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Introducing the circular assessment of suppliers (CAoS) tool: A Kraljic matrix-based tool to facilitate circular procurement in private organizations

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ABSTRACT

The emerging paradigm of the circular economy necessitates instruments capable of monitoring advancements in a timely and reliable fashion, thereby fostering superior decision-making and instantaneous feedback within corporations. Although numerous tools offer comprehensive evaluations of a company's circular endeavors, certain strategic facets associated with the circular economy are often overlooked. For example, there is a notable scarcity of frameworks or tools designed to assist private businesses in choosing suppliers in alignment with circular economy principles. This manuscript aims to introduce the Circular Assessment of Suppliers (CAoS) tool, a straightforward instrument that private organizations may utilize to gauge their suppliers' adherence to circular principles. The tool's genesis is rooted in the Kraljic Matrix, an approach employed to categorize a company's suppliers by subdividing them based on the intricacy of the supply market. Its development was concluded after conducting a review of the literature concerning circular supply chains and then choosing the appropriate criteria with expert guidance. This manuscript also unveils industrial implementations of this tool, as evidenced by two case studies. By integrating such a tool, a company can dynamically evaluate all suppliers, thus augmenting the circularity of procurement decisions. This tool could also function as a means to engage suppliers in dialogues about mutual circular priorities within the value chain.

1. Introduction

Over the decades, corporate social responsibility (CSR), which implies that companies have responsibilities toward the societies in which they operate and make profits (Kolling et al., 2023), has received attention in both academic and professional communities (Wang et al., 2016). CSR encompasses aspects of business ethics and human rights as well as environmental related matters (Koh et al., 2022). Within the environmental domain, circular economy practices have emerged as a key component of CSR, reflecting the growing emphasis on sustainable business operations (Kolling et al., 2023). Building on this evolution in CSR, recent advancements in the circular economy paradigm challenge the traditional linear production model, introducing innovative concepts that extend the utility of goods, materials, and resources beyond their initial consumption and disposal (Ghisellini et al., 2016).

As the world grapples with transformative shifts such as the circular economy, there is an immediate demand for tools and frameworks that facilitate progress in a prompt, reliable manner, thereby enhancing decision-making and real-time feedback in businesses (Di Maio et al., 2017). In this context, several researchers have commenced developing tools to delve into the multifaceted nature of circularity, providing valuable insights to firm management for enhancing circularity (Cayzer et al., 2017; Ellen MacArthur Foundation, 2015; Evans and Bocken, 2014). These tools, accessible to firms of all sizes, require no specific personnel training and can operate with limited data, yet they can still deliver beneficial suggestions to the end-user. The potential impact of such tools could be significant, especially when considering that Small and Medium Enterprises (SMEs), though individually having minimal environmental impact, cumulatively exert a substantial environmental footprint, dominating the business landscape in the US and Europe (Parker et al., 2009).

A prime example of tools to gauge circularity is the Material Circularity Indicator (MCI), an initiative by the Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2015). This tool, purposed for assessing a firm's products and business models, is freely accessible online as an Excel sheet. Based on a handful of queries regarding material origin,

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usage intensity, recycling, and reuse activities, the tool is fairly easy to use.

Numerous other instruments, such as the CEIP tool (Cayzer et al., 2017), and those developed by Evans and Bocken (2014), are available to measure circular performance. Saidani et al. (2019) cataloged 55 tools recently designed to support businesses transitioning toward a circular economy.

Despite the plethora of tools for comprehensive circular performance assessment of a company, certain strategic aspects related to the circular economy are neglected.

It is important to note that, to our knowledge, there are very few practical tools presently available to assist businesses in selecting suppliers in accordance with circular economy principles. Given the escalating pressures on organizations to embed CSR practices in their supply chains, supplier selection emerges as a pivotal process. This underscores the urgency for targeted research to delve into the specific environmental aspects within CSR-centric procurement strategies. In this context, integrating circular economy principles into procurement activities, as emphasized by Qazi and Appolloni (2022), becomes a critical aspect of CSR, representing a significant step towards sustainable business practices. Although numerous documents and research related to public administration purchases exist, including guidelines for public tenders (Alhola et al., 2019; Katriina et al., 2017; Kristensen et al., 2021), these do not always meet the needs of private companies, as public purchases often only extend to specific products or services (Alhola et al., 2019). The procurement function encompasses the acquisition of goods and services, and is occasionally referred to as the sourcing, purchasing, or supply function (Sanders, 2020). It bears significant operational, financial, and environmental implications for private organizations. Procurement, which accounts for over 50% of total product/service costs, has surfaced as a pivotal factor in an organization's success by enhancing overall performance and optimizing supplier management (Monczka et al., 2015). Considering the weight of procurement, the adoption of circular procurement—which bridges procurement practices with circular economy principles—is vital to realizing circular objectives at both micro and macro levels.

Several definitions of circular procurement exist (Khan et al., 2021). Nevertheless, the most widely accepted definition of circular procurement (Xu et al., 2022), as posited by the United Nations Environment Programme (UNEP), states that "Circular procurement occurs when the buyer purchases products or services that adhere to the principles of the circular economy, aiding the assessment of designing, making, selling, reusing and recycling products to ascertain how to extract maximum value from them, both in usage and at the end of their life" (UNEP, 2021). In our study, we have opted to adopt this definition of circular procurement. In line with this definition, circular procurement is implemented by assessing and selecting suppliers based on their capacity to contribute to the principles of the circular economy. Thus, businesses can evaluate their suppliers using various circular economy criteria or impose requirements on them to achieve circular economy performance alongside the traditional standards of cost, quality, safety, and technical performance (Carballo-Penela et al., 2018).

Navigating the paradox between economic efficiency (expressed by criteria such as cost and quality, among others) and circular economy in supplier selection can be difficult, and often result in a dynamic tension between these typically competing business objectives (Xiao et al., 2019). In this context, a tool for supplier selection could simplify the decision-making process, not only reducing cognitive workload for managers but also enabling them to recognize conflicting concepts and develop effective strategies for complex scenarios. The paper thus aims to contribute to the literature by introducing a tool designed to assist businesses in selecting suppliers in accordance with circular economy principles.

The tool showcased in this study is based on the Kraljic Matrix. Criteria for circular supplier selection were identified through a comprehensive review of circular supply chain literature and with input from experts. This tool comprises 10 criteria, assessed through a mix of qualitative and quantitative questions. These criteria have been evaluated by both business and academic experts to ensure their broad applicability for most service and manufacturing suppliers and ease of data acquisition. The paper also includes two case studies from businesses that have implemented the tool. The tool is also provided as an Excel file attachment in this research. Such a tool offers a general picture of a company's suppliers' circularity performance, thereby enhancing the circularity of purchasing decisions. It could also serve as an instrument for engaging suppliers in dialogues about shared circular priorities in the value chain. By offering this tool, we address the demand for further research into how private procurement might facilitate the transition to a circular economy.

The paper is organized as follows: section 2 introduces the theoretical and practical literature that forms the foundation for the development of the tool. Section 3 outlines the methodological approach used to develop the tool. Section 4 details the functioning of the tool and presents two case studies of its application. Section 5 discusses the results within the context of the relevant theoretical and practical literature. Finally, section 6 presents the conclusions of the study.

2. Literature background

2.1. Navigating paradoxes in supply chain management

In the academic literature, a paradox is characterized as "persistent contradictions among interdependent elements" (Lewis, 2000, p. 760). Effective management of these paradoxes can open new growth opportunities for organizations (Smith et al., 2017). Recent research has begun to adopt an explicit paradox perspective in examining sustainability tensions, as evidenced in studies by Slawinski and Bansal (2015), Sharma and Bansal (2017), and Xiao et al. (2019). For instance, in their research, Hahn et al. (2014) developed a conceptual framework focusing on managerial sensemaking. The authors concluded that managers with a paradoxical perspective tend to possess a dual understanding of sustainability issues, characterized by both contradictory viewpoints and a more deliberate, thorough approach to addressing these issues. This is attributed to their increased awareness of potential risks and tensions.

Paradox theory has also been integrated into sustainable supply chain management, acknowledging the rise of conflicting objectives in the industry and suggesting its utility for practitioners (Zhang et al., 2021). When managers view sustainability and conventional business goals as conflicting, they tend to prioritize one over the other, leading to a trade-off situation (Angus-Leppan et al., 2010). This approach, causes managers to favor their preferred aspect, often neglecting the other (Hargrave and Van de Ven, 2017), and results in a lack of engagement with the tensions between business and sustainability goals (Van der Byl and Slawinski, 2015). In such a context, the challenge lies in broadening the mindset of managers who have been educated in binary thinking, where complexity is simplified into a choice between "x" or "y" (Marsh and Macalpine, 1999).

In supply chain management, while purchasing managers focus on traditional goals like delivery reliability, quality, and cost, sustainability managers emphasize different aspects like sustainability practices. However, embracing of a paradox perspective argue that acknowledging and accepting contradictory elements as valid and interdependent can enhance managerial and organizational effectiveness (Lewis, 2000; Lüscher and Lewis, 2008; Smith and Lewis, 2011).

Lüscher and Lewis (2008) advocate for managers to engage in paradoxical thinking, a process wherein they can embrace and interpret contradictions, understanding that resolving dilemmas may often necessitate amalgamating opposing solutions. This concept empowers individuals to acknowledge conflicting ideas and formulate effective strategies for complex situations (Xiao et al., 2019). Paradoxical thinking, within this framework, can resolve tensions by transitioning to a more holistic and inclusive approach that recognizes the interrelatedness and mutual dependence of contrasting elements (Andriopoulos and Lewis, 2009).

The tool proposed in this research demonstrates how embracing these paradoxes can foster innovative and effective solutions. Specifically, this tool aids in navigating the paradox between economic efficiency and circular economy, mirroring the dynamic tension between these typically competing business objectives. More precisely, implementing a tool for supplier selection could streamline the decision-making process, reducing cognitive workload for managers but also empowering them to acknowledge conflicting ideas and formulate effective strategies for complex situations.

2.2. Tools and criteria for the selection of circular suppliers

Academic literature has devoted considerable attention to the topic of supplier selection. Initially, most research focused on identifying criteria related to quality, price, the supplier's ability to meet deadlines, and historical performance in identifying appropriate suppliers (e.g., Weber et al., 1991; Choi and Hartley, 1996; Thiruchelvam and Tookey, 2011). More recently, with the emergence of sustainability themes, these have also begun to appear in supplier selection research. The literature on green supply chain management (GSCM) asserts that suppliers should enhance their environmental performance by obtaining certifications or proposing green practices (Fu et al., 2012).

Several studies elucidate how supplier selection in green supply chain management is considered a significant procurement decision (Seuring and Müller, 2008).

While numerous studies have explored the subject from diverse angles, including green and sustainable supplier perspectives, the literature still insufficiently addresses supplier selection from a circular economy standpoint (Haleem et al., 2021). Only in recent years has this topic begun to gain increasing importance. Indeed, initially, circularity themes and circular economy practices were studied within the corporate environment (Gusmerotti et al., 2019), but today the role of the supply chain in transitioning towards the circular economy paradigm in companies is becoming increasingly relevant (Amir et al., 2023).

In research on the topic, academic studies predominate, proposing approaches for selecting suitable indicators for choosing one or more suppliers. For instance, Alavi et al. (2021) introduced a decision support system that allows companies to customize and allocate weights to economic, social, and circular criteria using a fuzzy best-worst method. To demonstrate the proposed approach, the authors conducted a case study in a petrochemical company.

Another relevant example is provided by Echefaj et al. (2023), offering an analysis of sustainable, resilient, and circular dimensions used in supplier selection models. This analysis aims to assist businesses in identifying criteria from their classification according to the industrial sector.

Ad hoc criteria selection processes for individual suppliers, as the one suggested by Alavi et al. (2021), present implementation challenges due to the extensive effort required from businesses evaluating suppliers. Initially, a company must select appropriate criteria and then assess suppliers accordingly. This process, whether for large enterprises with numerous suppliers or SMEs with limited human resources dedicated to supplier selection, results in a significant workload.

Other studies, conversely, aim to develop a supplier selection model tailored to a specific industrial sector. For example, Münch et al. (2022) employed a fuzzy decision-making trial and evaluation laboratory approach for supplier selection in a circular supply chain, focusing on a case study in the electric vehicle sector. The authors contend that the most crucial criteria for circular supplier selection in electric vehicle supply chains include environmental certifications, resource consumption, and waste generation. Studies like that of Münch et al. (2022) are extremely detailed and beneficial for specific industrial sectors, but their application for supplier evaluation in other sectors is challenging due to the high specificity of the criteria used.

Other research, such as the study by Haleem et al. (2021), proposed a more universal evaluation approach applicable to businesses across various sectors. The authors developed a framework for assessing suppliers in the context of circular economy implementation, encompassing six criteria and twenty-four sub-criteria derived from recent literature and expert inputs. The authors suggest that these identified criteria and sub-criteria offer organizations a method to evaluate suppliers, assisting suppliers in developing an effective and efficient circular economy-based supply chain.

Xie et al. (2022) also proposed a set of circular economy criteria, informed by Industry 4.0 principles, for evaluating and selecting sustainable suppliers. Specifically, the authors identified 16 subcategories pertinent to supplier selection decisions, utilizing a hybrid methods that integrates literature reviews with insights from industry experts.

While the approaches suggested by Haleem et al. (2021) and Xie et al. (2022) are broadly generic and applicable across various industrial contexts, these studies do not adequately distinguish the relative importance among different suppliers. Specifically, they fail to effectively differentiate between suppliers that are critical for business operations and those that are less essential. As a result, their performance evaluations do not vary according to the criticality of the suppliers.

Building upon the existing literature, our study seeks to transcend the limitations of current research and address a gap in the scholarly discourse. Our research specifically aims to go beyond just identifying criteria, with the objective of developing a tool that can be easily employed by firms in any industrial sector. Additionally, our approach includes evaluating the relative importance of different suppliers, drawing on the Kraljic matrix. It aims to offer a pass or fail evaluation for each supplier. More specifically, the tool can be utilized following an initial evaluation of general criteria, such as price, the supplier's capability to meet deadlines, and quality, to further distinguish a supplier based on their circular performance.

2.3. Operational framework for selecting circular suppliers: The Kraljic matrix

Kraljic, in 1983, conceived a matrix to assist purchasers in dissecting the strategic significance of their primary procured products or materials, and thus their suppliers. In the Kraljic framework, the products/materials to be procured are organized along two axes: strategy and risk. These axes propose that the profit impact of a specific supply item may be quantified in terms of the volume procured, as a percentage of the total purchase costs, or in terms of its effect on product quality or business growth. Factors such as availability, the number of suppliers, competitive demand, make-or-buy options, storage considerations, and substitute possibilities, are all considered when appraising supply risk. The company categorizes all its procured items into the classes portrayed in Fig. 1 based on these criteria: strategic (high-profit impact, high-supply risk), bottleneck (low-profit impact, high-supply risk), leverage (high-profit impact, low-supply risk), and non-critical (low-profit impact, low-supply risk). Considering these four categories, companies may find it necessary to employ an array of strategies to support suppliers' decisions.

Strategic commodities exert a substantial influence on corporate profitability, coupled with a heightened risk of supply. Frequently, only a single supplier is accessible for procuring such commodities, a situation that can entail serious supply risks (Krause et al., 2009). Companies sometimes establish partnerships with their suppliers to mitigate supply risks (Grajczyk, 2016). An enhanced relationship yields mutual commitment and trust, which, in turn, are apt to reduce supply risks.

Bottleneck commodities, although they have a modest impact on the company's financial performance, are vulnerable to supply risks. In such cases, suppliers often command a privileged position of influence (Kempeners and Van Weele, 1997). To counteract the adverse effects of this unfavorable situation, it is generally recommended to implement a procurement plan. Other strategies proposed by procurement

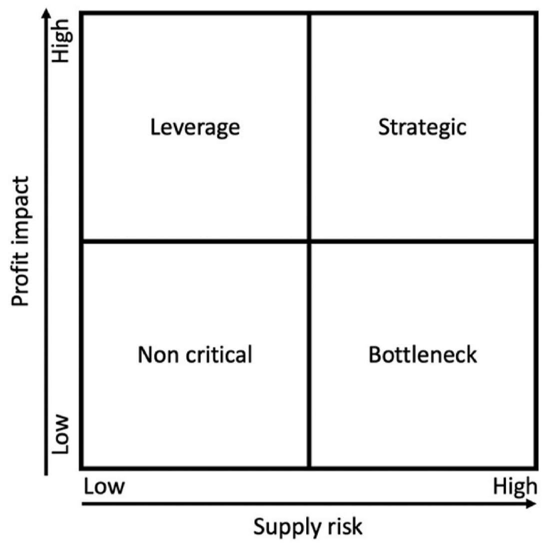

Fig. 1. Kraljic Matrix, a strategic tool for analyzing a company's purchasing portfolio, developed by Kraljic (1983).

professionals include finding new suppliers or transitioning to the non-critical quadrant.

Leverage commodities can be procured from a multitude of suppliers. These commodities make up a substantial portion of the final product's cost price but have a relatively low supply risk. As slight percentage reductions in costs can translate into significant savings, the buyer is incentivized to negotiate with suppliers (Olsen and Ellram, 1997). This creates a purchase strategy that maximizes buying power (Grajczyk, 2016).

Lastly, non-critical commodities are characterized by a low unit price and a plethora of available providers. These commodities pose minimal technical or business complications from a purchasing perspective (Caniels and Gelderman, 2005). The procurement practices for non-critical products should aim to reduce logistical and administrative complexity (Olsen and Ellram, 1997).

Building on the work of Krause et al. (2009), who suggested integrating Kraljic's framework with "key performance criteria" related to sustainability, there have been various endeavors to adapt this framework to address sustainability concerns. For instance, Pagell et al. (2010) proposed a sustainable purchasing portfolio matrix rooted in supply risk and the threat to the triple bottom line, using the Kraljic matrix as a foundation. Dabhilkar et al. (2016) highlighted the need for its critical appraisal or modification by practitioners aspiring to integrate a sustainable supply chain.

More recently, Garzon et al. (2019) recommended a method, also based on the Kraljic matrix, for selecting suppliers according to multiple criteria, including sustainability. Yet, to our knowledge, the Kraljic matrix has not been previously applied to assess suppliers based on their circularity performance. Based on the literature background discussed in this section, we propose the following research question:

RQ: How can companies operationally utilize the Kraljic Matrix to navigate the paradox between economic efficiency and the circular economy in selecting suppliers?

3. Methodological approach

To develop the tool, we first established the rationale for utilizing the Kraljic Matrix in supplier selection. Subsequently, we adopted a methodological approach consistent with similar studies in the literature, as evidenced in works by Echefaj et al. (2023), Haleem et al., (2021), Xie et al. (2022), and Münch et al. (2022). Specifically, after having established the rationale, the study began with a systematic analysis of the literature to identify a comprehensive list of potential criteria to use in the evaluation of suppliers. The methodological approach then involved an expert evaluation to filter the most pertinent criteria gleaned from the literature. The third methodological step was the development of a taxonomy to classify and organize the identified criteria. Finally, the tool, developed through these steps, was tested using two case studies. Fig. 2 graphically summarizes the methodological approach used.

Table 1 shows how a similar approach, for the research in criteria, has been used in other research on the topic and indicates the number of references used by each study for the literature review, the number of experts consulted, and the presence of case studies to corroborate and test the proposed approach for supplier selection.

The subsequent subsections meticulously delineate the methods employed.

3.1. Rationale behind the use of the kraljic matrix for supplier selection

The rationale for employing the Kraljic Matrix in supplier selection lies in its ability to identify incremental circularity requirements for evaluating different types of suppliers.

Specifically, when a product or service is classified within the non-critical category according to the Kraljic Matrix, it suggests that while the item may still hold relevance, it does not have a strategic impact on the business's core operations. This classification indicates a lower dependency on specific suppliers, as there tends to be a broader market availability for these products or services (Caniels and Gelderman, 2005). In this context, the CAoS tool suggests that a company looking to select its suppliers based on circularity criteria can impose more stringent circularity requirements. Since the product is non-critical, stricter supplier requirements will have a lesser impact on the economic and operational aspects of the company.

Conversely, for suppliers of strategic items, which are characterized by high supply risk and high profit impact, the CAoS tool's rationale is to advance less stringent circularity requests. In this scenario, imposing very strict circularity requirements could lead to the easy exclusion of the few available suppliers (Krause et al., 2009), thereby potentially jeopardizing the company's operations.

For suppliers of bottleneck commodities and leverage commodities, the CAoS tool's rationale is to set intermediate circularity requests compared to those discussed previously. These items either have a relatively low supply risk or a modest impact on the company's financial performance (Kempeners and Van Weele, 1997). Consequently, suppliers of such items can be assessed using an intermediate level of circularity requests, which are less stringent than those for non-critical

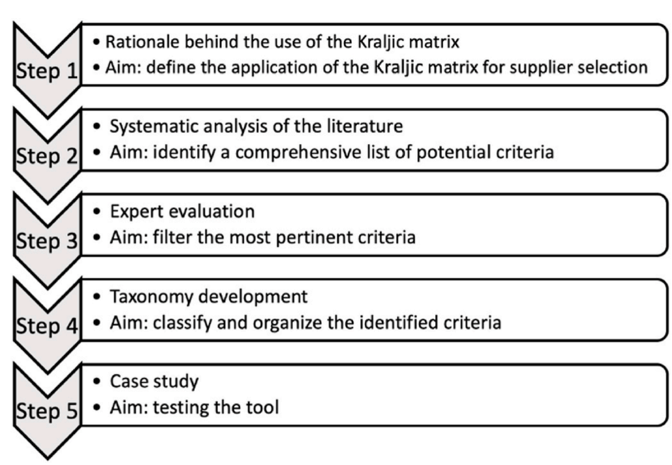

Fig. 2. Step-by-step methodological approach used for the development of the CAoS tool.

item suppliers but more stringent so compared to suppliers of strategic items.

The approach proposed in the CAoS tool is one of incremental circularity requests depending on the type of item provided by the supplier. By employing this approach, a company can more effectively navigate the paradoxes in supplier selection, opting for suppliers with stricter circularity criteria for non-critical items, while adopting a more lenient approach for suppliers of products critical to the company's operations.

3.2. Identifying relevant criteria for evaluating suppliers with a systematic literature review

The groundwork for the development of the CAoS tool involved a systematic review of scholarly and non-academic sources to glean current knowledge and practices concerning supplier circularity assessment, as well as to identify key supplier evaluation criteria. The methodological approach adhered to the guidelines proposed by Tranfield et al. (2003) and Kitchenham and Charters (2007), and was informed by practical examples of literature reviews conducted in various studies (e.g. Cassia et al., 2020).

We sourced academic publications from the Scopus and Web of Science (WoS) databases. These were chosen over EBSCO, Google Scholar, and similar databases due to their superior selection of high-quality, peer-reviewed publications in the domain of business and management (Aguillo, 2012). We chose to exclusively gather publications written in English. Employing targeted keywords, we collated published material indexed in Scopus and WoS. Initial keyword selection was based on scanning several review sources to pinpoint the most relevant terms (Alhola et al., 2019; Braulio-Gonzalo and Bovea, 2020; Katriina et al., 2017; Xu et al., 2022). In greater detail, we used the following search string to look for academic publications:

> *("circular economy") AND ("purchas*" OR "procure*" OR "supplier selection" OR "vendor selection" OR "supplier evaluation" OR "vendor evaluation" OR "sourcing")*

Our research methods resulted in the identification of 374 documents published in academic journals. To filter out articles not entirely in line with our research objectives, the team of researchers scrutinized the titles and abstracts of all retrieved papers, retaining only those most relevant and discarding those with only a tangential connection to circular economy procurement. This strategy facilitated the elimination of 248 papers. The remaining 126 articles were reviewed to ascertain their eligibility and retain only those focused on circular procurement and providing criteria for supplier selection. In this phase, the full text of the articles was evaluated to pick those concerned with circular economy procurement. This method enabled us to identify 42 papers, which were then selected for further analysis (see Fig. 3).

In addition to academic literature, we explored grey literature as it also boasts a substantial volume of research on circular procurement published in formats such as working papers and technical reports. Using the previously mentioned search query, we conducted our grey literature search via the Google search engine, resulting in the discovery of 19 documents in English and in Italian. Upon screening these by reviewing the executive summary, introduction, and title, we eliminated three documents that did not fully align with our research objectives. Consequently, we retained and further investigated 16 documents.

After the search procedure concluded, 42 scholarly articles and 16 non-academic documents were meticulously read, independently and iteratively discussed by the researchers involved in the study, thereby ensuring reliability through consensus and minimizing bias. A worksheet was formulated to collect specific information from each source about the description of the suggested procurement aspect, the purpose of the measurement, the calculation methodologies (if available). This comprehensive literature review and detailed analysis of criteria proposed by researchers led to the delineation of an exhaustive initial draft of variables. Following this stage, we identified a comprehensive list of potential 16 criteria for assessing suppliers.

3.3. Identification of relevant circular economy criteria to evaluate suppliers

To filter the most pertinent criteria gleaned from the literature, we consulted 8 academic and business experts,[1] requesting their evaluation through a structured questionnaire anchored on a Likert scale ranging from 1 to 5. Specifically, we sought the experts' assessment of each of the 16 criteria based on the following factors.

i. The criterion's relevance in evaluating supplier circularity, where a score of 1 indicates total irrelevance, and a score of 5 signifies absolute relevance.
ii. The criterion's alignment with the adopted definition of circular economy procurement, with 1 denoting complete inconsistency and 5 implying total consistency.
iii. The absence of overlap between the criterion and other criteria. Here, a rating of 1 indicates complete overlap, while a rating of 5 shows no overlap.
iv. The criterion's applicability to the majority of service and manufacturing suppliers. In this context, a score of 1 indicates inapplicability, and a score of 5 suggests high applicability.
v. The ease of obtaining the criterion from a supplier. A rating of 1 denotes difficulty in obtaining the criterion from suppliers, whereas a rating of 5 indicates that it is easily obtainable.

We employed the Relative Importance Index (RII) to ascertain the relative importance of each criterion as judged by the respondents (Johnson and LeBreton, 2004). This approach, known for its adequacy in analyzing ordinal data derived from a Likert scale, has been utilized across various fields (Chan, 2012; Morssi, 2021). The RII is calculated using the following equation:

$$RII = \frac{\Sigma\omega}{A * N}$$

Where ω symbolizes the weighting assigned to each factor by the respondents (ranging from 1 to 5 in our research), A is the highest weight (i.e., 5), and N is the total number of respondents (i.e., eight experts in our research). In more detail, we calculated the RII for each of the five factors separately for each criterion. This was done by summing the weights given by all respondents for a specific factor and then dividing by the maximum possible score multiplied by the total number of respondents (5 * 8). After computing the RII for each factor separately, we then calculated the overall RII for each criterion by taking the average of these five RIIs. This method provides a balanced evaluation of each criterion, reflecting its importance across all the evaluated aspects.

Regarding the number of experts involved, the figure aligns with that of scholars who have conducted similar studies in this field, such as Echefaj et al. (2023), Haleem et al., (2021), Xie et al. (2022), and Münch et al. (2022), as detailed in Table 1. Additionally, there are examples of research employing the RII with a small sample of experts, as seen in El Baz et al. (2022).

The RII operates on a scale from 0 to 1, with 1 signifying the utmost

[1] The experts selected for this study were chosen for their expertise in the field of circular economy and their experience in assisting companies to identify circular economy strategies. Specifically, three experts were from the academic domain: one with over 15 years of experience in sustainability issues and circular economy, and the other two experts each with 8 years of experience in the same fields. The remaining five experts were chosen from the consultancy field, with three of them having over 15 years of experience in sustainability issues and circular economy, and the remaining two possessing 5 years of experience in the topic.

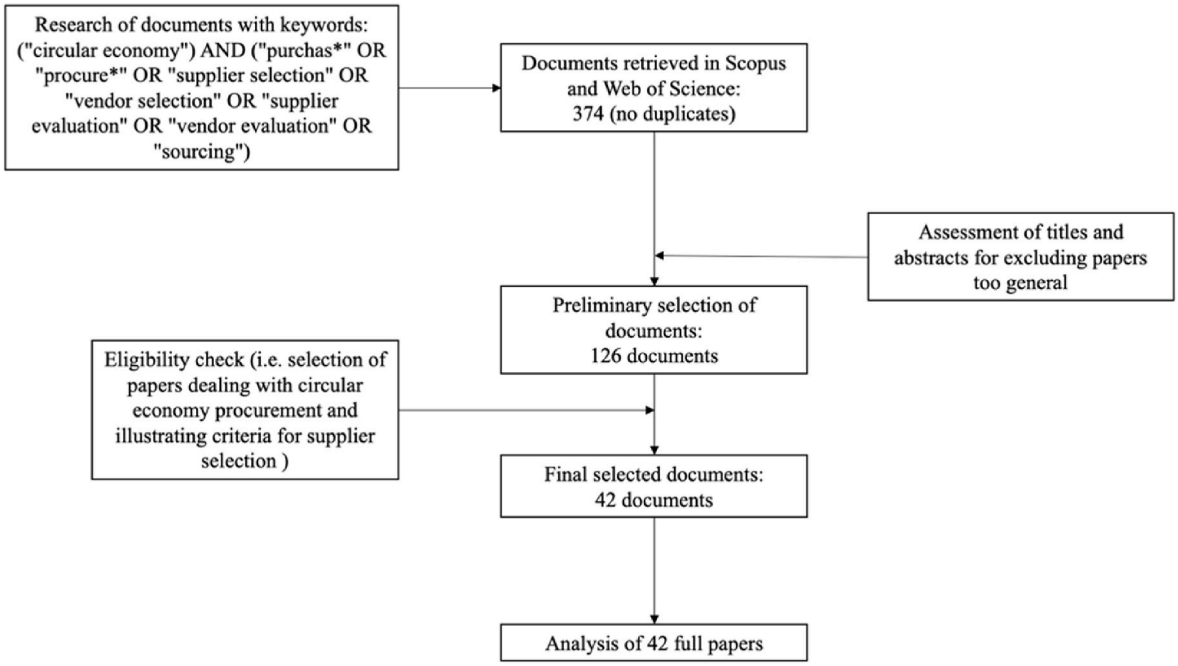

Fig. 3. Detailed protocol adopted for systematically retrieving pertinent academic literature, outlining each step from initial search criteria to final selection of papers.

Table 1
Comprehensive list of reference parameters previously employed in various studies related to the topic.

Authors	Literature review	Number of experts	Case study
Echefaj et al. (2023)	187 papers	Five experts	No
Haleem et al., (2021)	60 papers	Three experts	Yes (one case study in the Automotive sector)
Xie et al. (2022)	Based on a literature review (number of papers not stated)	Four experts	Yes (one case study with a manufacture of lawnmowers)
Muench et al. (2022)	Based on a literature review (number of papers not stated)	Eighteen sectorial experts	Yes (one case study in the Automotive sector)

Table 2
Results from the RII assessment, detailing the prioritization and significance of various criteria evaluated.

Criteria to evaluate the circularity of a supplier	RII	Ranking	Importance level
Use of renewable energy sources from the supplier	81.5%	1	H
Circularity in waste management activities by the supplier	81.0%	2	H
Fulfilment of legal environmental requirements inherent to the business activity	79.5%	3	H-M
Distance from the supplier	79.0%	4	H-M
Adoption of forms of reverse logistics	78.0%	5	H-M
Use of circular materials by the supplier	76.0%	6	H-M
Possession of Environmental Management System by the supplier	73.5%	7	H-M
Adoption of means of transportation with a lower environmental impact	70.5%	8	H-M
Possibility to activate industrial symbiosis pathways with the supplier	69.5%	9	H-M
Possibility of buying the functional output instead of a product from the supplier	66.5%	10	H-M
Possibility to request the minimization of the packaging from the supplier	59.5%	11	M
Information provided to customers about the best ways to manage the shelf-life of its products	59.0%	12	M
Adoption of systems for the optimization of loads and routes by the supplier	58.5%	13	M
Adoption of a system for selecting suppliers according to circularity criteria	58.5%	14	M
Adoption of training initiatives on environmental and circular economy issues	58.0%	15	M
Adoption of a system for monitoring material, energy and water consumption	56.5%	16	M

importance of a criterion for evaluating supplier circularity. RII scores were translated into five levels of importance as defined by Akadiri (2011): High (H) ($0.8 \leq$ RII≤ 1), High-Medium (H-M) ($0.6 \leq$ RII<0.8), Medium (M) ($0.4\leq$ RII<0.6), Medium-Low (M-L) ($0.2 \leq$ RII<0.4), and Low (L) ($0 \leq$ RII<0.2). The evaluation of the criteria is depicted in Table 2.

Upon concluding the evaluation process, we opted to retain only those indicators with an RII value exceeding 0.6. This corresponds to those rated as High-Medium importance according to the levels identified by Akadiri (2011). This cutoff was deemed necessary to select a limited number of relevant indicators that can be quickly compiled to evaluate suppliers. Different studies have applied various cutoffs in relation to RII. For example, Akadiri et al. (2013) used a cutoff of 0.4 to exclude criteria, Ryan et al. (2022) applied a 0.7 cutoff threshold, and Marzouk and Elkadi (2016), combining RII with a mean score, ended up excluding criteria with an RII lower than 0.67.

This process led us to a total of 10 criteria for assessing supplier circularity. These indicators, alongside their corresponding supporting references, are explored in the subsequent section and presented in Appendix 1.

3.4. Taxonomy development

A taxonomy to classify and organize the identified criteria has been developed, employing a method similar to that used by Echefaj et al.

(2023) in a related context. This taxonomy results in a hierarchical structure of the defined entities, as demonstrated in the work of Zekhnini et al. (2021). Given the systematic nature of the domain's view, a top-down approach is deemed most appropriate for this study. In more detail, upon meticulously reviewing the literature, we partitioned the 10 criteria for assessing supplier circularity into three subgroups: critical environmental criteria, criteria for evaluating the circularity of the relationship with the supplier, and criteria for assessing the internal circularity of a supplier.

The developed taxonomy categorizes environmental criteria into critical aspects that suppliers must meet. These represent fundamental requirements expected to be fulfilled even by suppliers of strategic items. A second subgroup consists of criteria for evaluating the circularity of the relationship with the supplier, emphasizing additional circular economy considerations in potential collaborations. The final subgroup identified in the taxonomy relates to criteria for assessing the internal circularity of a supplier. These criteria aim to establish an additional layer of screening. This categorization helps in differentiating suppliers based on their relevance and the nature of their contribution to the company's circular economy goals.

The rationale behind the developed taxonomy and the functioning of the instrument is illustrated in Fig. 4. The subsequent paragraphs provide a brief description of the three subgroups of criteria.

The criteria identified through the literature review were translated into questions intended for suppliers to gauge their degree of circular performance.

3.4.1. Critical environmentally related criteria

A significant factor to consider when assessing a supplier pertains to its vigilance over legal requirements, specifically within the environmental domain, relevant to its business operations (Ormazabal et al., 2017; Potrich et al., 2019). Literature draws a distinction between reactive and proactive firms (Aragón-Correa and Rubio-López, 2007). Reactive companies regard legal requirements as periodic or situational, typically arising from significant changes in operational structure. Conversely, proactive companies monitor environmental legal requirements systematically and regularly. Upon any significant change in the operational structure, these companies meticulously verify the applicable legal provisions, often engaging external consultants for support.

Another essential criterion for assessing suppliers is gauging their consideration of the environmental aspects associated with their business (Ormazabal et al., 2017). In such context, reactive businesses tend to consider environmental aspects only in response to environmental incidents or specific events such as a customer request. In contrast, proactive organizations conduct and periodically update—at least annually—an analysis of the relationship between their production activity and the environment (Buysse and Verbeke, 2003). A growing trend identified in the literature suggests that some organizations regard third-party certifications as a beneficial aspect when choosing suppliers and evaluating tenders (Marrucci et al., 2021; Rainville, 2021). Such certifications could include ISO 14001 or the Environmental Management Audit Scheme (EMAS). Indeed, suppliers possessing third-party certifications might provide an added value.

Based on the assessment derived from the literature and expert evaluations, two critical environmental criteria have been identified and are presented in Appendix 1.

3.4.2. Criteria for evaluating the circularity of the relationship established with the supplier

The significance of assessing the environmental impact of transportation during supplier selection is another key finding from the literature, an aspect often overlooked (Prosman and Sacchi, 2018). Environmental impacts, for instance, carbon emissions, are often used as a metric (Stavropoulos et al., 2021). However, gauging these emissions demands a wealth of information, such as the type of transportation and fuel used, which might be challenging to acquire during supplier evaluation. Considerations can be made based on the observation that emissions vary according to the mode of transportation; for instance, maritime transport tends to be more environmentally friendly than road transport (Spielmann et al., 2007). Research such as IEA (2022) has assessed the impacts of different transportation modes, ranking them according to their environmental impact, suggesting that aviation and trucks generally have a greater impact than trains and maritime transportation. As electric vehicles become increasingly available, companies are integrating them into their supplier screening processes (Wurster et al., 2021). Thus, another criterion for supplier evaluation focus on whether suppliers favor lower-impact transportation modes for their delivery fleets. Additionally, opting for a local supplier could significantly reduce transportation emissions, thereby improving circular economy performance (Yang et al., 2021).

Reverse logistics (i.e. the process of moving goods or materials in the opposite direction for the purpose of value addition, value recovery, or proper waste management) is another consideration when assessing a supplier's circular impact (Rogers and Tibben-Lembke, 2001; Hsu et al., 2013; Xu et al., 2022). Reverse logistics, for instance, can be implemented by a supplier who agrees to retrieve packaging after delivering the goods, thereby circumventing a disposable packaging system (Silva et al., 2013). This approach contributes significantly to the circular economy by reducing the volume of products entering waste streams. Reverse logistics can also be implemented by suppliers who adopt a closed-loop supply chain, allowing for the remanufacturing of products after their initial use by clients. This approach is particularly prevalent among suppliers of electrical and electronic products (Govindan et al., 2015). This process not only facilitates the reuse of materials but also reduces the influx of new materials into the production cycle, thus contributing to the circularity of resources.

Moreover, the significance of reverse logistics as a criterion for supplier selection has been underlined in various studies. For instance, Muffatto and Payaro (2004) highlight its importance in their research on electronic business strategies and performance metrics used by motorcycle manufacturers. They emphasize that supplier selection criteria should include considerations of reverse logistics capabilities.

Literature also indicates that industrial ecology, which balances economic development with resource and environmental conservation, is closely related to the circular economy (Murray et al., 2017). Within this framework, industrial symbiosis—a "physical exchange of materials, energy, water, and by-products among geographically proximate firms" (Chertow, 2007, p. 314)—can be seen as a form of circular procurement (Alhola et al., 2019; Qazi and Appolloni, 2022). It aims to keep materials in productive cycles, thereby reducing both immediate and long-term reliance on primary raw materials and the impacts of waste generation (Corsini et al., 2022). In this context, the potential to initiate an industrial symbiosis pathway with a supplier could be viewed as a circular procurement strategy.

Lastly, the literature highlights that procurement might focus more on functional output rather than the product itself (Tukker, 2015). Examples of this include buy-per-use, shared use, leasing concepts, and product-service systems (Alhola et al., 2019; Tukker, 2015). Traditional examples include renting versus leasing a piece of machinery. Utilizing a leasing business model could enable more effective use of items and prevent unnecessary storage of items like unused furniture (Alhola et al., 2019).

Based on the assessment derived from the literature and expert evaluations, five criteria for evaluating the circularity of the relationship established with the supplier have been identified and are presented in Appendix 1.

3.4.3. Criteria for evaluating the inner circularity of a supplier

Further criteria can be used to assess the circularity of suppliers. For example, literature provides ample evidence suggesting that circular procurement can promote the use of circular materials, thereby

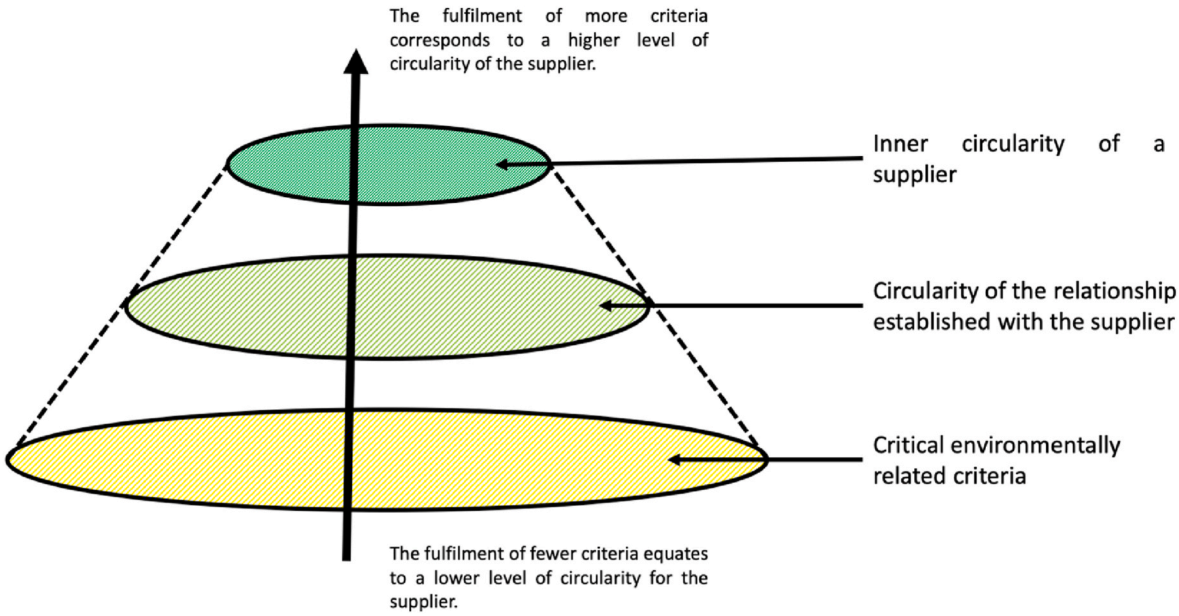

Fig. 4. Underlying rationale for the development of the taxonomy and the functioning of the CAoS tool.

differentiating suppliers who prefer alternatives to virgin and scarce materials (Černý et al., 2021; Ndubisi et al., 2020; Ntsondé and Aggeri, 2021). Within this context, the materials can range from compounds, materials, parts, components, to entire products. Circular materials typically include those inflows which, after extraction, are restored to their initial stock levels through natural growth or replenishment processes aligned with usage cycles, as well as previously used materials (e.g., recycled materials, second-hand products, or refurbished parts) (Dumée, 2022; WBCSD, 2022). Thus, assessing whether suppliers favor the use of circular materials over linear ones is another potential criterion for supplier evaluation.

Moreover, in light of the ongoing resource and energy crisis, several authors have suggested that circular procurement can facilitate a transition from non-renewable energy sources to renewable ones (Ntsondé and Aggeri, 2021). Hence, literature on circular procurement recommends examining suppliers to verify whether they use energy from renewable sources (Husgafvel et al., 2022; Pollice and Batocchio, 2018).

Lastly, the literature on circular procurement emphasizes the significance of selecting suppliers that exercise responsible waste management practices (Ashby, 2018; Veleva and Bodkin, 2018; Yen, 2018). Recycling and energy recovery from waste is widely accepted as a standard in many developed countries (Xu et al., 2022). Consequently, another criterion for evaluating suppliers is to ascertain, of the total waste produced by the supplier, what portion is directed towards material or energy recovery.

Based on the assessment derived from the literature and expert evaluations, three criteria for evaluating the inner circularity of a supplier have been identified and are presented in Appendix 1.

4. Results

4.1. Presentation of the circular assessment of suppliers (CAoS) tool

The CAoS tool has been crafted as a simple, easy-to-comprehend tool designed for extensive use. The decision to design it as an Excel file is substantiated by citing other Excel tools, like the Ellen MacArthur Foundation tool, which are noted for their intuitive nature. Following the Excel file, accompanying this article, the CAoS tool initiates with two boxes regarding the supplier's information—company name and description of the product or service procured – should be included. Subsequently, the tool evolves through four steps.

1. Preliminary classification of the product/service.
2. Establishment of the minimum circularity requirement that the supplier must fulfill.
3. Computation of the supplier's circularity level.
4. Evaluation of the supplier.

4.1.1. Preliminary classification of the product/service

In the initial stage, firms intending to gauge their supplier's circularity must categorize the product or service using the Kraljic matrix (Kraljic, 1983). To do that, they must answer: What type of product/service do we possess? The answer hinges on two variables—supply risk and profit impact, aligning with the Kraljic matrix's axes. The firm must discern whether (i) the product/service has numerous suppliers or the supplier being evaluated is critical, and (ii) the component procured from the evaluated supplier is integral to the final product/service, thereby impacting its profitability. Based on the answer the firm gives, the file automatically places the product/service within the right category (one of the four cells paint green).

4.1.2. Establishment of the minimum circularity requirement that the supplier must fulfill

Depending on the previous answers and the associated category, the company's product/service is associated with a specific circularity level[2] (Step 2) the supplier must observe. The supplier must be.

[2] In direct accordance with the rationale outlined in Section 3.1, the tool has been developed to ensure that:• "Circular" represents the highest level of circularity; a supplier is evaluated as "circular" if it meets all the critical environmentally related criteria, the majority of the criteria for evaluating the circularity of the relationship established with the supplier, and the majority of the criteria for evaluating the inner circularity of a supplier; the "circular" level is required for suppliers of non-critical items.• "Proactivist" represents an intermediate level of circularity; a supplier is evaluated as "Proactivist" if it meets all the critical environmentally related criteria and the majority of the criteria for evaluating the circularity of the relationship established with the supplier; the "proactivist" level is required for suppliers of leverage and bottleneck items.• "Basic" represents a beginner level of circularity; a supplier is evaluated as "Basic" if it meets all the critical environmentally related criteria and only some of the other criteria; the "basic" level is required for suppliers of critical items.

- Circular, for non-critical items.
- Proactivist, for bottleneck or leverage items.
- Basic, for strategic items.

Fig. 5 illustrates a scenario where the required circularity level is 'Proactivist' as the product/service is classified under the 'bottleneck' category in the Kraljic matrix.

4.1.3. Computation of the supplier's circularity level

Upon determining the required circularity level, the company proceeds to the third step, responding to the ten aforementioned questions to calculate the supplier's score. Each question is assigned a score between 0% and 100%, contingent on the selected response. As previously noted, the questions fall into three categories: (i) critical environmentally related criteria, (ii) circularity of the relationship established with the supplier, and the (iii) inner circularity of the supplier. Questions within each sub-category are differentially weighted based on their significance. The first two questions account for 50% of the total score, the second sub-category contributes 35%, and the final three questions comprise the remaining 15%. This structure is predicated on the belief that even if a supplier exhibits internal circularity (third sub-category), it is vital that they comply with identified environmentally related criteria (first sub-category) and maintain a circular relationship with the company (second sub-category).

Upon completion of all ten questions, the tool calculates both the total final score and the score obtained in each of the three sub-categories.

4.1.4. Evaluation of the supplier

The final step involves evaluating the supplier. As illustrated in Fig. 6, the tool reiterates the required supplier level and the actual supplier level. If the supplier's level aligns with or exceeds the requested one, the supplier successfully passes the screening.

A key advantage of this tool is its ability to highlight the supplier's positioning based on the three sub-categories. This allows the company to identify potential weaknesses, even if the supplier passed the screening, facilitating an informed decision about the supplier's suitability. In the example, the proactivist supplier reaches the half score threshold for all the three sub-categories (>50%). However, it may happen that a supplier obtains a final evaluation (e.g. circular) reaching the half score threshold only in two sub-categories. This can happen when, for instance, the supplier reaches the highest score in the first two sub-categories (100%) but not in the third one. Thus, through the graphical representation, this tool allows the company to evaluate the supplier on a comprehensive basis.

4.2. Case study 1: Testing the tool with a packaging company

In order to ensure the reliability and functioning of the CAoS tool, a test with two different companies has been carried out. In both cases, the CAoS tool was tested through interviews with the companies under analysis. Specifically, during an initial call, the interviewers and the company answered the tool's questions, performing a preliminary compilation. For questions to which the companies testing the tool did not have an immediate answer, a week was provided to contact the supplier and respond to the missing questions, aiming for a complete response to all the tool's questions.

The first chosen firm is an Italian enterprise specialized in the packaging industry. The motivation behind this choice stems from its dedication to embedding sustainability values into its operational procedures. Of particular importance to this company is the supplier selection, given its reliance on a strategic vendor.

The procurement wing of the company is bifurcated into two units: the administrative segment oversees the direct acquisition of materials, while the production division is responsible for selecting appropriate raw materials. Since 2021, they've embraced the ISO 9001 (Quality Management System), instituting internal measures to assure procurement process quality and efficiency. Concerning supplier types and selection challenges, the company favors a concise supplier list to avert potential hold-ups. However, for their primary material, cellulose, they have a singular source.

Regarding their existing supplier selection approach, the firm shared that they utilize a questionnaire to confirm a supplier's adherence to quality and sustainability standards. In their evaluation, they prioritize essential standards like sanitation and individual hygiene. They also place significant emphasis on the supplier's material production processes, such as certifications and various material treatment methods. Since their product, often used in the food sector, demands exacting standards, certain protocols must be faultlessly observed. This tool, already in place, gauges a supplier's sustainability orientation. Nevertheless, this comprehensive questionnaire doesn't factor in circularity aspects, assessing a supplier's environmental awareness. Hence, regarding their primary cellulose supplier, the company expressed interest in the CAoS tool's assessment.

Initiating the questionnaire required classifying the product via the apt Kraljic matrix. Given the limited supplier availability and that the product's procurement cost accounts for roughly 60% of the total expense, the supplier is categorized as a supplier of a "strategic item", thus necessitating a basic level of circularity.

After having identified the required level of circularity, the company responded to the ten questions, accruing a total score of 46% for the supplier.

This score largely emanates from responses to the two questions related to the critical environmentally related criteria. Regarding the other criteria, specifically those related to the relationship established with the supplier, and the criteria for evaluating the inner circularity of a supplier, only some are fully satisfied. However, since the critical environmentally related criteria are fully met, this supplier is deemed to be at a basic level, meeting the requirements identified by the CAoS tool.

Through this tool, however, the firm discerned that even if the supplier met the initial standard, there's room for elevating environmental circularity, especially in the second category. This mirrors the company executives' sentiments, who, despite the supplier's indispensable nature due to material technicalities, are keen on exploring

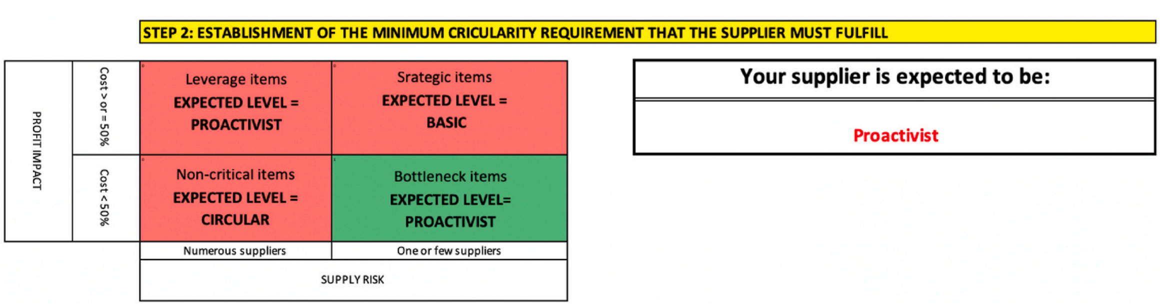

Fig. 5. Application of the Kraljic matrix in determining the desired level of circularity.

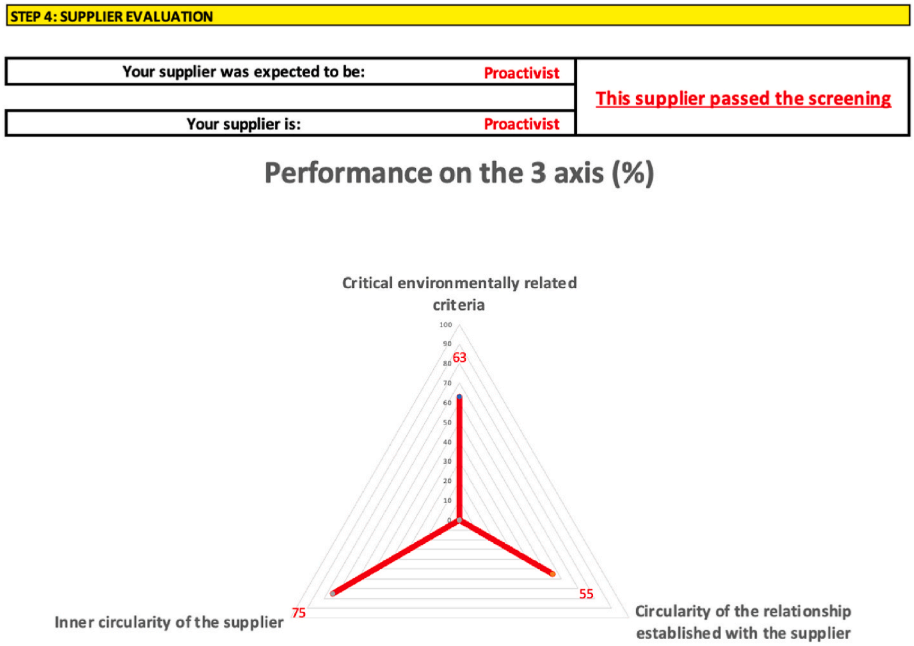

Fig. 6. Supplier evaluation dashboard facilitating informed decision-making in procurement.

proximate suppliers for sustainability or ones offering diverse cellulose types.

In trialing the tool with their pivotal supplier, the company pinpointed its procurement's circularity, gaining insights into areas demanding enhanced circularity. These findings (as illustrated in Fig. 7) can foster discussions with suppliers about circular objectives or influence procurement decisions.

4.3. Case study 2: Testing the tool with an agri-food company

The second application of the CAoS tool was conducted with a small company operating in the agri-food sector, primarily focused on cereal and olive production. This case also demonstrates the company's commitment to incorporating sustainability values into its operations. The company's supplier selection process is straightforward, based primarily on quality, price, and, in some cases, product certifications to meet organic farming requirements.

In this context, the CAoS tool was applied to assess the current electricity supplier, a provider of non-renewable energy. According to the steps outlined by the CAoS tool, considering the availability of various suppliers in the market and the procurement cost being less than 50% of the total, the electricity supplier is classified in the Kraljic matrix as a non-critical item supplier. Based on this categorization, the supplier requires the level of "circular".

Upon determining the required level by the tool, the company answered ten questions to evaluate the electricity supplier. The supplier systematically complies with legal requirements in the environmental field and possesses ISO 14000 certification. Therefore, the score in the "critical environmentally related criteria" section is 100%.

Regarding the "circularity of the relationship established with the

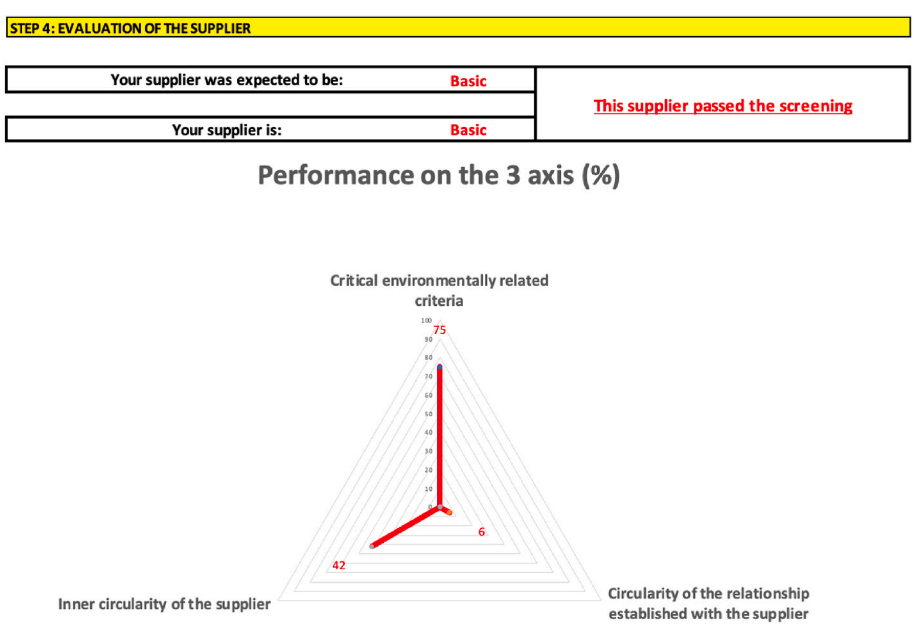

Fig. 7. Supplier evaluation dashboard as applied in the first case study, showcasing the results of supplier circular performance.

supplier" section, only the first two questions of the CAoS tool were applicable. For both, it was noted that the service is provided without the need for transportation and thus those questions were judged as not applicable, resulting in a 100% score in this section.

In the "inner circularity of the supplier" section, the question about using circular materials in service delivery was answered as not applicable; the same response was given to the penultimate question. The final question, regarding waste disposal, was marked as non-applicable for a service provider, leading to a 0% score in this section.

After applying the questions, the supplier is evaluated at three levels: "basic", "proactivist", "circular". In this specific case, the supplier is rated as "proactivist". As a "circular" level of circularity is required, the tool suggests not retaining the supplier. Fig. 8 illustrates the tool's recommendation.

In this case, after applying the CAoS tool, a dialogue was initiated with the small company's owners about possibly switching to a more circular-oriented supplier. In considering this change, the owners are set to conduct a comprehensive analysis, weighing not only the economic costs but also the potential image-related benefits of altering their supplier.

5. Discussion

This research starts from the premise that the purchasing function becomes central to a company's efforts towards circularity. Specifically, the study seeks to integrate the suggestions of Krause et al. (2009), namely, to combine Kraljic's framework with "key performance criteria" related to sustainability. However, unlike the approach proposed by Krause et al. (2009), which suggests integrating specific strategies for product selection in the four quadrants of Kraljic's matrix, the approach in the tool presented in this research is based on making incremental requests for different types of items suppliers. Using this approach, a company can better navigate paradoxes in supplier selection by choosing suppliers with stricter circularity criteria for non-critical suppliers, while adopting a more lenient selection mode for suppliers of products critical to the company's operations.

The tool proposed in our research, in contrast to the approaches by Echefaj et al. (2023) and Alavi et al. (2021), can be seen as more easily applicable in SMEs as it does not require the effort of selecting appropriate criteria and then assessing suppliers accordingly. This approach, consisting of a standardized tool for all companies, unlike the method used for instance by Münch et al. (2022), is faster, allowing for the immediate use of the tool by different companies.

However, the authors of the study consider it plausible that the tool could be adapted to work in companies operating in a specific sector, as in the approach suggested by Münch et al. (2022). Specifically, this would involve maintaining the unchanged structure of the tool (i.e., division into three categories and the fact that questions within each sub-category are differentially weighted based on their significance) and adding specific questions pertinent to the company's operational sector. For example, a specific criterion of circularity for the selection of a supplier in a company operating in the food sector could be efficiency in the use of water resources (Banaeian et al., 2018; Viles et al., 2020). This principle may also apply in various service industries, notably the hotel sector, which is widely recognized for its environmental impact (Sorin and Sivarajah, 2021). In this particular context, tailoring the tool to the hotel industry could involve, for example, eliminating the indicator pertaining to industrial symbiosis and incorporating an alternative metric that, for instance, evaluates supply chain transparency of suppliers.

5.1. Implications on paradox theory in supplier selection

Our study contributes to advancing paradox theory in supply chain management by presenting an alternative to the prevalent perspective on the relationships among environmental and economic goals, which is typically framed in terms of either win-wins or trade-offs (Van der Byl and Slawinski, 2015).

Although the CAoS tool does not directly contribute to the development of the theory, it can be regarded as a practical demonstration of how organizations can reconcile contradictory objectives by stimulating paradoxical thinking (Xiao et al., 2019). Indeed, it enables an assessment that considers circularity goals while allowing integration into the economic and efficiency-related logics. An example of how the CAoS tool can stimulate paradoxical thinking is illustrated in the latter part of the second case study, where the company's owners began to contemplate switching to an alternative supplier. As posited by Marsh and Macalpine (1999), an instrument that is action-focused and aids in scrutinizing the complex structure of a problem provides a valuable method of analysis, a function that the CAoS tool fulfills. In such a context, the tool can act also as a catalyst for the development of a corporate culture that values the circular economy. Through its implementation, the principles of the circular economy can become an integral part of business strategies, influencing daily decisions and fostering

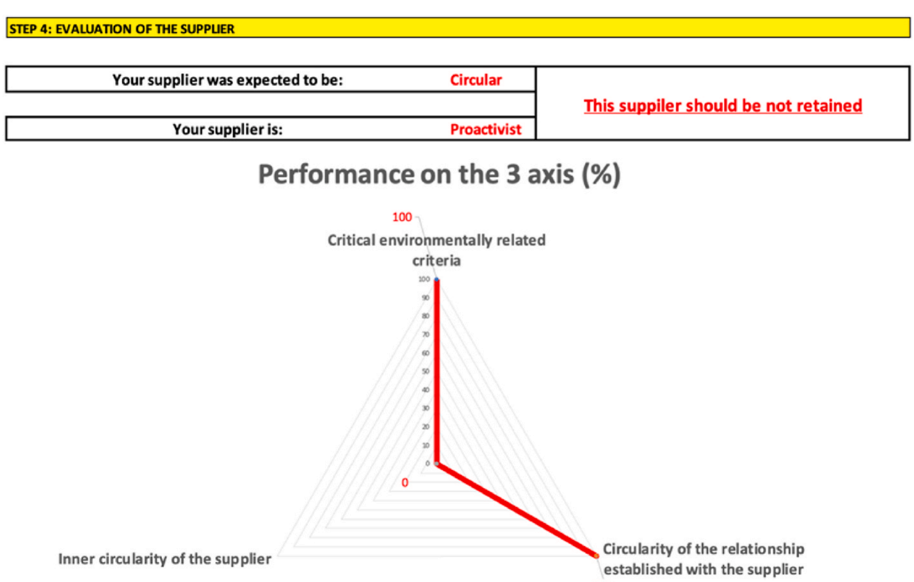

Fig. 8. Supplier evaluation dashboard as applied in the second case study, showcasing the results of supplier circular performance.

wider CSR practices. Indeed, it can serve as a practical instrument to address emerging paradoxes, facilitating the promotion of open dialogue within the organization advocated by Berti and Cunha (2023).

6. Conclusions

The paper aims to introduce the CAoS tool, a straightforward instrument that firms can use to assess the circularity of their suppliers, thus aiding in navigating the paradox between economic efficiency and circular economy, while aligning with broader CSR objectives.

The tool has been developed based on the Kralijc Matrix. Criteria for circular supplier selection were identified through a comprehensive review of circular supply chain literature and with input from experts. The CAoS tool consists of 10 criteria measured with qualitative and quantitative questions, evaluated by business and academic experts to be widely applicable for most service and manufacturing suppliers and easy to obtain. The paper also presents two case studies from businesses that have tested the tool. The tool is available as an attached Excel file in the present research.

In essence, our research underscores the significance of a holistic approach to supplier evaluation, especially in the realm of the circular economy. It particularly illuminates the diverse facets of circularity criteria applicable to supplier assessments, spanning from environmental considerations to relational and internal operational of suppliers.

The impetus for developing a tool to assess suppliers from a circular economy perspective stems from the understanding that the circular economy cannot be achieved by a single firm acting in isolation. The efficacy of circular practices is constrained if they are not uniformly implemented across the entire value chain. In this context, the tool might be useful not only as an enabler for businesses to make more informed decisions, potentially motivating other stakeholders in the chain to embrace circular practices, but also as a means for value chain partners to identify priorities and foster collaboration towards shared objectives, thereby easing the transition to a circular economy. Moreover, the tool can assist in pinpointing linear risks, such as supply capacity limitations and supplier dependence, to bolster company resilience and advance circular economy performance.

Realizing a completely integrated circular supply chain is a challenging and complex task, particularly when not all stakeholders are committed to circular practices. While the CAoS tool alone may not be sufficient to establish a circular supply chain, it represents a positive step towards promoting circular practices at least at the supplier level.

This work has limitations that should be noted. The CAoS tool should not be the sole basis for decision-making, and the circularity score achieved by a supplier should be used as a guide rather than a final judgment. The tool intentionally does not cover technical and economic aspects of supplier selection but only a pass or fail evaluation for each supplier. The tool can thus be employed following an initial assessment of general criteria, such as price, the supplier's ability to meet deadlines, and quality, to further discern a supplier based on their circular economy performance.

Another limitation to be noted is that while the tool concentrates on the circularity of suppliers, it only tangentially addresses the circularity of the products or services provided by those suppliers. It is important to recognize that there are other tools available for conducting a comprehensive assessment of the circular performance of a product or service, such as a complete life-cycle analysis. Another potential limitation may be linked to the criteria used for the evaluation. Despite these criteria being selected through a meticulous methodological procedure, biases could be present. These biases could stem from the keywords selected for the literature search, the assessments conducted by experts, the number of experts engaged, and the choice to include only indicators deemed to have high or medium-high importance. In addition, it is important to acknowledge that, in some rare situations, the utility of the CAoS tool may be relatively limited. This may occur in scenarios where no suppliers fulfill the circular criteria established by the tool, or when the products offered by circular suppliers are prohibitively costly, making the transition to a circular supplier economically impractical. Future research in this context is therefore essential. For example, future studies could concentrate on longitudinal research to evaluate the long-term effects of the CAoS tool on supplier performance and circularity. This would entail monitoring key performance indicators over an extended period to discern how the tool impacts supplier behavior and the overall circularity of the supply chain.

It is important to acknowledge also that although our research may offer significant insights for supplier selection in the context of the circular economy, the absence of an integrated approach encompassing the entire value chain may represent a limitation of our study. In this regard, future research could investigate ways to enhance collaboration and integrate circular practices throughout entire supply chains.

Additionally, future research could explore the development of industry-specific versions of the CAoS tool. Given that different industries face distinct challenges and requirements regarding circularity, customizing the tool to accommodate these specificities could significantly improve its efficacy and rate of adoption. Finally, we call for further research in the development and provision of actionable tools, as demonstrated in our study, to evaluate suppliers and, more broadly, the performance of the circular economy. This will not only enable research to significantly contribute to the transition towards a circular economy but also permit researchers to engage with and more critically analyze these tools.

CRediT authorship contribution statement

Filippo Corsini: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Chiara De Bernardi:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Natalia Marzia Gusmerotti:** Writing – review & editing, Writing – original draft, Methodology, Investigation. **Marco Frey:** Writing – review & editing, Writing – original draft, Supervision, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2024.142085.

Appendix 1. Questions to assess the circularity of suppliers

Subgroups	Questions to assess the circularity of the supplier	Type of supplier
Critical environmentally related criteria	How does the supplier keep under control the legal requirements, in the environmental field, inherent to its business?	Product and service suppliers
	How does the supplier consider the environmental aspects inherent to his business?	Product and service suppliers
Circularity of the relationship established with the supplier	Does the supplier prefer means of transportation with a lower environmental impact for their fleet of vehicles used for deliveries (e.g. ships, trains, or electric vehicles)?	Product and service suppliers
	How far the supplier, with respect to my office/plant, is located?	Product and service suppliers
	Has the supplier foreseen the activation of forms of reverse logistics aimed at the reuse of the packaging?	Only product suppliers
	Is the supplier offering the possibility to buy the functional output instead of a product? (e.g. buy-per-use, shared use, leasing concepts)	Product and service suppliers
	Is it possible to activate an industrial symbiosis path with the supplier?	Only product suppliers
Inner circularity of a supplier	Does the supplier prefer the use of circular materials (in the products and/or services provided)?	Product and service suppliers
	Does the supplier utilize energy from renewable sources?	Product and service suppliers
	With respect to the total waste produced by the supplier, how many of those are sent to material or energy recovery?	Only product suppliers

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