the efficient valorization of residual biomass.

In this research, the research group used the software QGIS 3.34 “Prizren” that is the major version of the free, open-source Geographic Information System QGIS designated as a Long-Term Release (LTR), released at the end of 2023. Prizren comes from the name of the city that hosted the FOSS4G (Free and Open-Source Software for Geospatial) 2023 conference, following the QGIS tradition of naming versions after places associated with the project's community events. LTR means that the release is stable and suitable for long-term use in operational and production environments. This makes it especially appropriate for organizations, educators, and users who prefer a stable platform with extended support for bug fixes over frequent feature changes (QGIS, 2026). The release includes a broad set of enhancements to the core software, such as improvements to existing APIs (Application Programming Interface) and expression functions, enhancements in map rendering and print layout capabilities, and expanded options in both 2D and 3D visualization (QGIS, 2026).

The 3.34 Prizren release, being an LTR, is often preferred in agricultural settings where long-term project stability and fewer disruptive updates are important, especially when models and workflows are shared or documented over time (QGIS, 2026).

Some key features and improvements in QGIS 3.34 Prizren include:

1) expanded rendering and symbolization options: for example, alternate rendering modes for selected features (custom color or symbol) allow more tailored visualization,
2) improved 2D/3D capabilities: enhancements to 3D rendering, memory-limit settings for GPU layers, and warnings when memory thresholds are reached,
3) better print layout and export tools: multiple selection of elements in layouts, “open file after export” checkbox for outputs (PDF, SVG, image) improve map production workflows,

4) stability and performance enhancements: as an LTR release, this version emphasizes long-term maintenance, security updates, and plugin compatibility over bleeding-edge new features (Formation-qgis, 2025).

8.1.3 Materials and Methods

The aim of this deliverable is multiple Figure 83:

a) quantification of agricultural residues related to the selected crops, in the Italian territory, at the local scale based on provinces;
b) quantification of energy potential of residues related to the selected crops, in the Italian territory, observing the local scale based on provinces;
c) mapping, through GIS model, the amounts of the aforementioned residues quantified and the energy potential of residues, for national and local scale of observation.

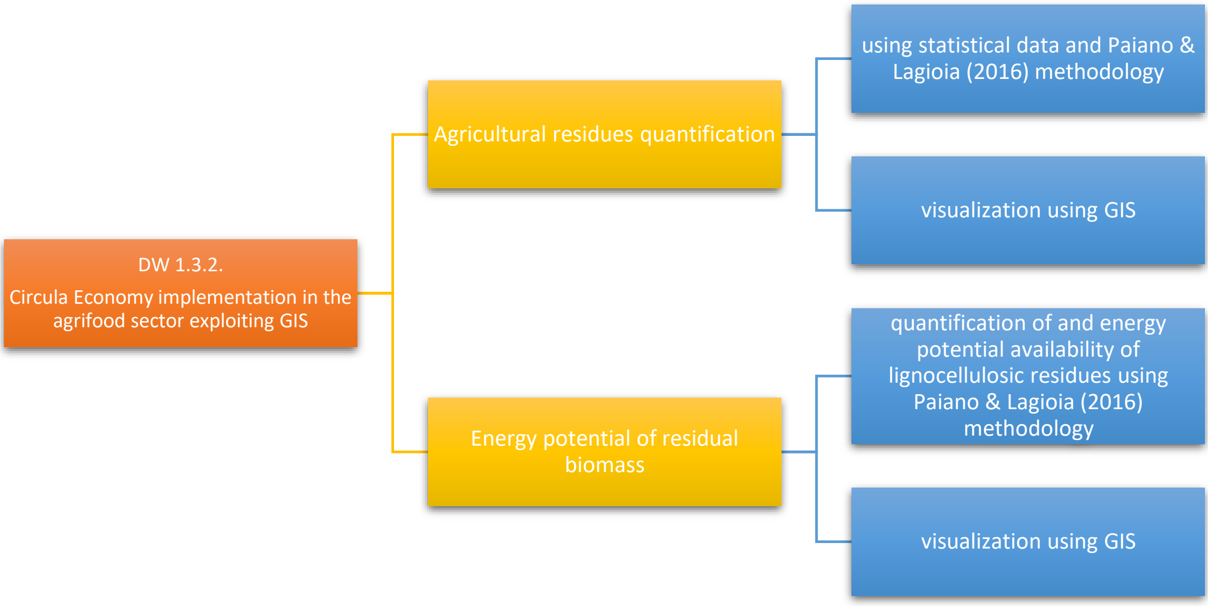


Figure 83 Methodological path

Therefore, the method developed for this deliverable is based on a combination of statistical methods, equations, and spatial approaches.

Considering the first objective, the authors followed the procedure showed in Fig. 1, after having built the dataset on total production, harvested production and production area of the selected crops, through the consultation of the ISTAT 2025 platform, they calculated the arithmetic mean of the values recorded over a 5-year time period, from 2020 to 2024, observing the data at a micro level, based on all Italian provinces.

8.1.4 Agricultural residues quantification

Subsequently, the methodology of Paiano & Lagioia (2016) was applied to quantify agricultural residues by grouping them for each single crop, starting from ISTAT data previously collected and processed. These residues could be classified into three types, the Main Herbaceous/Arboreal Residue (R_1), the Secondary Residue (R_2), and a third type treated like Agro-Industrial Residue (R_3). After the first quantification, it was subtracted the share of residues (AR1, AR2 and AR3) already used in other sectors. Then, the moisture shares (MR1, MR2 and MR3) have been taken away from the total mass of residues to obtain the net value.

The main residues (R_1) are:

- Herbaceous: for grain legumes;
- Arboreal: branch pruning of all the arboreal crops.

The secondary residues (R_2) are wood from the up-rooting of trees (only arboreal crops). Among the agro-industrial residues (R_3) only grape marc are taken into consideration. Particularly, for the 4 selected legumes (fava, pea, lentil, chickpea), only the main residues were calculated (R_1), indeed, for the analysed arboreal crops (peach, apple, grape) were calculated both the Secondary Residues and Third Residues (only for grapes).

The calculation of Main Residues (R_1) follows the formula (Eq.1):

$$R_1 = P\,[tons] * RR_1 * \left(1 - \frac{MR_1}{100}\right) * AR_1 \qquad \text{Eq. 1}$$

Where:

R_1 is the Main Residue [tons];

P is the Production of the Main Output [tons];

RR_1 is the Ratio Residue/Main Output;

MR_1 is the Moisture content of the Main Residue;

AR_1 is the Index Availability Factor [%] of the Main Residue.

The Secondary Residues (R_2), is generated after several years of cultivation and depends by the span life of the crop, the Equation 2 was used:

$$R_2 = PR_2 * \frac{\left(1 - \frac{MR_2}{100}\right)}{SL} * AR_2 * ha \qquad \text{Eq. 2}$$

Where:

R_2 is the Secondary Residue [tons];

PR_2 is the Production of the Secondary Residues along the span life of the crop [tons/ha];

MR_2 is the Moisture content of the Secondary Residue (differ by crops);

SL is the Span Life of the crop (years);

AR_2 is the Index Availability Factor [%] of the Secondary Residue.

The agro-industrial residue is produced per year, and the formula (Eq.3) was used only for the grape crop:

$$R_3 = P\,[tons] * RR_3 * \left(1 - \frac{MR_3}{100}\right) * AR_2 \qquad \text{Eq. 3}$$

Where:

R_3 is the Agro-Industrial Residue [tons];

P is the Production of the Main Output [tons];

RR_3 is the Ratio Residue/Main Output;

MR_3 is the Moisture content of the Agro-Industrial Residue;

AR_3 is the Index Availability Factor [%] of the Main Residue.

The following Table express values used for calculations:

Table 89 Values used for the quantification of different types of residues

Crop	RR_1	MR_1 [%]	AR_1 [%]	PR_2 [tons/ha]	MR_2 [%]	SL [years]	AR_2 [%]	RR_3	MR_3 [%]	AR_3 [%]
Pea	1.5	15%	90%							
Fava	1.5	15%	90%							
Lentil	1.5	15%	90%							
Chickpea	1.5	15%	90%							
Grape	a*	45%	95%	20	30%	25	10%	0.19	50%	75%
Apple	0.1	40%	95%	85	40%	20	10%			
Peach	0.2	40%	95%	75	40%	15	10%			

For grape, the a* formula (in the RR_1 column) was used to quantify the Main Residue due to a specific correlation found between this and the yield:

$$R_1 = (Y * 0.113 + 2.0) * ha$$

Where:

R_1 is the Main Residue of grapes;

Y is the yield expressed in tons/ha;

0.113 is Ratio found between the Main Residues and the Yield;

2.0 is a constant based on Paiano et al. (2012);

ha are the hectares considered.

The equations 1 - 3 were necessary for quantifying the residues (tons) for the legumes and the fruits orchards selected.

Consequently, these data were interpolated with available geospatial data to obtain a graphical representation of the distribution of quantified residual biomass, through the use of a thematic map that allows us to visualize (with shades of color) the Italian provinces with the highest/lowest residue production.

8.1.5 Energy potential of residual biomass

Based on the previous methodology, a model for the energy potential of residues has been developed to propose energy recovery in compliance with the principles of the Circular Economy (DW1.3.2).

After quantification of the residues for each crop selected, at the micro (provincial) level, the researchers carried out an energy assessment, expressed in GJ, able to identify the provinces with the greatest recovery potential (residue/potential). Hence, to do this, the Paiano & Lagioia (2016) methodology was used.

The waste (tons) value, for each province, was multiplied by the corresponding LHV (Lower Heating Value). Particularly, the formulas used to calculate the energy value of the residues (in GJ) vary depending on the type of crop.

For all the selected legumes:

$$Legumes: (R_1 + R_2) \times 16\ GJ/t$$ Eq. 4

Conversely, for the fruit orchards it depends on the type of crop:

$$Peaches: (R_1 + R_2) \times 18\ GJ/t$$ Eq. 5

$$Apples: (R_1 + R_2) \times 18\ GJ/t$$ Eq. 6

$$Grapes: (R_1 + R_2) \times 18\ GJ/t + R_3 * 21\ GJ/t$$ Eq. 7

Where:

GJ/t is the Low Heating Value (LHV) of the corresponding crop residues.

Subsequently, all energy values were aggregated to obtain a provincial (micro-level) total dataset, showing the areas with the highest potential for energy recovery (GJ).

Afterwards, the provincial data of potential energy recovery, related to the analyzed crops, were interpolated to obtain a graphical representation using the GIS software (QGIS), in order to show areas with higher values. Indeed, this study aimed to identify more suitable areas for implementing waste recovery practices able to generate biomass energy, in line with the principles of the CE.

Finally, since CE aims to minimize waste, extend product life cycles, and regenerate natural systems by closing material and energy loops (Geissdoerfer et al., 2017), the use of GIS can support this transition by providing spatial data to analyze, map, and optimize resource flows across territories. Moreover, in the agricultural context, sector selected by the research group, this transition is closely linked to Utilized Agricultural Area (UAA), which represents the land actively used for agricultural production (arable land, permanent crops, and permanent grassland). Particularly, the nexus between UAA, CE, and GIS lies in how agricultural land is spatially managed and monitored to enhance circularity, productivity, and ecosystem regeneration.

8.1.6 Utilized Agricultural Area (UAA)

The term UAA represents a standardized statistical indicator that quantifies the total land area actively used for agricultural production. UAA reflects the area that a farm uses for the production of crops or the support of livestock, excluding land that is not part of the agricultural production process (European Commission, 2024).

Hence, UAA includes:

- arable land (e.g., cropland for cereals, vegetables, fallow land);
- permanent grassland and pasture (land under grass cover used for grazing);
- permanent crops (e.g., orchards, vineyards, olive groves);
- kitchen gardens and small plots used for producing food by household farms (European Commission, 2024).

Moreover, UAA is used as an indicator of agricultural land intensity and land-use change. It allows monitoring of agricultural land use and land-use change, assessment of farm structure and production capacity, comparison of agricultural landscapes across regions or countries, and support for agri-environmental policy evaluation (FAO, 2016; European Commission, 2024).

8.1.7 Remote Sensing Indices

In the context of CE, remote sensing plays a pivotal role since they provide quantitative, spatially explicit indicators that support several strategies by monitoring biomass regeneration, water efficiency, land restoration, and urban material stocks. For example, the NDVI is useful to estimate biomass production and crop productivity, supports biomass valorization (bioenergy, composting), monitors ecosystem regeneration and evaluates land-use efficiency (Rouse et al., 1974; Pettorelli et al., 2005). Moreover, NDMI supports CE by acting as a spatial moisture efficiency indicator, and NDWI contributes by acting as a spatial water monitoring indicator, supporting circular water management systems.

8.1.7.1 NDVI - Normalized Difference Vegetation Index

NDVI is a common remote sensing index used for quantifying vegetation greenness and vigor by comparing the reflectance of near-infrared (NIR) and red light from vegetation canopies (Rouse et al., 1974). NDVI is calculated as (Eq. 8):

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \qquad \text{Eq. 8}$$

Where:

NIR: Near-infrared reflectance (strongly reflected by healthy vegetation);

Red: Red light reflectance (strongly absorbed by chlorophyll).

NDVI covers a range of values from -1 to +1, where higher values indicate dense, healthy vegetation, and lower or negative values correspond to bare soil, water, or built-up areas. Specifically:

- NDVI values between 0.2-0.5 indicate sparse vegetation;
- NDVI values between 0.5-0.8 indicate dense and healthy vegetation;
- NDVI values < 0 may indicate the presence of water, snow, or clouds.

NDVI values can be detected from satellite imagery (e.g., Landsat, Sentinel-2, MODIS) and enable seasonal monitoring of crop growth, drought stress, and land cover changes (Pettorelli et al., 2005).

8.1.7.2 NDMI - Normalized Difference Moisture Index

NDMI is a remote sensing index used to estimate vegetation water content or moisture status. Particularly, NDMI uses the reflectance difference between near-infrared (NIR) and shortwave-infrared (SWIR) bands (Eq. 9):

$$NDMI = \frac{(NIR - SWIR)}{(NIR + SWIR)} \qquad \text{Eq. 9}$$

Where:

NIR: Near-infrared reflectance (strongly reflected by healthy vegetation);

SWIR: Shortwave-infrared reflectance (sensitive to leaf water content).

NDMI covers a range of values from -1 to +1, where higher values indicate high vegetation water content or wet conditions, and lower values indicate dry vegetation or water stress (Wilson & Sader, 2002). Specifically:

- NDMI values between 0.3-0.6 indicate well-hydrated vegetation;
- NDMI values < 0.2 indicate dry or stressed vegetation;
- NDMI values < 0.0 may indicate bare soil, water, or clouds (Key & Benson, 2006).

8.1.7.3 NDWI - Normalized Difference Water Index

NDWI represents a remote sensing index used for observing vegetation water content and surface water presence. NDWI exploits the difference in reflectance between near-infrared (NIR) and shortwave-infrared (SWIR) bands (Eq. 10):

$$NDWI = \frac{(GREEN-NIR)}{(GREEN+NIR)} \quad \text{Eq. 10}$$

Where:

Green: Green light reflectance (as water reflects it, absorbing the infrared energy used in the other half of the formula);

NIR: Near-infrared reflectance, which is strongly reflected by vegetation.

NDWI covers a range of values from -1 to +1, with higher values indicating higher water content in vegetation or the presence of open water, while lower values indicate dry vegetation or soil (McFeeters, 1996). Specifically:

- NDWI values between 0.3-0.5 indicate high vegetation water content or surface water;
- NDWI values ≈0 indicate moderate moisture levels;
- NDWI values < 0 indicate dry vegetation or bare soil (Xu, 2006).

8.1.8 Results

8.1.8.1 Agricultural residue's data and energy valorization

In this sub-section the research group presented some results concerning one of the eight selected and previously mentioned crops (the apple supply chain). It should be noted that the complete results for all selected crops have been uploaded to the AMELIA platform.

Particularly, Table 90 shows the Low Heating Value (GJ) and the corresponding quantity of apple agricultural residues (tons) for each Italian province. The data covered a wide range of territorial contexts, allowing a comparative analysis of energy valorization potential across the Italian regions. In this Table, some provinces, such as Bolzano and Trento, displayed notably higher values of Low Heating Value (LHV), due to higher agricultural residues, compared to others, sections like Pisa and Livorno exhibited much lower quantities.

This distribution enables identification of priority areas for CE implementations.

Table 90 Example of LHW and residue's data for apples (tons and GJ)

PROVINCE	Total Residues (t)	Low Heating Value (GJ)
Agrigento	109.87	1 977.66
Alessandria	168.48	3 032.58
Ancona	30.76	553.61
Aosta	374.21	6 735.69
Arezzo	725.91	13 066.37
Ascoli Piceno	96.25	1 732.55
Asti	103.14	1 856.46
Avellino	60.86	1 095.44
Bari	80.93	1 456.74
Barletta-Andria-Trani	6.74	121.24
Belluno	174.28	3 137.07
Benevento	514.10	9 253.71
Bergamo	36.04	648.63
Biella	38.81	698.61
Bologna	1 421.35	25 584.25
Bolzano	59 262.21	1 066 719.81
Brescia	124.58	2 242.45
Brindisi	27.23	490.10
Cagliari	0.79	14.27
Caltanissetta	1.88	33.75
Campobasso	199.98	3 599.64
Caserta	3 474.87	62 547.64
Catania	698.12	12 566.17
Catanzaro	215.93	3 886.65
Chieti	208.79	3 758.24
Como	25.05	450.92
Cosenza	260.39	4 687.08
Cremona	20.47	368.42
Crotone	16.96	305.23
Cuneo	9 277.36	166 992.40
Fermo	55.46	998.30
Ferrara	5 440.60	97 930.77
Firenze	76.50	1 377.06
Foggia	117.56	2 116.04

PROVINCE	Total Residues (t)	Low Heating Value (GJ)
Forli'-Cesena	791.85	14 253.33
Frosinone	27.92	502.63
Gorizia	38.51	693.16
Grosseto	114.20	2 055.51
Imperia	5.92	106.60
Isernia	51.86	933.50
La Spezia	6.66	119.88
L'Aquila	284.78	5 125.95
Latina	92.58	1 666.50
Lecce	16.71	300.73
Lecco	9.95	179.18
Livorno	12.26	220.69
Lodi	1.37	24.69
Lucca	36.68	660.27
Macerata	71.10	1 279.71
Mantova	371.06	6 679.14
Massa Carrara	17.47	314.41
Matera	11.34	204.06
Messina	223.26	4 018.68
Milano	8.23	148.19
Modena	595.42	10 717.52
Monza e della Brianza	8.76	157.72
Napoli	407.37	7 332.57
Novara	18.84	339.04
Nuoro	93.66	1 685.90
Oristano	88.62	1 595.12
Padova	1 164.75	20 965.45
Palermo	60.43	1 087.79
Parma	25.74	463.29
Pavia	194.76	3 505.65
Perugia	247.88	4 461.75
Pesaro e Urbino	19.82	356.73
Pescara	236.55	4 257.93
Pescara	236.55	4 257.93

PROVINCE	Total Residues (t)	Low Heating Value (GJ)
Piacenza	41.90	754.11
Pisa	47.45	854.12
Pistoia	5.15	92.72
Pordenone	1 854.04	33 372.67
Potenza	572.88	10 311.91
Prato	0.66	11.8746
Ravenna	2 751.67	49530.0096
Reggio di Calabria	161.82	2912.76
Reggio nell'Emilia	119.37	2148.6924
Rieti	63.39	1140.966
Rimini	19.59	352.674
Roma	129.89	2337.9354
Rovigo	1 237.17	22269.0276
Salerno	337.46	6074.19
Sassari	35.77	643.86036
Savona	14.18	255.2742
Siena	70.61	1270.9332
Sondrio	2 306.46	41516.2692
Sud Sardegna	79.98	1439.64108
Taranto	111.72	2011.014
Teramo	142.23	2560.2048
Terni	6.49	116.8344
Torino	989.94	17818.86276
Trento	31 210.70	561792.5316
Treviso	353.14	6356.47392
Udine	1 984.72	35725.00572
Varese	10.22	183.8754
Venezia	1 044.58	18802.4814
Verbano-Cusio-Ossola	17.32	311.6718
Vercelli	68.24	1228.40928
Verona	12 459.97	224279.5014
Vibo Valentia	20.10	361.746
Vicenza	184.24	3316.2858
Viterbo	140.049	2520.882

Therefore, findings provide a detailed quantitative basis for further analysis described in the next section.

8.1.8.2 Visualization of residue's data via GIS

In order to further analyses the results regarding LHV and agricultural residues distribution, the following sub-section presents the spatial visualization of the data related of one the eight selected crops, the apple residues, using GIS.

By mapping the results at the provincial level (Figure 84), it becomes possible to identify geographic trends, regional clusters, and priority areas that may not be immediately evident from the tabular data alone.

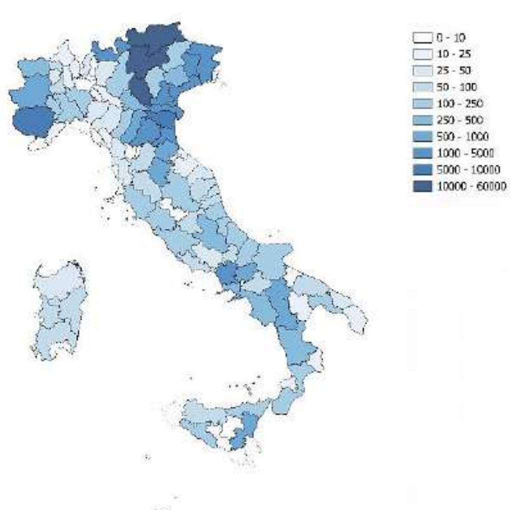


Figure 84 Map of residue's apples (tons)

This geospatial approach not only facilitates a more intuitive understanding of the dataset, but also supports more informed planning and decision-making for resource valorization.

8.1.8.3 Assessment of energy potential from agricultural residues

Agricultural residues, often considered a waste of primary production, represent a substantial source of renewable energy and raw materials for CE strategies. Generally, LHV (GJ) of crop residues provides a quantitative measure of their potential for bioenergy generation and additional valorization routes, aligning with European sustainability objectives.

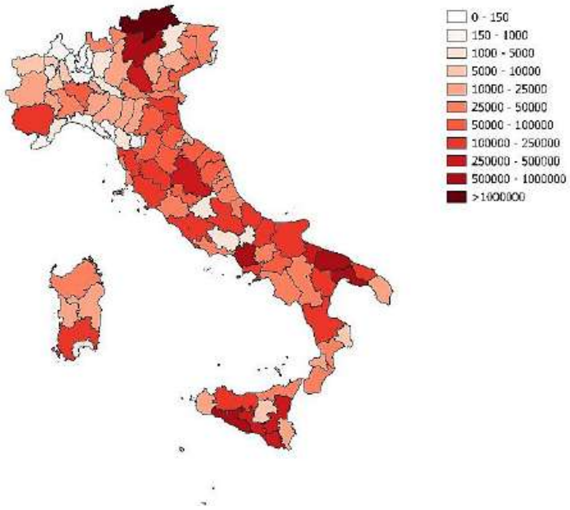


Figure 85 GIS distribution of LHV's data of the analysed crops (GJ)

Moreover, through GIS-based mapping of the LHV data (GJ) for the eight selected crops, the research group conducted a spatial analysis of their energy potential. Hence, Figure 85 provides crucial insight into geographic disparities, allowing stakeholders to clearly target provinces with the greatest opportunities for resource valorization, development of bioenergy infrastructures, and implementation of CE strategies. The spatial perspective complements the previously reported tabular data, facilitating integrated planning and policy design. Therefore, the valorization of agricultural residues represents a fundamental component in the transition to a Circular bioeconomy. Crop by-products such as straw, chaff, stalks, and other lignocellulosic residues, once considered waste to be disposed of, are now considered valid raw materials for the production of bioenergy, bioproducts, animal feeds, etc.

Furthermore, the strategic reuse of agricultural residues for energy and material production contributes to the implementation of CE practices by promoting sustainable land use, improving rural economic resilience, and supporting decarbonization goals (European Commission, 2020).

Finally, this application, in line with Motola et al. (2009) and applying Paiano & Lagioia (2016) emphasized how these kinds of assessments can represent a significant step in planning the reuse of agricultural residues. It is also essential to understand biomass potential at multiple levels of observation, from national to local/provincial, to better plan circular reuse policies and practices.

8.1.8.4 Spatial Analysis of Utilized Agricultural Area (UAA)

The research group conducted a comprehensive spatial analysis of UAA for eight economically significant crops across the Italian territory. As above mentioned, the analysis focused on nectarines, peaches, apples, table grapes, peas, chickpeas, lentils, and fava beans.

UAA data for the year 2023 were extrapolated from ISTAT (Italian National Institute of Statistics) database through ISTAT data portal, specifically from the "Crops: Areas and production - overall data - provinces" dataset (ISTAT, 2024). This dataset provides comprehensive agricultural statistics at the provincial level (NUTS-3 - Nomenclature of territorial units for statistics as administrative units), enabling detailed assessment of crop distribution patterns across the entire Italian territory. Provincial-level data were downloaded in tabular format and imported into QGIS 3.34 "Prizren" for spatial integration.

The spatial framework integrated vector layers representing provincial administrative boundaries with the agricultural census data through attribute joints based on provincial codes. Thematic choropleth maps were generated for each of the eight crops, illustrating the spatial distribution and concentration of cultivated area per hectare. An example related to peaches is displayed in Figure 86.

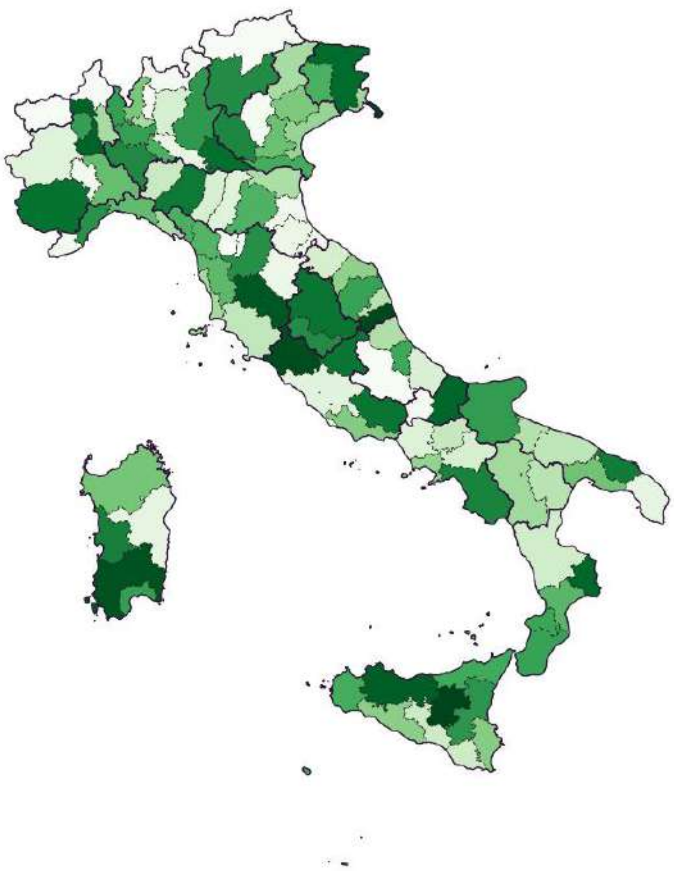


Figure 86 UUA of peaches production at provincial level (ISTAT, 2024)

This approach allowed for the identification of key production areas and regional specialization patterns, which are essential for understanding agricultural land use dynamics and supporting targeted policy interventions (Cillis et al., 2020).

Provincial-level UAA mapping provides critical information for agricultural planning, resource allocation, and sustainability assessments, as it captures the heterogeneity of agricultural systems across different agro-climatic zones (Vizzari et al., 2018).

8.1.8.5 Meteorological Analysis for Apulia Region

A focused meteorological analysis was performed for the Apulia region, covering the years 2021, 2022, and 2023. Three key climatic variables were examined: precipitation (pluviometric data), moisture, and temperature. These parameters are fundamental for understanding crop performance, water availability, and climate-related stress factors in Mediterranean agricultural systems (Bindi & Olesen, 2011).

Precipitation data were acquired from regional meteorological stations and processed to generate annual and periodic rainfall maps in QGIS. The analysis revealed inter-annual variability in rainfall distribution, with significant implications for rainfed agricultural systems prevalent in the region (Figure 87).

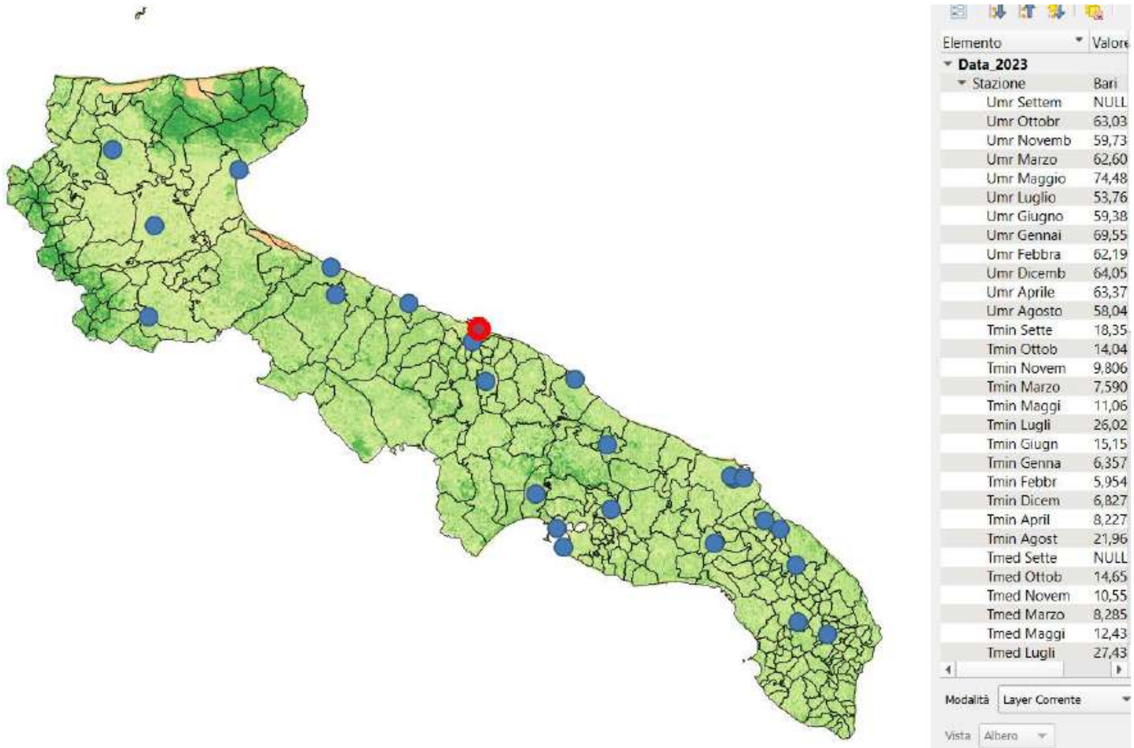


Figure 87 Pluviometric data in the Apulian region (2023)

Moisture data were derived from pluviometric stations around the region.

Concerning the volumetric soil water, content could be extracted and analyzed to assess water availability during critical crop development stages.

Temperature data were obtained from the same stations, including mean, minimum, and maximum temperature values aggregated at monthly and seasonal scales. Thermal stress indicators, such as growing degree days (GDD) and heat stress events (days with maximum temperature > 35°C), could be calculated to evaluate the impact of thermal conditions on crop phenology and yield potential (Porter & Gawith, 1999).

8.1.8.6 Remote Sensing Indices Analysis

A comprehensive remote sensing analysis was performed across the entire Italian territory using Sentinel-2 satellite imagery. As above mentioned, the analysis focused on three key vegetation and water indices: NDVI, NDMI and NDWI. These indices provide quantitative information about vegetation health, water content, and surface water presence, respectively (Mandanici & Bitelli, 2016).

8.1.8.7 Data Acquisition and Preprocessing

Sentinel-2 imagery was acquired and processed using Google Earth Engine (GEE), a cloud-based platform for planetary-scale geospatial analysis (Gorelick et al., 2017). The analysis focused on the year 2023 to ensure temporal consistency with UAA data from ISTAT. Sentinel-2 carries the MultiSpectral Instrument (MSI), which captures imagery in 13 spectral bands ranging from visible to shortwave infrared wavelengths at spatial resolutions of 10 m, 20 m, and 60 m. For this analysis, the following bands were utilized (ESA, 2015):

- **Band 3 (Green)**: 560 nm, with 10 m resolution – used for NDWI calculation;
- **Band 4 (Red)**: 665 nm, 10 m resolution - used for NDVI calculation;
- **Band 8 (Near-Infrared, NIR)**: 842 nm, 10 m resolution - used for NDVI, NDMI, and NDWI calculation;
- **Band 11 (Shortwave Infrared, SWIR-1)**: 1610 nm, 20 m resolution - used for NDMI calculation.

All Sentinel-2 imagery was processed using GEE's cloud-optimized data catalog, specifically the COPERNICUS/S2_SR_HARMONIZED collection, which provides atmospherically corrected surface reflectance (Level-2A) products. Cloud and cloud-shadow masking was implemented in GEE using the *s2cloudless algorithm*, a machine learning-based cloud probability detection method that achieves machine-learning cloud probability method used for masking (Sentinel Hub, 2020). The *s2cloudless algorithm* generates a cloud probability layer for each Sentinel-2 scene, and pixels with cloud probability exceeding 50% were masked out prior to compositing.

To generate annual cloud-free composites for 2023, all available Sentinel-2 scenes covering the Italian territory were filtered, masked, and aggregated using median compositing in GEE. Median compositing is robust to outliers and effectively it removes residual cloud contamination while preserving spectral characteristics of surface features (Griffiths et al., 2013). The resulting cloud-free mosaics were exported from GEE at 20 m spatial resolution to ensure consistency across all spectral bands and facilitate integration with provincial boundary data in QGIS.

8.1.8.7.1 Index Calculation and Spatial Processing

The three remote sensing indices (NDVI, NDMI, NDWI) were calculated in GEE using the normalized difference formulas previously described (Equations 8, 9, and 10). GEE's parallelized computing infrastructure enabled efficient processing of the entire Italian territory at 20 m resolution for the whole year 2023 (Gorelick et al., 2017).

For NDVI calculation, Band 4 (Red) and Band 8 (NIR) were extracted from the cloud-masked Sentinel-2 composite and processed according to Equation 8. The resulting NDVI raster provided a synoptic view of vegetation health and density across Italy for the 2023 growing season (Figure 88).

Figure 88 NDVI of the Italian territory (2023)

For NDMI and NDWI calculations, Band 3 (Green), Band 8 (NIR) and Band 11 (SWIR-1) were used following Equations 9 and 10. Since Band 11 has a native resolution of 20 m while Band 8 has basic 10 m resolution, all bands were harmonized to 20 m spatial resolution during export from GEE to ensure spatial consistency and facilitate raster algebra operations. The 20 m resolution represents an optimal balance between spatial detail and computational efficiency for regional-scale agricultural monitoring (Castaldi et al., 2021).

The calculated indices were exported from GEE as TIFF rasters in the EPSG:32632 (WGS 84 / UTM zone 32N) coordinate reference system, which is appropriate for Italy and minimizes geometric distortion (Snyder, 1987). The TIFF format ensures compatibility with QGIS and preserves full radiometric precision as 32-bit floating-point values ranging from -1 to +1.

Following export from GEE, the index rasters were imported into QGIS 3.34 "Prizren" for final cartographic processing, including clipping to the Italian national boundaries, application of standardized color ramps for visualization, generation, and creation of publication-quality map layouts. The QGIS Raster Calculator was used to apply classification thresholds and generate categorical maps identifying vegetation health classes, moisture stress zones, and surface water areas according to the criteria defined in the methodology section (Figure 89).

Figure 89 NDMI of the Italian territory (2023)

8.1.8.7.2 Spatial Analysis

The integrated analysis of UAA distribution, meteorological variables, and remote sensing indices provides a comprehensive spatial framework for monitoring agricultural systems, assessing climate impacts, and supporting precision agriculture applications across diverse production contexts in Italy.

8.1.9 Conclusions and practical implications

In agricultural systems, crop residues and other biomass streams represent a significant renewable feedstock for bioenergy and bio-based materials, which can be effectively valorized within a CE framework.

It is important to underline that the sustainable reuse of agricultural biomass within CE context, which must be adequately regulated and supported, including with economic incentives, suggests a multifaceted approach to resource efficiency, environmental protection, and economic development.

By employing GIS tools, spatial datasets from land-use, crop distribution, topography, biomass yields, and transport infrastructure can be integrated to map and quantify available biomass resources with high spatial precision.

This spatial-explicit assessment supports the identification of optimal sites for biomass conversion facilities, the estimation of logistics and supply-chain costs, and the evaluation of environmental trade-offs.

Furthermore, the coupling of agriculture, biomass valorization and GIS-based mapping contributes to closing nutrient and energy loops on the farm, enhancing resource efficiency, and enabling scalable deployment of circular bio-economy strategies.

Therefore, the DW 1.3.2, keeping in mind the challenges and concerns highlighted above, emphasized the development of new supply chains from residual solid biomass as an approach to implementing the CE in the short term.

However, while the use of biomass offers numerous advantages, it also presents limitations and environmental, regulatory, and technical challenges that must be considered. However, it should be underlined that one of the main limitations to the use of residual biomass is the supply of this raw material, which is not concentrated in limited areas but is widely distributed with a high rate of territorial dispersion. Therefore, its collection and transportation can be difficult. As Paiano & Lagioia (2016) highlighted, this limitation affects logistical aspects, which significantly increases biomass costs.

Ultimately, it has been stressed that the environmental and economic sustainability of biomass must significantly be considered in the transition towards circularity models, to address climate change and energy supply from alternative sources.

8.2 Olive oil

8.2.1 Circular Economy Indicators for the Valorization of By-Products in the Olive Oil Supply Chain: Evidence from a Systematic Review

8.2.1.1 Why circularity metrics matter in the olive oil sector

The olive oil supply chain generates substantial by-products (e.g., olive pomace, pruning residues, pits/biomass, and olive mill wastewaters). These streams create environmental and management challenges, yet they also represent opportunities to implement circular economy (CE) models that recover value, reduce impacts, and support bioeconomy pathways. This study argues that "what gets measured gets managed": without clear indicators and monitoring tools, progress towards circularity remains fragmented and difficult to scale, especially for SMEs that dominate the Mediterranean olive oil landscape.

8.2.1.2 Objectives and research questions

The systematic review aims to map and critically analyse indicators and assessment tools used to measure circular economy performance in the context of olive-oil by-product valorization. Four research questions guide the work: (RQ1) which tools/indicators are used to assess circularity; (RQ2) what sustainable practices are emerging for by-product valorization; (RQ3) which challenges limit the implementation of CE indicators; and (RQ4) how indicators can support eco-design decisions.

8.2.1.3 Methods: PRISMA systematic review and bibliometric mapping

The authors follow PRISMA 2020 guidelines and search Scopus and Web of Science using a CE-indicator query targeted to olive oil by-products (e.g., wastewater, olive pomace/cake, leaves, wood/biomass). Data collection was completed in June 2024. Filters retained peer-reviewed English open-access articles from 2015–2024, focusing on relevant disciplinary areas. Records were screened via Rayyan to remove duplicates and support eligibility decisions.Bibliometric mapping is performed with CiteSpace 6.4 R1. Co-citation and co-occurrence analyses identify the most relevant keywords, authors and references. Network quality is reported using modularity (Q) and silhouette (S) metrics.

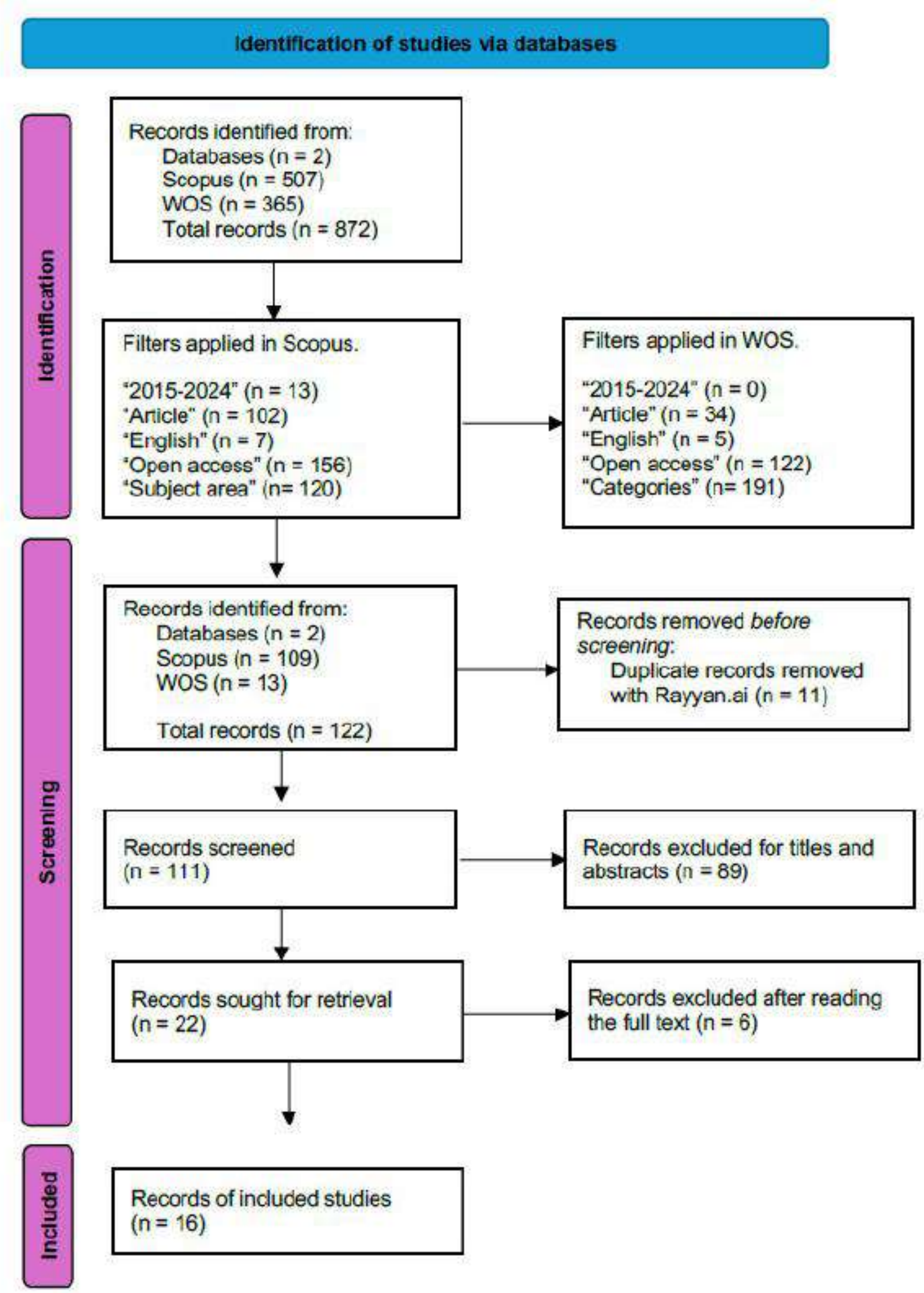


Figure 90 PRISMA flowchart summarising identification, screening, and inclusion (from the source article).

8.2.1.4 Evidence base and bibliometric structure

From an initial 872 records (507 Scopus; 365 Web of Science), the final sample includes 16 studies. After filtering, 122 records remained (109 Scopus; 13 WOS); 11 duplicates were removed, 89 records were excluded at title/abstract screening, and 6 were excluded after full-text assessment.The CiteSpace keyword co-citation network contains 120 nodes and 323 links; the largest connected component includes 75 nodes (62%), indicating a strong core thematic group. The network exhibits high modularity (Q = 0.7894) and a very high weighted mean silhouette (S = 0.958), suggesting well-defined and internally coherent research clusters.

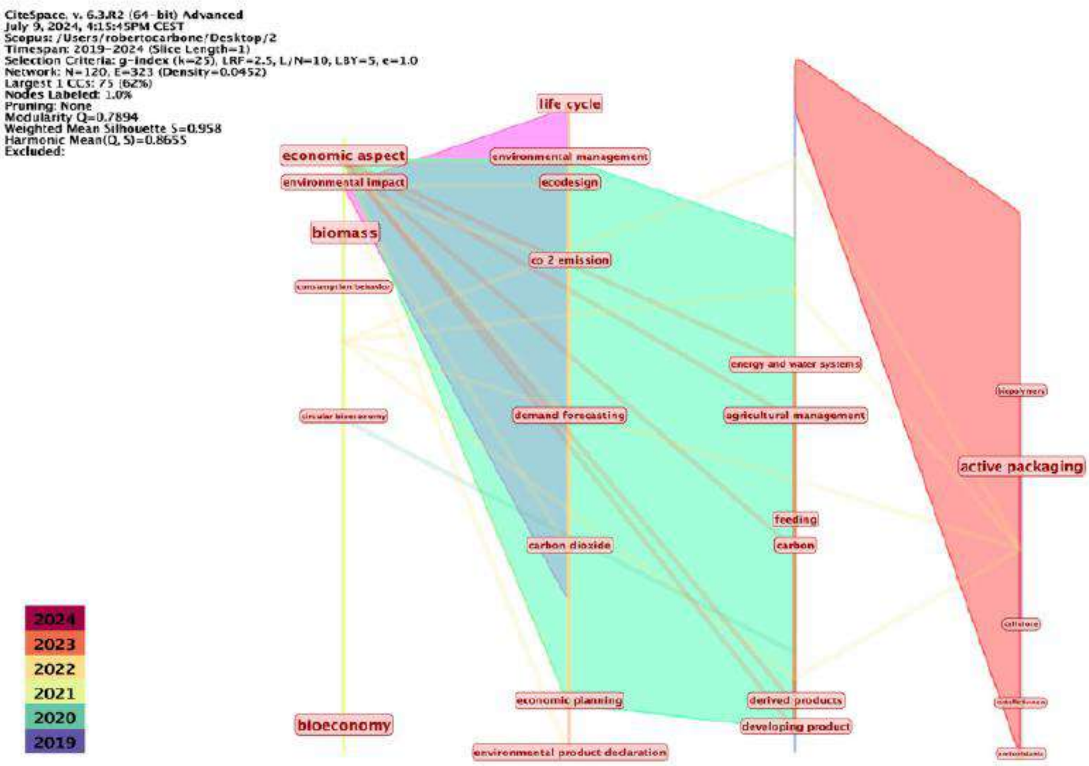


Figure 91 Keyword co-citation network (CiteSpace) highlighting thematic clusters and emerging topics (from the source article)

8.2.1.5 Main thematic clusters and geographical distribution

The bibliometric synthesis groups the literature into five broad clusters: (i) circular bioeconomy in the olive oil industry, (ii) sustainable management of agricultural resources, (iii) sustainable management of by-products, (iv) smart/active packaging derived from olive by-products, and (v) indicators used in the olive oil industry. Across clusters, recurring themes include CO_2 emissions reduction, water management, demand forecasting, and environmental accounting approaches.In terms of country contributions, Italy leads with 5 articles, followed by Spain and Greece (3 each), with Germany, the Netherlands, Hungary, France, and Portugal contributing 1 article each.

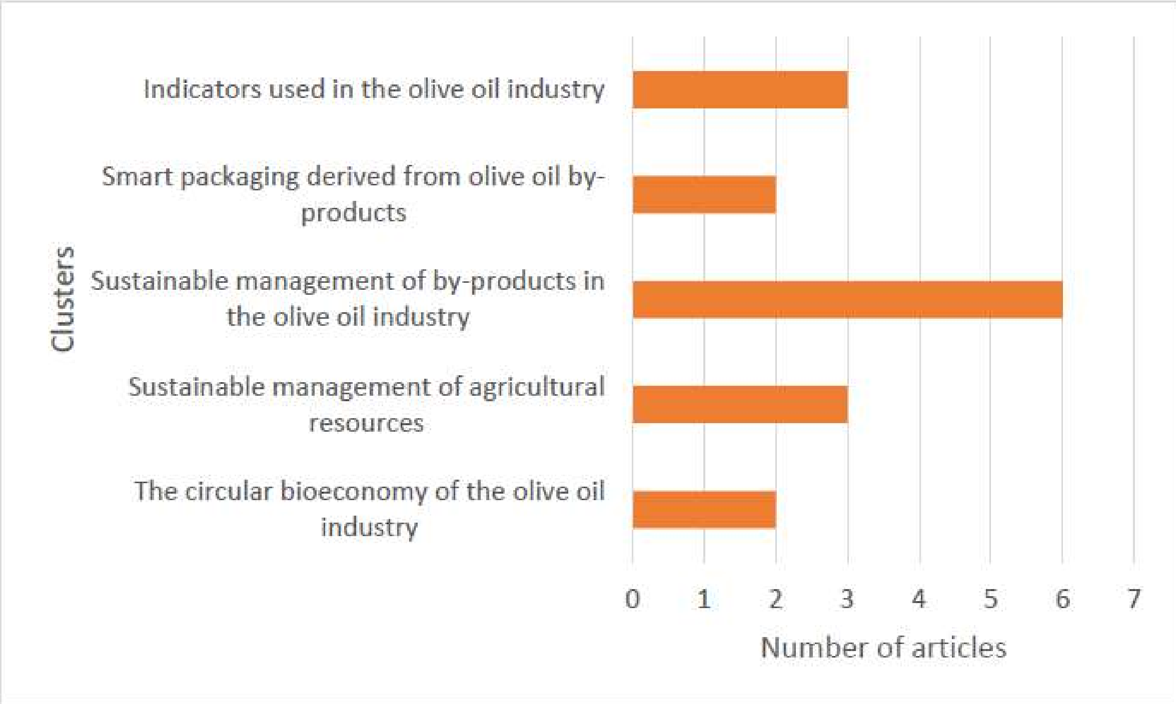


Figure 92 Distribution of included studies across the five thematic clusters (from the source article).

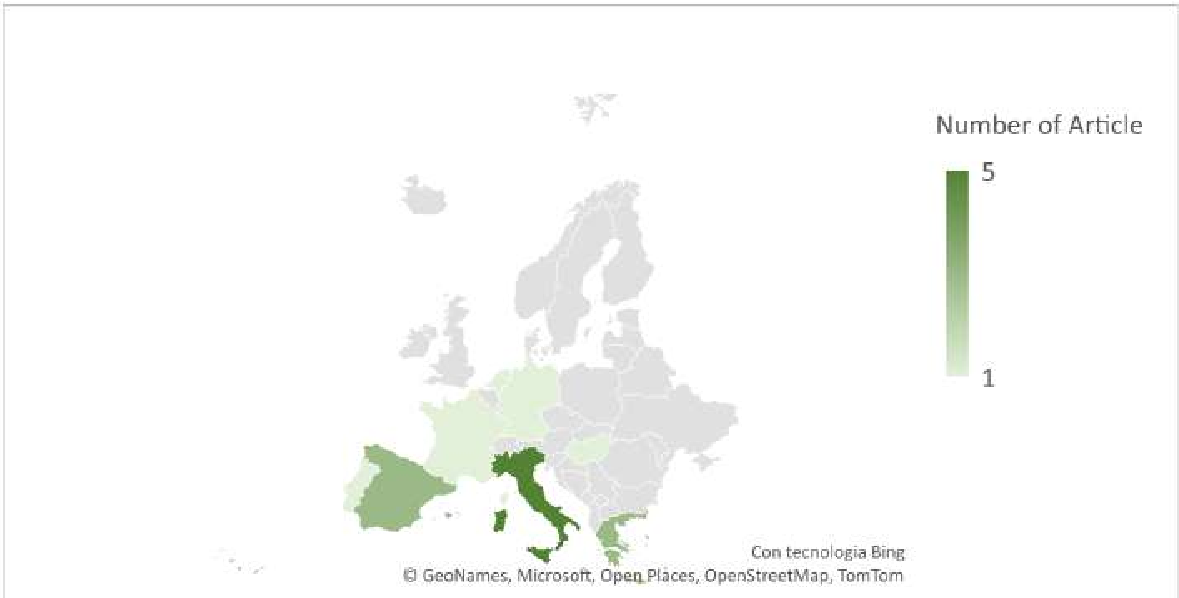


Figure 93 Countries contributing to the included literature (from the source article).

8.2.1.6 Key indicators and assessment tools identified

A central outcome of the review is the prominence of the Material Circularity Indicator (MCI), highlighted as a key CE metric for the sector. MCI aims to quantify how much a product reduces linear material flows and increases restorative flows, while also considering duration/intensity of use through a Utility Flow Index. The review also emphasises complementary environmental methodologies, notably Life Cycle Assessment (LCA), Environmental Product Declarations (EPDs), and Water Footprint (WF) approaches.The review stresses that MCI alone is not sufficient to represent overall circularity. Limitations include methodological complexity, difficulty in estimating indices (e.g., Linear Flow Index and Utility Flow Index) due to variable reuse/recovery rates, and the fact that MCI is mainly designed for technical cycles and non-renewable resources, which can underrepresent biological cycles central to agri-food systems.

8.2.1.7 Examples of by-product valorization pathways and sustainability practices

Across the included studies, several valorization routes recur: (i) converting olive pomace into biofuels or biogas (including co-digestion scenarios), (ii) extracting or using by-products (e.g., skins, pits, stones) as inputs for biopolymers and active packaging with antioxidant properties, (iii) producing biochar from olive pits as a soil amendment supporting carbon sequestration, and (iv) transforming vegetation water/wastewaters into fertilizers or reusing treated wastewater, provided careful monitoring of pollutants and salinity.Water Footprint assessment is presented as particularly relevant in Mediterranean contexts. The reviewed paper summarises that WF distinguishes blue, green, and grey components. It reports evidence from the literature on grey WF for olive oil mills with values of 8.69 and 45.5 litres of water per litre of olive oil in two cases, with nitrates identified as a primary wastewater pollutant and a corresponding export of virtual grey water reported as 161,955 m^3.

8.2.1.8 Barriers, research gaps, and implications for policy and eco-design

The review identifies three recurring implementation bottlenecks: (1) lack of standardized metrics and comparability across studies; (2) limited data availability and data-collection capacity, especially among SMEs; and (3) the cost and complexity of comprehensive tools such as LCA, which can hinder adoption.Despite these barriers, the paper argues that robust CE indicators can support eco-design by revealing where material inputs can be reduced, where wastes can be redirected into new cycles, and where environmental hotspots occur along the supply chain. Policy levers suggested include training and awareness for SMEs, technical support for data management, and financial incentives to reduce adoption costs for LCA/EPD-type assessments.

8.2.2 Clustering Olive Oil Mills Through a Spatial and Economic GIS-Based Approach (Sicily, Italy)

8.2.2.1 Background and aims

Sicily is among Italy's main olive-growing regions and hosts a large number of olive oil mills, most of which are small or medium enterprises. In such contexts, economic performance and long-term sustainability depend strongly on local availability of olives, logistics, and territorial structure. This study develops an integrated spatial–economic GIS workflow to (i) map and analyse the distribution of 603 active mills in Sicily, (ii) quantify their relationship with olive groves through road-network-based service areas, and (iii) compare profitability indicators across statistically defined spatial clusters (hot spots vs cold spots).

8.2.2.2 Data and study area

The study area is the Sicily region (25,420 km²). A georeferenced database of 603 active mills was assembled by integrating multiple official sources with web searches and targeted verification. Olive groves were extracted from the official land-use/land-cover map (Corine-based, 1:10,000), while elevation was derived from a 10-m DEM. Production and processing indicators were also considered at the provincial level to contextualise the spatial patterns.

8.2.2.3 Spatial methodology: service areas and spatial association

A central methodological contribution is replacing Euclidean distance assumptions with a road-network service-area approach. For each mill, the service area is computed on the actual road network using OpenRouteService/OpenStreetMap routing within QGIS. The analysis uses a maximum road distance of 15 km, which corresponds to an acceptable truck reach of ~45 minutes assuming an average speed of ~20 km h^{-1}. The olive grove surface falling within each service area is then calculated.Spatial clustering is assessed through Local Indicators of Spatial Association (LISA). Global Moran's I is applied to mill points using elevation as the attribute, and Getis-Ord Gi* is applied to service-area polygons using olive grove surface as the attribute. Incremental Spatial Autocorrelation (ISA) is used to select statistically meaningful distance thresholds rather than arbitrary ones.

8.2.2.4 Main spatial results

Kernel Density Estimation (KDE) shows the highest mill densities in Trapani, Agrigento and Ragusa, with peaks of about 0.1 mills per km². ISA identifies the strongest clustering scale for Moran's I at 36,000 m. Using this threshold, mills show significant clustering by elevation (Moran's I = 0.322; z-score = 47.306; $p < 0.01$). For Gi*, ISA identifies a peak at 18,000 m (z-score = 45.992; $p < 0.01$), which is used to map hot-spot and cold-spot service areas. Three main hot-spot zones are highlighted: (i) between Trapani and Agrigento, (ii) in Messina province, and (iii) in Ragusa extending partly into Catania.

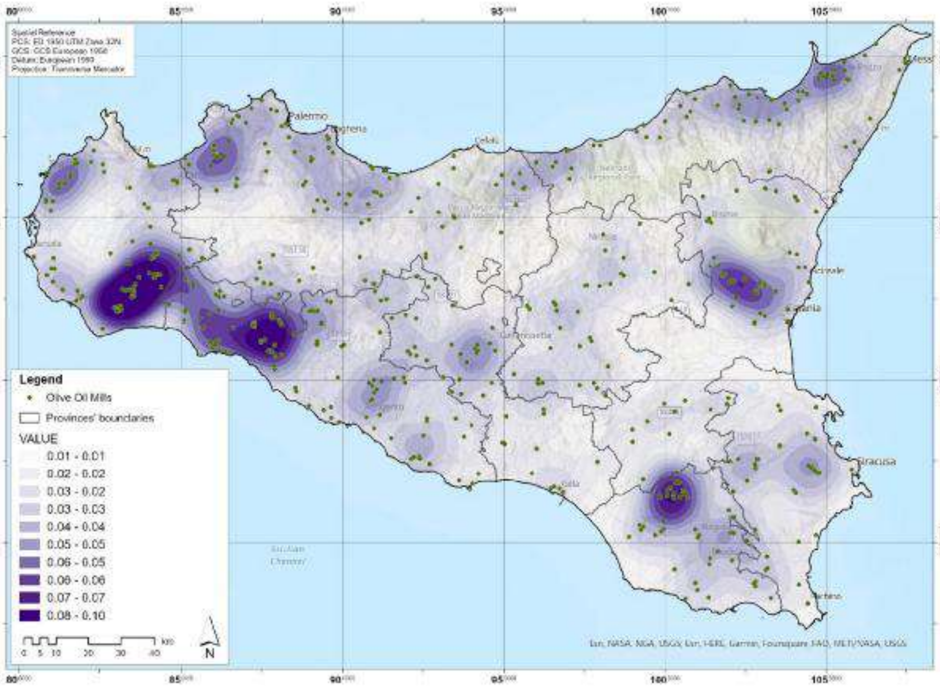


Fig. 5. Kernel Density Estimation (KDE) of the surveyed olive oil mills expressed as number per square kilometer. In light grey are the boundaries of the nine Sicilian provinces.

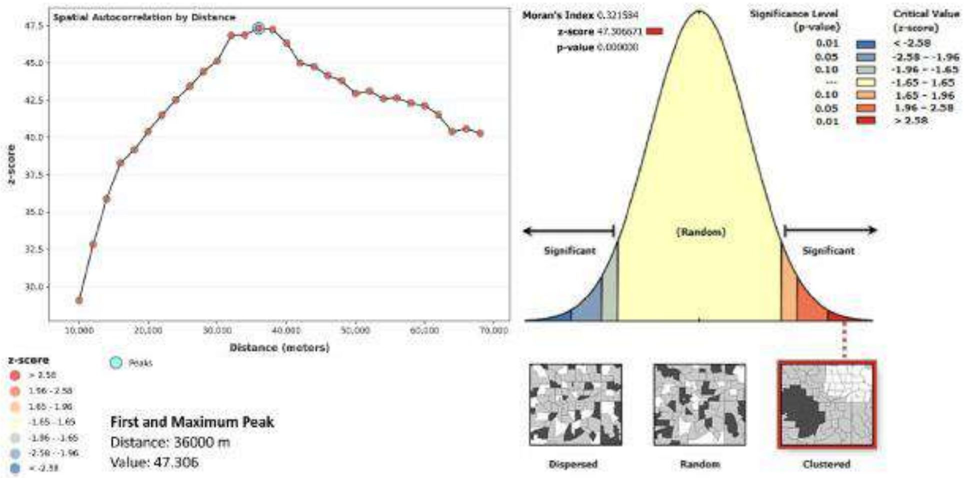


Fig. 6. On the left, the graph representing the incremental spatial autocorrelation (ISA) based on Moran's *I* index applied to the olive oil mills using their elevation as attribute value, applying 30 incremental distance bands with a Euclidean bandwidth of 2000 m from a beginning distance of 10,000 m. Values are represented as z_{score}. On the right, a graph depicting the normal distribution highlighting the significant statistical intervals of p-values and z-scores (corresponding to the three confidence level classes of 99%, 95%, and 90%) and reporting the obtained global Moran's I index and z-score (with a p-value <0.01).

Figure 94 KDE and ISA outputs used to detect clustering scales (from the source article).

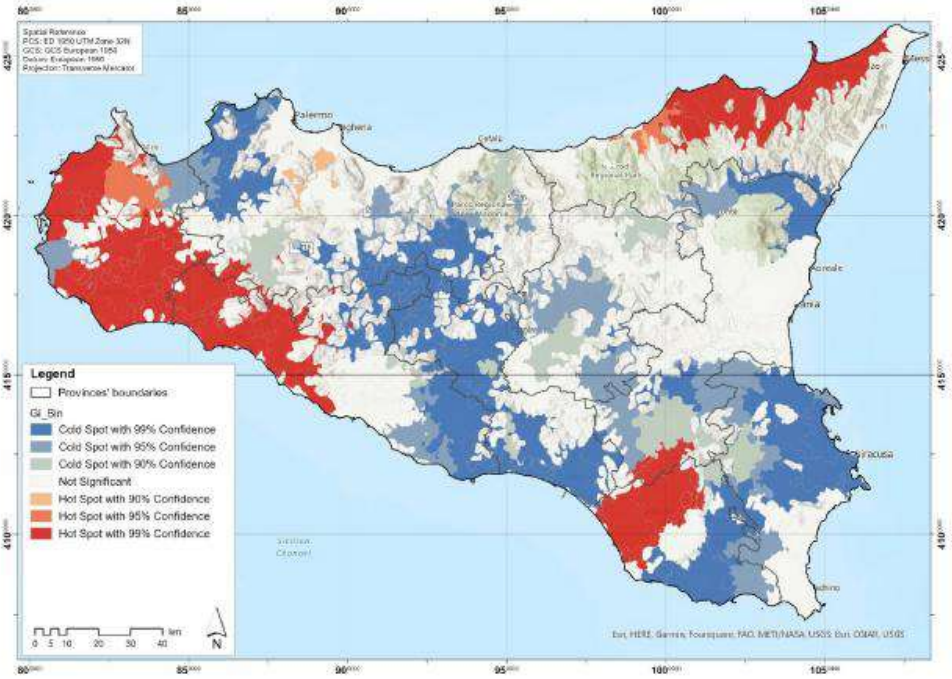


Fig. 8. Getis-Ord G_i^* index of the obtained service areas and mapped according to cold-spot and hot-spot areas and the three confidence level classes (99%, 95%, and 90%). The light grey class indicates service areas that showed no significant results. In light grey are the boundaries of the nine Sicilian provinces.

Figure 95 Getis-Ord Gi hot/cold spot mapping of service areas (from the source article).*

8.2.2.5 Economic analysis

Profitability is evaluated for the milling service by computing Profit = Total Revenues − Total Costs. Revenues are estimated as the quantity of olives milled (three-year average 2020/21–2022/23) multiplied by the 2023 provincial milling price. Costs include materials (e.g., water and electricity), labour and services (including depreciation and other overheads). Economic indicators are then compared across the two extreme and statistically robust clusters (hot spot and cold spot) identified through Gi* at confidence levels >99%.

8.2.2.6 Key quantitative outputs

Indicator	**Value / Hot spot**	**Value / Cold spot**	**Notes**
Active mills surveyed	603	—	Region-wide census
Service area definition	15 km (45 min)	15 km (45 min)	Road-network based; ~20 $km\ h^{-1}$
Moran's I (elevation)	I = 0.322	—	z = 47.306; p < 0.01; 36 km band
Gi* peak distance	18 km	18 km	z = 45.992; p < 0.01
Average revenue per mill (cluster)	≈ €68k	—	Hot-spot mills show higher outputs
Average profit margin per mill (cluster)	€29,285.63	€17,720.68	Table 5 (Average values)
Sicily hot/cold averages (profit margin)	€32,951.94	€19,761.81	Table 5 (Sicily rows)

8.2.2.7Interpretation and implications

The combined GIS and economic assessment indicates that spatial structure is a major driver of economic sustainability in the milling sector. Hot-spot service areas—where olive groves and mills are concentrated—support higher volumes processed per mill and yield higher profitability. Average profit margins in hot-spot areas (~€29.3k per mill) are nearly double those in cold-spot areas (~€17.7k), highlighting the role of accessibility to olive groves and the advantages of operating in dense production districts. The approach offers a planning tool for policymakers and stakeholders: it can support decisions on facility distribution, potential cooperation or consolidation, and sustainability strategies tied to territorial logistics.

8.2.2.8 Limitations and potential extensions

Results depend on the accuracy and timeliness of land-use layers and on average cost/price inputs. Updating spatial datasets, incorporating scenario-based transport speeds and seasonal constraints, and extending the economic scope beyond milling services (e.g., bulk and bottled oil revenues, and explicit by-product management costs) would strengthen future applications and improve transferability to other Mediterranean regions.

8.2.3 Exploring Spatial and Economic Feasibility of Olive Mill Wastewater Disposal and Reuse in Sicily Through GIS Analysis

8.2.3.1 Context and objective

Olive mill wastewaters (OMWWs) are a problematic by-product of the olive oil sector, especially for three-phase extraction systems, because of their high organic load and inhibitory compounds (e.g., polyphenols). While olive pomace can be valorised through established markets, OMWW management remains a regulatory and operational burden for mills. At the same time, controlled land application can recycle nutrients and organic matter, potentially reducing farmers' fertiliser needs and supporting circular economy strategies.This manuscript proposes a feasibility-oriented planning workflow for Sicily (Italy) that moves beyond generic suitability screening. It integrates: (i) regulatory compliance, (ii) agronomic and hydropedological constraints, and (iii) an explicit cost comparison between field application and transport to biogas plants. The final goal is to identify which mills can realistically manage OMWW via nearby land spreading and which mills require alternative solutions.

8.2.3.2 Study area, inventory and key assumptions

The study covers the entire Sicily region (25,420 km²) and includes a georeferenced census of 603 active olive oil mills. OMWW generation is estimated using a coefficient of about 0.8 m³ per tonne of crushed olives. For operational consistency and as a precautionary approach, the analysis adopts an application limit of 50 m^3 ha^{-1} $year^{-1}$ for calculating spreading capacity, even though higher limits may apply to some plant types under specific authorisations.Spatial processing is implemented in GIS software (ArcGIS Pro and QGIS) using official land-use/land-cover data (Corine-based regional map), regional soil information (including identification of clayey/low-permeability units), and hydro-geomorphological hazard layers from the regional Hydrogeological Plan.

8.2.3.3 GIS methodology: four phases from 'allowed' to 'feasible'

Phase I – Regulatory compliance (ope legis suitability): areas prohibited by the regional decree implementing the national framework are excluded (including buffer restrictions and other constraints). Very small polygons (<1 ha) are removed to reflect operational feasibility.Phase II – Agro-environmental suitability: agronomically suitable agricultural lands are retained (excluding land uses explicitly prohibited), while hydropedologically unsuitable areas are removed. Key exclusions include clayey soils with low permeability, zones with high hydraulic hazard (PI3–PI4), and landslide-prone areas (high/very high classes).Phase III – Economic suitability: costs are compared between (a) hauling OMWW to the nearest biogas plant and (b) applying OMWW to fields. Transport distances are computed on the road network (OpenStreetMap/OpenRouteService). The analysis identifies the break-even distance at which the two options cost the same.Phase IV – Final suitability mapping: for each mill, a road-network service area is delineated using the break-even distance as the maximum radius. Within each service area, available suitable hectares are compared with estimated OMWW production to determine whether complete field application is feasible.

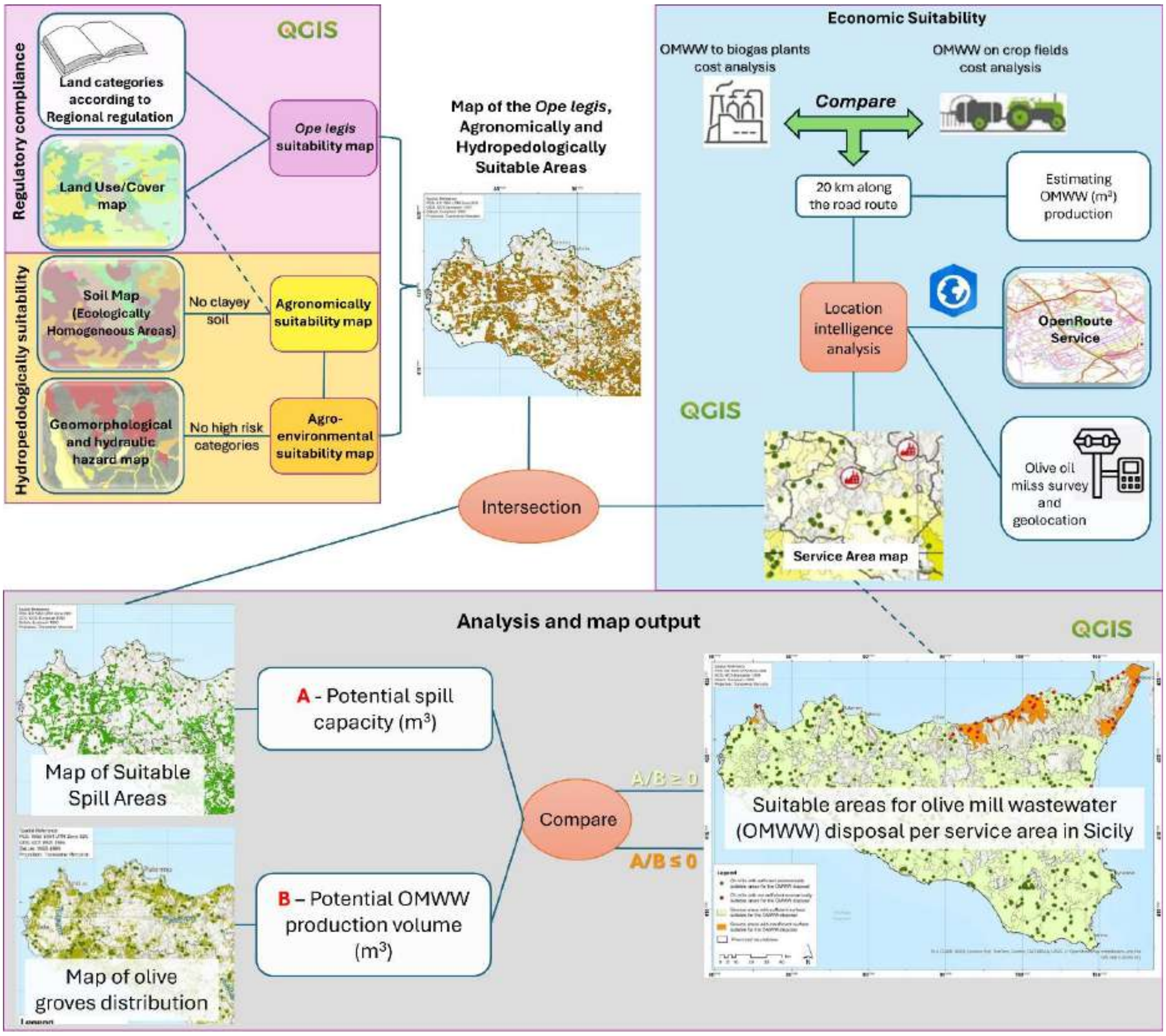


Figure 96 Flow chart of the proposed methodology for mapping suitable areas for OMWW disposal in Sicily.

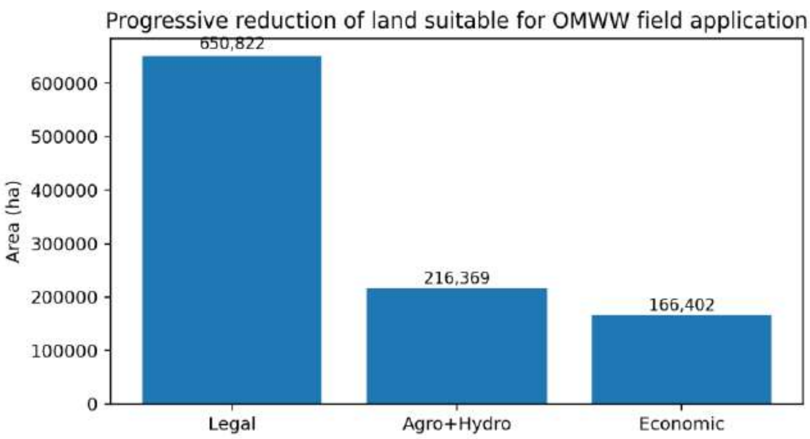


Figure 97 Progressive reduction of land suitable for OMWW field application across the three screening stages.

8.2.3.4 Main results

Regulatory screening identifies 650,822 ha (25.19% of Sicily) as legally eligible for OMWW field application. When agronomic, soil and hazard constraints are applied, the area decreases to 216,369 ha (8.38%). Incorporating the economic constraint linked to service areas reduces the final economically suitable land to

166,402 ha (6.44%). This stepwise contraction highlights that legal eligibility can substantially overestimate real environmental capacity.The cost model yields a break-even transport distance of 20 km: delivering 50 m³ of OMWW to a biogas plant is approximately equivalent to applying the same volume to land at 20 km from the mill. Therefore, for distances shorter than 20 km, field application is the cheaper option; beyond this threshold, transport to biogas becomes economically competitive.Applying the service-area logic, 553 mills (91.71%) have sufficient suitable land within their 20-km road-network catchments to dispose of their OMWW through field spreading. The remaining 50 mills (8.29%) lack adequate capacity and require alternative strategies (e.g., cooperative logistics, access to additional parcels, or valorisation via anaerobic digestion).

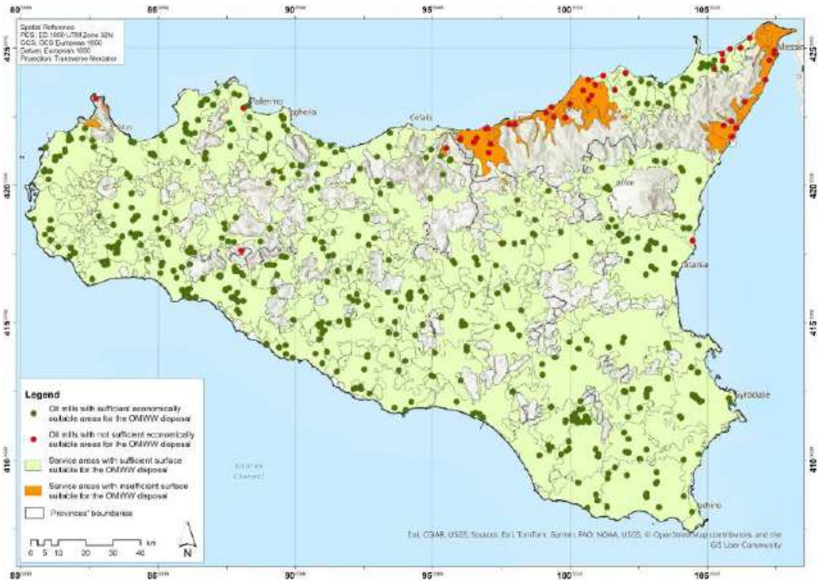


Figure 98 Availability of suitable areas for olive mill wastewater (OMWW) disposal per service area in Sicily.

8.2.3.5 Interpretation and practical implications

A central contribution of the study is the translation of spatial suitability into operational feasibility by adding an explicit economic rule. Rather than treating accessibility as a qualitative weight, the manuscript quantifies a transport-and-labour break-even point (20 km) and uses it to define road-network service areas around each mill. This provides a clear planning boundary that operators and authorities can apply in practice.The results suggest that most Sicilian mills can rely on short-haul land spreading as the least-cost management option, provided that site conditions meet soil and hazard constraints. For the minority of mills without sufficient nearby capacity, policy and sectoral actions can be targeted (e.g., cooperative infrastructure, contracts with external landholders, or dedicated valorisation routes to biogas facilities).

8.2.3.6 Limits and future developments

The economic comparison is based on average tabular transport costs and standard labour rates, which may fluctuate during peak seasonal periods and across local contexts. Future work could integrate dynamic cost data and stakeholder inputs to refine thresholds. In addition, the approach could be strengthened by coupling suitability maps with Earth-observation monitoring for compliance checks and by incorporating groundwater vulnerability or long-term soil organic matter dynamics to better capture cumulative impacts.

8.2.4 Circular Economy Adoption in Sicilian Olive Mills: Evidence from the Norm Activation Model

8.2.4.1 Aim and contribution

The study examines what drives the adoption of circular economy (CE) practices in olive milling enterprises in Sicily. It applies the Norm Activation Model (NAM)—Awareness of Consequences (AC), Ascription of Responsibility (AR), and Personal Norms (PN)—and integrates socio-demographic and firm characteristics to explain whether mills adopt at least one CE technique (binary outcome). A key contribution is clarifying how moral activation interacts with organizational capacity in a traditional agri-food sector.

8.2.4.2 Why circularity is relevant in olive milling

Olive mills generate by-products such as pomace, husks, and vegetation water. Without appropriate management, these streams can create environmental pressure. CE principles encourage valorization and closed-loop solutions, but uptake remains heterogeneous, suggesting that both behavioral factors (values, responsibility) and contextual constraints (scale, know-how, operating model) shape decisions.

8.2.4.3 Conceptual model (NAM) at a glance

NAM predicts pro-environmental action when actors understand the consequences of their actions (AC), feel responsible (AR), and activate a moral obligation (PN). The manuscript tests: (H1) whether NAM explains CE adoption; (H2) whether AC and AR build PN and AC reinforces AR; (H3–H4) whether socio-demographic and firm characteristics further explain adoption.

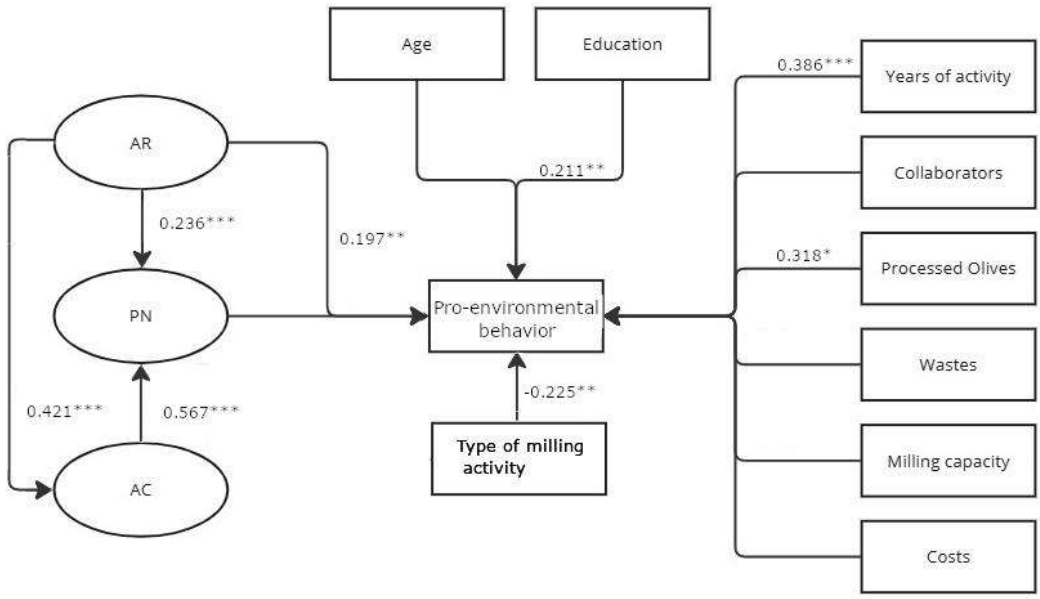


Figure 99 Graphic presentations of the relationships checked using the structural model

8.2.4.4 Data and methods

A CAWI survey was administered between July and October 2024, yielding 112 valid responses from olive milling enterprises. NAM items were adapted from validated scales and measured on 5-point Likert responses. The dependent variable equals 1 if the respondent reported adopting at least one CE practice. Hypotheses were tested using Partial Least Squares Structural Equation Modeling (PLS-SEM) with bootstrapping (5,000 replications), after checking construct reliability/validity and multicollinearity (VIF).

Table 91 Path coefficients and standard errors (SE) related to the structural model

Constructs	Personal Norms (SE) -	Ascription of Responsibility (SE)	Pro-environmental behavior (SE)
PN			-0.111 (0.102)
AR	0.236 (0.079)***		0.197 (0.096)**
AC	0.567 (0.063)***	0.421 (0.082) ***	
Variables			
Age			-0.066 (0.096)
Education			0.211 (0.088)**
Years of activity			0.386 (0.095)***
Collaborators			-0.097 (0.078)
Olive processed (t)			0.318 (0.191)*
Type of milling activity			-0.225 (0.090)**
Wastes (mc)			-0.174 (0.175)
Milling capacity (100 kg/h)			-0.086 (0.087)
Costs (€/100kg)			0.104 (0.099)
R square	0.481	0.170	0.221

8.2.4.5 Main findings

The measurement model met standard thresholds (acceptable loadings, internal consistency, and convergent validity), and the overall model showed adequate explanatory power for social science applications. In the structural results, AC and AR significantly strengthened PN, and AC strongly increased AR, supporting a cascading NAM process (awareness → responsibility → moral obligation).

Personal Norms (PN) were not a significant direct predictor of observed CE adoption, indicating an attitude–behavior gap.

Ascription of Responsibility (AR) was positively associated with CE adoption, suggesting that responsibility perceptions matter more than moral norms alone.

Education and experience (years of activity) increased the likelihood of CE adoption, consistent with the role of knowledge and managerial capability.

Firm size (proxied by olives processed) was positively related to adoption, reflecting greater resources and capacity for innovation in larger mills.

Subcontracted milling was negatively related to adoption, likely because reduced operational control limits the feasibility of circular solutions.

8.2.4.6 Implications

The evidence suggests that moral activation is necessary but not sufficient: mills may recognize environmental impacts and feel responsible, yet still require enabling conditions to act. Policies should therefore combine behavioral tools (education, targeted communication, technical training) with structural support (incentives, advisory services, pilot/demonstration plants, and facilitation of by-product valorization chains). Strengthening partnerships among mills, waste operators, and bio-based industries can reduce transaction costs and accelerate diffusion of CE solutions.

8.2.4.7 Limits and future directions

Because adoption is self-reported, measurement bias cannot be ruled out. Future research could triangulate survey answers with operational data, incorporate market and policy variables (e.g., access to finance, regulation), and integrate NAM with complementary behavioral theories to better explain the intention–action gap in traditional agri-food contexts.

8.2.5 Environmental Sustainability of Olive Oil Mills in Sicily (LCA) – Extended Summary

8.2.5.1 Overview and study design

The report compares the environmental impacts of three Extra Virgin Olive Oil (EVOO) extraction configurations in Sicily using Life Cycle Assessment (LCA) in line with ISO 14040/14044. The analysis covers the agricultural phase and the milling stage up to the "mill gate", excluding packaging, distribution, retail and use.Three scenarios are modelled:1) Three-phase extraction (baseline): produces pomace and olive-mill wastewater.2) Two-phase extraction: produces wet pomace as the main by-product and avoids the wastewater stream.3) Two-phase extraction in a circular system: co-products are valorised by (i) recovering water from pomace for polyphenol extraction (modelled conservatively as wastewater treatment), (ii) using dried pomace and recovered leaves as livestock feed, and (iii) using the pit fraction as an energy source at the mill.

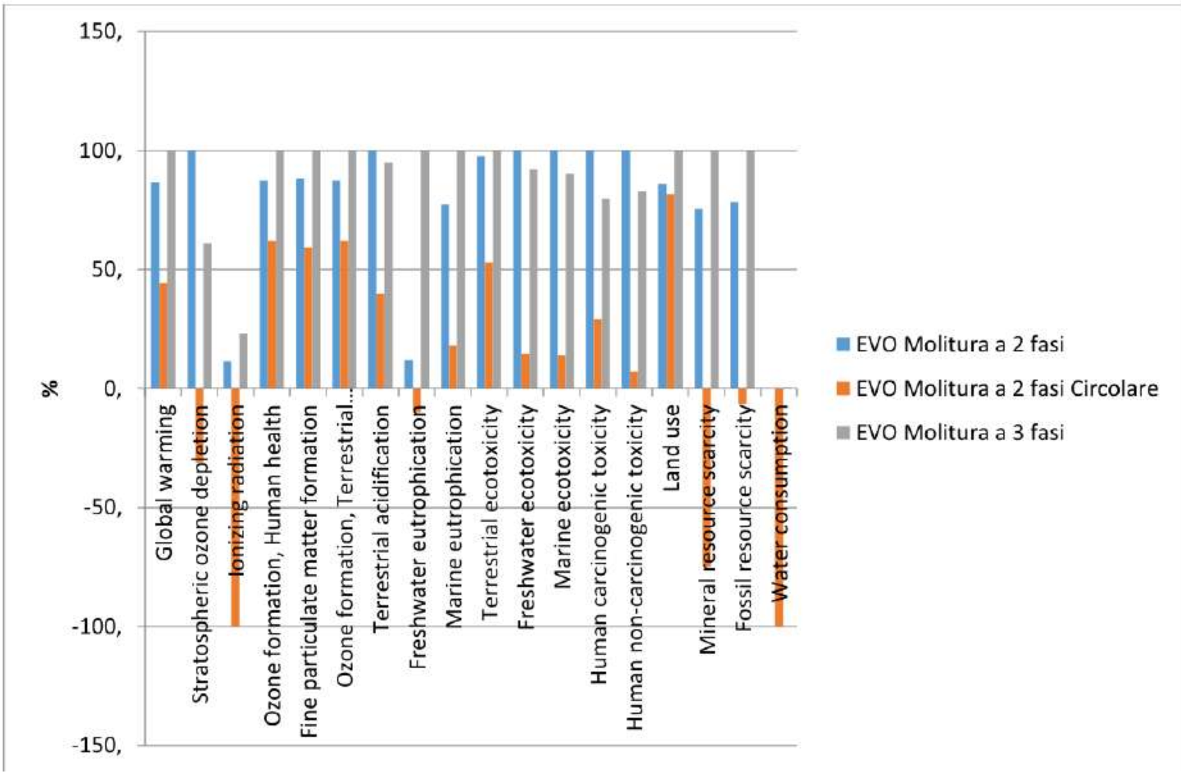


Figure 100 Normalised comparison of midpoint impacts across scenarios

Primary data for cultivation were collected from a farm (averaged over two production years), while background data for inputs and services (fertilisers, pesticides, machinery, electricity, waste management) were taken from Ecoinvent (v3.10, cut-off). Milling electricity was measured from on-site meters. Modelling was performed in SimaPro 9.6 with the ReCiPe 2016 midpoint method.

8.2.5.2 Key findings

The results indicate that the circular two-phase configuration is the least impactful option in almost all categories because avoided impacts from co-product valorisation (feed substitution and renewable heat from pits) offset a substantial share of the burdens. In several categories the net result becomes negative (a net benefit), notably for stratospheric ozone depletion, ionising radiation, mineral and fossil resource scarcity, and water consumption.Comparing the two conventional options, the two-phase system is generally preferable to three-phase because it reduces energy use and, above all, eliminates the olive-mill wastewater issue. However, when pomace is treated purely as waste, the larger mass that must be handled can worsen toxicity-related indicators (ecotoxicity and human toxicity). The report notes that, on normalised results, the difference between standard two-phase and three-phase is about 10%, while the improvement of the circular system is close to 30% relative to the three-phase baseline.

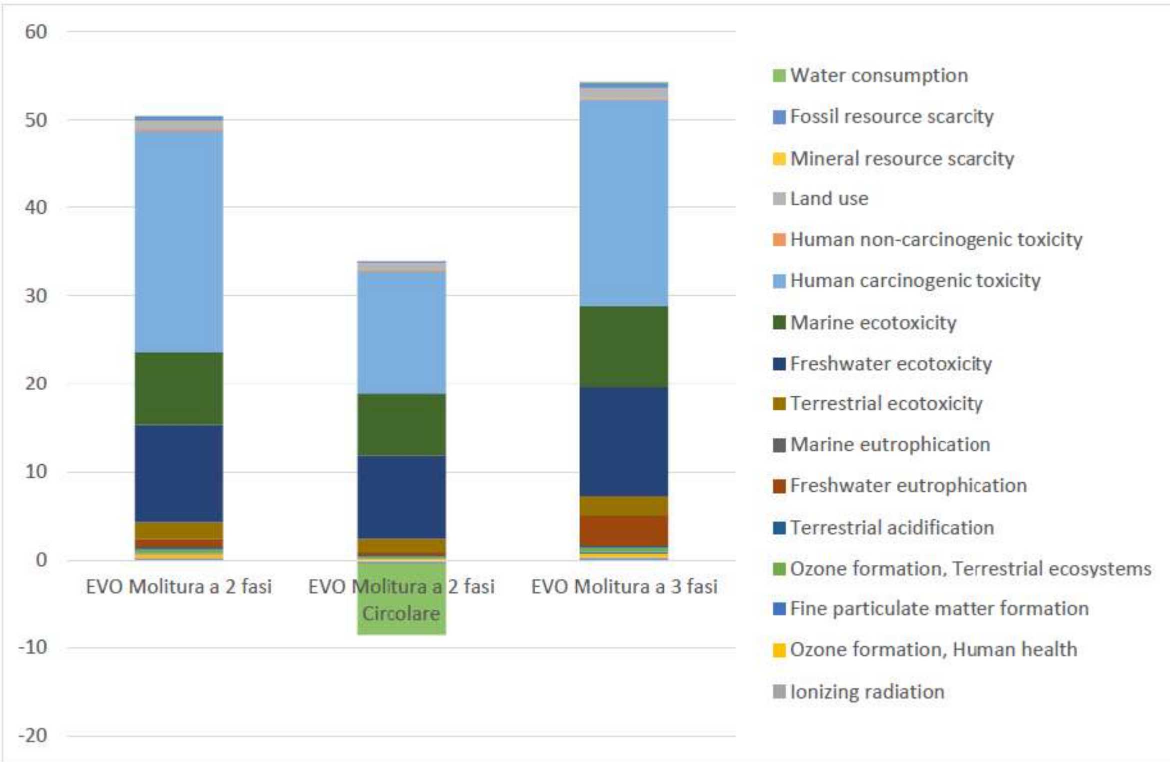


Figure 101 Normalised impact analysis

8.2.5.3 Interpretation and hotspots

A contribution analysis in the report highlights that the largest share of impacts is typically associated with olive cultivation and the management of high-mass co-product streams relative to the small volume of oil produced. The milling operations themselves contribute only marginally to most categories, which is consistent with many environmental product declarations for olive oils.In the circular two-phase scenario, olive cultivation remains the dominant positive contributor, but co-product management shifts from being a burden to delivering credits, except for the residual wastewater management linked to polyphenol extraction (not fully modelled due to data limitations).

8.2.5.4 Conclusions and implications

Overall, three-phase extraction shows the highest impacts because it combines higher energy demand with the need to manage both pomace and wastewater. Standard two-phase extraction improves performance mainly by avoiding wastewater, but benefits are maximised only when pomace, pits and leaves are valorised rather than disposed of. The circular two-phase configuration demonstrates the strongest potential for footprint reduction through practical circular-economy measures.Implication for operators and policymakers: prioritise the transition away from three-phase lines, enable infrastructure and markets for by-product valorisation (animal feed and renewable heat), and address agricultural hotspots (fertiliser and pesticide management, field emissions, and water use) since they remain the main drivers of impacts after milling improvements.

8.2.6 Circular Economy Partnerships

An additional research activity aims to investigate the willingness of managers of agro-industrial processing companies to adopt circular economy (CE) models through collaborative partnerships. The study focuses in particular on enterprises operating in the olive oil sector, where the implementation of circular practices is increasingly considered a strategic opportunity to improve environmental sustainability while enhancing economic competitiveness. Although the scientific paper presenting the results is currently under preparation, the empirical phase of the study has already been completed and the collected data are currently being analysed.

The initiative is motivated by the growing policy support for circular economy practices within the European Union. EU funding programmes increasingly encourage companies to adopt circular strategies aimed at reducing waste generation, improving resource efficiency, and promoting the valorization of agro-industrial by-products. In many cases, access to these financial incentives requires the creation of formal partnerships among companies operating within the same value chain or in related sectors. Such partnerships are expected to facilitate cooperation in resource management, knowledge exchange, and innovation processes that enable the transition toward more sustainable production systems.

Within this framework, a structured survey was designed to assess the feasibility and attractiveness of potential collaborative agreements among companies interested in implementing circular economy practices. The methodological approach is based on a choice experiment model, which allows researchers to analyse how managers evaluate different hypothetical partnership arrangements. Participants in the survey were asked to assess alternative contractual proposals characterized by a set of attributes describing the structure and conditions of the partnership. By analysing respondents' preferences across different scenarios, the study aims to identify the factors that most strongly influence firms' willingness to participate in circular economy initiatives.

Several key elements define the partnership structures presented in the survey scenarios. First, the agreements may involve joint investments in shared resources, such as processing facilities, specialized machinery, or technical personnel. Shared infrastructure can significantly reduce individual investment costs and enable firms to adopt technologies that would otherwise be economically unfeasible at the individual company level. Second, the partnerships include mechanisms for knowledge sharing, such as the adoption of common technical standards, training programmes, and awareness-raising initiatives aimed at improving the management of by-products and the implementation of circular practices across the supply chain.

Another important component concerns the creation of additional economic value for participating firms. By cooperating within a structured partnership, companies may benefit from improved access to credit, increased credibility when applying for public funding schemes, and enhanced market reputation associated with environmentally responsible production. These potential advantages represent significant incentives for firms to engage in collaborative circular economy initiatives, particularly in sectors characterized by a high prevalence of small and medium-sized enterprises.

The proposed contractual arrangements also specify the duration of the partnership, which may range between three and ten years, depending on the scale of investments and the strategic objectives of the collaboration. Furthermore, the contracts may include specific exit clauses allowing participants to withdraw under predefined conditions, thereby reducing the perceived risk associated with long-term cooperative commitments.

The data collection phase was carried out by a certified national survey agency responsible for conducting interviews with olive oil mill operators. The survey reached a total of 307 respondents, providing a substantial dataset for the analysis of managerial preferences and attitudes toward collaborative circular economy initiatives. At the time of writing, the research team is engaged in the data processing and econometric analysis of the collected responses.

The results of the choice experiment are expected to provide valuable insights into the economic, organizational, and contractual factors that influence the adoption of circular economy strategies in the agro-industrial sector. Ultimately, the findings will support policymakers and industry stakeholders in designing more effective cooperation frameworks and policy instruments capable of fostering the transition toward circular production systems.

8.3 Cereals: Environmental Sustainability of Durum Wheat Flour Milling

8.3.1 Executive summary

The study compares two pest control options used during industrial milling of durum wheat into unpackaged flour: chemical treatment versus heat (thermal) treatment. The Life Cycle Assessment (LCA) follows ISO 14040/14044 and assesses impacts per Functional Unit (FU) of 1 kg of unpackaged durum wheat flour, using primary data from two mills in the province of Syracuse (Sicily, Italy).

The results highlight a trade-off. Heat treatment increases energy- and climate-related burdens because plant heating requires substantial electricity. Chemical treatment shows lower energy-related impacts but higher toxicity and ecotoxicity indicators due to the use of chemical agents. Contribution analysis confirms that the pest control step is the main differentiator between scenarios.

8.3.2 Goal, scope and modelling

System boundaries include only the milling phase (receiving and pre-cleaning, cleaning, milling, storage, and pest control). Packaging, distribution, retail and use are excluded. Construction of milling machinery is excluded due to lack of data. Electricity consumption was allocated to unit operations based on operating times; co-products and waste were quantified through on-site records and data sheets.

Background data for electricity production and waste management were taken from ecoinvent v3.10 (cut-off). Modelling was performed in SimaPro 9.6; impacts were calculated with ReCiPe 2016 midpoint indicators. Economic allocation was applied between products and co-products, using ISMEA wholesale prices as reference values (semolina €508.72; bran €141.84).

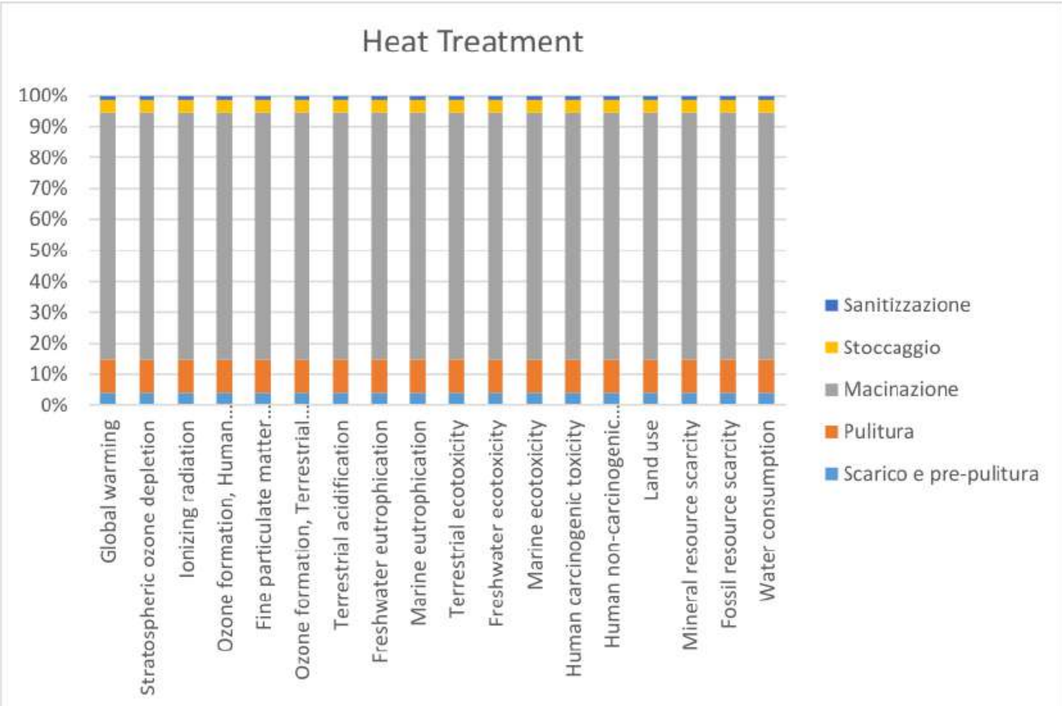
8.3.3 Key results

Heat treatment shows higher impacts in categories driven by electricity use. For example, Global Warming equals 3.40E-02 kg CO_2 eq for heat treatment versus 2.75E-02 kg CO_2 eq for chemical treatment. Fossil resource scarcity is 1.12E-02 vs 8.88E-03 kg oil eq, and water consumption is 6.28E-04 vs 5.21E-04 m3.

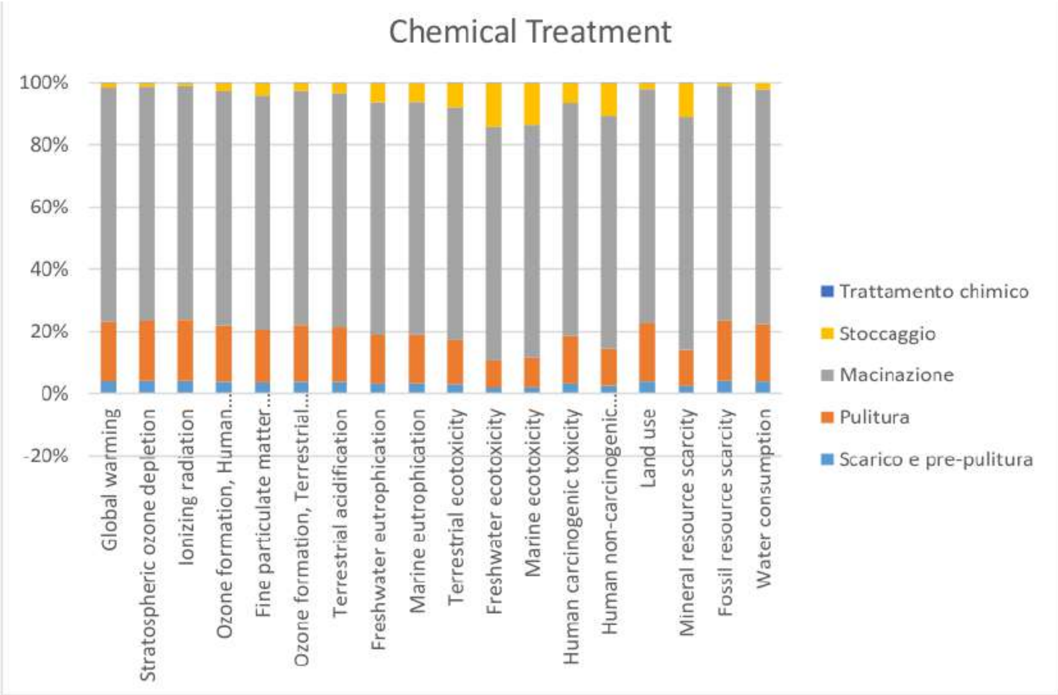
Chemical treatment performs worse in toxicity-related categories. Terrestrial ecotoxicity is 1.89E-01 kg 1,4-DCB (chemical) versus 1.73E-01 kg 1,4-DCB (heat); Human non-carcinogenic toxicity is 1.73E-02 vs 1.33E-02 kg 1,4-DCB.

Table 92 Comparison between scenarios based on impact characterization

Impact Category	Unit	Chemical Treatment	Heat Treatment
Global warming	kg CO2 eq	2,75E-02	3,40E-02
Stratospheric ozone depletion	kg CFC11 eq	1,27E-08	1,59E-08
Ionizing radiation	kBq Co-60 eq	3,10E-03	3,93E-03
Ozone formation, Human health	kg NOx eq	4,45E-05	5,24E-05
Fine particulate matter formation	kg PM2.5 eq	2,53E-05	2,79E-05
Ozone formation, Terrestrial ecosystems	kg NOx eq	4,80E-05	5,66E-05
Terrestrial acidification	kg SO2 eq	6,80E-05	7,79E-05
Freshwater eutrophication	kg P eq	5,72E-06	5,69E-06
Marine eutrophication	kg N eq	6,03E-07	6,04E-07
Terrestrial ecotoxicity	kg 1,4-DCB	1,89E-01	1,73E-01
Freshwater ecotoxicity	kg 1,4-DCB	1,33E-03	7,60E-04
Marine ecotoxicity	kg 1,4-DCB	1,84E-03	1,13E-03
Human carcinogenic toxicity	kg 1,4-DCB	2,93E-03	2,88E-03
Human non-carcinogenic toxicity	kg 1,4-DCB	1,73E-02	1,33E-02
Land use	m2a crop eq	7,62E-04	9,23E-04
Mineral resource scarcity	kg Cu eq	6,04E-05	4,52E-05
Fossil resource scarcity	kg oil eq	8,88E-03	1,12E-02
Water consumption	m3	5,21E-04	6,28E-04



Heat treatment contribution analysis



Chemical treatment contribution analysis

Figure 102 Contribution analysis by process phase (heat treatment and chemical treatment).

8.3.4 Interpretation and improvement options

The contribution plots indicate that, in the heat treatment scenario, the sanitization/thermal step dominates most energy-related categories (e.g., Global Warming, Fossil resource scarcity and Water consumption), confirming the role of heating electricity demand. In the chemical treatment scenario, the pest control step drives the highest toxicity and ecotoxicity scores, while other categories are more evenly shared among milling, cleaning, pre-cleaning and storage operations.

To reduce impacts, heat treatment can be improved through energy efficiency (heat recovery, insulation, optimized cycles) and lower-carbon electricity procurement. Chemical treatment can be improved by reducing dosage, selecting less hazardous substances, strengthening containment/handling, and managing residues appropriately.

8.3.5 Mills Circular Economy Practices

Another ongoing research activity investigates the willingness of managers of companies operating in the cereal processing industry to adopt circular economy (CE) practices within their production systems. The objective of this study is to better understand the motivations, opportunities, and organizational capabilities that influence firms' decisions regarding sustainability and circular innovation within the agro-industrial sector.

The cereal processing industry represents a strategic segment of the agri-food system, characterized by high resource consumption and significant potential for improving resource efficiency. Circular economy strategies in this sector may involve the reduction of production waste, the recovery and reuse of process resources such as water and energy, and the valorization of by-products through alternative uses such as composting or the production of bio-based fertilizers. Despite the growing policy emphasis on circular economy principles at the European level, the adoption of these practices by firms often depends on economic feasibility, technological capabilities, and the willingness of managers to undertake organizational changes.

To investigate these aspects, the study adopts a choice experiment methodology, which allows the evaluation of managers' preferences for different circular economy investment scenarios. The survey presents respondents with a set of hypothetical decision situations in which they are asked to choose between alternative circular economy initiatives characterized by different attributes. These attributes describe key aspects of potential investments aimed at improving circularity within cereal processing operations.

The proposed scenarios include different types of circular interventions. One possible strategy involves the reduction, recovery, and potential reuse of process resources, such as water and energy, through technological improvements and process optimization. Another possible strategy focuses on the recovery and valorization of production residues, which may be transformed into compost or other organic fertilizers. Each alternative is described through a combination of attributes that capture the economic and organizational implications of the investment.

Among the attributes considered in the experiment are the payback period of the investment, expressed in years, and the level of public financial support, reflecting the role of policy incentives in facilitating the adoption of circular economy practices. Additional attributes describe the degree of organizational change required, ranging from incremental adjustments to more radical transformations of the production process. Finally, the scenarios also consider the level of supply chain involvement, distinguishing between initiatives implemented internally within the firm and those requiring collaboration with suppliers or other partners along the value chain.

The data collection phase was carried out by a certified national survey agency, which administered the questionnaire to managers of industrial cereal milling companies across Italy. The survey reached a total of 120 industrial mills, providing a representative dataset on managerial attitudes and decision-making processes related to circular economy investments in the sector.

At the time of writing, the data collection phase has been completed and the research team is currently engaged in the processing and econometric analysis of the collected responses. The results are expected to provide valuable insights into the economic, organizational, and policy-related factors that influence the adoption of circular economy strategies in the cereal processing industry. These findings will contribute to the development of policy recommendations and support strategies aimed at facilitating the transition toward more sustainable and circular production systems within the agri-food sector.

9 CE implementation in the agrifood sector exploiting UAV

9.1 Overview and Rationale for High-Resolution Monitoring

The transition towards a Circular Economy (CE) in the livestock sector is often hindered by the lack of primary, site-specific data regarding methane (CH_4) emissions, a critical environmental hotspot that accounts for a substantial share of global anthropogenic emissions. Within the framework of the GRINS project, the research conducted aims to bridge this data gap by developing and validating an innovative monitoring methodology based on Unmanned Aerial Vehicles (UAVs). While traditional Life Cycle Assessment (LCA) studies frequently rely on generic Ecoinvent datasets or IPCC model-based estimates, this study implements a direct, on-site measurement approach to enhance the accuracy and reliability of emission inventories for the Italian dairy and beef sectors.

9.2 Methane Emissions in Livestock Systems: The Need for High-Resolution Monitoring

The critical role of anthropogenic CH_4 reduction in mitigating global temperature rise is underscored by its potent greenhouse effect, which is 28 times more impactful than CO_2 over a 100-year horizon, with the livestock sector, particularly cattle farming, serving as a primary contributor through enteric fermentation and manure management. While LCA studies consistently identify CH_4 as the dominant driver of environmental impact in these systems, current climate accountability is hampered by a reliance on bottom-up IPCC empirical models derived from obsolete parameters that frequently underestimate real-world emissions. Consequently, there is an urgent need for primary, site-specific data to comply with ISO 14040/14044 standards and bridge the data gap between controlled experimental settings and variable, large-scale operational farm conditions. Traditional top-down monitoring methods, such as respiration chambers or tracer gas techniques, are often limited by high costs, labor intensity, or a lack of herd-level representativeness; in contrast, UAV based methodologies, such as those employing open-path laser sensors, offer a low-cost, high-frequency, and statistically robust alternative for capturing net farm-scale fluxes. The present research addresses this gap by pursuing a twofold objective: first, to develop and validate a reliable UAV-based measurement tool capable of providing site-specific primary data that reflects actual farm management practices; and second, to quantify the methodological advantage of this approach through a comparative LCA.

By evaluating derived UAV emission factors against conventional IPCC Tier 2 models and generic Ecoinvent databases, this research seeks to empirically demonstrate how superior Data Quality Ratings (DQR) and direct measurements translate into more accurate Climate Change impact assessments, ultimately providing a replicable and efficient framework for farmers, researchers, and policymakers to support environmentally responsible livestock production.

9.3 Site Characterization and Experimental Setup

The experimental phase of the project was designed to capture the operational and environmental heterogeneity of the Italian dairy sector. The selection of three pilot sites, distributed across Southern, Central, and Northern Italy, ensures that the developed LCI factors are representative of the national intensive production model based on the *Holstein Friesian* breed.

9.3.1 Site Characterization and Experimental Setup

The trials were conducted between July and November 2024 at three dairy cattle farms strategically distributed across Italy to ensure the generalizability of the results. All sites utilize the Holstein Friesian breed and operate under intensive management, yet they exhibit operational heterogeneity in terms of scale, feeding frequency, and manure handling. Herd sizes are expressed in total head and converted into Animal Units (AU), defined as a 500 kg reference dairy cow.

- ✓ Site A (Calabria, Southern Italy):
  This site represents a large-scale intensive system hosting 1,682 head (1,214.2 AU), including 723 lactating cows and 959 head among dry cows and young cattle. The farm covers 479 ha (471 ha UAA), resulting in a stocking rate of 2.58 AU/ha. It is characterized by a high average milk yield of 40.47 kg FPCM/day (3.60% fat, 3.36% protein), totaling approximately 8.92 million kg FPCM per year. Animals are fed twice daily with a total mixed ration-based regime; dairy cows receive a high ration in corn silage (56.9%), while growing cattle diets reach up to 82.2% corn silage inclusion. The facility features a sophisticated waste management system where manure is directed daily to six on-site biodigesters.

- ✓ Site B (Marche, Central Italy):
  Representing a medium-sized intensive farm, Site B hosts 538 head (478.7 AU), primarily focused on lactating (368) and dry cows (124). Despite its smaller size, it maintains a significantly high stocking rate of 11.13 AU/ha on a total area of 45 ha. The average milk yield is 35.03 kg FPCM/day (4.0% fat, 3.5% protein), for an annual production of 3.94 million kg FPCM. Feeding occurs twice daily, with dairy cows receiving a ration based on wheat silage (50.3%) and concentrate. Notably, Site B provides a critical data point for diverse manure handling: while equipped with one biodigester for daily waste removal, it is the only site that also manages a portion of solid manure in outdoor heaps with an average retention time of six months.

- ✓ Site C (Lombardia, Northern Italy):
  Located in the heart of the Po Valley, Site C represents the technological frontier of the study. It hosts 720 head (696 AU), consisting exclusively of dairy (600) and dry cows (120). With 445 ha of total area, the stocking rate is 1.59 AU/ha. This site achieves the highest milk yield at 42.53 kg FPCM/day (4.50% fat, 3.82% protein), totaling 7.78 million kg FPCM per year. Management is highly automated, with a feeding frequency of three times daily (every eight hours) and an hourly manure removal system. The site operates a large-scale anaerobic digestion plant equipped with ten biodigesters, representing the maximum management intensity in the study.

9.3.2 UAV Platform and High-Precision Positioning

To overcome the vertical accuracy limitations of standard GPS, the research employed a DJI Matrice 350 RTK quadcopter. The integration of a Real-Time Kinematic (RTK) module allowed centimetric spatial precision (1.5 cm vertical and 1 cm horizontal accuracy). This resolution is fundamental for the correct spatial allocation of methane plumes. Furthermore, the drone was equipped with a 24 GHz radar altimeter (NRA24) to maintain a constant altitude relative to the terrain, ensuring consistent topographic profiling during the transects.

9.3.3 Methane Detection: OP-TDLAS Technology

The core of the measurement suite is an Open-Path Tunable Diode Laser Absorption Spectrometer (OP-TDLAS), specifically the Laser Falcon model. This sensor operates at a near-infrared wavelength of 1.65 µm, corresponding to the maximum absorption peak of CH_4.

- ✓ *Measurement Principle*: The system utilizes the Lambert-Beer law, measuring the attenuation of the laser beam reflected from the ground to calculate the path-integrated concentration (ppm · m).
- ✓ *Sampling Frequency*: Data were recorded at 10 Hz, allowing for high-frequency capture of turbulent methane plumes.
- ✓ *Operational Constraints*: Flight altitudes were restricted to a maximum of 40 meters above ground level, with an effective optical path length of 35 meters, to ensure optimal signal integrity and minimize down-washing effects caused by the drone's rotors.

9.3.4 Data Acquisition and Quality Assurance

A total of 108 flights were performed across the three sites to ensure statistical robustness. The experimental design included:

- ✓ *Meteorological Synchronization*: A dedicated weather station recorded wind speed/direction, temperature, and pressure at a height of 2 meters, synchronized with the UAV flight logs.
- ✓ *Algorithm-Based Filtering*: A bespoke post-processing algorithm was implemented to eliminate false positives and filter out artifacts caused by external environmental interferences or calibration drifts.
- ✓ *Mass Balance Flights*: The drone maintained a constant velocity of 2-3 m s^{-1} along site-specific flight paths, specifically designed to intercept the net flux from both enteric fermentation (stables) and manure management units (biodigesters and heaps).

This structured monitoring approach, combining diverse geographical contexts with high-precision aerospace technology, provides the primary data baseline required to accurately reflect the environmental footprint of the Italian cattle supply chain.

9.4 Results and Discussion: UAV-Based Emission Quantification

This section presents the empirical findings derived from the monitoring campaigns, comparing direct UAV measurements with international standard models and analyzing the factors that influence the precision of methane quantification in livestock systems.

9.4.1 Enteric Methane Emissions and Comparative Analysis

The enteric methane emission rates, net of manure contributions, were quantified across the three dairy farms to assess the biological methane output of the herds. The average measured emissions showed a consistent range across the sites: 0.190 to 0.231 kg CH_4 AU^{-1} day^{-1} for Site A, 0.182 to 0.241 kg CH_4 AU^{-1} day^{-1} for Site B, and 0.182 to 0.242 kg CH_4 AU^{-1} day^{-1} for Site C.

A comparative analysis with the IPCC models revealed a high level of agreement, particularly with the Tier 1 model, where the maximum relative deviation was only 1.88% (Site A). Discrepancies were slightly more pronounced when compared to Tier 2 estimates, reaching 6.60% at Site B. These variations are primarily attributed to the instantaneous nature of UAV observations, which capture real-time fluctuations in methane release, such as post-feeding peaks, that are typically smoothed out in static annual models. Notably, Site C exhibited the lowest and most stable emission profile, likely due to its high level of technological automation, including robotic milking and frequent, automated feed distribution.

9.4.2 Analysis of Methodological Uncertainties

The uncertainty of the UAV-based mass balance approach was evaluated in relation to environmental and operational variables.

- ✓ *Wind Dynamics*: A strong negative correlation was observed between uncertainty and wind speed. Optimal precision (<20% uncertainty) was consistently achieved with wind speeds exceeding 2.0 m/s and directional variability below 31 degrees. Conversely, wind speeds below 1 m/s led to uncertainties as high as 48% due to plume stagnation and atmospheric instability.
- ✓ *Source Intensity*: Uncertainty decreased as the number of livestock increased, as larger herds produce a stronger methane signal, improving the signal-to-noise ratio for the OP-TDLAS sensor.
- ✓ *Feeding Rhythms*: At Sites A and B, higher uncertainties were recorded in the hours immediately following feed distribution due to the turbulence of vigorous enteric fermentation. In contrast, at Site C, the automated three-meal-a-day strategy promoted a more constant fermentation rate, resulting in stable measurement uncertainty independent of the feeding time.

9.4.3 Manure-Derived CH4 and Management Impact

Manure emissions were quantified by channelling both solid and liquid waste to anaerobic biodigesters across all sites. At Site B, specific UAV flights over outdoor manure heaps were conducted to capture emissions from traditional storage practices. The findings confirm an inverse relationship between the frequency of manure removal and methane emissions. Site C, featuring hourly manure removal, emerged as the most efficient system for mitigating manure-derived CH_4. UAV-derived data for Site B indicated an average emission of 26 kg CH_4/head/year, which is closely aligned with IPCC Tier 1 factors (27 kg) but suggests that Tier 2 models (18 kg) might underestimate emissions when outdoor storage is involved.

9.4.4 Data Quality Rating (DQR) and LCA Implications

To evaluate the suitability of the data, a formal Data Quality Analysis was performed following ISO 14040/14044 standards. The results highlight the superior resolution of the UAV approach:

- ✓ UAV-Based Dataset (DQR = 1.2): Received the highest scores for technological and geographical representativeness. The ability to capture real-time, site-specific fluxes at high spatial resolution makes it the most robust tool for farm-level environmental auditing.
- ✓ IPCC Tier 2 (DQR = 1.6): Represents a solid baseline but lacks the temporal granularity to capture diurnal or seasonal variability.
- ✓ Ecoinvent 3.9 (DQR = 2.6): Showed the lowest quality for Italian specific contexts, as the data are generic and do not reflect the technological advancements (e.g., automated feeding, biogas integration) of modern Italian farms.

9.4.5 Contribution to Dynamic LCA (D-LCA) and Precision Farming

The high-frequency data generated by this study provides the necessary input for Dynamic LCA (D-LCA), which accounts for the time-dependency of climate forcing. By capturing emission spikes linked to feeding events and management changes, the UAV methodology allows for the optimization of farm operations to minimize impacts during peak release periods. This integration of spatially explicit emission maps with automatic milking and feeding data paves the way for a truly data-driven, precision livestock farming approach, supporting the transition toward a more resilient and circular agrifood sector in Italy.

9.5 Conclusions and Future Perspectives of UAV Monitoring Activity

The acquisition of primary data through the direct measurement of methane emissions has proven to be an essential step in enhancing the accuracy, transparency, and site-specific relevance of environmental impact assessments within livestock systems. Unlike model-based approaches that rely on average and often obsolete parameters, monitoring *via* sensors mounted on UAV systems allows for the capture of real-time variability and farm-specific operational conditions, drastically reducing uncertainty and improving the effectiveness of mitigation strategies.

The experimental results obtained across the three national pilot sites demonstrated that the aerial mass balance method is a reliable and effective monitoring tool, with average daily enteric emissions ranging between 0.20 and 0.21 kg CH_4/AU/day. The differences observed between the farms clearly reflected variations in management practices; specifically, technologically advanced systems, equipped with high levels of automation and optimized manure management, showed significantly lower emission fluxes. Although methodological uncertainty is primarily influenced by wind speed and atmospheric conditions, the analysis confirmed strong statistical robustness, especially in the presence of stable wind regimes and significant herd sizes that enhance the signal-to-noise ratio of the laser sensor.

Comparison with IPCC Tier 1 and Tier 2 model estimates showed a good overall agreement, but the UAV-based approach guaranteed a superior DQR of 1.2, compared to 1.6 for the Tier 2 model and 2.6 for the Ecoinvent database. This higher data quality translates into LCA results that are much more sensitive to the actual context, highlighting a climate change impact that is 5.2% higher than evaluations based on theoretical models and 11.2% higher than generic database values. Such discrepancies underscore how traditional models can underestimate real emissions, making direct monitoring an indispensable tool for climate reporting and participation in carbon credit markets.

Looking ahead, the UAV methodology represents a significant advancement in methane quantification for the Italian livestock sector, providing high-resolution data suitable for validating mitigation practices such as anaerobic digestion, improved dietary strategies, and precision manure management. Future research must focus on expanding this applicability across diverse environmental conditions and systematically integrating empirical drone-derived data into updated frameworks for emission factors. This effort will support the development of more precise national inventories, the elaboration of evidence-based policies, and the rigorous verification of sustainability commitments made by agrifood companies within the GRINS project framework.

10 Circular procurement and supply chain

10.1 Introduction

This chapter provides a comprehensive synthesis of the activities undertaken and the objectives achieved during the research project. The research program focused primarily on circular procurement systems and innovation in sustainable supply chains, while also exploring related themes that emerged during the research process.

Sustainability has become a key element in supply chain management due to growing expectations from consumers, investors, and policymakers. Companies are increasingly required to integrate environmental, social, and governance (ESG) principles into their strategic and operational processes. This shift has been accelerated by regulatory developments at the national and supranational levels, notably the European Union's Green Deal and Corporate Sustainability Reporting Directive, as well as by the increasing materiality of climate-related financial risks. As a result, supply chain management has evolved from a purely efficiency-oriented discipline toward a broader framework that incorporates sustainability, resilience, and responsible sourcing.

The central theme of the research concerns circular procurement and sustainable supply chains. Circular procurement integrates circular economy principles into purchasing strategies, promoting reuse, recycling, lifecycle thinking, and responsible material sourcing. By embedding circularity criteria into supplier selection, contract design, and product specification, organizations can reduce their environmental footprint while simultaneously strengthening supply chain resilience. However, during the project, additional research streams were explored, including technological innovation, emerging digital technologies, organizational resilience, and sustainability governance.

The transition toward a circular economy is essential to address climate change, resource scarcity, and sustainability pressures affecting global industries. Circular economy principles aim to reduce waste generation, extend product lifecycles, and promote regenerative economic systems capable of maintaining material value across multiple production cycles (Wang et al., 2024). Industrial symbiosis, extended producer responsibility, and product-as-a-service business models are among the mechanisms through which circular principles can be operationalized within supply chains.

The research project conducted by the teams of the University of Rome Tor Vergata advances knowledge at the intersection of circular economy, sustainable supply chain management, and digital technologies enabled by Industry 4.0 and Industry 5.0. Technologies such as artificial intelligence, blockchain, and the Internet of Things are increasingly recognized as key enablers of sustainable supply chains because they allow organizations to monitor material flows, optimize logistics operations, and improve transparency across supply networks (Nicoletti and Appolloni, 2022a; Nicoletti and Appolloni, 2022b). The convergence of these digital capabilities with circular economy principles represents a frontier of both academic inquiry and managerial practice.

Figure 103 presents graphically the structure of the research shows in the following paragraphs.

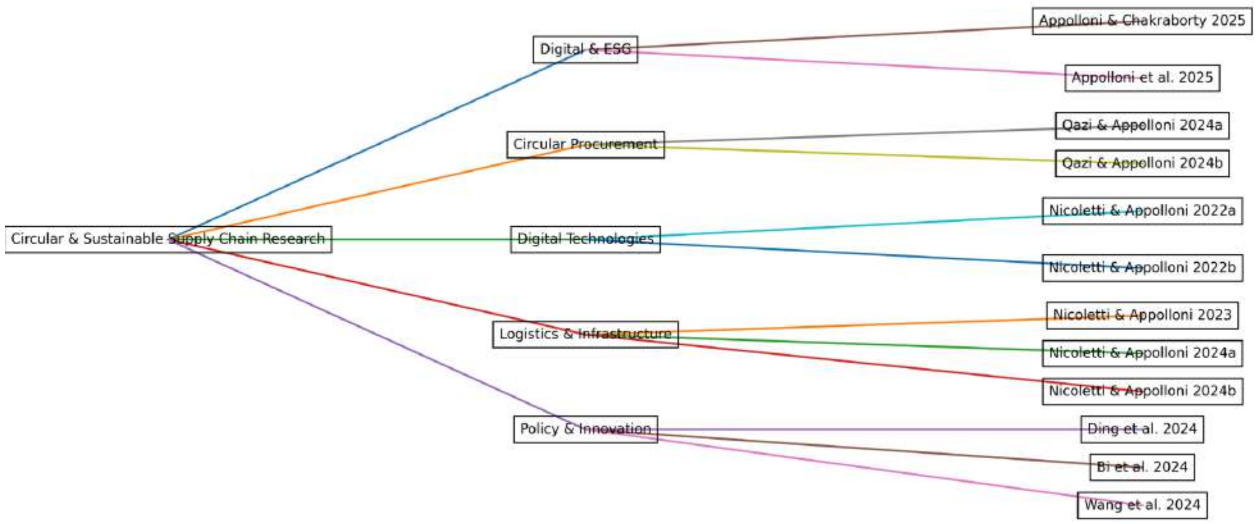


Figure 103 structure of the research

10.2 Materials and Methods

The research methodology adopted in the project reflects the complexity of sustainability and innovation within supply chains. The research teams used a multidisciplinary approach that combined theoretical analysis, empirical research, and secondary data. This pluralistic methodological stance was considered essential to capture the heterogeneous nature of circular procurement challenges across diverse industrial and institutional contexts. The research began with a systematic literature review designed to identify the main theoretical contributions related to circular procurement, sustainable supply chain management, and digital transformation. The literature review followed the PRISMA protocol, screening over two thousand articles from peer-reviewed journals indexed in Scopus and Web of Science. Meta-analysis techniques and text-mining methods were used to analyze academic literature and identify key research streams and theoretical gaps. Bibliometric analysis was used to map the intellectual structure of the field and identify the most influential scholars, journals, and research clusters.

The research presented in this report is based on a comprehensive combination of qualitative and quantitative methodologies. Mixed-methods approaches were used, integrating in-depth interviews with CEOs, managers, and AI designers alongside structured surveys to explore cultural drivers and customer behavior patterns (Appolloni et al., 2026). This study examines how Hofstede's cultural dimensions influence the use of AI in achieving ESG (Environmental, Social, and Governance) goals, with organizational attitude and policy acting as moderating factors. Using a mixed-methods approach, the research first identifies culturally relevant factors through interviews and grounded theory, then tests these relationships with survey data from 448 respondents in India using Partial Least Squares Structural Equation Modeling. The findings show that positive organizational attitudes significantly strengthen the impact of AI on ESG outcomes, while formal policies generally have limited influence due to rigidity and lack of contextual adaptability. The study highlights how cultural traits like power distance, uncertainty avoidance, and individualism shape AI adoption in different contexts. Overall, it contributes to existing knowledge by linking culture, AI adoption, and ESG performance, emphasizing the need for flexible, culturally aware, and attitude-driven approaches to responsible and sustainable organizational practices.

The promotion of green technology innovation (GTI) is regarded as an effective way to protect the environment and achieve sustainable development. (Bi et al., 2024) The "Zero Waste City" construction pilot policy (ZWCP) is an important policy for promoting waste management and achieving sustainable development and the circular economy. The paper explores the effect of ZWCP on GTI using the difference-in-differences model and machine learning. The result shows that ZWCP significantly promotes GTI. In addition, causal forest modeling, a type of machine learning method, similarly validates this result. The mechanism effect suggests that ZWCP promotes GTI by increasing research expenditure and enhancing informational development. The heterogeneity effect suggests that ZWCP is more effective at promoting GTI when implemented in Western, low-administrative-level, and resource-based cities. The paper provides a reference for waste management policies and the development of GTI in other countries.

This chapter examines how blockchain and the Industrial Internet of Things (IIoT) can enhance sustainability in logistics (Nicoletti and Appolloni, 2026). By combining blockchain's transparency, immutability, and decentralization with IIoT's real-time data collection, organizations can improve traceability, reduce fraud, ensure compliance with sustainability standards, and lower environmental impact. Case studies across industries like food processing, manufacturing, and transportation show that these technologies increase operational efficiency, transparency, and customer trust. However, challenges such as implementation complexity, privacy issues, and regulatory constraints remain. Future developments point toward deeper integration of blockchain and IIoT, especially through smart contracts that automate logistics processes using real-time data, improving efficiency, security, and sustainability across the supply chain.

A study explores how different factors influence consumer behavior toward sustainable agri-food products in India using Behavioral Reasoning Theory (BRT) (Appolloni and Chakraborty, 2025). It finds that environmental concern, health awareness, and support for local farmers encourage consumers to buy sustainable products. High prices and limited availability act as key barriers, especially in a price-sensitive market like India. Environmental concern plays a moderating role by strengthening positive motivations and weakening negative ones. The research suggests that addressing these barriers while promoting key benefits can boost sustainable consumption. It also contributes to theory by expanding BRT and offers practical guidance for businesses and policymakers to encourage eco-friendly purchasing in developing countries. In parallel, systematic literature reviews were conducted to analyze the development and challenges of circular procurement and reverse logistics within the Industry 5.0 framework.

A study examines the role of circular supply chain management as a key driver of the circular economy, with a particular focus on procurement—an area often overlooked despite its large share of organizational spending. By reviewing 100 peer-reviewed papers, the research provides a comprehensive analysis of how circularity can be integrated into procurement practices (Qazi and Appolloni, 2022). It identifies 55 key barriers and enablers, grouped across different levels (micro, meso, and macro). The findings highlight that achieving circular procurement requires coordinated efforts from all stakeholders, along with significant changes in sourcing strategies and procurement operations. The study contributes both theoretically, by guiding future research frameworks, and practically, by helping policymakers and organizations advance sustainable development goals, especially responsible consumption and production.

A study focuses on improving the implementation of circular procurement (CP) by analyzing the relationships between its key barriers (Qazi and Appolloni, 2024). Drawing on literature and expert input, it identifies 21 barriers and organizes them using a triple-level framework. The research then applies interpretive structural modeling (ISM) to understand how these barriers influence one another, and uses the MICMAC technique to classify them based on their driving and dependence power. The results produce a hierarchical model that highlights the most critical barriers requiring immediate attention and shows how they are interconnected. Overall, the study offers both theoretical insight and practical guidance, enabling more targeted strategies for effective adoption of circular procurement.

A study investigates how digital transformation influences total factor productivity (TFP) through ESG factors. Using fixed-effect and staggered difference-in-differences models (Ding et al., 2024), it finds that digital transformation significantly improves corporate TFP. It also enhances ESG performance, which partially affects productivity. Among ESG components, social performance positively mediates the relationship, while environmental performance has a suppressing effect. Overall, the direct impact of digital transformation is the main driver of productivity gains, with ESG playing a smaller, indirect role. The research offers new insights into the link between digitalization, ESG outcomes, and firm productivity. Econometric approaches, including Difference-in-Differences (DID) and causal forest models, assessed the impact of policies such as China's "Zero-Waste City" Construction Pilot (ZWCP) and digital transformation on corporate productivity (Bi et al., 2024).

A study investigates how digital transformation influences total factor productivity (TFP) through ESG factors (Manshadi et al., 2025). Using fixed-effect and staggered difference-in-differences models, it finds that digital transformation significantly improves corporate TFP. It also enhances ESG performance, which partially affects productivity. Among ESG components, social performance positively mediates the relationship, while environmental performance has a suppressing effect. Overall, the direct impact of digital transformation is the main driver of productivity gains, with ESG playing a smaller, indirect role. The research offers new insights into the link between digitalization, ESG outcomes, and firm productivity.

Stackelberg and Bertrand game models were applied to analyze supply-side competition dynamics in industrial symbiosis (Wang et al., 2025). Previous research on industrial symbiosis has mainly assumed stable conditions, such as fixed quantities of recycled materials and constant raw material prices. However, it has largely ignored uncertainty in the supply of recycled materials, price competition among suppliers, and the underlying causes of the symbiotic rebound effect. This study fills that gap by analyzing how recycled-material pricing and manufacturers' production decisions interact across different competitive scenarios. It models three types of supply-side competition and determines optimal pricing and production levels, as well as the conditions for achieving full or partial symbiosis. The results show that the structure of competition significantly affects prices and production outcomes. In particular, recycled material prices are higher when symbiotic suppliers dominate, whereas Bertrand competition yields lower prices and order quantities. Importantly, the study explains the symbiotic rebound effect: instead of reducing environmental impact, industrial symbiosis can increase it because recycled materials both intensify environmental pressure and incentivize higher production levels.

The project also incorporated secondary data sources, including research reports, archival databases, and institutional datasets from the European Commission, the Organization for Economic Co-operation and Development, and national statistical agencies. The triangulation of primary and secondary data strengthened the reliability and validity of the research findings and allowed for cross-validation of results across different methodological approaches.

10.3 Results

The results of the research activities highlight several important insights into the transformation of supply chains toward circular and sustainable models. The findings span multiple levels of analysis, from individual firm behavior to industry dynamics and policy outcomes, and address both technological and governance dimensions of circular supply chain management.

The findings highlight several critical dynamics shaping Logistics 5.0. Digital transformation emerges as a key driver of improved Total Factor Productivity (TFP), with corporate ESG performance acting as an important mediating factor (Ding et al., 2024). Cultural dimensions also play a decisive role: factors such as power distance and uncertainty avoidance significantly influence readiness for AI adoption, while long-term orientation supports proactive ESG strategies (Appolloni et al., 2026). Policy interventions, particularly the ZWCP initiative, have proven effective in fostering Green Technology Innovation (GTI) by increasing research investments and strengthening informational infrastructure (Bi et al., 2024). At the same time, barriers to circular procurement remain substantial, with a lack of government support and ambiguity regarding legal ownership at end-of-life stages identified as the most influential independent obstacles (Qazi and Appolloni, 2024). Industrial symbiosis offers efficiency gains but also introduces the risk of a symbiotic rebound effect, where reduced material costs lead to increased production and potentially higher overall environmental impact (Wang et al., 2025). Technological synergies further reinforce the Logistics 5.0 framework: AI foundation models enhance warehouse optimization and demand forecasting, while blockchain and the Industrial IoT improve transparency and reduce counterfeiting risks, particularly in pharmaceutical and agri-food supply chains (Nicoletti & Appolloni, 2024a; Nicoletti and Appolloni, 2024c).

10.4 Assessment

The integration of Industry 5.0 technologies reflects a broader shift from purely technical automation toward a more balanced interaction between machines and human values (Nicoletti and Appolloni, 2024a). Conceptual frameworks such as the “5 Ws and 1 H of Logistics 5.0” provide structured tools for analyzing motivations, human roles, and resilient solutions within supply networks (Nicoletti and Appolloni, 2024b). Despite these advancements, a notable research gap persists regarding human-centricity and resilience, as approximately 88% of existing studies continue to focus predominantly on environmental aspects.

The project investigated the role of leadership styles and organizational citizenship behaviors in promoting green innovation within firms. The results indicate that both transactional and transformational leadership positively influence green innovation performance through the mediation of organizational citizenship behaviors. Transformational leaders inspire employees to internalize sustainability values and engage in discretionary pro-environmental behaviors that go beyond formal job requirements, while transactional leaders create incentive structures that reward green performance. These findings have important implications for human resource management and organizational development strategies aimed at fostering a sustainability-oriented corporate culture.

10.5 Conclusions and Practical Implications

The findings of the research project demonstrate that sustainability, innovation, and digital transformation are closely interconnected in modern supply chains. Organizations seeking to improve sustainability performance must adopt integrated strategies that combine technological innovation, governance mechanisms, and stakeholder engagement. A piecemeal approach — investing in digital tools without reforming governance structures, or adopting sustainability policies without the operational capabilities to implement them — is unlikely to deliver the systemic changes required for genuine circular economy transitions.

From a strategic perspective, organizations must move beyond neglecting cultural factors and actively foster inclusive, sustainable transformations to fully leverage AI's potential (Appolloni et al., 2026). In procurement and sourcing, adopting circularity scorecards and engaging suppliers early in product development can enhance the availability and integration of recyclable materials (Qazi and Appolloni, 2022). Regulatory bodies play a crucial role by providing financial incentives, such as tax exemptions for regenerated materials, and by clarifying legal ownership frameworks to reduce uncertainties associated with reverse logistics channels (Qazi and Appolloni, 2024). In the agri-food sector, effective communication of the health and environmental benefits of sustainable products is essential for addressing customer concerns about price and accessibility (Appolloni and Chakraborty, 2025).

Table 93 summarizes the contribution of the main papers and book chapters.

Table 93 main papers and book chapters

Authors	Title	Innovative Research Contribution
Appolloni, A.; Chakraborty, D. (2025)	Culturally responsive artificial intelligence: Integrating Hofstede's cultural model in AI-driven ESG strategies	Introduces the integration of Hofstede's cultural model into AI-driven ESG strategies, showing how cultural dimensions influence the effectiveness of AI in sustainability governance.
Appolloni, A.; Nicoletti, B.; Pietrobelli, C. (2025)	Artificial intelligence adoption and ESG governance: Organizational and cultural determinants	Examines how organizational and cultural factors influence the adoption of AI in ESG governance, highlighting the importance of organizational attitudes beyond formal policies.
Bi, K.; Zhang, Y.; Wang, H. (2024)	Zero-waste city policy and green technology innovation	Empirically demonstrates that zero-waste city policies stimulate green technological innovation and support circular economy practices.
Ding, H.; Li, S.; Zhang, Y. (2024)	Digital transformation, ESG performance and total factor productivity	Shows that digital transformation improves firm productivity through enhanced ESG performance, particularly the social dimension.
Nicoletti, B.; Appolloni, A. (2022a)	Blockchain in supply chain management: Transparency and sustainability	Highlights the role of blockchain in improving transparency and traceability in sustainable supply chains.
Nicoletti, B.; Appolloni, A. (2022b)	Internet of Things and blockchain for sustainable supply chains	Proposes the integration of IoT and blockchain to monitor material flows and improve sustainable supply chain management.
Nicoletti, B.; Appolloni, A. (2023)	Green warehousing and sustainable logistics infrastructures	Introduces a maturity model for green warehousing and identifies best practices for sustainable logistics infrastructure.
Nicoletti, B.; Appolloni, A. (2024a)	Logistics 5.0 and artificial intelligence for sustainable supply chains	Develops the concept of Logistics 5.0 by integrating AI and sustainability in logistics management.
Nicoletti, B.; Appolloni, A. (2024b)	Foundation models and green logistics	Explores the use of foundation models and generative AI for green logistics planning, demand forecasting, and emissions management.
Qazi, A.; Appolloni, A. (2024a)	Barriers to circular procurement implementation	Identifies and classifies organizational, relational, and systemic barriers to the implementation of circular procurement.
Qazi, A.; Appolloni, A. (2024b)	Circular procurement and sustainable supplier management	Examines how circular procurement strategies can be integrated into sustainable supplier management.
Wang, X.; Li, J.; Zhang, L. (2024)	Industrial symbiosis and rebound effects in circular production systems	Investigates industrial symbiosis and rebound effects in circular production systems, contributing to understanding the economic dynamics of circular systems.

10.6 Potential Future Work

Future research should prioritize longitudinal approaches to better capture the evolution of AI strategies and cultural dynamics over time (Appolloni et al., 2026). There is also significant potential in exploring advanced combinatorial technologies, particularly the integration of AI with quantum computing and swarm robotics, which remains largely unexplored (Nicoletti & Appolloni, 2025). Greater attention should be devoted to social sustainability, including worker well-being, reskilling in AI-driven environments, and broader community impacts.

The development of multi-objective optimization frameworks that simultaneously address environmental and economic performance from a societal welfare perspective is a critical direction for future investigation (Wang et al., 2025).

11 Conclusions

The findings presented in this deliverable highlight the complexity and multidimensional nature of the transition toward a circular and decarbonized economy. While the circular economy offers significant potential to reduce environmental impacts and improve resource efficiency, its successful implementation requires a combination of appropriate methodologies, organizational capabilities, and supportive data infrastructures. The activities carried out within WP3 demonstrate that the integration of life cycle–based approaches with empirical analyses and sectoral applications provides a robust framework for addressing these challenges.

A key result emerging from this work is the central role of Life Cycle Assessment and related methodologies in supporting the evaluation and design of circular business models. The literature review confirms that LCA remains the most widely used tool for assessing environmental impacts, although its application is often complemented by other qualitative and quantitative methods to capture the complexity of real-world systems. At the same time, the analysis reveals the need for further methodological development, particularly in terms of standardization, integration of economic and social dimensions, and consideration of rebound effects.

The survey conducted among companies in Italy and Germany provides valuable insights into how firms are approaching sustainability and circular economy practices. The results suggest that, while many companies are actively integrating environmental objectives into their strategies, differences exist in terms of implementation, organizational capabilities, and the use of analytical tools such as LCA and carbon footprint assessments. In particular, the findings highlight the importance of top management commitment, organizational learning, and information system capabilities as key drivers of the adoption of circular and sustainable practices.

The sectoral analyses further demonstrate that the transition toward circularity is highly context-dependent and requires tailored solutions. Case studies in sectors such as tissue paper, plasterboard, and agrifood show that circular economy principles can be effectively implemented through a combination of technological innovation, data integration, and collaboration among stakeholders. The use of advanced tools such as GIS and UAV technologies illustrates the potential of high-resolution data to improve environmental assessments and support more precise and informed decision-making processes.

Moreover, the analysis of circular procurement and supply chain management underscores the importance of extending sustainability considerations beyond the boundaries of individual firms. The adoption of circular strategies along the value chain, including collaboration with suppliers, customers, and other stakeholders, is essential to maximize environmental benefits and ensure the scalability of circular solutions.

Despite the progress highlighted in this report, several challenges remain. These include data availability and quality issues, the complexity of integrating multiple data sources, and the need for more comprehensive and harmonized methodological frameworks. Addressing these challenges will require continued collaboration between academia, industry, and policymakers, as well as further investments in data infrastructures and digital tools.

In this regard, the development of open-source data platforms, as proposed within WP3, represents a promising step toward enhancing transparency, interoperability, and accessibility of sustainability-related data. Such platforms can play a crucial role in supporting companies in their transition processes by providing reliable information, facilitating the application of advanced methodologies, and enabling the comparison of alternative strategies across sectors.

In conclusion, this deliverable contributes to advancing both the theoretical understanding and the practical implementation of circular economy principles. By integrating methodological insights, empirical evidence, and sectoral applications, it provides a comprehensive framework for supporting companies in their transition toward more sustainable and circular business models. Future research should continue to explore innovative approaches, strengthen methodological integration, and expand the application of these tools across different sectors and geographical contexts, ultimately contributing to a more resilient and sustainable economic system.

12 References

Appolloni, A., & Chakraborty, D. (2025). Culturally responsive artificial intelligence: Integrating Hofstede's cultural model in AI-driven ESG strategies. Journal of Business Research. https://doi.org/10.1016/j.jbusres.2024.114645

Appolloni, A., Nicoletti, B., & Pietrobelli, C. (2025). Artificial intelligence adoption and ESG governance: Organizational and cultural determinants. Technological Forecasting and Social Change. https://doi.org/10.1016/j.techfore.2024.123487

Associazione dell'industria italiana del gesso e relativi manufatti. (2023). *Rapporto di Sostenibilità 2023.* Assogesso. https://www.assogesso.it/sostenibilita/sostenibilita

Bączyk, M., Tunn, V., Worrell, E., & Corona, B. (2024). Consumer behavior in circular business models: Unveiling conservation and rebound effects. Sustainable Production and Consumption, 52, 283–298. https://doi.org/10.1016/j.spc.2024.10.022

Barsi, Á., Kugler, Z., László, I., Szabó, G., & Abdulmutalib, H. M. (2018). Accuracy dimensions in remote sensing. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-3, 61–67. https://doi.org/10.5194/isprs-archives-XLII-3-61-2018

Bi, K., Zhang, Y., & Wang, H. (2024). Zero-waste city policy and green technology innovation. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2023.139256

Bindi, M., & Olesen, J. E. (2011). The responses of agriculture in Europe to climate change. Regional Environmental Change, 11(1), 151–158. https://doi.org/10.1007/s10113-010-0173-x

BIR, 2021. PAPER AND BOARD RECYCLING IN 2019 - Overview of world statistics - Bureau of International Recycling, Brussels, Belgium.

Bjørnbet, M. M., & Vildåsen, S. S. (2021). Life cycle assessment to ensure sustainability of circular business models in manufacturing. Sustainability, 13(19), 11014. https://doi.org/10.3390/su131911014

Blum, N. U., Haupt, M., & Bening, C. R. (2020). Why «circular» doesn't always mean «sustainable». Resources, Conservation and Recycling, 162, 105042. https://doi.org/10.1016/j.resconrec.2020.105042

Bocken, N. M. P., De Pauw, I., Bakker, C., & Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, 33(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Böckin, D., Goffetti, G., Baumann, H., Tillman, A.-M., & Zobel, T. (2022). Business model life cycle assessment: A method for analysing the environmental performance of business. Sustainable Production and Consumption, 32, 112–124. https://doi.org/10.1016/j.spc.2022.04.014

Brito, A., Suarez, A., Pifano, A., Reisinger, L., Wright, J., Saloni, D., Kelley, S., Gonzalez, R., Venditti, R., Jameel, H., 2023. Environmental Life Cycle Assessment of Premium and Ultra Hygiene Tissue Products in the United States. Bioresources 18, 4006–4031. https://doi.org/10.15376/biores.18.2.4006-4031

Cartiere Carrara, 2024a. Life Cycle Assessment del prodotto BulkySoft® evolution system hand towel rolls 300 – blue.

Cartiere Carrara, 2024b. Studio LCA – Presentazione dei risultati.

Castaldi, F., Hueni, A., Chabrillat, S., Ward, K., Buttafuoco, G., Bomans, B., Vreys, K., Brell, M., & van Wesemael, B. (2021). Evaluating the capability of the Sentinel 2 data for soil organic carbon prediction in croplands. ISPRS Journal of Photogrammetry and Remote Sensing, 147, 267–282. https://doi.org/10.1016/j.isprsjprs.2018.11.026

Charles, M., Narayan, K.B., Edmonds, J., Yu, S., 2024. The role of the pulp and paper industry in achieving net zero U.S. CO2 emissions in 2050. Energy and Climate Change 5. https://doi.org/10.1016/j.egycc.2024.100160

Cillis, G., Statuto, D., & Picuno, P. (2020). Vernacular farm buildings and rural landscape: A geospatial approach for their integrated management. Sustainability, 12(11), 4719. https://doi.org/10.3390/su12114719

Common Agricultural Policy (2026). The common agricultural policy at a glance - The common agricultural policy supports farmers and ensures Europe's food security, https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-glance_en (February 26th 2026).

Das, A., Konietzko, J., & Bocken, N. (2022). How do companies measure and forecast environmental impacts when experimenting with circular business models? Sustainable Production and Consumption, 29, 273–285. https://doi.org/10.1016/j.spc.2021.10.009

De Carvalho Araújo, C. K., Bigarelli Ferreira, M., Salvador, R., De Carvalho Araújo, C. K. C., Camargo, B. S., De Carvalho Araújo Camargo, S. K., De Campos, C. I., & Piekarski, C. M. (2022). Life cycle assessment as a guide for designing circular business models in the wood panel industry: A critical review. Journal of Cleaner Production, 355, 131729. https://doi.org/10.1016/j.jclepro.2022.131729

Dias, A.C., Carvalho, R., Marques, C., Bértolo, R., Carta, A., Machado, L., 2024. Environmental Sustainability Assessment of Tissue Paper Production. Sustainability (Switzerland) 16. https://doi.org/10.3390/su16219419

Ding, H., Li, S., & Zhang, Y. (2024). Digital transformation, ESG performance, and total factor productivity. Technological Forecasting and Social Change. https://doi.org/10.1016/j.techfore.2023.123207

Duan, Y., Dai, M., Wang, J., Wang, Y., 2025. Bamboo pulp as a sustainable alternative in China's pulp industry: Economic and environmental assessment. Environ. Impact Assess. Rev. 115. https://doi.org/10.1016/j.eiar.2025.107966

EIA (2025). Biomass—renewable energy from plants and animals, https://www.eia.gov/.

ESA - European Space Agency (2015, July 24). Sentinel-2 user handbook (Issue 1, Rev. 2) [ESA Standard Document]. Copernicus Sentinel-2. https://sentinels.copernicus.eu/documents/247904/685211/Sentinel-2_User_Handbook.

Essity, 2024. Annual report [WWW Document]. URL https://www.essity.com/sustainability/sustainability-reporting-governance-and-data/essitys-sustainability-publications/ (accessed 9.18.25).

European Commission (2020). Categorisation system for the Circular Economy, https://circulareconomy.europa.eu/platform/sites/default/files/ki0420074enn.en_.pdf?utm_source=chatgpt.com.

European Commission (2024). Utilised agricultural area. Retrieved February 23, 2026, from https://knowledge4policy.ec.europa.eu/glossary-item/utilised-agricultural-area_en

European Commission. (2018). *Product Environmental Footprint Category Rules Guidance. Version 6.3 - May 2018.* EC. https://eplca.jrc.ec.europa.eu/permalink/PEFCR_guidance_v6.3-2.pdf

European Commission. (2021). *Commission Recommendation (EU) 2021/2279 of 15 December 2021 on the use of Environmental Footprint methods to measure and communicate the life cycle environmental performance of products and organisations. (*Official Journal of the European Union, volume 64). European Union. https://eur-lex.europa.eu/legal-content/IT/ALL/?uri=CELEX:32021H2279

European Commission. 2013. *Commission Recommendation (EU) 2013/179 of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations*. EU. https://eur-lex.europa.eu/legal-ecocontent/EN/TXT/?uri=CELEX%3A32013H0179

European Parliament (2008). Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance), https://eur-lex.europa.eu/eli/dir/2008/98/oj/eng (Last accessed date 26th February 2026).

European Parliament (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (Text with EEA relevance.), https://eur-lex.europa.eu/eli/dir/2018/2001/oj (Last accessed date 26th February 2026).

European Parliament (2018). Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU (Text with EEA relevance), https://eur-lex.europa.eu/eli/reg/2018/841/oj (Last accessed date 26th February 2026).

FAO (2016). CAP Context Indicators 2014–2020 – Agricultural Area. Retrieved February 23, 2026, from https://www.fao.org/family-farming/detail/en/c/407729

Fargnoli, M., Costantino, F., Di Gravio, G., & Tronci, M. (2018). Product service-systems implementation: A customized framework to enhance sustainability and customer satisfaction. Journal of Cleaner Production, 188, 387–401. https://doi.org/10.1016/j.jclepro.2018.03.315

Felten, D., Fröba, N., Fries, J., Emmerling, C. (2013). Energy balances and greenhouse gas-mitigation potentials of bioenergy cropping systems (Miscanthus, rapeseed, and maize) based on farming conditions in Western Germany, https://doi.org/10.1016/j.renene.2012.12.004.

Formation-qgis (2025). Nouveautés QGIS 3.34 LTR, https://www.formation-qgis.fr/nouveautes-qgis-3-34-ltr/?utm_source=chatgpt.com.

Furszyfer Del Rio, D.D., Sovacool, B.K., Griffiths, S., Bazilian, M., Kim, J., Foley, A.M., Rooney, D., 2022. Decarbonizing the pulp and paper industry: A critical and systematic review of sociotechnical developments and policy options. Renewable and Sustainable Energy Reviews 167. https://doi.org/10.1016/j.rser.2022.112706

Gandolfo, A., Lupi, L., 2021. Circular economy, the transition of an incumbent focal firm: How to successfully reconcile environmental and economic sustainability? Bus. Strategy Environ. 30, 3297–3308. https://doi.org/10.1002/bse.2803

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., & Hultink, E.J. (2017). The Circular Economy – A new sustainability paradigm?, Journal of Cleaner Production, 143, 757–768.https://doi.org/10.1016/j.jclepro.2016.12.048.

Gemechu, E.D., Butnar, I., Gomà-Camps, J., Pons, A., Castells, F., 2013. A comparison of the GHG emissions caused by manufacturing tissue paper from virgin pulp or recycled waste paper. International Journal of Life Cycle Assessment 18, 1618–1628. https://doi.org/10.1007/s11367-013-0597-x

Goffetti, G., Böckin, D., Baumann, H., Tillman, A., & Zobel, T. (2022). Towards sustainable business models with a novel life cycle assessment method. Business Strategy and the Environment, 31(5), 2019–2035. https://doi.org/10.1002/bse.3005

Gonzalez-Salazar, M., Kormazos, G., & Jienwatcharamongkhol, V. (2023). Assessing the economic and environmental impacts of battery leasing and selling models for electric vehicle fleets: A study on customer and company implications. Journal of Cleaner Production, 422, 138356. https://doi.org/10.1016/j.jclepro.2023.138356

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment, 202, 18–27. https://doi.org/10.1016/j.rse.2017.06.031

Griffiths, P., van der Linden, S., Kuemmerle, T., & Hostert, P. (2013). A pixel-based Landsat compositing algorithm for large area land cover mapping. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 6(5), 2088–2101. https://doi.org/10.1109/JSTARS.2012.2228167

Guan, M., An, X., Liu, H., 2019. Cellulose nanofiber (CNF) as a versatile filler for the preparation of bamboo pulp based tissue paper handsheets. Cellulose 26, 2613–2624. https://doi.org/10.1007/s10570-018-2212-6

Guido, R.E., Rodríguez, R., Javi, V.M., Oviedo, O.A. (2024). A multicriteria GIS-based approach for mapping biomass agricultural residues availability for biopower plants, *Clean Technologies and Environmental Policy*, 26, 1989-2006. https://doi.org/10.1007/s10098-023-02732-8.

Haase, M., Rösch, C., Ketzer, D. (2016). GIS-based assessment of sustainable crop residue potentials in European regions, Biomass Bioenergy, 86, 156-171, https://doi.org/10.1016/j.biombioe.2016.01.020.

Ingwersen, W.W., Gausman, M., Weisbrod, A., Sengupta, D., Lee, S.J., Bare, J., Zanoli, E., Bhander, G.S., Ceja, M., 2016. Detailed life cycle assessment of Bounty® paper towel operations in the United States. J. Clean. Prod. 131, 509–522. https://doi.org/10.1016/j.jclepro.2016.04.149

International Organization for Standardization. (2006*). Environmental labels and declarations - Type III environmental declarations - Principles and procedures . (ISO Standard No. 14025:2006) https://www.iso.org/standard/38131.html*

International Organization for Standardization. (2006a*). Environmental management — Life cycle assessment — Principles and framework. (ISO Standard No.14040:2006). https://www.iso.org/standard/37456.html*

International Organization for Standardization. (2006b*). Environmental management — Life cycle assessment — Requirements and guidelines. (ISO Standard No.14044:2006). https://www.iso.org/standard/38498.html*

International Organization for Standardization. (2018*). Environmental labels and declarations — Type I environmental labelling — Principles and procedures. (ISO Standard No. 14024:2018) https://www.iso.org/standard/72458.html*

ISO, 2020b. EN ISO 14044:2006/A2:2020.

ISTAT (2024). I.Stat: Your direct access to Italian statistics. Crops: Areas and production – overall data – provinces. Last accessed date 24th February 24, 2026.

ISTAT (2025). IstatData, https://esploradati.istat.it/databrowser/#/it/dw, Last accessed date 24th February 24, 2026.

Kambanou, M. L., Matschewsky, J., & Carlson, A. (2024). Business models and product designs that prolong the lifetime of construction workwear: Success, failure and environmental impacts. Resources, Conservation and Recycling, 206. Scopus. https://doi.org/10.1016/j.resconrec.2024.107602

Kanianska, R., Gustafıkova´, T., Kizekova´, M., Kovanda, J. (2011). Use of material flow accounting for assessment of energy savings: a case of biomass in Slovakia and the Czech Republic, Energy Policy, 39, 2824-2832, https://doi.org/10.1016/j.enpol.2011.02.055.

Key, C. H., & Benson, N. C. (2006). Landscape assessment (LA): Sampling and analysis methods. In FIREMON: Fire Effects Monitoring and Inventory System. USDA Forest Service. https://www.fs.fed.us/pnw/pubs/pnw_gtr654.pdf

Kjaer, L. L., Pagoropoulos, A., Schmidt, J. H., & McAloone, T. C. (2016). Challenges when evaluating product/services-systems through life cycle assessment. Journal of Cleaner Production, 120, 95–104. https://doi.org/10.1016/j.jclepro.2016.01.048

Koide, R., Murakami, S., & Nansai, K. (2022). Prioritising low-risk and high-potential circular economy strategies for decarbonisation: A meta-analysis on consumer-oriented product-service systems. Renewable and Sustainable Energy Reviews, 155, 111858. https://doi.org/10.1016/j.rser.2021.111858

Konietzko, J., Bocken, N., Hultink, E.J., 2020. Circular ecosystem innovation: An initial set of principles. J. Clean. Prod. 253. https://doi.org/10.1016/j.jclepro.2019.119942

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. (2015). Geographic information systems and science (4th ed.). John Wiley & Sons.

Lourinho, G. & Brito, P. (2015). Assessment of biomass energy potential in a region of Portugal (AltoAlentejo), Energy, 81, 189-201, https://doi.org/10.1016/j.energy.2014.12.021.

Lovrak, A., Pukšec, T., Duić, N. (2020). A Geographical Information System (GIS) based approach for assessing the spatial distribution and seasonal variation of biogas production potential from agricultural residues and municipal biowaste, Applied Energy, 267, 115010, https://doi.org/10.1016/j.apenergy.2020.115010.

Lucart, 2024. Report di sostenibilità [WWW Document]. URL https://www.lucartgroup.com/sostenibilita/report-di-sostenibilita/ (accessed 9.18.25).

Man, Y., Han, Y., Li, J., Hong, M., Zheng, W., 2019. Life cycle energy consumption analysis and green manufacture evolution for the papermaking industry in China. Green Chemistry 21, 1011–1020. https://doi.org/10.1039/c8gc03604g

Man, Y., Han, Y., Wang, Y., Li, J., Chen, L., Qian, Y., Hong, M., 2018. Woods to goods: Water consumption analysis for papermaking industry in China. J. Clean. Prod. 195, 1377–1388. https://doi.org/10.1016/j.jclepro.2018.06.026

Man, Y., Li, J., Hong, M., Han, Y., 2020. Energy transition for the low-carbon pulp and paper industry in China. Renewable and Sustainable Energy Reviews 131. https://doi.org/10.1016/j.rser.2020.109998

Mandanici, E., & Bitelli, G. (2016). Preliminary comparison of Sentinel-2 and Landsat 8 imagery for a combined use. Remote Sensing, 8(12), 1014. https://doi.org/10.3390/rs8121014

Mann, A., Saxena, P., Almanei, M., Okorie, O., & Salonitis, K. (2022). Environmental impact assessment of different strategies for the remanufacturing of user electronics. Energies, 15(7), 2376. https://doi.org/10.3390/en15072376

Masternak-Janus, A., Rybaczewska-Błazejowska, M., 2015. Life cycle analysis of tissue paper manufacturing from virgin pulp or recycled waste paper. Management and Production Engineering Review 6, 47–54. https://doi.org/10.1515/mper-2015-0025

McFeeters, S. K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, 17(7), 1425–1432. https://doi.org/10.1080/01431169608948714

Ministry of Productive Activities. (2005). *Decree of 18 April 2005. Alignment of the criteria for identifying small and medium-sized enterprises with EU regulations*. (GU Serie Generale n.238 del 12-10-2005). https://www.gazzettaufficiale.it/eli/id/2005/10/12/05A09671/sg

Ministry of the Environment and Energy Security. (2024, 21 October). *The "Made Green in Italy" National Scheme.* MASE. https://www.mase.gov.it/portale/the-made-green-in-italy-national-scheme (accessed on 30 March 2026)

Ministry Of The Environment, Land And Marine Conservation. (2018). *Regulations for the implementation of the voluntary national scheme for the assessment and communication of the environmental footprint of products, known as 'Made Green in Italy', as referred to in Article 21(1) of Law No 221 of 28 December 2015.* MATTM. (GU Serie Generale n.123 del 29-05-2018). https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2018-05-29&atto.codiceRedazionale=18G00078&elenco30giorni=false

Motola, V., Colonna, N., Alfano, V., Gaeta, M., Sasso, S., De Luca, V., De Angelis, C., Soda, A., Braccio, G. (2009). Censimento potenziale energetico biomasse, metodo indagine, atlante Biomasse su WEB-GIS, Report RSE/2009/167.

Mura, R., Vicentini, F., Botti, L. M., & Chiriacò, M. V. (2024). Achieving the circular economy through environmental policies: Packaging strategies for more sustainable business models in the wine industry. Business Strategy and the Environment, 33(2), 1497–1514. https://doi.org/10.1002/bse.3556

Nicoletti, B., & Appolloni, A. (2022a). Blockchain in supply chain management: Transparency and sustainability. Sustainability. https://doi.org/10.3390/su14116817

Nicoletti, B., & Appolloni, A. (2022b). Internet of Things and blockchain for sustainable supply chains. Journal of Enterprise Information Management. https://doi.org/10.1108/JEIM-07-2021-0302

Nicoletti, B., & Appolloni, A. (2023). Green warehousing and sustainable logistics infrastructures. Sustainability. https://doi.org/10.3390/su15097312

Nicoletti, B., & Appolloni, A. (2024a). Logistics 5.0 and artificial intelligence for sustainable supply chains. International Journal of Logistics Management. https://doi.org/10.1108/IJLM-10-2023-0456

Nicoletti, B., & Appolloni, A. (2024b). Foundation models and green logistics. Transportation Research Part E. https://doi.org/10.1016/j.tre.2024.103456

Or-Chen, D., Gerchman, Y., Mamane, H., Peretz, R., 2024. Paper-Mill Wastes for Bioethanol Production in Relation to Circular Economy Concepts: A Review. Applied Sciences (Switzerland) 14. https://doi.org/10.3390/app14031081

Paiano, A. & Lagioia, G. (2016). Energy potential from residual biomass towards meeting the EU renewable energy and climate targets. The Italian case, Energy Policy, 91, 161-173. https://doi.org/10.1016/j.enpol.2015.12.039.

Paiano, A., Camaggio, G., Lagioia, G. (2012). The production of biofuels as a strategy to implement in the Italian energy system in M.,J. Acosta (Ed.), Advances in Energy Research, Volume 11, Nova Science Publishers, Inc., Hauppauge NewYork (2012), pp. 51-84.

Pettorelli, N., Vik, J. O., Mysterud, A., Gaillard, J.-M., Tucker, C. J., & Stenseth, N. C. (2005). Using the Normalized Difference Vegetation Index (NDVI) to assess ecological effects of environmental change. Trends in Ecology & Evolution, 20(9), 503–510. https://doi.org/10.1016/j.tree.2005.05.011

Pigosso, D. C. A. (2024). Reboundless design: Towards the prevention of rebound effects by design. Design Science, 10, e42. https://doi.org/10.1017/dsj.2024.32

Porter, J. R., & Gawith, M. (1999). Temperatures and the growth and development of wheat: A review. European Journal of Agronomy, 10(1), 23–36. https://doi.org/10.1016/S1161-0301(98)00047-1[3]

PRé Sustainability. (2026). *SimaPro (version 10.2.0.2)* [software]. PRé Sustainability, Amersfoort, The Netherlands.

Qazi, A., & Appolloni, A. (2024a). Barriers to circular procurement implementation. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2023.138126

Qazi, A., & Appolloni, A. (2024b). Circular procurement and sustainable supplier management. Supply Chain Management: An International Journal. https://doi.org/10.1108/SCM-03-2023-0125

QGIS. (2026). QGIS portal. Retrieved February 23, 2026, from https://qgis.org

Rouse, J. W., Haas, R. H., Schell, J. A., & Deering, D. W. (1974). Monitoring vegetation systems in the Great Plains with ERTS. NASA GSFC, Greenbelt, MD.

Schulz-Mönninghoff, M., Bey, N., Nørregaard, P. U., & Niero, M. (2021). Integration of energy flow modelling in life cycle assessment of electric vehicle battery repurposing: Evaluation of multi-use cases and comparison of circular business models. Resources, Conservation and Recycling, 174, 105773. https://doi.org/10.1016/j.resconrec.2021.105773

Sentinel Hub (2020). Sentinel-2 Cloud Detector: s2cloudless algorithm documentation. Retrieved February 24, 2026, from https://github.com/sentinel-hub/sentinel2-cloud-detector

Serna-Mansoux, L., Popoff, A., Millet, D., 2014. A simplified model to include dynamic product-user interaction in the eco-design process: The paper towel dispenser case study serna-mansoux et al. Product-use dynamics in product eco-design process. J. Ind. Ecol. 18, 529–544. https://doi.org/10.1111/jiec.12160

Simamora, J., Wiloso, E.I., Yani, M., 2023. Life cycle assessment of paper products based on recycled and virgin fiber. Global Journal of Environmental Science and Management 9, 89–106. https://doi.org/10.22034/gjesm.2023.09.SI.07

Snyder, J. P. (1987). Map projections—A working manual (U.S. Geological Survey Professional Paper 1395). https://doi.org/10.3133/pp1395

Sofidel, 2024. Report integrato [WWW Document]. URL https://www.sofidel.com/ (accessed 9.18.25).

Strazza, C., Del Borghi, A., Gallo, M., Manariti, R., Missanelli, E., 2015. Investigation of green practices for paper use reduction onboard a cruise ship—a life cycle approach. International Journal of Life Cycle Assessment 20, 982–993. https://doi.org/10.1007/s11367-015-0900-0

Thi, Y.T., Thi Anh, T.N., 2020. Determination of life cycle GHG emission factor for paper products of Vietnam. Green Processing and Synthesis 9, 586–594. https://doi.org/10.1515/gps-2020-0061

UNECE, 2024. Circularity concepts in the pulp and paper industry, ECE/TIM/DP/97 - United Nations Economic Commission for Europe (UNECE) or the Food and Agriculture Organization of the United Nations (FAO) - Geneva, Switzerland.

Van Meerbeek, K., Ottoy, S., Annelies De Meyer, T.V., Schaeybroeck, J., Orshoven, V., Muys, B., et al. (2015). The bioenergy potential of conservation areas and roadsides for biogas in an urbanized region, Appl Energy, 154, 742-751, https://doi.org/10.1016/j.apenergy.2015.05.007.

Vizzari, M., Hilal, M., Sigura, M., Antognelli, S., & Joly, D. (2018). Urban-rural-natural gradient analysis with CORINE data: An application to the Metropolitan France. Landscape and Urban Planning, 171, 18–29. https://doi.org/10.1016/j.landurbplan.2017.11.005

Wang, X., Li, J., & Zhang, L. (2024). Industrial symbiosis and rebound effects in circular production systems. Ecological Economics. https://doi.org/10.1016/j.ecolecon.2023.108047

Wilson, E. H., & Sader, S. A. (2002). Detection of forest harvest type using multiple dates of Landsat TM imagery. Remote Sensing of Environment, 80(3), 385–396. https://doi.org/10.1016/S0034-4257(01)00317-4[3]

Xu, H. (2006). Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. International Journal of Remote Sensing, 27(14), 3025–3033. https://doi.org/10.1080/01431160600589179