

A New Circular Economy Index and its impact on Corporate Carbon Emissions

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Abstract

We develop the Corporate Circular Economy Index (CCEI) to provide empirical evidence on the relationship between corporate Circular Economy practices and carbon emissions. Using a decade-long dataset of STOXX Europe 600 firms, the index integrates multiple dimensions, including policy disclosures, monitoring mechanisms, initiatives, and resource efficiency. Applying a Generalized Method of Moments estimation, our analysis reveals a notable causal relationship: an increase in the index from the 25th to the 75th percentile is associated with an 18% reduction in carbon dioxide emissions.

Through Partial Least Squares Path Modelling, we identify key corporate policies driving emission reductions, including social sustainability measures, biodiversity protection, green investments, target setting, and clear governance structures via Corporate Social Responsibility Committees and Environmental Management Teams. Our findings remain robust across alternative carbon emission standardizations, econometric methods, and controls for endogeneity. These results highlight the importance of specific Circular Economy dimensions in improving corporate sustainability outcomes. In addition, the proposed Circular Economy Index, along with its components and sub-indices, is accessible and applicable for practitioners across different corporate contexts.

Keywords: *Circular Economy; Corporate Environmental Performance; Carbon Emissions; Circularity Indicator; Corporate Social Responsibility; ESG*

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1. INTRODUCTION

Recent threats such as supply chain instability, raw material scarcity, and excessive waste generation pose serious challenges to current production and consumption models (Webster, 2017; Ellen MacArthur Foundation, 2018). In this context, two contrasting perspectives have emerged regarding the Circular Economy (CE) paradigm and its ability to address these challenges.

On the one hand, circularity is expected to close material loops, reduce pressure on critical resources, and improve lifecycle management efficiency (Webster, 2017; Bianchi & Cordella, 2023). On the other hand, critics argue that CE promotes only a limited sustainability transformation and does not fundamentally challenge existing production systems, as “circular” does not necessarily imply “sustainable” (Elia et al., 2017; Hobson, 2021). Despite these

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criticisms, the CE framework has gained strong support from institutions and industries worldwide (Arranz et al., 2022; Katz-Gerro & López Sintas, 2019; Millar et al., 2019), and is often presented as a promising pathway for both corporate profitability and ecological stability (Webster, 2017). This paper aims to analyze, at the corporate level, the extent to which adopting circularity can improve sustainability performance, which has been linked to increases in firm value and competitiveness (Nguyen, 2020).

We provide empirical evidence on the feasibility of achieving more sustainable outcomes through corporate adoption of circular practices while maintaining competitiveness. To examine the relationship between corporate CE actions and sustainability outcomes, we construct a novel index—the Corporate Circular Economy Index (CCEI)—building on the Triple Bottom Line framework (Elkington, 1997).

Our empirical analysis investigates the relationship between corporate CE actions and changes in carbon emissions. The CCEI aggregates environmental, social, and governance (ESG) indicators that capture firms' commitment to circularity. These indicators are grouped into four sub-indices: (i) policies, (ii) monitoring mechanisms, (iii) initiatives beyond regulatory requirements, and (iv) resource efficiency. The indices are constructed annually for firms included in the STOXX Europe 600 index over the period 2013–2022. These data are matched with firm-level characteristics and carbon emission data obtained from annual reports and the Thomson Reuters Eikon database.

To address potential endogeneity concerns, we employ a Generalized Method of Moments (GMM) approach to examine the relationship between the CCEI (and its sub-indices) and carbon emissions. We complement this analysis with Partial Least Squares Path Modelling (PLS-PM), which allows us to identify the specific corporate actions that contribute most significantly to each sub-index and to the overall index.

Our results show that, controlling for firm characteristics, companies with higher levels of circular economy engagement exhibit lower carbon emissions. This relationship holds across all four sub-indices, although their economic significance varies. In particular, PLS-PM results indicate that the Policies sub-index accounts for approximately 50% of the variation in the CCEI, followed by Initiatives (around 30%), while Monitoring and Resources jointly account for the remaining 20%.

The main contributors to each sub-index include: (i) social policy measures for the Policies sub-index; (ii) governance structures and clear command chains for Monitoring; (iii) environmental investments and partnerships for Initiatives; and (iv) target-setting mechanisms for Resources.

We further conduct a range of robustness checks using alternative econometric methods, control variables, and emissions scaling approaches (e.g., OLS, fixed effects, and alternative size proxies). The results remain consistent, reinforcing the relevance of the CCEI in explaining variations in corporate carbon emissions.

These results can serve as a blueprint for widening the core of the concept of Circular Economy, so it encompasses social, governance and economic concerns, providing solidarity to this novel framework, integrating circularity and sustainability concepts, and bridging gaps in the measurement of corporate actions and their environmental outcomes.

Therefore, this study contributes to the body of literature on Circular Economy by introducing a novel index which acts as a comprehensive tool for evaluating corporate circularity practices and their impact on carbon emissions and by offering policymakers a measurable framework to design and assess regulations that promote sustainability. For practitioners, the CCEI provides actionable insights into the effectiveness of specific ESG-related actions, helping businesses prioritize strategies that reduce emissions, and enhance circular economy adoption, and ultimately improve their competitiveness.

The remainder of the paper is structured as follows. Section two reviews the current conception of the Circular Economy framework and its critiques, it also presents the reasoning behind the relationship between circularity and sustainability highlighting the role corporations have. The literature review, in section three, details on the construction of the novel index and sub-indices are presented, so are the resulting statistical model and the sample. Section four presents the econometric results and discusses the vigorous tests performed. Finally, some concluding comments and implications are discussed in section five.

2. THEORETICAL BACKGROUND

2.1 A multilevel analysis of the concept of circular economy

The literature presents an ambivalent view of the CE. While some scholars highlight its potential to promote the decoupling of resource use from economic growth (Ghisellini et al., 2016; Webster, 2017), others question its practical feasibility and effectiveness when implemented (Korhonen et al., 2018).

Critics have raised several concerns regarding the CE framework. Hobson (2021) argues that CE lacks a solid theoretical foundation, leaving key conceptual questions insufficiently explored. Skene (2018) and Velenturf et al. (2019) raise technical concerns, particularly regarding the quality and usability of recovered materials. Other studies emphasize sociological and systemic limitations, questioning whether CE can adequately address the social, political, and philosophical challenges embedded in current production systems (Calisto Friant et al., 2020; Larrinaga & Garcia-Torea, 2022; Millar et al., 2019; Pitkänen et al., 2020).

Additionally, several authors highlight market-related barriers to CE implementation, including the need for significant shifts in consumer behavior (Kirchherr et al., 2018) and the persistence of corporate practices rooted in linear economy models. These dynamics often result in the adoption of superficial policies or greenwashing practices (Calisto Friant et al., 2020; Hobson & Lynch, 2016; Hobson, 2021; Kirchherr et al., 2018), or limit CE to a narrow focus on technological innovation (Ehrenfeld, 2007; Mies & Gold, 2021).

Among all the criticism, the ambivalent connection between circularity and sustainability raises an issue that can be addressed from the governance perspective. Several authors, such as Skene (2018), Korhonen et al. (2018) or Bianchi & Cordella (2023), have posed the question of whether circular necessarily implies sustainability. As Korhonen et al. (2018) argue, “a cyclic flow does not secure a sustainable outcome,” highlighting inherent limitations in achieving fully sustainable systems through circularity alone.

The literature addressing this relationship can be broadly categorized into three levels of analysis.

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At the macro level, research focuses on how circular systems may mitigate resource depletion through closed-loop production. However, several studies suggest that increasing recycling rates does not necessarily reduce resource extraction, particularly under current consumption patterns (Bianchi & Cordella, 2023; Corona et al., 2019). Other authors point to the vagueness of policy measures and the tendency to rebrand existing initiatives under the CE label (Fitch-Roy et al., 2019; Hobson, 2021). Moreover, some argue that CE can only significantly enhance sustainability when embedded within broader post-capitalist frameworks, such as degrowth or doughnut economics (Thompson et al., 2024).

At the industry level, the transition towards circular production models has also been questioned. While practices such as product lifespan extension, collaborative consumption, and product-service systems are often promoted as circular solutions, their overall contribution to sustainability remains uncertain and sometimes limited. For example, literature shows that increasing the service sector in Europe at the expense of producing new goods, would pose a burden to other manufacturing-dependant geographies, being the economic benefits limited to Europe (Skene, 2018). Besides, environmental (and social) benefits are not always guaranteed in these circular industries either (Knäble et al., 2022; Pigosso & Mcalooone, 2016) nor are lengthened lifespans when confronted with novel energy-efficient alternatives (Skene, 2018).

The third stream of literature focuses on the corporate level, which is the primary focus of this study. This perspective examines the role of firms in transitioning towards sustainable economic models through the adoption and disclosure of CE practices. From a traditional shareholder-oriented perspective, firms are assumed to prioritize profit maximization, often complying only minimally with environmental regulations or engaging in greenwashing (Valenzuela & Böhm, 2017). However, other studies suggest that firms may derive private benefits from engaging in environmental, social, and governance (ESG) initiatives (Wong et al., 2021), or may genuinely pursue broader societal objectives (D'Souza, 1984; Hoffman et al., 2010; Stephan et al., 2013).

Hart (1997) emphasizes the critical role of firms in driving the transition towards sustainable models, given their global reach, access to resources, and capacity to implement change. From an agency theory perspective (Jensen & Meckling, 1976), firms can be viewed as networks of relationships among stakeholders, providing a platform for dialogue and coordination. In this sense, corporate governance structures can facilitate the transition to circular and sustainable business models by aligning stakeholder interests (Minoja et al., 2024). Recent studies also highlight the importance of governance mechanisms in shaping CE disclosure and practices (Esposito et al., 2023), emphasizing the central role of firms in linking production and consumption processes and, therefore, in closing material loops (Esposito et al., 2020; Gunarathne et al., 2021).

Despite these advances, there remains a lack of empirical research examining the relationship between corporate circular actions and sustainability outcomes. Existing studies often describe corporate CE practices as fragmented, diffuse, and influenced by external drivers such as stakeholder pressure or digitalization (Mora-Contreras et al., 2023). Opferkuch et al. (2022) show that while many firms reference CE in their sustainability reports, few provide substantive analysis. Similarly, Elia et al. (2017) find that existing assessment methods rely heavily on non-standardized, single indicators, particularly focused on resource use. Overall, prior research suggests that at the firm level, CE practices remain limited to areas such as eco-design, green procurement, cleaner production, and waste management (Ghisellini et al., 2016). Moreover,

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qualitative evidence indicates that industry practitioners themselves do not always perceive a clear link between circularity and sustainability (Walker et al., 2022).

These limitations, combined with the lack of standardized measurement frameworks, motivate the need to consider a broader set of corporate actions that may contribute to circularity. In line with the Triple Bottom Line perspective, this study adopts an inclusive approach, incorporating environmental, social, and governance dimensions into the analysis. As argued in the literature, for the Circular Economy to effectively support sustainable development, it must contribute positively to all three pillars of sustainability (Korhonen et al., 2018; Kravchenko et al., 2019).

2.2 Circularity and ESG measures

To address the challenges identified in the literature regarding the relationship between circularity and sustainability at the corporate level, we propose the development of a new index to measure Corporate Circular Economy actions and their impact on sustainability outcomes.

Corporate strategies aimed at promoting circularity can take multiple forms, including environmental disclosure, supply chain restructuring, employee engagement in sustainable practices, and lifecycle monitoring of products beyond the firm's direct operations. While the relationship between Circular Economy practices and corporate performance has been explored in terms of competitive advantage (Oláh et al., 2022), the impact of such practices on sustainability outcomes remains less clear, despite evidence suggesting a positive relationship between sustainability performance and firm value (Nguyen, 2020).

The proposed index aims to capture circularity at the corporate level by moving beyond purely resource-based metrics (Elia et al., 2017) and incorporating a broader operational perspective. Specifically, the index integrates ESG indicators, reflecting the multidimensional nature of sustainability and corporate circularity. Although ESG criteria have become central to sustainable finance and corporate disclosure frameworks, questions remain regarding their alignment with CE principles. In particular, it is not always clear how each ESG dimension contributes to circularity, nor whether circular practices inherently lead to sustainable outcomes.

To construct the index, we draw on existing literature to establish a mapping between CE principles and ESG indicators.

The selection of environmental indicators is based primarily on the work of Kristensen and Mosgaard (2020), who provide a comprehensive review of micro-level circularity indicators. Their framework identifies key CE strategies, including recycling, end-of-life management, remanufacturing, disassembly, reuse, and resource efficiency. However, they also note the lack of standardization and the tendency to focus on a limited subset of these strategies. To address these limitations, our approach seeks to cover a broad range of CE principles through environmental indicators that reflect different dimensions of corporate environmental performance.

Social circularity indicators are selected based on the work of Padilla-Rivera et al. (2021), who use a fuzzy Delphi method to identify relevant social dimensions of circularity. Their findings highlight the importance of issues such as labor conditions, community engagement, and social responsibility in supporting CE transitions. Notably, governance is also identified as a relevant component within the social dimension.

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However, within the ESG framework, governance is treated as a distinct category encompassing mechanisms that shape corporate decision-making and accountability. Therefore, governance indicators are selected based on studies examining the relationship between corporate governance structures and sustainability performance (Palea et al., 2024; Biswas et al., 2018; Del Valle et al., 2019).

In addition, and following the distinction between active and passive CE strategies proposed by Mies and Gold (2021), we include additional ESG indicators aimed at capturing the proactive role of firms and their stakeholders in advancing circularity. Table 1 provides the details of the measures considered as indicators in the index, showing their match to one of the three ESG categories.

Tab. 1 – ESG categories and indicators. Source: own research

Category	Symbol	Indicators
Environmental Circularity Indicators	E	Resource Reduction Policy, Water Efficiency Policy, Energy Efficiency Policy, Environment Management Team, Environmental Restoration Initiatives, Staff Transportation initiatives, Self-Reported Environmental Fines, Environmental Partnerships, Internal Carbon Price per Tonne, Eco-Design Products, Take-back and Recycling Initiatives, Environmental Products, Environmental Investments Initiatives, Environmental Project Financing, Environment Management Training, Environmental Materials Sourcing, Waste Recycling Ratio, Renewable Energy Use, Resource Reduction Targets, Toxic Chemicals Reduction, Waste Reduction Initiatives, e-waste reduction initiatives, environmental expenditures investments, biodiversity impact reduction and environmental expenditures in R&D.
Social Circularity Indicators	S	Customer Health & Safety Policy, Employee Health & Safety Policy, Supply Chain Health & Safety Policy, Fair Trade Policy, Child Labour Policy, Forced Labour Policy, Human Rights Policy, Training and Development Policy, Freedom of association policy, community involvement policy, Employee Satisfaction, and Net Employment Creation
Governance Circularity Indicators	G	CSR Sustainability Committee, CSR Sustainability External Audit, Independent Board Members, CSR reporting on firms' global activities

Note: Table 1 shows the rationale behind the choice of indicators for the construction of the CCEI. It is based on an ESG approach for which a list of indicators from Thompson Reuters' Eikon database have been drawn, regarding their relationship with the Circular Economy and the three pillars of sustainability.

To assess the relationship between these indicators and environmental performance, carbon emissions (measured in kilotons of CO₂ equivalent) are used as the main outcome variable. Environmental circularity measures are expected to have a direct impact on emissions by promoting resource efficiency and reducing waste. However, some authors argue that CE may not necessarily reduce environmental impact, as it can reinforce existing consumption patterns by facilitating the continued use and recycling of materials without addressing overconsumption (Hobson & Lynch, 2016; Weghmann, 2020). Similarly, certain CE-related innovations, such as digital peer-to-peer platforms, may generate unintended environmental consequences due to behavioral rebound effects (Maitre-Ekern & Dalhammar, 2019). The relationship between social circularity measures and carbon emissions remains underexplored. Nevertheless, existing research suggests that social responsibility and stakeholder engagement can positively influence environmental performance (Alotaibi & Alajlan, 2021; Stanwick & Stanwick, 1998), indicating a potential indirect link between social indicators and emissions reduction.

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In the governance domain, a growing body of literature examines the relationship between governance quality and environmental performance. At the macro level, studies show that stronger governance systems are associated with lower emissions (Gani, 2012; Sarwar & Alsaggaf, 2021). At the corporate level, governance mechanisms such as board composition, external auditing, and CSR committees have been linked to improved carbon performance and sustainability disclosure (Aslam et al., 2020; Biswas et al., 2018; Elsayih et al., 2021; Esposito et al., 2023; Velte et al., 2020). However, causality remains difficult to establish. Some studies suggest that higher emissions may drive greater disclosure rather than the reverse (Hassan & Romilly, 2018). Despite these limitations, the inclusion of governance indicators remains essential for understanding the mechanisms through which firms implement and monitor circularity strategies.

3. METHOD: THE CORPORATE CIRCULAR ECONOMY INDEX

3.1 Index construction

To construct the CCEI, we follow an index-building approach adapted from corporate governance research (Djankov et al., 2008), which groups related firm actions into broader conceptual categories. In our case, we identify corporate actions associated with CE practices across ESG dimensions, and examine their relationship with carbon emissions.

Unlike previous studies, we look at actions or policies that a company can take with respect to the Circular Economy, irrespective if they pertain to the environmental, social, or governance areas. The aim behind the huddle of actions is verifying which ones, if any, prove to facilitate a reduction in carbon emissions. A similar approach is taken in Mora-Contreras et al. (2023); these authors built a complete theoretical framework, linking main CE drivers as pressures, strategic change, learning curves, and industry 4.0 to a three-legged sustainability performance concept through a collection of corporate CE practices, considering the concept's different fields of action (Take, make, distribute, use, and recover). In our study, the social, environmental, and governance circularity actions, accounted for in the ESG indicators described above would serve as drivers for potentially affecting corporate. We group indicators according to organizational action types. Specifically, we define four categories: (i) policies, (ii) monitoring mechanisms, (iii) initiatives beyond regulatory requirements, and (iv) resource efficiency. These categories capture different dimensions of corporate engagement with circularity.

Policies subindex

Policies serve as written evidence of corporations' guiding principles, reflecting their strategy, and defining their red lines in the different areas of firms' operations. The indicators included in this subindex respond to the different policies related to the broad understanding of the Circular Economy that companies report having been established. These are mostly related to the social sphere of sustainability; however, they all are also considered in the Circular Economy literature. Policies regarding customers' and workers' health and safety are in line with the design of Circular Business Models according to the EU (EEA, 2017). Fair trade engagement is also positively influenced by ethical consumption behavior related to Circular Economy (Kutaula et al., 2022), therefore, an indicator on fair trade policy is also included. Other social aspects' policies such as child labor, forced labor, or freedom of association are also seen as related to circular innovations (Board of Innovation, 2023). Considering human

rights and upstream workers' health and safety also play a role in accelerating a transition towards circularity (Fuller, 2020).

In close relationship with the core of the concept of the Circular Economy, two other social policy indicators are included, the existence of a training and development policy and of a community involvement policy. These are, according to the Circle Economy Foundation (2024), part of the enabling elements for shifting to a Circular Economy, as they serve to strengthen and advance knowledge and to create partnerships, respectively.

Finally, the policies subindex includes three indicators closely related to the principles of the Circular Economy, these being, the reposting of a resource reduction policy (European Parliament, 2023), a water efficiency policy (Delgado et al., 2024), and an energy efficiency policy (European Commission, 2020).

Monitoring subindex

This subindex includes indicators that can have an influence on the company's progress towards the Circular Economy and that are related to the company's management, monitoring, and reporting practices. These are highly related to the governance pillar of ESG. The existence of a sustainability committee within the corporate governing bodies proves to have a significant role in improving sustainability performance, both environmental and social (Biswas et al., 2018); likewise, after the COVID pandemic, Circular Economy has become one of the main areas of concern of CSR committees (ESADE, 2021). Equally, having an established environmental management team is also considered as an enabler to improve circularity (Circle Economy, 2024). The publishing of a sustainability report and its subsequent audit also prove to be relevant for corporations to move towards circularity (Circle Economy, 2022; Cutaia et al., 2020; Opferkuch et al., 2021) and to overcome greenwashing and ESG-laundering (GRI, 2022). From a macroeconomic perspective auditing is also presented as a way to enhance states efforts to adopt a Circular Economy (European Court of Auditors, 2023). Finally, the number of independent board members, a governance indicator related to the firms' structure and monitoring is also included, as firms' characteristics have also been studied in the light of Circular Economy (Vitolla et al., 2023).

Initiatives subindex

This subindex includes all the proactive actions adopted by firms in terms of the Circular Economy. Within this category, all the indicators about circular-economy related initiatives that companies can take, are clustered. These actions go from initiatives of having a staff transportation program, to increase transport-sharing to the workplace (Circular Economy Policy Research Center, 2019), to proactivity in self-reporting environmental fines, which reduces governmental auditing efforts and positively relate with efficient environmental remediation (Innes, 1999), or to the establishment of internal carbon prices (Klevtun & Nilsson, 2021).

Other proactive actions that enhance circularity are those related to creating environmental partnerships with other stakeholders or employing resources on eco-designing products and on take-back initiatives, which go in line with the EU relatively new Extended Producer Responsibility, Waste and the Eco-design directives. Other actions falling into this category are those related to financing and investing on environmental initiatives and R&D, training, and developing staff's skills related to environmental management. This subindex also includes

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initiatives related to waste and biodiversity impact reduction which fall closer to the core of a Circular Economy. A final indicator that is gathered in this subindex is employees' satisfaction. A measurement of the firm's efforts towards creating a healthy working environment, which can serve as an enabling element for circularity (Circle Economy Foundation, 2024), employees' engagement proves to be necessary for advancing towards this new economic paradigm (Veleva et al., 2017).

Resources subindex

This subindex includes the resources used by firms and their efficient use in terms of the Circular Economy. Even though consensus on how to define a Circular Economy is still lacking, the core elements of the concept always revolve around the idea of phasing out waste, regenerating nature, and lengthening products useful lives (Goddin et al., 2019). Therefore, a subindex encompassing all the circularity related measures regarding the establishment of efficiency and reduction targets has been considered. This final subindex includes the existence of established targets for resource reduction, toxic chemical reduction, and water efficiency. It also includes indicators on the use of renewable energy, percentage of waste that is recycled, and use of recycled water. For employees, as these are also company's resources, an indicator on employment creation and another one on employees' turnover have been included (Board of Innovation, 2023).

The Aggregate Corporate Circular Economy Index

We believe the framework of the previous sub-indices establishes an original approach to measuring the impact of Circular Economy performance indicators around types of actions that companies can take. These sub-indices explain the proactivity of a firm towards the Circular Economy in terms of: (1) the existence of policies adopted by the firm in the area of circularity; (2) the use of monitoring mechanisms that translate into higher control over discretionary decisions that could hinder good environmental performance; (3) the establishment of initiatives that aim at improving sustainability issues; and (4) the reduction in the use of resources and the improvement on their efficiency.

To code the indicators inside each of these four sub-indices, we assign a value equal to one if the company reports engaging in a specific action, and zero otherwise. For those indicators, which are reported as figures, we first calculate the annual sample mean across all companies and then dichotomize the indicator for each company giving it a score of one if the value is above or equal to the mean and zero otherwise. The sub-indices are constructed by adding the values for each of the actions clustered and by dividing the results by the number of possible actions in that category. Therefore, each subindex is standardized to range between zero and one. Finally, the overall "Corporate Circular Economy Index" (CCEI) results from the evenly weighted aggregation of the values of each of the four sub-indices. This aggregate index is standardized in the same way, dividing it by four (i.e. the number of sub-indices integrating it), which results in a value ranging from zero to one; the higher this value is, the more circular actions are disclosed. Figure 1 builds a graphical summary the steps taken to build the index. Further details on the index construction are included in the Table A1 in the supplementary material, which also presents a detailed definition of all the variables included.

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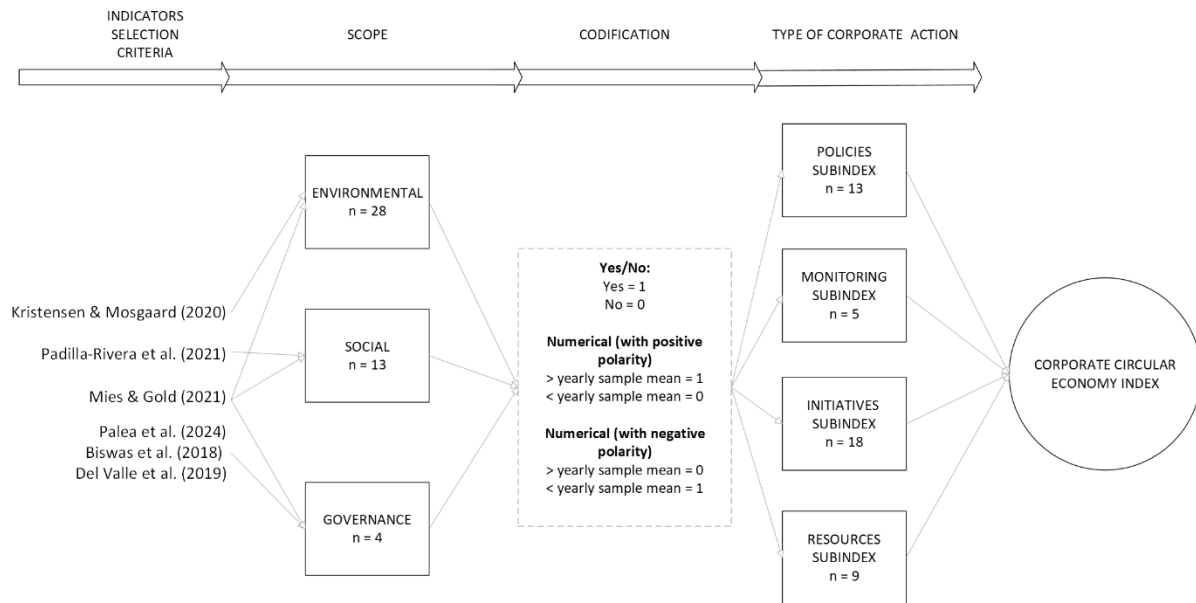


Fig. 1 – Step-by-Step CCEI construction. Source: own research

Note: This figure presents the process for the construction of the index. The first step is identifying indicators in literature that link Circular Economy with corporate actions in either the Environmental, Social and Governance field. Then these indicators are dichotomized. If they are yes/no questions, a “yes” corresponds to 1, and “no” to 0. If they are quantitative indicators, the dichotomization depends on the desired polarity. In those indicators with a desired positive polarity (e.g. net employment creation), a score higher than the sample yearly average translates into 1, and a score lower than average, into 0. In indicators with a negative desired polarity (e.g. liters of water consumed) a score under the sample yearly average translates into 1, and a higher than average score into 0. The next step is the grouping of indicators into different types of corporate actions that can be undertaken, these build the different sub-indices, namely, policies, monitoring, initiatives and resources sub-indices. Finally, the Corporate Circular Economy Index is built as the average of the four sub-indices.

The use of clustered indicators allows us to define the relationships between emissions and corporate actions of a certain kind. If a positive relationship is uncovered between any of these measures and the emissions released by the firm, it would suggest that those kinds of actions are not only ineffective for reducing carbon emissions, but also detrimental to the environment and possibly contributing to increasing the ecological burdens put on the planet. As the literature has argued that some Circular Economy actions have done before (Corvellec et al., 2022; Hobson, 2021; Korhonen et al., 2018; Kravchenko et al., 2019), These studies include all the components considered to create each subindex that form the global Corporate Circular Economy Index (CCEI) proposed.

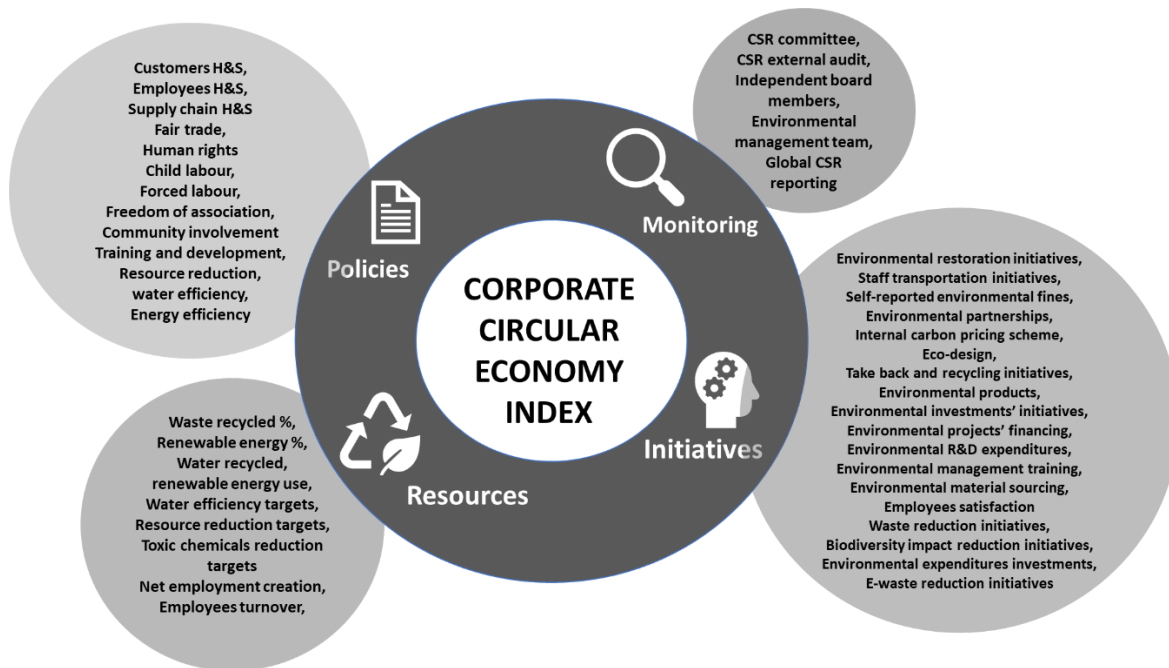


Fig. 2 – Indicators inside each of the sub-indices. Source: own research

Note: This figure shows the allocation of selected indicators into the built sub-indices, namely, Policies, Monitoring, Initiatives and Resources, which then feed the novel CCEI. Further details on the construction of the index and the definitions of the variables are provided in the Supplementary Material.

3.2 Sample and empirical design

The variables that are the components of the indices described above were collected for all the companies that form the STOXX Europe 600 index during the period starting in 2013 and ending in 2022. The focus on large European firms is motivated by their compliance with the EU Non-Financial Reporting Directive (2014/95/EU), which ensures greater availability and comparability of ESG-related data. This can lead to a bias on results, as the European Union holds a front-runner position in sustainable transition, with stricter regulation coupled with technological innovation, relating to better environmental performance (Ahmed, 2020). Nevertheless, the challenges posed to other regions replicating the CCEI for their companies rely only on their obligation to disclose data on corporate circularity indicators. Information disparities should be solved by the gradual implementation of mandatory disclosure policies that respond to the Triple C framework, making disclosures credible, convenient, and comparable (Singhania & Saini, 2023).

Other countries such as Canada, Australia, Japan, or the United States, present regulations in line with Europe's. However, these are primarily sectorial or voluntary, and its scope is limited beyond climate risk indicators, building in the present a less integrated framework. In a similar vein, developing countries present some limitations to sustainability reporting with countries as China having mandatory disclosure norms, while others such as Brazil or India have mostly voluntary disclosure systems (Singhania & Saini, 2023). Nevertheless, companies publicly listed in those regions also have incentives to disclosing data, as the tendency of big corporations disclosing corporate sustainability information is increasing, even if, not required by regional legislation, given stakeholders' demands on knowing companies' non-financial actions, which ultimately affects their decision making. In line with this, are the, still in-the-making ISSB (International Sustainability Standards Board) standards which, once fully

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developed and implemented, will set a comprehensive global baseline for disclosing non-financial information providing an international guideline, as this initiative is backed by the G7, the G20, and the Central Bank Governors from at least 40 jurisdictions (IFRS, 2024). Furthermore, businesses all around the globe are adopting globally recognized frameworks as GRI in sustainability reporting or SASB which focuses on sector-specific ESG disclosures. All these efforts will ultimately reduce disparities in data availability around the globe (Singhania & Saini, 2023).

Moreover, the sustainability effect of small- and medium-sized companies adopting CE practices has already been addressed in literature (Dey et al., 2020) concluding that only some of the field of actions considered improved the socio-ecological performance. Specifically, those actions gathered under the production and use phase strategies, but not in extraction, distribution, and end-of-life strategies. Nevertheless, although these companies given their size, are not subject to mandatory disclosure, complicating data collection on the indicators, they would still benefit from the settling of a list of circularity indicators and their impact on corporate environmental performance.

For our index construction, the sources of data for each variable integrating the indices are the information publicly disclosed by the companies and gathered in the Thomson Reuters' ESG Eikon database. This data has been complemented with general annual information about various firms' characteristics, and carbon emissions, which also disclosed by the companies in their annual reports. To standardize the measurement and obtain size-adjusted results, the main dependent variable used in the analysis is computed by dividing the kilotons of CO₂ equivalent emissions of the company by the firm's total revenues. The independent variables are the different indices created and presented in the previous section as well as several company characteristics.

Following prior literature (Pindado & Rodrigues, 2005; Adam & Goyal, 2008), the control variables used in the model are: (i) Leverage or LEV (total debt of the company divided by total asset); (ii) ROA (return on assets); and (iii) the market-to-book ratio, MB, measured as the market capitalization of the firm divided by the book value of assets (Kanas, 2013; Forti & Schiozer, 2015; Lepetit et al., 2018). All the control variables have been winsorized at 1% level. The supplementary material includes a detailed definition of all these variables.

3.3 Dealing with Construct validity and endogeneity issues

Our database combines time series with cross-sectional data, thus creating unbalanced panel data. Given the relevance of the existence of policies and targets from a first year versus subsequent years, and in order to solve potential endogeneity problems, we estimate the model through the dynamic panel data method using the Generalized Method of Moments (GMM).

We initially explored fixed effects (FE) and random effects (RE) panel data techniques to capture unobserved heterogeneity and obtain baseline estimates of the relationship between the CCEI and carbon emissions (the FE model can be seen in the supplementary material, table A2). However, FE and RE methods are limited when addressing endogeneity issues that arise from potential simultaneity, measurement error, and omitted variable bias, especially when dealing with dynamic panels where lagged dependent variables are included as regressors (Barros et al., 2020; Hill et al., 2019).

The GMM methodology, in contrast, offers several key advantages in this context, as it effectively handles the dynamic nature of our panel data by using lagged values of the dependent and independent variables as instruments, helping to mitigate bias that can occur when past values of the dependent variable are correlated with the error term. It also provides a robust framework for dealing with endogeneity by employing internal instruments (Arellano, 2003; Bianchi & Cordella, 2023), thereby yielding more consistent and reliable estimates. This is particularly important given the potential reverse causality between corporate circularity practices and carbon emissions. Employing GMM aligns with best practices in the literature, in which dynamic panel data models are frequently employed to study similar phenomena in corporate governance and sustainability (e.g., Aly et al., 2024; Arellano, 2003; Blundell & Bond, 1998; Cancela et al., 2020).

By adopting GMM, we address both the dynamic structure of our data and the endogeneity concerns that FE–RE methods could not fully overcome, enhancing the credibility and robustness of our empirical findings.

To assess the model construction validity, the real extent to which the indicators are able to explain sub-indices behaviors and the extent to which these are able to explain CCEI and the changes in carbon emissions, have been studied, following Black et al. (2017) and Blanco-Mazagatos et al. (2024) Confirmatory Factor Analysis (CFA). These results complemented with an analysis of the major explanatory components inside each of the sub-indices are discussed in section 4.3 Major contributors’ analysis.

4. RESULTS

4.1 Descriptive Results

An initial set of descriptive statistics for our sample is shown in Table 2. The overall mean for CCEI is almost 0.58, exhibiting wide variation going from 0.00, as there are some firms which do not report on any of the studied indicators, to 0.82, showing that not a single firm that reports all the indicators. The extent of the variation is a bit surprising as one would think that the largest listed corporations, as the ones in the STOXX Europe index, would have similar high control mechanisms and sustainability disclosures. The high variation also suggests a potential gain from higher disclosure standardization, as expected with the adoption of European-led legislation.

The Policies subindex has the highest mean value (0.60) out of the four sub-indices in our CCEI. This means that the average company in our sample discloses having more than half of the circularity policies measured. Meanwhile, the lowest mean score is that of the Initiatives subindex, as it only reaches a value of 0.31 for the average corporation. Most companies do not seem to be taking a proactive, leading role in moving towards circularity. This lack of proactivity shown in major firms’ initiatives can reflect the tick-in-the-box dynamic that the industry has on a theoretical gamechanger as CE with a great potential in post-capitalist or post-consumeristic economic model. Finally, it is in the establishment of monitoring practices where firms in the sample vary the most, having the Monitoring subindex the largest standard deviation, equivalent to 0.33.

Tab. 2 – Summary of descriptive statistics. Source: own research

Variable	Observations	Mean	Std. Dev.	Q25	Q50	Q75	Min	Max
CO ₂ Sales	6,000	0.1337	0.4817	0.0007	0.0113	0.0489	0.0000	8.2388

<https://doi.org/10.7441/joc.2026.SI.05>

CCEI	6,000	0.5789	0.4674	0.2374	0.5344	0.6423	0.0189	0.8833
Policies	6,000	0.6069	0.3031	0.4615	0.6923	0.8461	0.0000	1.0000
Monitoring	6,000	0.6204	0.3354	0.4000	0.8000	0.8000	0.0000	1.0000
Initiatives	6,000	0.3159	0.2071	0.1666	0.3333	0.5000	0.0000	0.8888
Resources	6,000	0.3263	0.2179	0.1111	0.3333	0.4444	0.0000	0.8888
Leverage	6,000	0.2270	0.1372	0.2225	0.3356	0.4480	0.0272	0.4480
Return on assets	6,000	0.4105	0.2469	0.0121	0.0121	0.0420	0.1134	0.8281
Market to book	6,000	1.132	0.9984	0.8001	0.8001	0.0661	0.0669	3.1710
Log Assets	6,000	23.10	1.5194	21.8966	22.9752	24.8991	20.8511	25.6574

Note: The table provides firms level data, from the constituents of STOXX EURO 600 index. For each variable the table shows the number of observations, mean, standard deviation, the percentile 50, the percentile 75 and the minimum and maximum values. A detail definition of variables is provided in Table A1 in the supplementary material.

Table 2 provides descriptive statistics for the 600 corporations throughout 10 years. Figure 3 has been included aiming to depict the evolution of the indices and carbon emissions throughout the period under study. The figure shows a slight reduction through time of the mean carbon emissions in kilotons over sales for the STOXX Europe 600 firms. Meanwhile, the CCEI and its components show significant growth. All areas of corporate circularity captured by the indices show an upward trend. The graph also suggests that the Policies subindex has increased markedly. Large listed European firms have increased their actions towards the consecution of a circular business model, as institutionally led policies have been trickling into the industry in the past few years. This is probably triggered by national responses to the rise of European Green regulation as the Circular Economy Action Plan. This plan may be a large explanation of the important increase in the indices starting in 2015.

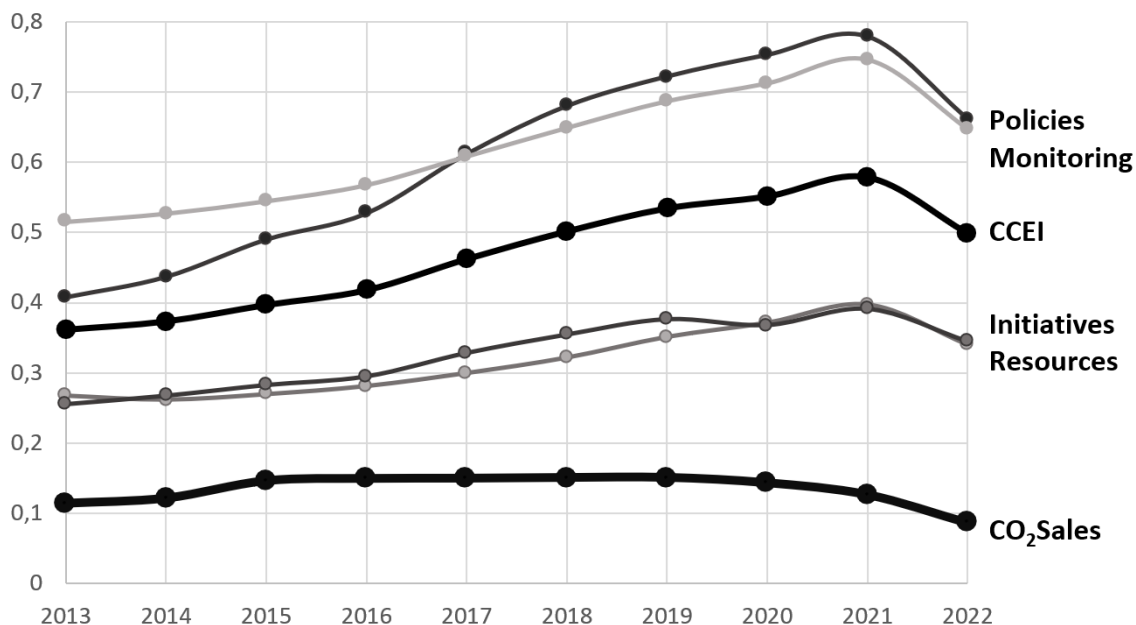


Fig. 3 – Evolution of the Corporate Circular Economy Actions and Carbon Emissions.

Source: own research

Note: The graph shows the mean annual amount of carbon emissions divided by sales for the STOXX EURO 600 constituents, as well as their mean score for CCEI and its sub-indices Policies, Monitoring, Initiatives and Resources for the period 2013 to 2022.

Although Figure 3 suggests that the carbon emitted by corporations have fallen over the period under study, it is still unclear if part of the reason behind this trend is related to the adoption of corporate circularity actions or if it is all due to other unknown causes. These questions are tackled in the analysis below.

4.2 Analytical results

Prior to introducing multi-variate regression results, Table 3 presents correlations among our variables. Given the nature of the variables measured, an important degree of correlation may be expected. Table 3 confirms that the correlations across the sub-indices of our CCEI are very high, suggesting they move closely together. While each subindex captures distinct aspects of circular economy practices, their interactions often complement and reinforce one another. Effective monitoring mechanisms are often implemented to ensure adherence to policies and firms with comprehensive policies invest in monitoring to track compliance. In the same line, policies can also set the perfect breeding ground for inspiring initiatives and the establishment of specific targets aligned with companies’ strategic goals. The establishment of specific efficiency targets also promote creativity and innovation in adapting initiatives to meet these benchmarks.

Table 3 also suggests that larger, more profitable, and more valuable firms have lower standardized carbon emissions. This could be explained by the fact that these firms may have a higher margin to maneuver or are able to better implement mechanisms for carbon reductions through circularity measures or other actions. The econometric work presented below controls for company characteristics in order to have a better assessment of the effect of Corporate Circular Economy measures.

Tab. 3 – Correlation matrix. Source: own research

	CO ₂ Sales	CCEI	Policies	Monitoring	Initiatives	Resources	Leverage	Return on assets	Market to Book	Log Assets
CO ₂ Sales	1.0000									
CCEI	0.1526 ^a	1.0000								
Policies	0.1261 ^a	0.9210 ^a	1.0000							
Monitoring	0.1490 ^a	0.9170 ^a	0.7872 ^a	1.0000						
Initiatives	0.1697 ^a	0.8803 ^a	0.7454 ^a	0.7516 ^a	1.0000					
Resources	0.1004 ^a	0.8393 ^a	0.7123 ^a	0.6567 ^a	0.7012 ^a	1.0000				
Leverage	0.0757 ^a	0.1283 ^a	0.1278 ^a	0.1079 ^a	0.1210 ^a	0.09687 ^a	1.0000			
Return on assets	-0.0916 ^a	0.0208	0.0163	0.0125	-0.0032	0.0507 ^b	-0.0156	1.0000		
MB	-0.1267 ^a	-0.0567 ^a	0.0380	-0.1010 ^a	-0.1596 ^a	0.0107	-0.1293 ^a	0.0804 ^a	1.0000	
Log Assets	0.1024 ^a	0.4219 ^a	0.30150 ^a	0.4101 ^a	0.4804 ^a	0.3128 ^a	0.0346 ^b	-0.0283	-0.6112 ^a	1.0000

Note: The table provides pairwise correlation of all variables at the firm-year level for the STOXX EURO 600 constituents for the years 2013 to 2022. Table A1 in the supplementary material provides the definition of all variables. ^a, ^b, and ^c indicate significance at the 99%, 95%, and 90% confidence level, respectively.

Table 4 presents the results of multi-variate regressions using a GMM model. The table shows six different specifications which include the same control variables, year dummies and industrial sector dummies to account for macro effects and industry variations. The six specifications only vary in terms of the Circular Economy subindex or index included. In particular, we consider the aggregate CCEI (column 1), each subindex individually (columns 2-5) to deal with the documented correlation across sub-indices, and all four sub-indices together (column 6) on the spirit of running a “horse race” between sub-indices. We use lagged variables for our indices as measures adopted in a year may impact the emissions reported the following year.

Tab. 4 – Dynamic panel data estimation for carbon emissions, the aggregated index and sub-indices. Source: own research

Variables	(1)	(2)	(3)	(4)	(5)	(6)
CO ₂ Sales _{lagged}	0.2678 ^a (0.0008)	0.2636 ^a (0.0007)	0.2671 ^a (0.0010)	0.2679 ^a (0.0007)	0.2665 ^a (0.0010)	0.2624 ^a (0.0009)
CCEI _{lagged}	-0.4395 ^a (0.0210)					
Policies _{lagged}		-0.2673 ^a (0.00872)				-0.3278 ^a (0.0011)
Monitoring _{lagged}			-0.3142 ^a (0.0153)			0.1387 ^a (0.0039)
Initiatives _{lagged}				-0.5218 ^a (0.0265)		0.1618 ^a (0.0298)
Resources _{lagged}					-0.4552 ^a (0.0186)	-0.0958 ^a (0.0177)
Leverage _{i,t}	0.3762 ^a (0.0262)	0.4326 ^a (0.0227)	0.3142 ^a (0.0153)	0.2204 ^a (0.0257)	0.2952 ^a (0.0308)	0.4117 ^a (0.0241)
Return on assets _{i,t}	-0.0231 ^a (0.0036)	-0.0184 ^a (0.0227)	-0.0236 ^a (0.0044)	-0.0176 ^a (0.0040)	-0.0256 ^a (0.0046)	-0.0157 ^a (0.0034)
Market to Book _{i,t}	0.0034 ^a (0.0031)	0.0152 ^a (0.0027)	-0.0551 ^c (0.0035)	-0.0096 ^a (0.0032)	-0.0062 ^c (0.0040)	-0.0180 ^a (0.0032)
Log Assets _{i,t}	0.1187 ^a (0.0037)	0.1181 ^a (0.0029)	0.1014 ^a (0.0042)	0.1055 ^a (0.0040)	0.087 ^a (0.0036)	-0.1633 ^a (0.0342)
Constant	-2.5340 ^a (0.0849)	-2.5870 ^a (0.0705)	-2.1039 ^a (0.0982)	-2.2253 ^a (0.0910)	-1.8329 ^a (0.0086)	0.1177 ^a (0.0039)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes
# Groups	599	599	599	599	599	599
# Observations	5252	5252	5252	5252	5252	5252
Wald Test (d.f.)	141957.3(6) ^a	147536.6(6) ^a	118195.2(6) ^a	174727.8(6) ^a	131253.0(6) ^a	144336.1(9) ^a
m1	-2.60	-2.56	-2.63	-2.64	-2.93	-2.89
m2	-1.44	-1.44	-1.44	-1.44	-1.45	-1.45
Hansen test (d.f.)	290.39(212)	312.54(212)	247.95(206)	270.62(206)	291.78(206)	312.99(203)

Note: The table provides GMM (generalized method of moment) estimation for STOXX EURO 600 constituents for the period from 2013 to 2022. The dependent variable is CO₂Sales and it includes the lag of this variable and the lag of variables CCEI, Policies, Monitoring, Initiatives and Resources. A detailed definition of all variables is provided in the supplementary material (Table A1). For each variable, the table shows the estimated coefficients and the standard errors. All regressions include industry and year fixed effects. The Wald test reflects the validity of instruments (degrees of freedom in brackets). The m2 is a test to check the absence of second order correlation, and the Hansen test is used for the over-identification of restrictions. Significance level: ^a, ^b, and ^c indicate significance at the 99%, 95%, and 90% confidence level, respectively.

The results in Table 4 show that higher past carbon emission levels significantly affect current levels of carbon emissions, as it was expected. Importantly, the table also shows that there is a negative and significant relationship between our lagged Circular Economy (sub)indices and the subsequent year corporate carbon emissions. In particular, the findings show a significant negative relationship between the global index (CCEI) and carbon emissions. The economic magnitude of these results is also important. The estimates from column one implies that an increase in a firm’s CCEI from the 25th to the 75th percentile of the distribution translates in an annual reduction of CO₂ emissions of more than 18%.

The table also shows a negative and significant relationship between carbon emissions and all the Polices, Monitoring, Initiatives, and Resources sub-indices when included separately. In terms of economic magnitude, the Initiatives subindex, closely followed by the Resources subindex are the most impactful. Yet, the other two sub-indices are also statistically significantly related to lower carbon emissions.

For the Monitoring subindex, it has an indirect nature that can explain its less-pronounced impact on emissions, as conducting an external sustainability audit provides control but does not reduce emissions by itself. Therefore, its effect as a facilitator can be overshadowed by other actions and by indicators with a more direct impact. In support of Biswas et al. (2018) and Palea et al. (2024) conclusions on the importance of good governance over sustainability, the significance of subindex Monitoring, even if diluted when considered together with the other sub-indices, promotes the idea that a good corporate governance structure is influential and may also trigger executive actions ultimately leading to a reduction in carbon emission. Although longer timeframes could be considered in order to maximize the potential of this and Policies sub-indices, given their indirect nature.

The Policies and Resources sub-indices maintain their negative coefficient and significance throughout all the columns, meaning that their influence on reducing emissions and their effect is stronger and more direct than the other sub-indices'. While Resources, which clusters efficiency targets and resource management optimizations, show a strong negative coefficient which can denote its direct impact in operational factors that build the company environmental footprint; Policies provide a framework with explicit guidelines to promote corporate strategic lines of action, which influence all the other actions, and indirectly the environmental performance.

4.3 Main contributors' analysis

In order to understand which of the particular indicators is more influential in each subindex, we use Partial Least Squares Path Modelling (PLS-PM) to study indices composition and weighting. PLS-PM is a methodology of statistical data analysis at the intersection of regression models, structural equation models, and multi-variate analysis methods that allows us to know what are the principal components of the sub-indices and the overall CCE index (Vinzi et al., 2010). According to this methodology, we developed a Confirmatory Factor Analysis following Debicki et al. (2016) and Blanco-Mazagatos et al. (2024), in order to understand which indicators are the main contributors of the sub-indices.

This method is sometimes preferred over a Principal Component Analysis (PCA), as it allows to create and validate constructs, in this case, sub-indices built by us relying on a theoretical background. PCA would create components without considering if the contributors of each component are policies, initiatives, or other types of actions. This feature makes the interpretation of PCA results less clear. Therefore, given the nature of our CCEI, we chose PLS-PM as the main analysis. Nevertheless, we also run a classic Principal Components analysis (results can be shown under request).

Since our CCEI is modelled as a reflective-formative second-order construct, we evaluate the measurement model of the reflective sub-indices by examining item reliability, internal consistency, as well as convergent validity (Roldán & Leal, 2003). We also assess the sub-indices' internal consistency by studying Cronbach's alpha and composite reliability. To confirm convergent validity of the results, Cronbach's alphas should be above 0.5, and composite reliability above 0.7. In order to confirm convergent reliability, we only use those sub-indices' components for which the average variance extracted exceeds the recommended threshold of 0.5 (Fornell & Larcker, 1981). Table 5 shows the components that meet the threshold, thereby confirming the convergent validity of these variables. All item loadings are

significant at $p < 0.01$. Therefore, we can obtain the main components for each of the sub-indices.

According to the results of the PLS-PM model, the most relevant indicators in the Policies subindex are the reporting of a policy dealing with child labour, forced labour, and human rights. The establishment of a policy that deals with supply chain actors health and safety, as well as an efficient use of water also contribute significantly to the Policies subindex. For the Monitoring subindex, it is the components related to having an established team and a clear chain of command and communication that have the highest influence in the subindex.

In the case of the Initiatives subindex, initiatives regarding investments and funding are the most relevant, but environmental investments initiatives and environmental expenditures investments are also influential. The consideration of environmental criteria in materials' sourcing, initiatives to reduce negative impacts to biodiversity, and the establishment of environmental partnerships are also relevant building blocks for this subindex too. Finally, only two of the Resources subindex's components comply with Fornell & Larcker (1981) criteria: the establishment of reduction targets for resource and water consumption. These two are in line with the core definition of both, the Resources subindex, and the Circular Economy.

If one were to draw conclusions from the previous analysis, the list just outlined could be a good set of actions in which a company should focus on the most to improve its circularity performance. However, one could also argue that although these are the main components, the results of the GMM analysis has also shown that the overall CCEI and the sub-indices are significant in terms of the measurement of circularity potential and its relationship with carbon emissions.

Tab. 5 – Reliability and convergent validity. Source: own research

Subindex/indicator	Factor Loading
Policies ($\alpha = 0.809$, AVE = 0.525, CR = 0.865)	
Child Labour Policy	0.809 ^a
Forced Labour Policy	0.777 ^a
Human Rights Policy	0.688 ^a
Freedom of Association Policy	0.680 ^a
Supply Chain Health & Safety Policy	0.613 ^a
Water Efficiency Policy	0.556 ^a
Monitoring ($\alpha = 0.522$, AVE = 0.689, CR = 0.815)	
Environment Management Team	0.848 ^a
CSR Sustainability Committee	0.792 ^a
Initiatives ($\alpha = 0.729$, AVE = 0.487, CR = 0.822)	
Environmental Investments Initiatives	0.660 ^a
Environmental Partnerships	0.656 ^a
Environmental Expenditures Investments	0.655 ^a
Biodiversity Impact Reduction	0.644 ^a
Environmental Materials Sourcing	0.575 ^a
Resources ($\alpha = 0.759$, AVE = 0.806, CR = 0.892)	
Resource Reduction Targets	0.813 ^a
Water efficiency targets	0.771 ^a

Note: The table shows the reliability and convergent validity of the sub-indices Policies, Monitoring, Initiatives and Resources in the PLS-PM model built for the sample of STOXX EURO 600 constituents for the period from 2013 to 2022. α corresponds to Cronbach Alphas, AVE to Average Variance Extracted, and CR to Composite Reliability, most of which are in the accepted threshold, $\alpha > 0.7$, AVE > 0.5 and CR > 0.7 . The table shows the indicators within each subindex with the higher factor loading. Significance level: ^a indicate significance at the 99% confidence level

To conclude our PLS-PM analysis, Table 6 confirms that the fit of the formative measurement model is correct, as the outer weights of all the first-order constructs (the sub-indices) that belong to the index are significant. The values show that the Policies subindex has a weight of more than 50% in explaining the Corporate Circular Economy Index (CCEI), the Initiatives subindex explains more than 37% and lagging behind, the Monitoring and Resources sub-indices explains only around 22% each. The sum of all outer weights is more than 100% because sub-indices are not completely independent. In our case, there are no significant collinearity concerns, as the Variance Inflation Factor (VIF) of all the constructs/sub-indices is below 3.

Tab. 6 – Quality criteria of second order measurement. Source: own research

Formative second order construct facets/sub-indices	Outer weights	VIF
CCEI		
Policies	0.524 ^a	1.312
Monitoring	0.219 ^a	1.393
Initiatives	0.374 ^a	1.428
Resources	0.222 ^a	1.281

Note: The table present the quality data for the construction of the CCEI through PLS-PM methodology for the sample of STOXX EURO 600 constituents for the period from 2013 to 2022. It presents *Policies*, *Monitoring*, *Initiatives* and *Resources* sub-indices' outer weights and VIF, variance inflation factor, which is on the accepted threshold (<3). It is a one-tailed T-statistic. Significance level: ^a indicate significance at the 99% confidence level.

With the previous results, considering only the main components of each subindex we construct the Figure 4, using the PLS-PM methodology, that indicates the outer weight of each subindex into the CCEI and the influence of this index created into the reduction of carbon emissions by each firm.

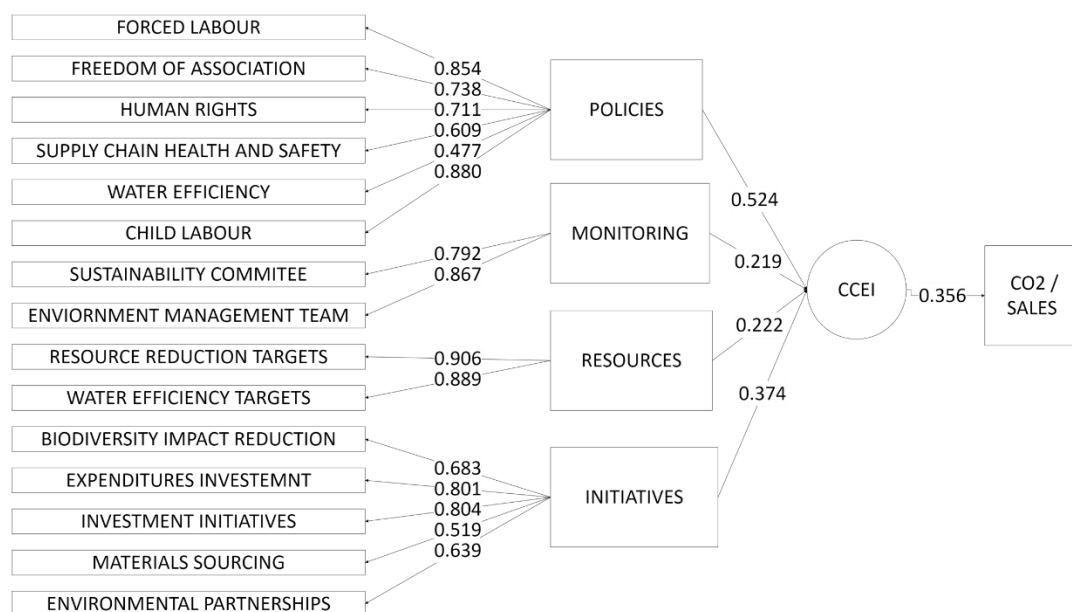


Fig. 4 – PLS-PM depiction of the model under study. Source: own research

Note: The figure represents the PLS-PM graphical depiction of the CCEI, the sub-indices with their outer weights and the main contributors with their factor loadings. The model depicted is formative for the construction of the sub-indices and reflective for the construction of the CCEI index and its relationship with the dependant variable CO₂Sales as it can be appreciated in the arrows' direction.

4.4 Robustness checks

We have performed three main robustness checks to validate the findings above. We conduct a first set of robustness tests using GMM with a reduced number of items within each subindex. To select the principal components included, we follow the PLS-PM results obtained in the previous section. Table 7 presents the findings of this additional test when the GMM model is run considering only the PLS-PM significant principal components of each subindex: only the variables with a significative factor loading, as indicated by Table 5, have been included to recalculate every subindex and the global index (CCEI). That is, only 14 out of the previously considered 45 variables are included in this model.

Tab. 7 – Dynamic panel data estimation for carbon emissions, the aggregated index and sub-indices. Source: own research

Variables	(1)	(2)	(3)	(4)	(5)	(6)
<i>Dependent variable CO₂Sales</i>						
CO ₂ Sales _{lagged}	0.2875 ^a (0.0007)	0.2729 ^a (0.0006)	0.2857 ^a (0.0015)	0.2270 ^a (0.0003)	0.2688 ^a (0.0003)	0.3679 ^a (0.0742)
CCEI _{lagged}	-0.3396 ^a (0.0121)					
Policies _{lagged}		-0.1524 ^a (0.0041)				-0.0878 ^c (0.0552)
Monitoring _{lagged}			-0.3601 ^a (0.0198)			-0.2151 (0.2608)
Initiatives _{lagged}				0.01420 ^a (0.0074)		0.2870 (0.3476)
Resources _{lagged}					-0.0311 ^a (0.0035)	0.0553 (0.1062)
Leverage	0.2001 ^a (0.0194)	0.1975 ^a (0.0155)	0.1936 ^a (0.0285)	-0.0236 ^b (0.0078)	0.0242 ^a (0.0076)	0.1886 (0.1732)
Return on assets	-0.0321 ^a (0.0023)	-0.0308 ^a (0.0017)	-0.0297 ^a (0.0021)	-0.0270 ^a (0.0013)	-0.0283 ^a (0.0012)	-0.0299 ^a (0.1188)
Market to Book	0.0040 ^a (0.0003)	0.0050 ^a (0.0003)	0.0025 ^a (0.0004)	-0.0029 ^a (0.0002)	-0.0016 ^a (0.0001)	0.0058 (0.0035)
Log Assets	0.0758 ^a (0.0031)	0.0603 ^a (0.0021)	0.0728 ^a (0.0042)	0.0154 ^a (0.0011)	0.0325 ^a (0.0010)	0.0537 ^a (0.0201)
Constant	-1.5557 ^a (0.0682)	-1.5076 ^a (0.0494)	-1.4202 ^a (0.0895)	-0.3044 ^a (0.0252)	-0.6462 ^a (0.0235)	-1.1220 ^a (0.4534)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes
# Groups	599	599	599	599	599	599
# Observations	5252	5252	5252	5252	5252	5252
Wald Test (d.f.)	225917.1(6) ^a	314900.3(6) ^a	67830.79(6) ^a	867437.3(6) ^a	1020000(6) ^a	4606.94(9) ^a
m1	-2.69	-2.63	-2.63	-2.64	-2.93	-2.89
m2	-1.46	-1.40	-1.44	-1.44	-1.45	-1.45
Hansen test (d.f.)	302.81(206)	349.56(206)	246.67(206)	438.1(206)	444.40(214)	338.42(256)

The table provides GMM (generalized method of moment) estimation. for STOXX EURO 600 constituents for the period from 2013 to 2022. The dependent variable is CO₂Sales for Panel A and CO₂Assets for Panel B. It includes the lag of this variable and the lag of the variable CCEI and sub-indices. CCEI and the subindex in the table are built considering only the components identified through the PLS-PM model, details provided in Section 5.3. A detailed definition of all variables is provided in Table A1 in the supplementary material. For each variable, the table shows the estimated coefficients and the standard errors. For each variable, the table shows the estimated coefficients and the standard errors. All regressions include industry and year fixed effects. The Wald test reflects the validity of instruments (degrees of freedom in brackets). The m2 is a test to check the absence of second order correlation, and the Hansen test is used for the over-identification of restrictions. Significance level: a, b, and c indicate significance at the 99%, 95%, and 90% confidence level, respectively.

Following the format of previous tables, Table 7 presents a GMM model for the aggregate CCEI (column 1), each subindex individually (columns 2-5), and the four sub-indices altogether (column 6). The regressions' control variables and fixed effects are also as in previous table. The findings in this table confirm that results in Table 5 showing a statistically significant negative relationship between the global index (CCEI) and carbon emissions. The same pattern emerges when looking at each subindex as before.

The second robustness analysis substitutes CO₂ emissions over sales by CO₂ emissions over assets as the dependent variable in the GMM model. Although one can think that the volume of sales talks about actual production and is more easily comparable across countries, an argument could be made that sales may be more directly linked to carbon emissions for some sectors or types of firms, while assets may be a more relevant concept for other sectors. A caveat of this view is that assets may be less comparable across countries as accounting practices vary internationally.

Tab. 8 – Dynamic panel data estimation for carbon emissions, the aggregated index and sub-indices. Source: own research

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Co2Assets _{lagged}	0.4830 ^a (0.0973)	0.4015 ^a (0.0980)	0.4009 ^a (0.0968)	0.3994 ^a (0.0973)	0.4029 ^a (0.0972)	0.3889 ^a (0.1011)
CCEI _{lagged}	-0.0519 ^c (0.0293)					
Policies _{lagged}		-0.0466 ^a (0.0179)				-0.1281 ^a (0.0481)
Monitoring _{lagged}			-0.0295 (0.0255)			0.0087 (0.1106)
Initiatives _{lagged}				-0.0104 (0.0763)		0.1606 (0.1654)
Resource _{lagged}					-0.0492 ^a (0.0397)	0.0823 (0.0694)
Leverage	-0.0320 (0.0091)	-0.0119 (0.0583)	-0.0522 (0.0765)	-0.0717 (0.0748)	-0.0402 (0.0659)	-0.0136 (0.0604)
Return on assets	-0.0121 (0.0091)	-0.0113 (0.0082)	-0.0111 (0.0084)	-0.0115 (0.0092)	-0.0128 (0.0088)	-0.0082 (0.0083)
Market to Book	-0.0222 (0.0089)	-0.0199 (0.0098)	-0.0242 ^a (0.0082)	-0.0268 ^b (0.0106)	-0.0245 ^b (0.0097)	-0.0128 (0.0114)
Log Assets	0.0002 ^b (0.0116)	0.0034 (0.0117)	-0.0032 (0.0110)	-0.0109 (0.0145)	-0.0057 (0.0110)	-0.0037 (0.0114)
Constant	0.1001 (0.2581)	0.0217 (0.2600)	0.1819 (0.2436)	0.3546 (0.3274)	0.2333 (0.2518)	0.1411 (0.2634)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Sector dummies	Yes	Yes	Yes	Yes	Yes	Yes
# Groups	599	599	599	599	599	599
# Observations	5250	5250	5250	5250	5250	5250
Wald Test (d.f.)	244.73(6) ^a	230.92(6) ^a	258.97(6) ^a	257.99(6) ^a	233.48(6) ^a	268.49(9) ^a
m1	-2.12	-2.10	-2.13	-2.13	-2.13	-2.08
m2	-0.78	-0.77	-0.76	-0.75	-0.80	-0.64
Hansen test (d.f.)	426.91(259)	433.02(259)	441.75(259)	465.89(259)	421.69(259)	365.82(256)

The table provides GMM (generalized method of moment) estimation. for STOXX EURO 600 constituents for the period from 2013 to 2022. The dependent variable is CO₂Assets and it includes the lag of this variable and the lag of the variable CCEI. A detailed definition of all variables is provided in Table A1 in the supplementary material. For each variable, the table shows the estimated coefficients and the standard errors. All regressions include industry and year fixed effects. The Wald test reflects the validity of instruments (degrees of freedom in brackets). The M2 is a test to check the absence of second order correlation, and the Hansen test is used for the over-identification of restrictions. Significance level: ^a, ^b, and ^c indicate significance at the 99%, 95%, and 90% confidence level, respectively.

Table 8 presents GMM results substituting the dependent variable by CO₂/Assets, calculated as the firm's total carbon emissions in kilotons at the end of the year divided by total assets. As

the table shows, we can confirm the results for the overall CCE index and the individual sub-indices of Policies and Resources as in Table 4. Meanwhile, the sub-indices of Monitoring and Initiatives, although pointing in the right direction of reductions, do not reach statistical significance.

Our final set of robustness tests uses alternative econometric methods. Although GMM seems the most adequate estimation method given the potential econometric problems outlined before, we also run an Ordinary Least Square (OLS) model as well as a Fixed effects' model (following the suggestion of a Hausman test). Results are weaker for some sub-indices, but they broadly confirm the previous findings obtained through the GMM estimation in Table 4. These results are presented in Table A2 in the supplementary material.

5. CONCLUSIONS

Circular Economy is subject to becoming the central economic framework in the foreseeable future. Not only is it backed by institutional support, but it is also promoted by corporations as the source of their shift to sustainable practices, while developing a competitive advantage. However, some of the literature has argued that circular does not necessarily mean sustainability (Korhonen et al., 2018; Skene, 2018; Bianchi & Cordella, 2023). With this in mind, this paper aimed to shed some empirical light about this relationship through the creation of a new Corporate Circular Economy Index. The index measures the effect of the circularity-related actions adopted by corporations in terms of their carbon performance, as a proxy for sustainability.

Our results show that greater effort put into corporate circularity actions is indeed linked to lower carbon emissions. The results hold when these actions are studied altogether, or clustered in groups according to their nature. The economic magnitude of the impact is also substantial. In terms of specific groups of actions, our findings echo the results in the literature of corporate governance (La Porta et al. 2013) and in literature of the environmental assessment of Circular Economy actions (Alesina & Giuliano, 2016; Kravchenko et al., 2019; Mora-Contreras et al., 2023).

The establishment of circularity corporate policies and their public disclosure, such as health and safety policies for different stakeholders (Padilla-Rivera et al., 2021) have a consistent impact on sustainability performance. Similarly, the use of monitoring mechanisms, such as the establishment of a delimited chain of command, expert ESG committee, and having external audits, proves also relevant for reducing emissions.

In this sense, promoting policy actions that improve disclosures of the corporate Circular Economy efforts can be meaningful in the quest for sustainability. It should be noted that Europe has been making moves along these lines during the past decade by standardizing and raising the requirements for non-financial information disclosure, materialized through directives, e.g. 2014/95/EU Directive on Disclosure of non-financial and diversity information. The CCEI offers a promising tool to complement and build on this Directive, as it provides policymakers with a standardized framework to assess corporate progress in circularity. The index aligns with the commission CE Action Plan's emphasis on resource efficiency, sustainable product design, and transparency in reporting. It provides policymakers with a specific list of indicators to monitor, avoiding double data requirements, as indicators used for

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index construction are not newly crafted but common in non-financial reporting. Therefore, improving the standardization in disclosures. The CCEI can help businesses settling on the indicators related to circularity to disclose, in areas where the flexibility of the Directive limits its requirements to the comply-or-explain principle. In this sense, the construction of the index and its validation can improve businesses with their resources' allocation strategies, by defining where to put the focus, improving resource efficiency and ultimately improving firms' competitive positions in increasingly sustainability-driven markets. The definition and delimitation of these specific indicators can also help corporations to define, keep track, and report on the hotspots that can benefit more from adopting circular practices.

In addition, the results obtained by the Partial Least Squares Path Modelling (PLS-PM) bring additional insights about what lies behind the jumble of Circular Economy conceptions. As the main components identified are seldom related to the “lengthen, close-loops, and regenerate” core of the concept. This brings into light the flaws that other authors have already identified arguing the Circular Economy has a loosely defined framework (Ehrenfeld, 2007; Mies & Gold, 2021; Nobre & Tavares, 2021; Mora-Contreras et al., 2023). This may also open the floor to a more inclusive, ethically-grounded, and social conception of the Circular Economy (Hobson, 2021; Larrinaga & Garcia-Torea, 2022; Pitkänen et al., 2023) or one that can survive in post-consumeristic futures (Maitre-Ekern & Dalhammar, 2019; Thompson et al., 2024), in which social policies, such as those related to combating child and forced labor, promoting human rights, and keeping an eye on the supply chain and its health and safety policy, are relevant components to move towards holistic circularity. To this end, the CCEI can serve as an agent for change extending the intrinsic meaning of circularity by providing a value to indicators within the social realm and shaping the concept to fit alternative production models' dynamics, not dominated by economic growth.

A Circular Economy in which experts constitute corporate CSR Committees and well-trained environment teams to lead and decide on circular actions should be also considered core to the concept. The same can be said for a Circular Economy in which proactive environmental initiatives create a positive social, environmental, and economic impact through investments and partnerships with stakeholders. Finally, the concept of corporate circularity should be broadened to consider resources' reduction targets which are not limited to efficiency measures, and that will in a broad sense improve competitiveness.

All these results are in line with the European Commission latest set of regulations. A good example is the 2022 European Corporate Sustainability Due Diligence Directive, which aims to compel European companies to systematically supervise social and environmental effects across their supply chains, encompassing both primary and secondary suppliers. This directive is designed to safeguard human rights and the environment, fostering a more equitable and sustainable global economy. CCEI can provide corporations with incentives to improve their sustainability and proactively improve their supply chain management, as evidence shows that it is a relevant building block for improving environmental performance. Besides, it can help policymakers to design policies that would specifically target those biggest contributors to the index and verify the effect of such, on sustainability.

The CCEI can also contribute to advancements made in linking corporate circularity practices to sustainability outcomes. Although this research presents some limitations that can hinder its applicability in some contexts, it opens new research opportunities for further investigating the topic and perfecting the index to fit in diverse cultural backgrounds, sectors, and company sizes.

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It currently focuses on large public European firms, subject to a very specific set of regulations, resulting in the average value of the index for the sample under study being potentially higher than if analyzed in other contexts. Therefore, comparisons and extrapolations should be made with caution.

While this focus on European and large corporations ensures consistency with established regulatory environments, future adaptations could broaden its relevance to smaller enterprises and firms in diverse economic or cultural contexts globally. The reliance on publicly disclosed ESG data for the index construction provides transparency and accessibility but may overlook efforts by firms with less mature reporting systems. Integrating complementary data sources, such as third-party audits or advanced monitoring technologies, could enhance the robustness and inclusivity of the index.

The study of the different interactions between sub-indices, given their interconnected nature, also provides a limitation. These interactions have not been modelled in this manuscript, but it also opens a field for further analysis, starting from the idea that the binary nature of the indicators included in the different sub-indices might not capture the nuanced relationships they have with one-another, which can distort statistical coefficients. Furthermore, considering longer timeframes and additional lagging of the indirect sub-indices as Monitoring or Policies might shed some light on the real effect these can have on corporate carbon performance.

One last limitation, or opportunity for future research, relates to the weighting of sub-indices and indicators. The equal weighting applied in the study ensures balance but may not fully capture sector-specific variations in the impact of circular actions. Refining the weighting to reflect empirical evidence or industry-specific dynamics could increase the precision of the CCEI's insights for practitioners and policymakers. A different approach to weighting could be based on stakeholders' opinions on the relevance of different sustainability targets for the industry, such as collaborative sustainable Development Goals ratings for building a composite indicator (Antón-Maraña et al.; 2024).

Our research results can advance towards a greater understanding on the effects of different actions taken by corporations in line with CE principles and how they affect their sustainability performance, in line with previous works in the topic (Mora-Contreras et al., 2023). We hope our paper opens new areas of research as our new index allows to create a more objective and tractable way of accounting for the circularity milestones achieved in the race against the clock for a sustainable future by corporations. We also hope our paper helps provide valuable insights on the evolution of corporate efforts to achieve a Circular Economy and the real impact of those actions on different firm variables, whether sustainability-related, finance-related, or both. This index may also prove useful in assessing the effectiveness of government initiatives such as the European Circular Economy Action Plan, help to shape future institutional actions, and make the Circular Economy a more sustainable, socially, ethically aware, and cohesive framework.

Endnotes

1. As stated in the European Court of Auditors' report on the European framework for monitoring EU's transition (European Court of Auditors, 2023), proposed and used indicators do not achieve to comprehensively encompass all the progress made, lacking specifically those regarding the circular redesign of products.

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