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ACCOUNTABILITY FOR CIRCULAR, SUSTAINABLE AND HUMAN CENTERED-VALUE - CHAINS IN CERAMIC INDUSTRY

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Abstract

"Lo studio dell'azienda è l'analisi scientifica di una particolare realtà economica, in tutti i suoi aspetti ed in tutte le sue interconnessioni con i sistemi più ampie e più piccoli in cui opera: l'importanza dell'economia aziendale non sta quindi nell'ampiezza del suo oggetto, ma nel tentativo di analizzare una realtà complessa che non è riconducibile ad un generico soggetto del sistema economico".

(G.ZAPPA, Il reddito d'impresa, 1937)

In the contemporary scenario, dominated by growing alarm over environmental and social crises, the need for a profound rethink of traditional economic modal has arisen. The imperative of a transition towards sustainability-oriented practices has become imperative for governments, companies and international organizations, especially in industrial sectors whose environmental and social impact is particularly burdensome.

Among these, the ceramic industry stands out for its economic relevance, while, at the same time, making a considerable contribution in terms of pollutants emissions, consumption of natural resources, waste management and a safe working context. In this frame, the idea of Circular Economy (CE) has gained prominence in academic and policy debates, offering an alternative paradigm (Suchek et al., 2022) to the linear economic model, based on extraction, production, consumption and disposal.

The CE , which is fully included in the broader concept of sustainability (Geissdoerfer et al., 2017), aims to close material cycles through strategies such as reduce, reuse and recycling, with the aim of minimizing pressure on natural resources. Such a model aligns with the principles of sustainability, not only in an environmental dimension, but also in a social and economic one, envisaging an economy capable of fulfilling the needs of today's generations without compromising the possibilities of future ones.

Nonetheless, the transition to a circular and sustainable economy presents itself as a complex challenge, especially with regard to the accountability and reporting of business practices.

It is in this backdrop that this research project is embedded, which aims to investigate the dynamics of accountability within circular and sustainable ceramic supply chains.

The thesis is organized in three main chapters, each of which aims to examine a specific aspect of the central theme, exploring the accountability and sustainability dynamics, with a particular focus on how these practices can be integrated and optimized along the value chain.

The approach of analysis is characterized by an initial focus on accounting practices adopted by listed companies and subsequently by unlisted companies (mostly SMEs).

The reasons underlying this modus operandi are manifold. First, large, listed companies are often subject to more stringent sustainability regulations, such as the EU directives on non-financial reporting. Examining these companies helps to understand how they are adapting to emerging standards and regulations, providing a model that SMEs can follow to anticipate future requirements or improve their sustainability practices (Tereshchenko et al., 2023). Moreover, large companies have a significant impact on supply chains and local communities (Mariadoss et al., 2016). Examining their approach to sustainability can help SMEs understand how to be part of a more sustainable supply chain or how to differentiate themselves by adopting sustainable practices that can attract sustainability-oriented partnerships or customers.

Among the main sustainability reporting standards currently used globally are the Global Reporting Initiative (GRI), the Sustainability Accounting Standards Board (SASB), and the Task Force on Climate-related Financial Disclosures (TCFD). These standards provide detailed guidelines on how companies should report their environmental, social, and governance impacts.

The GRI, in particular, is widely recognized for its focus on transparency and comprehensiveness of sustainability data, while the SASB focuses on sector-specific issues that may influence a company's financial performance.

The TCFD, on the other hand, emphasizes the risks and opportunities related to climate change, offering specific guidelines for properly assessing climate risks in business decision-making.

Despite the breadth and diversity of these standards, recent years have seen a growing need for a more homogeneous and binding regulatory framework that can ensure greater comparability and transparency among companies.

In this context, the European Union has promoted the introduction of the Corporate Sustainability Reporting Directive (CSRD), which represents a revision and enhancement of the previous Non-Financial Reporting Directive (NFRD). The CSRD introduces a series of stricter reporting obligations for companies, expanding the scope of firms required to report and imposing more rigorous transparency requirements.

The CSRD is innovative in several respects. First, it significantly broadens the range of companies subject to sustainability reporting obligations, including not only large listed companies but also many small and medium-sized enterprises that meet certain size thresholds. Additionally, the directive requires that the information provided by companies be verified by an external auditor, thereby ensuring greater reliability and accuracy of the reported data. Secondly, the CSRD introduces a more integrated approach to reporting, requiring companies to provide information not only on their environmental and social impacts but also on how these impacts affect their financial performance. This reflects a more holistic view of sustainability, recognizing that ESG factors can materially impact a company's economic prospects. Finally, the CSRD aligns with other international and European regulatory initiatives, such as the Taxonomy Regulation and the European Green Deal, promoting a consistent and integrated approach to sustainability.

In examining the details of this thesis, particular attention is given to two key aspects introduced in the topic– specific and the cross – cutting European Sustainability Reporting Standards (ESRS) of the CSRD: the concepts of the circular economy and the supply chain. CE, which is addressed in Chapter 1, is specifically covered under the environmental reporting standard ESRS E5, highlighting the relevance of adopting closed-loop production models that minimize environmental impact.

Chapters 2 and 3 take a value chain analysis perspective, an approach that is both innovative and challenging. As noted in Paragraph 5.2 of ESRS 1 on general requirements, "*Obtaining value chain information could also be challenging in the case of SMEs and other value chain entities that fall outside the scope of CSRD*" (EFRAG, 2022)[1].

The subsequent sections will provide a more detailed discussion of the three chapters of the thesis.

The first chapter, entitled "Circularity and default probabilities: an empirical investigation based on the 3R principles", aims to examines the impact of Circular Economy (CE) practices on firms' probability of default (PD) in both the short and medium term. Grounded in the 3R principles of CE, the analysis identifies three key dimensions of circularity, which collectively form an aggregate circularity score. The first dimension,

[1] EFRAG, 2022, Draft European Sustainability Reporting Standards ESRS 1 General Requirements, https://www.efrag.org/lab6

Reduce, captures the year-over-year reduction in greenhouse gas (GHG) emissions. The second, Reuse, measures the proportion of renewable energy consumption, while the third, Recycle, reflects the percentage of waste that is recycled or recovered.

Using an Ordinary Least Squares (OLS) regression model, the study analyzes a sample of 108 European firms listed in the STOXX Europe 600 Index over the 2017–2021 period. The findings reveal three primary insights. First, CE practices are significantly associated with a lower PD in both the short and medium term, even after controlling conventional economic and financial indicators. Second, among the three dimensions, the Reduce dimension emerges as the most influential in mitigating PD. Third, the negative relationship between circularity and PD is more pronounced in the short term. This suggests that the immediate benefits of CE adoption—such as tax incentives, improved credit access, and enhanced corporate reputation—may outweigh the initial implementation costs, which tend to be distributed over time.

These findings are relevant for both corporate managers, who can leverage the inverse relationship between CE practices and PD, and for supranational policymakers, who may use CE regulations to enhance financial system stability.

Subsequently, in the second chapter entitled “Mitigating supply chain emissions through strategic supplier assessment”, given the recent regulatory developments, companies are increasingly mandated to reduce and report emissions across their supply chains.

Integrating strategic supplier evaluations that incorporate emissions performance as a criterion facilitates the identification of environmentally sustainable supply chains. However, obtaining direct emissions data from suppliers is often complex and costly, highlighting the need for reliable proxies. To address this challenge, the study examines a dataset comprising economic, social, governance, and emissions-related metrics from 374 suppliers of an Italian ceramic manufacturer.

Through the application of dimensionality reduction techniques and linear regression analysis, the study reveals that effective emissions proxies vary across different supply chain phases. For suppliers in the material-processing sector, economic performance emerges as a significant proxy, with stronger financial outcomes closely associated with higher emissions levels. Conversely, within the logistics sector, social sustainability practices related to employee welfare are found to influence emissions. Meanwhile, for service sector suppliers, adopting sustainable governance practices contributes to emissions mitigation.

The findings underscore that the suitability of emissions proxies is dependent on the sectoral context within the ceramic supply chain. These insights provide valuable contributions to understanding how companies can address increasing regulatory, and stakeholder demands to assess and disclose supply chain emissions effectively.

One aspect that the second and the third chapter have in common is the context of analysis, the supply chain of a ceramic company, Florim S.p.A. SB. The company's active engagement enabled the execution of a critical empirical study, which served as the foundation for this doctoral thesis and facilitated the examination of sustainability reporting issues in light of the recent regulatory developments introduced by the Corporate Sustainability Reporting Directive (CSRD), set to be implemented in the near future.

Finally, in the third chapter entitled “”, through the lens of agency theory, it is explored the extent to which sustainable corporate governance can alleviate agency problems in small and medium-sized enterprises (SMEs). While the importance of Sustainability Disclosure (SD) practices is well-established in the context of large corporations, there remains a notable lack of empirical research examining the interplay between governance characteristics and sustainability efforts within SMEs. This paper investigates how specific governance attributes—namely, CEO duality, board size, board independence, average board age, and board gender diversity—affect the level of SD.

The study focuses on the upstream and downstream supply chain of an Italian ceramic firm, comprising 197 companies. By employing the European Sustainability Reporting Standards (ESRS) framework, an SD indicator was developed for each firm. A fractional logistic regression analysis was then conducted, revealing that board size, board independence, and average board age significantly enhance SD levels. In contrast, no statistically significant association was found between SD and either CEO duality or board gender diversity.

This research contributes to the SME literature by providing empirical evidence on the influence of governance structures on sustainability practices. Furthermore, it is among the first studies to investigate the relationship between governance traits and SD using the newly introduced ESRS framework, offering valuable insights for scholars and practitioners alike.

The contribution of this thesis lies in the integrated and multidimensional approach adopted to analyse accountability and sustainability practices in the ceramics industry. Firstly, the thesis offers one of the first empirical analyses of the impact of the circular economy on the likelihood of business failure, a topic that, despite its relevance, has so far been little explored in academic literature. Secondly, the research delves into the relationship between ESG practices and environmental performance, contributing to a deeper understanding of the role of sustainability policies in mitigating the environmental impact of firms. Finally, the analysis of sustainability disclosure provides new evidence on the importance of the governance structure for the quality of non-financial reporting, with relevant implications for regulation and corporate policies.

Chapter I: CIRCULARITY AND DEFAULT PROBABILITIES: AN EMPIRICAL INVESTIGATION BASED ON THE 3R PRINCIPLES

1. Introduction. – 2. Literature review: the role of sustainability in explaining PD. – 3. Dataset and descriptive statistics. – 3.1. Dataset and economic-financial variables description. – 3.2. Circularity score. 4. Empirical analysis. – 5. Results. – 6. Conclusion.

Abstract: This paper empirically investigates the role of Circular Economy (CE) in explaining firms' probability of default (PD) in the short and the medium term. Based on the 3R principles of CE, we identify three main dimensions of circularity whose mean represents an overall circularity score. The first, Reduce, measures the degree of reduction in GHG emissions with respect to the previous year, the second, Reuse, measures the share of renewable energy used and the third, Recycle, measures the share of waste recycled or recovered. We adopt and OLS regression over a sample of 108 European companies, from the STOXX Europe 600 Index over the period 2017 – 2021. Three main results emerge. First, both in the short- and medium-term circularity practices are associated to a lower PD even after accounting for usual economic – financial indicators. Second, among the three dimensions of circularity the really relevant one is Reduce. Third, when comparing the effect of circularity in the short term versus the medium term, it emerges that the negative relationship with the PD is more pronounced in the short term, suggesting that immediate benefits of CE (e.g. tax benefits, easier access to credit, better reputation) offset implementation costs, which instead can be amortized over years. These results are of interests both for managers, who may exploit the negative association of CE and PD, and for supranational institutions that via circularity regulation may also contribute to a more stable financial system.

1. **Introduction**

Corporate Social Responsibility (CSR) practices have evolved into a focal aspect of contemporary business paradigms, reflecting a progressive recognition of the interconnection between corporate operations with social and environmental issues. Escalating environmental degradation and resource scarcity are increasingly compelling companies to adopt CSR practices in their business activities, to mitigate their environmental footprint while simultaneously enhancing economic efficiency and resilience. The European Commissions has given attention to environmental sustainability: for instance, in December 2019 it launched the Green Deal (European Commission, 2019), which represents a comprehensive strategy to make Europe climate-neutral by 2050.

Moreover, recent legislative developments at the European level have introduced a further nuance within the CSR, specifically the concept of Circular Economy (CE). This concept stands in opposition to the traditional linear “take-make-dispose” model of production and consumption, emphasizing the regenerative use of resources, waste reduction and the establishment of sustainable value chains (Keulen and Kirchherr, 2020). Within this new framework, it is possible to identify two main initiatives. First, the CE Action Plans (CEAP) adopted by the European Commission outline a series of concrete measures to promote the transition to a CE in Europe, with specific objectives and targeted actions (European Commission, 2015 and 2020). Second, in 2023 the European Financial Reporting Advisory Group (EFRAG) presented a set of standards for reporting sustainability, known as European Sustainability Reporting Standards (ESRS), where the ESRS E5 standard is entirely focused on the topic of CE (EFRAG, 2023).

As a response, in the last decades EU-27 member states have significantly increased their circularity rate, measured by the share of material recycled and fed back into the economy, which increased from just above 8% in 2004 to 11.7% in 2021 (European Court of Auditors, 2023). However, it remains a highly relevant and timely issue for years to come, as the Commission's 2020 CEAP objective is to double the 2020 circularity rate by 2030.

It is important to emphasize that, although the concepts of CSR, Environmental, Social, and Governance (ESG), and CE are interrelated and have been usually considered proxies for sustainability, they do not completely overlap. In fact, CSR, which dates back to the 1950s, refers to the voluntary commitment of companies to conduct their business ethically and responsibly, considering the impacts on the environment, stakeholders and, more broadly, on the society at large.

Hence CSR serves as a precursor of corporate sustainability as it applies sustainable development principles at the business level and represents the capability to satisfy the needs of the firm's direct and indirect stakeholders without compromising the ability of future stakeholders to meet their own needs (Murmura et al., 2017).

The acronym ESG for Environmental, Social and Governance was introduced by the famous UN Report "Who cares win" (Compact, 2005) indicating a set of criteria that investors and stakeholders use to assess a company's performance in environmental, social, and governance dimensions. Thus, ESG can be thought of as a metric for CSR (Muñoz-Torres et al., 2018; Gillan et al., 2021). Finally, CE, or circularity, is a model of production and consumption that aims to minimize waste, maximize resource efficiency, and create a closed-loop system where products, materials, and resources are kept in use for as long as possible. Over the years, different definitions of CE have been proposed (Geissdoerfer et al., 2017; Kircherr et al., 2017; Kircherr et al., 2023), without reaching a consensus (De Pascale et al., 2021).

Nonetheless, the definition most frequently referenced in academic studies is the one proposed by Murray et al., (2017) p. 371, according to which: "*By circular, an economy is envisaged as having no net effect on the environment; rather it restores any damage done in resource acquisition, while ensuring little waste is generated throughout the production process and in the life history of the product.*"

On the other hand, in the international regulatory and business context, a reliable frame of reference is represented by the Ellen MacArthur Foundation, a non-profit organization, which defines the circular economy as follows: *"The circular economy is a system where materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting. The circular economy tackles climate change and other global challenges, like biodiversity loss, waste, and pollution, by decoupling economic activity from the consumption of finite resources".*[2]

This latter definition is based on three key principles: eliminate pollution, circulate products and materials and regenerate nature.

Overall, the concept of circular economy embodies a holistic and systemic approach to economic development that prioritizes resource efficiency, environmental sustainability, and long – term perspective. Such a concept has been interpreted by the academic literature

[2] https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

through the 3R framework of Reduce GHG emissions (the so-called Scope1), Reuse energy from renewable sources and Recycle of materials, in order to optimize production in a sustainable manner (Kircherr et al., 2017).

The nature of the relationship between CSR practices and the resulting economic-financial impacts, specifically on creditworthiness, as measured by default probability (PD) has long been debated (Naili and Lahrichi, 2020; Kaur et al., 2023).

The existing literature focuses on the relationship between ESG or more generally sustainability factors and default probability (Meles et al., 2023; Do 2022; Li et al., 2022). Despite the growing importance of the CE in terms of policies and regulations, research on CE remains relatively scarce in comparison to studies on sustainability or on the ESG, suggesting that topic is still largely unexplored.

Against this backdrop, the final aim of this paper is to gauge the role of sustainability in explaining firms' PD, with a specific focus on circularity and its three dimensions (Reduce, Reuse, Recycle), i.e. the 3R framework. To this end, we have measured circularity score based on the Eco Efficiency Indicator proposed by Park & Behera (2014), which considers a threefold partition of CE based on CO2 emission, energy consumption, raw materials.

The paper aims to address three main research questions: To what extent does circularity influence companies' PDs? Do the 3R of circularity contribute in different ways to explain the PD? Does circularity affect PDs more in the short term or in the medium term?

The research is performed on a sample of 108 companies, belonging to the STOXX Europe 600 from 2017 to 2021. In order to assess the relationship between circularity practices of a firm and its probability of default, we estimate an OLS regression with fixed effects in which we regress PD on companies' circularity scores and economic/financial variables.

Data on PD were obtained through the Bloomberg data provider, at 1-year and 5-year, to investigate the likelihood of default of the companies in the short and medium term respectively.

The present research contributes to a recent strand of literature on the relationship between CSR practices and companies' default risk in two main directions.

First, it is a first attempt to assess circularity considering a threefold distribution based on its multidimensional nature that encompasses: greenhouse gas emissions, energy from renewable sources and waste reduction policies.

Second our analysis is based on Bloomberg PD score while the most existing studies use other scores such as those by Credit Research Initiative, Risk Management Institute, Altman z – score or KMV model. This latter contribution is relevant given the current debate about the quality and divergence of different PD scoring providers.

Our study reveals that, even after accounting for profitability and other financial ratios, circularity, and particularly GHG reduction policies, significantly explains the PD by means of a negative association, which is more pronounced in the short term rather than in the medium term.

The reminder of this paper is structured as follows. Section 2 reviews the literature on the relation between sustainability and PD and Section 3 describes the dataset and the main variables used in the analysis. Section 4 illustrates the empirical model to test the effect of CE in explaining PD, Section 5 discusses results. Last Section concludes.

2. Literature review: the role of sustainability in explaining PD

The sustainable finance literature has been growing very fast following different strands. A first and very productive strand covers the field of sustainable assets such as green bonds (e.g. Zerbib, 2019; Bertelli et al., 2021) and sustainable portfolio strategies and performance (e.g. Friede et al., 2015; Revelli and Viviani, 2015; Cunha et al., 2021; Bertelli and Torricelli, 2022 and 2024). A second strand focuses on the implication of sustainability on the firms' credit worthiness, encompassing multiple aspects, including: credit ratings (Dorfleitner and Grebler, 2020; Zanin, 2021); credit risk from the perspective of credit default swap spreads (Bannier et al., 2022; Barth et al., 2022; Zhang et al., 2023), and firms' default risk (Pizzi et al., 2020; Atif and Ali, 2021; Do, 2022).

As for the literature on firms' default risk, most papers essentially investigate the role of sustainability issues (represented by either ESG ratings or CSR practises) in explaining probability of default or financial distress measures by means of a regression analysis except from Zeng et al. (2022) that include ESG ratings in PD prediction.[3]

A substantial body of research has employed a single country as a reference point. Rizwan et al. (2017) explore the impact of CSR engagement for 1,119 non-financial US-listed companies between 2000 and 2012.[4] They rely on Merton model (1974) for the estimation of

[3] Zeng et al. (2022) use a KMV methodology, which relies on Merton's model (Merton, 1974) for default risk estimation, to compute the distance to default and the expected default probability of a sample of Chinese internet finance firms from 2016 to 2020. Then, they correct such estimates in order to integrate ESG ratings into the evaluation model.

[4] CSR engagement score is based on the KLD Research and Analytics database, which ranks companies in various dimensions of CSR. A total of 13 dimensions are considered: community, diversity, governance, employee relations, human rights, environment, products, alcohol, gambling, firearms, military, tobacco and

distance-to-default, a reverse measure of default risk, and find evidence that companies with greater CSR commitment are exposed to a lower default risk.

Another analysis on the US stock market was conducted by Boubaker et al. (2020), who showed that, in the period 1991-2012, companies with high CSR, measured by MSCI ESG rating, are subject to lower financial distress risk, proxied by the Z-score of Altman (1968). In particular, this result is mainly driven by the governance component of sustainability.

The negative association between sustainability issues and default risk is confirmed also by Atif and Ali (2021) by considering US non-financial companies from 2006 to 2017 and finding that ESG disclosure, calculated by Bloomberg as a score from 0 to 100, has a positive relationship with Merton's distance-to-default and a negative one with credit default swap spread.

Shifting emphasis towards Asian markets, Li et al. (2022), based on a five-year time frame from 2015 to 2020, provide evidence that Chinese companies with higher ESG ratings show lower company's default risk.[5] Specifically, the impact of this relationship is even stronger for non-manufacturing companies than for manufacturing companies. Remaining within the Asian market, a recent study conducted by Okimoto and Takaoka (2024) and focusing on Japanese bonds from 2007 to 2018 confirms that ESG performance, provided by Refinitiv, acts also in mitigating corporate bond credit spreads.[6]

On the other hand, there are studies based on multi-country data. By focusing on the environmental aspects only, Kabir et al. (2021) measure the effect of carbon emissions on Merton's distance-to-default.[7] In the period 2004-2018 they find a negative impact of emissions on worldwide companies' distance to default, moreover environmental commitments and initiatives can act as mitigators of this effect.

Likewise, Meles et al. (2023) investigate the explanatory power of green innovation, retrieved by the Thomson ASSET4 database, on a sample of European firms from 2003 to 2019 and reveal that green innovation is negatively related to companies' default risk, based on both market-based and accounting-based indicators.

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nuclear energy. Of these dimensions, the first seven present data in the form of strengths and concerns, while the remaining six are dichotomous variables with a score of 1 if the company is engaged in one of the above activities and zero otherwise.

[5] Company's PD data are retrieved from Risk Management Institute database, while ESG ratings are retrieved from Sino – Securities Index Information Service database.

[6] Data are obtained from Japan Standard Bond Price Thomson Reuters Eikon database.

[7] They considered four different measurements of carbon emissions: total carbon emissions, direct carbon emissions, indirect carbon emissions, and Scope 3 carbon emissions.

Further, Mirza et al. (2024), by focusing on a European sample over the period 2012-2022, find that higher emissions are positively associated to default risk, whereas higher environmental score has a mitigating effect.

By shifting from an environmental perspective to an overall ESG consideration, Badayi et al. (2020) use Thomson and Reuters Datastream ESG data as a proxy for CSR and investigate their effect on the PD, proxied by Altman Z – score, of 496 firms from 17 developing countries in 2010-2017. Results show that CSR practices reduce the PD in Asian, Latin American, and European regions, with the exception of the African and Middle Eastern region.

When dealing with mandatory ESG disclosure, Do and Vo (2023) adopt a difference-in-difference model on firms in 17 emerging countries over the period 2000-2018 and show that companies situated in countries with mandatory ESG regulation have increased their distance to default (provided by Credit Research Initiative (CRI)) compared to firms not subject to mandatory ESG disclosure.

Regarding the family firm's context, Maquieira et al. (2024), by examining a worldwide sample over 6 years between 2015 and 2021, reveal that there is positive relationship between ESG and Altman Z-score.[8] Furthermore, by looking at the separate ESG pillars, the result is confirmed for both E and S. Finally, Do (2022) empirically find a negative relation between CSR and the PD of firms from 36 countries in 2002-2016. Firm-level CSR performance is derived from Thomson Reuters ASSET4, while default probability is considered over different time horizons ranging from 1 month to 5 years and is obtained from the CRI.

Overall, very little has been said about the role of CE-based activities, which can be considered a proxy for environmental sustainability, in explaining companies' probability of default.

Nevertheless, we are particularly interested in investigating the role of CE on PD, because, as Kumar et al. (2023) pointed out, CE and finance are not totally detached concepts from each other. Contrarily, these two concepts exhibit an interconnected relationship wherein they mutually foster and influence each other.

To the best of our knowledge, only Zara and Ramkumar (2022) empirically investigate the role of CE practices in explaining firms' PD. Specifically, they perform an OLS regression analysis, based on 222 European firms in the period 2013 – 2018. However, the authors use a broad concept of CE: the circularity score used in their estimates is based on 140 ESG

[8] Both ESG and default risk data are collected from Thomson Reuters Eikon database.

indicators (covering the three ESG pillars) that are considered relevant for CE and among them they select the industry material ones according to the materiality framework proposed by the Sustainability Accounting Standards Board (SASB). The authors find that circularity practices exert a de-risking strategy both in the short and long term, even after including economic and financial control variables in the analysis.

In summary, despite the rapid growth of CE practices, there is a lack of empirical research in the literature on the relationship between CSR practices and firms' PD. As a matter of fact, Agrawal et al. (2023) identify as a promising field for future research to understand the extent to which circular companies are profitable and capable of meeting their economic obligations, thereby challenging the assumption that these companies are not economically viable due to higher initial costs.

To fill this gap, this paper aims to investigate the extent to which CE, from the 3R perspective, can be considered a determinant of companies' PD.

3. Dataset and descriptive statistics

In this section we illustrate the dataset used and the variables considered. First in Section 3.1 we describe the sample selection process, and the main economic-financial variables used in the analysis. Then, in Section 3.2 we discuss the theoretical motivation behind the setup of circularity score, and we clarify its computation.

3.1 Dataset and economic-financial variables description

For our sample we consider the 925 stocks that were part of the STOXX Europe 600 Index from January 2016 to December 2022.[9] We focus on the period subsequent to the enter into force of the UN 2030 Agenda and we include also Covid-19 pandemic outburst. Yearly circular economy and financial variables of companies are retrieved for the period 2017-2021 from Bloomberg, which draws on companies' reports and communications, and, in cases of missing circularity data, we examined companies' websites and all publicly disclosed information.[10] We consider only non-financial companies, because of the distinct nature of financial ones, for which circularity has less impact on business activities and decisions. Moreover, in order to have a balanced and reliable dataset, we exclude companies for which

[9] The STOXX Europe 600 Index is a stock market index composed of 600 leading companies by capitalization of the European market and it offers a comprehensive coverage in terms of industry and country.

[10] From the analysed period we exclude 2016 due to incomplete data concerning companies' environmental performance and 2022 since, at the time the analysis was conducted, many data were not yet available.

circularity variables are not available or inconsistent for all the years considered. This process brings to a significant reduction in the sample size due to three main reasons. First, there is a lack of standardization both between companies and within the same company over time. Second, circularity information exhibits different granularity and disclosure levels given that some companies provide more detailed and comprehensive information about circularity practices, while others offer only limited or surface-level insights. The final issue refers to missing data for earlier years due to incomplete historical records or change in measurement practices, especially for specific environmental indicators (e.g. consumption of renewable energies and amount of recycled waste).

Hence, the final sample includes 108 companies and consists of a balanced panel containing 540 firm-year observations. Despite the limited number of components, it is quite representative of the overall market in terms of industry and country as reported in Table 1 and Table 2 respectively. The two most represented industries are Industrials and Materials, which represent one third of total companies considered. The latter, together with the other most significant sectors (Consumer Discretionary, Consumer Staples and Health Care), reach two third of the total sample and represent manufacturing companies for which circularity plays a crucial role due to the substantial energy and raw material requirements, as well as the significant waste generated. In terms of geographical distribution, Britain, Germany, and France stand out as the most represented countries, collectively accounting for half of the sample.

Table 1. Companies by sector

	N	**(%)**
Communications	5	4.630
Consumer Discretionary	14	12.963
Consumer Staples	11	10.185
Energy	7	6.481
Health Care	11	10.185
Industrials	15	13.889
Materials	21	19.444
Real Estate	11	10.185
Technology	8	7.407
Utilities	5	4.630
Total	108	100.000

Notes: the table reports sector breakdown in absolute terms (second column) and in percentage (last columns) according to the Bloomberg Industry Classification System (BICS) level 1.

Table 2. Companies by country

	N	(%)
Austria	1	0.926
Belgium	3	2.778
Britain	20	18.519
Czech	1	0.926
Denmark	2	1.852
Finland	4	3.704
France	16	14.815
Germany	18	16.667
Italy	9	8.333
Netherlands	7	6.481
Norway	2	1.852
Poland	1	0.926
Portugal	1	0.926
Spain	5	4.630
Sweden	8	7.407
Switzerland	10	9.259
Total	108	100.000

Notes: the table reports country breakdown in absolute terms (second column) and in percentage (last columns).

To empirically test the relationship between circularity and the PD in the short and in the medium term, as dependent variable we consider both 1-year PD and 5-year PD. Such measures are retrieved from Bloomberg and are calculated by the Bloomberg Issuer Default Risk model which is based on an equity perspective.

Table 3 presents descriptive statistics of both 1-year and 5-year probabilities of default which results to be on average small (0.2% and 1.8% respectively) with little variation (1.2% and 2.8% respectively), hence we use their log transformation in order to usefully increase the range of PD values.

The explanatory variables we focus on in the present analysis are the circularity one, but we also consider as controls the financial and performance ratios normally used in the PD estimation literature. As for circularity, we measure it both with a comprehensive score and its three main components presented and computed in Section 3.2.

As for the control variables, we include profitability ratios to control for income performance from an equity and total asset perspective by considering *Return on Equity* (*ROE*) and *Return on Assets* (*ROA*) respectively; *Interest coverage ratio*, calculated by dividing company's earnings before interest and taxes (EBIT) by its interest expenses, to assess a company's ability to pay interest expenses on its outstanding debt, hence controlling for liquidity risk; *Current ratio* is a ratio between current assets and current liabilities and controls for company's ability to meet short-term obligations with its short-term assets; *Net debt to EBITDA* (Earnings Before Interest, Taxes, Depreciation, and Amortization) is a financial ratio to assess company's financial leverage and ability to repay its debt obligations, thus it controls for company's solvency; *Market capitalization to total assets* is a ratio that measures the company's market value relative to the value of its total assets, hence controlling for company's market size.

From Table 3 it emerges that the companies in the sample show a certain variability in terms of control variables.

For instance, ROE exhibits a larger standard deviation and a wider range of values with respect to ROA, suggesting that the companies in the sample might be characterized by different financial structures or by a financial structure that significantly changed over the years.

Interest coverage ratio assumes both negative and (very) positive values implying that the ability to generate enough operating income to cover the interest on debt is different between companies and within the same company over the year. In particular the highest Interest coverage ratios are associated to 2017 and 2018, years of normal market condition, whereas the lowest values are mainly referred to 2020 when the Covid-19 pandemic hit companies by reducing their revenues while maintaining rigid financial commitments.

Table 3. Descriptive statistics of dependent and control variables

	N	Min.	Median	Mean	Max.	St. Dev.
Dependent variables						
1-year PD	540	0.000	0.000	0.002	0.184	0.012
5-year PD	540	0.000	0.010	0.018	0.321	0.028
log 1-year PD	540	-23.026	-10.085	-10.632	-1.693	3.899
log 5-year PD	540	-8.204	-4.582	-4.671	-1.136	1.177
Control variables						
ROE	540	-197.143	12.952	12.917	126.416	20.364
ROA	540	-21.637	4.930	5.531	41.460	5.746
Interest cov. Ratio	540	-31.237	9.033	21.533	704.143	52.977
Current ratio	540	0.135	1.258	1.451	17.135	1.195
Net debt to EBITDA	540	-6.944	1.594	2.557	52.319	5.341
Mkt cap. to tot. Assets	540	0.043	0.883	1.270	8.435	1.146

Notes: the table presents minimum, Median, Mean, Maximum and Standard Deviation (St. Dev.) of dependent and control variables. 1-year PD and 5-year PD are not reported in percentage. Log 1-year PD and log 5-year PD represent the natural logarithm of 1-year PD and 5-year PD respectively. ROE and ROA are expressed in percentage.

3.2 Circularity score

Since Circularity score represents the focus of our analysis, in its setup we aim to consider all the main features that characterize a circular economy. In doing so we combine a qualitative definition of circularity with quantitative indicators to measure firms' circularity involvement.

First, the interpretation of the main features of circularity (i.e. eliminate pollution, circulate products and materials, regenerate nature) passes through the 3R paradigm which consists in Reducing GHG emissions, Reusing energy from renewable sources and Recycling materials.

Second, we consider the Eco-Efficiency Indicator, originally proposed by Park & Behera (2014), which has been described by De Pascale et al. (2021) as a possible indicator for measure CE at meso level.[11] The Eco-Efficiency indicator is based on the World Business Council for Sustainable Development (WBCSD) definition of eco-efficiency, a concept that applies to any types of company and focuses on achieving more value with fewer resources and less environmental impact, hence optimizing resource use and reducing waste and pollution.

[11] Such an indicator has been classified among the meso level indicators since it has been originally proposed with the aim to simultaneously quantify the economic and environmental performance of industrial symbiosis networks.

Among the various ways described by the WBCSD to reach eco-efficiency and different indicators to measure it, Park & Behera (2014) select four sub-indicators to build their Eco-Efficiency Indicator: an economic indicator and three environmental indicators represented by raw material consumption indicator, energy consumption indicator, and CO2 emission indicator (WBCSD 1993 and 2000; Verfaillie and Bidwell, 2000).

In order to set up a circularity score for each company in the sample, we combine the 3R (Reduce, Reuse and Recycle) paradigm for CE with a measurement approach as the one represented by the three environmental indicators of the Eco-Efficiency Indicator.

Even if Park & Behera (2014) propose measurement at meso level, while our analysis is at companies' level, we get inspiration from their work to identify metrics for measuring circularity objectives, adapting these metrics based on publicly available information from companies. Therefore, we select three main dimensions, that in line with the 3R paradigm we call Reduce, Reuse and Recycle, which are computed as follows:

$$Reduce_{i,t} = -\frac{\frac{GHG_{i,t}}{TA_{i,t}} - \frac{GHG_{i,t-1}}{TA_{i,t-1}}}{\frac{GHG_{i,t-1}}{TA_{i,t}-1}} \times 100 \tag{1}$$

$$Reuse_{i,t} = \frac{RenewEnergy_{i,t}}{TotEnergy_{i,t}} \times 100 \tag{2}$$

$$Recycle_{i,t} = \frac{RecWaste_{i,t}}{TotWaste_{i,t}} \times 100 \tag{3}$$

where:

$GHG_{i,t}$ = scope 1 greenhouse gas (GHG) emissions of company *i* at time *t*, measured in thousands of metric tonnes of carbon dioxide equivalent (CO2e)

$TA_{i,t}$ = total asset of company *i* at time *t*

$RenewEnergy_{i,t}$ = energy consumed by company *i* at time *t* that was generated by a renewable energy source

$TotEnergy_{i,t}$ = total energy consumed by company *i* at time *t*, including energy directly consumed through combustion, through chemical and energy consumed as electricity

$RecWaste_{i,t}$ = waste recycled or recovered by company *i* at time *t*

$TotWaste_{i,t}$ = waste, both hazardous and non-hazardous, discarded by company *i* at time *t*

Reduce represents the degree of reduction in GHG emissions with respect to the previous year, Reuse can be interpreted as the share of renewable energy used and Recycle the share of waste recycled or recovered. To account for all the three dimensions equally, circularity score for company i at time t is the arithmetic mean of $Reduce_{i,t}$, $Reuse_{i,t}$ and $Recycle_{i,t}$:

$$C_{score_{i,t}} = \frac{Reduce_{i,t} + Reuse_{i,t} + Recycle_{i,t}}{3} \tag{4}$$

The circularity score is, hence, measured in percentage and its descriptive statistics are reported in Table 4. Circularity score ranges from -45.349% to 68.122% with an average value of 34.548%, very close to the median one (34.880%).

There are some negative circularity scores since the Reduce dimension shows also values below zero in cases where a company increases the amount of GHG with respect to the previous year. On the contrary, Reuse and Recycle exhibits only positive values in the ranges 0.005% to 96.038% and 1.362% to 100% respectively, with average values of 30.230% and 66.799% respectively. All 3R have a standard deviation around 20% and it reduces to 14% when considering circularity score.

Table 4. Descriptive statistics of circularity score and its components

	N	Min.	Median	Mean	Max.	St. Dev.
Reduce	540	-233.140	6.577	6.616	82.838	19.641
Reuse	540	0.005	24.392	30.230	96.038	25.141
Recycle	540	1.362	68.641	66.799	100.000	23.001
Circularity score	540	-45.349	34.880	34.548	68.122	14.935

4. Empirical analysis

In this Section we define the empirical model to be estimated, and we conduct some preliminary analysis in order to deal with multicollinearity and the choice between fixed and random effects model specification.

In the analysis, aimed to investigate the effect of circularity in explaining companies' probability of default, we estimate the ordinary least square (OLS) model in equation (5).

This approach, widely adopted in the literature on PD determinants, effectively captures the continuous nature of the dependent variable and facilitates the interpretation of the association between circularity and the PD. Moreover, the choice of OLS is justified since our dependent variable, the probability of default (PD), is a continuous variable whereas we do not consider a dichotomous variable indicating whether a firm has defaulted in the analysed period, given that our sample does not include defaulted companies.

$$logPD_{i,t} = \beta_0 + \beta_1 circularity_{i,t} + controls_{i,t} + \alpha_i + \lambda_t + u_{i,t} \quad (5)$$

where:

$logPD_{i,t}$ = log of Probability of Default (1 or 5 years) of company *i* at time *t*

β_0 = constant term

$circularity_{i,t}$ = overall circularity score of company *i* at time *t* or 3R: Reduce, Reuse and Recycle of company *i* at time *t*

$controls_{i,t}$ = vector of control variables for company *i* at time *t*: ROE, ROA, Interest coverage ratio, Current ratio, Net debt to EBITDA, Market capitalization to Total assets

α_i = company fixed effect

λ_t= year fixed effect

$u_{i,t}$= error term of company *i* at time *t*

In the model we consider both 1-year PD and 5-year PD in order to investigate separately the effect of circularity on short-term and medium-term PD. Moreover, circularity is both considered at the aggregate level (by means of the circularity score) but we also focus on its dimensions (Reduce, Reuse, Recycle) in order to see whether they impact PD differently.

By introducing both company (α_i) and year (λ_t) fixed effects we control for variables that are constant over time but differ across companies and for variables that are constant across companies but evolve over time respectively. Finally, in order to account for heteroskedasticity and autocorrelation in the error term $u_{i,t}$ we cluster standard errors at the firm level. Hence, we allow that the regression errors can be correlated over time within a company.

We begin the empirical analysis by examining correlation and the variance inflation factor (VIF) to ensure that multicollinearity is not an issue between the independent variables of regression in (5).

Not surprisingly, the circularity score is highly correlated with its three components, especially reuse and recycle, as it is an arithmetic mean of the three (Table 5).

However, there is no issue of multicollinearity in the model, as we conduct separate regressions where circularity is represented either by the circularity score or by its three components.

ROA shows a moderate correlation with ROE (65.3%), given that they both represent profitability ratios, and with Mkt capitalization to tot. Assets, probably because they share the same denominator, and their numerators (i.e. net income and Mkt capitalization respectively) are quite correlated.

However, Table 6 demonstrates that multicollinearity is not a concern in our analysis since VIF values, which quantifies how much the variance of an estimated regression coefficient is inflated due to multicollinearity, are below 10 (also below the more conservative threshold of 5) and tolerance (1/VIF) is always above 0.2 (Numan et al., 2022; El-Bannany, 2017).

In order to find the model specification more appropriate for our model, we perform a Hausman test (Hausman, 1978) and it confirms that a fixed effects model is preferred. Moreover, a fixed effects model is preferred also because in our context it is plausible that companies' characteristics might affect the regressors.

Table 5. Correlation among dependent variables

	Reduce	**Reuse**	**Recycle**	**Circular. score**	**ROE**	**ROA**	**Int. cov. Ratio**	**Current ratio**	**Net debt to EBITDA**	**Mkt cap. to tot. Assets**
Reduce	1									
Reuse	0.020	1								
Recycle	0.107	0.298	1							
Circolar. score	0.504	0.723	0.727	1						
ROE	0.078	0.095	0.136	0.157	1					
ROA	0.153	-0.007	0.047	0.087	0.653	1				
Int. cov. Ratio	0.043	0.048	0.048	0.070	0.172	0.391	1			
Current ratio	0.010	-0.119	-0.136	-0.132	0.037	0.148	0.031	1		
Net debt to EBITDA	-0.096	0.085	0.080	0.047	-0.174	-0.360	-0.162	-0.077	1	
Mkt cap. to tot. Assets	0.066	0.078	-0.006	0.070	0.335	0.620	0.460	0.106	-0.284	1

Table 6. variance inflation factor (VIF) for multicollinearity

	Circularity represented by circularity score		Circularity represented by 3R	
Variable	VIF	1/VIF	VIF	1/VIF
ROA	2.920	0.343	2.840	0.353
ROE	1.850	0.539	1.830	0.546
Mkt cap. to tot. Assets	1.850	0.542	1.810	0.552
Interest cov. Ratio	1.320	0.760	1.310	0.761
Net debt to EBITDA	1.180	0.846	1.170	0.854
Recycle	1.150	0.868		
Reuse	1.140	0.877		
Circolarity score			1.050	0.948
Current ratio	1.060	0.947	1.050	0.952
Reduce	1.040	0.960		
Mean VIF	1.500		1.580	

5. Results

Regression results based on fixed effects specifications are reported in Table 7 for log 1-year PD and in Table 8 for log 5-year PD. In both tables circularity is represented by a single aggregate measure (Model 1 and Model 2) and through its three components Reduce, Reuse, and Recycle (Model 3 and Model 4).

Moreover, we include time fixed effects because, by doing so, we allow time contribution to explain the variation in the dependent variable. The latter is particularly true for year 2020 in which Covid-19 pandemic affected the whole economy with an effect also on companies' probability of default. Coefficients for year dummies are always statistically significant but are not reported in the tables for the sake of brevity.

In Table 7 - Model 1 the circularity coefficient (-0.031) indicates a statistically significant negative association with the 1-year PD, suggesting that higher overall circularity is associated with a lower probability of default within one year.

Specifically, when circularity score increases by 1 percentage point, the associated difference in log 1-year PD is -0.031, which mathematically corresponds to multiply 1-year PD by 0.969 ($= e^{-0.031}$).

Hence, expressed in the percentage metric, a 1 percentage point increase in the circularity score is associated with a 3.052% decrease in 1-year PD. With the inclusion of economic and financial control variables (Table 7 - Model 2), which allows a more comprehensive understanding of the factors influencing default risk, the coefficient of circularity score remains significant even if it slightly decreases to -0.027, implying that a 1 percentage point increase in the circularity score is associated with a 2.664% decrease in 1-year PD.

Such a reduction with respect to 3.052% shows that part of the initial contribution of the circularity score in explaining the probability of default is shared with ROE, ROA, Net Debt to EBITDA, and Market Cap to Total Assets which show statistically significant coefficients. In particular, ROA and Market Cap to Total Assets have a negative relationship with PD, whereas ROE and Net Debt to EBITDA have a positive one.

While it is expected that a higher leverage is positively associated with companies' default risk, ROE positive coefficient equal to 0.013 (corresponding to an increase of 1.308% of 1-year PD as ROE increases by 1 percentage point) might appear counterintuitive. However, a higher ROE may be achieved through an increased leverage making the company more vulnerable to economic downturns or higher interest rates, thus showing a positive relationship with the probability of default.

Further, firms with high ROE might be focusing on short-term profitability at the expense of medium-term stability, hence increasing short-term PD. On the other hand, when circularity is represented by the 3R, only Reduce has an association (-0.011) which is statistically significant (Table 7 - Model 3 and Model 4), implying that a 1 percentage point increase in Reduce is associated with a 1.094% decrease in 1-year PD.

After the inclusion of control variables (Table 7 - Model 4), the role of Reduce remains quantitatively invariant, differently form the case in which the overall circularity score is considered.

This phenomenon might be attributed to the fact that, in comparison to the circularity score, Reduce shows a lower correlation with statistically significant economic and financial variables, except of ROA (Table 5).

Finally, in all models in Table 7, although the constant term is large and negative, its effect on PD is negligible give the log transform of the same: for instance, when constant is -12.002 (Model 1), its effect is close to zero (6.132E-06 $= e^{-12.002}$).

Table 8 reports result for 5-year PD and, comparatively with Table 7, emerges that when circularity is represented by a comprehensive score (Model 1 and Model 2) its association with medium- term PD is again negative and statistically significant, but lower than the one on short-term PD.

In fact, the coefficient of circularity score is -0.010 in Model 1, indicating that a 1 percentage point increase in the circularity score is associated with a 0.995% decrease in 5-

year PD. Such an effect reduces to 0.896% when considering also control variables (Model 2). In this latter case ROE is no longer significant, confirming that a higher ROE may result from decisions aimed at increasing short-term profitability, which might not lead to a significant reduction in PD in the medium term.

Further, when the 3R are considered, only Reduce has a statistically significant coefficient (-0.003 in Model 3 and Model 4), implying that a 1 percentage point increase in the Reduce dimension is associated with a 0.300% decrease in 5-year PD. As in Table 7, when circularity is represented by the 3R the role of Reduce remains quantitatively invariant when control variables are added.

Again, in all models of Table 8 the constant term is quite large and negative even if its effect remains close to zero. For instance, the constant term is equal to -5.059 and statistically significant in Model 1, but the effect on PD is equal to 0.006 ($= e^{-5.059}$).

In both Table 7 and Table 8, an increase in Reduce variable (represented by a reduction in GHG emissions with respect to the previous year) has a negative association with PD, which is quantitatively lower (in absolute terms) than the one produced by an increase in the circularity score (represented by a reduction in GHG emission beside an increase in the share of renewable energy used and waste recycled or recovered).

Thus, even if Reuse and Recycle alone are not able to explain PD, since their coefficients are not statistically significant, aggregated together with Reduce they have a crucial role to gauge companies' financial health. In addition, it emerges that the negative association of circularity issues, considered at the aggregate level or with individual dimensions, with PD is quantitatively higher for 1-year pd with respect to 5-year PD.

This result, consistent with the one obtained by Zara and Ramkumar (2022), might the consequence of immediate benefits (e.g. tax benefits, easier access to credit, better reputation) that offset implementation costs, which instead can be amortized over years. Moreover, in the medium term these benefits might stabilize and be less pronounced once production processes are optimized.

Table 7. Regression results for log 1-year PD as dependent variable

	Model 1	**Model 2**	**Model 3**	**Model 4**
Dep. Var	log 1-year PD	log 1-year PD	log 1-year PD	log 1-year PD
C_score	-0.031 ** (-2.46)	-0.027 ** (-2.31)		
Reduce			-0.011 ** (-2.50)	-0.011 ** (-2.49)
Reuse			-0.014 (-1.13)	-0.011 (-0.98)
Recycle			-0.005 (-0.40)	-0.001 (-0.11)
ROE		0.013* (1.91)		0.013 * (1.86)
ROA		-0.107 *** (-3.61)		-0.105 *** (-3.58)
Interest cov. ratio		-0.002 (-0.60)		-0.002 (-0.62)
Current ratio		-0.093 (-1.18)		-0.095 (-1.23)
Net debt to EBITDA		0.071 ** (2.37)		0.073 ** (2.35)
Mkt cap to Tot. assets		-0.737 * (-1.75)		-0.744 * (-1.85)
Constant	-12.002 *** (-30.20)	-10.615 *** (-14.46)	-12.277 *** (-14.30)	-11.070 *** (-9.97)
Company fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Clustered standad errors	yes	yes	yes	yes
Adjusted R2	0.587	0.629	0.586	0.628
F	(5, 107) = 129.43***	(11,107) = 67.05***	(7, 107) = 97.78***	(13, 107) = 58.54***
Observations	540	540	540	540

Notes: t-values are reported in brackets, ***, ** and * represent significance at 1, 5, 10% levels. Fixed effects are not shown for the sake of brevity

Table 8. Regression results for log 5-year PD as dependent variable

	Model 1	**Model 2**	**Model 3**	**Model 4**
Dep. Var	log 5-year PD	log 5-year PD	log 5-year PD	log 5-year PD
C_score	-0.010 ** (-2.56)	-0.009 ** (-2.43)		
Reduce			-0.003 ** (-2.48)	-0.003 ** (-2.59)
Reuse			-0.005 (-1.18)	-0.003 (-0.98)
Recycle			-0.002 (-0.57)	-0.001 (-0.20)
ROE		0.002 (0.91)		0.002 (0.87)
ROA		-0.030 *** (-3.20)		-0.030 *** (-3.20)
Interest cov. ratio		-0.001 (-0.55)		-0.001 (-0.56)
Current ratio		-0.015 (-0.67)		-0.016 (-0.72)
Net debt to EBITDA		0.022 ** (2.07)		0.023 ** (2.06)
Mkt cap to Tot. assets		-0.230 * (-1.81)		-0.232 * (-1.91)
Constant	-5.059 *** (-41.65)	-4.643 *** (-21.18)	-5.120 *** (-20.20)	-4.777 *** (-14.43)
Company fixed effects	yes	yes	yes	yes
Year fixed effects	yes	yes	yes	yes
Clustered standad errors	yes	Yes	yes	yes
Adjusted R2	0.592	0.634	0.590	0.634
F	(5, 107) = 143.98***	(11, 107) = 75.87***	(7, 107) = 107.74***	(13, 107) = 66.28***
Observations	540	540	540	540

Notes: t-values are reported in brackets ***, ** and * represent significance at 1, 5, 10% levels. Fixed effects are not shown for the sake of brevity.

6. Conclusion

The academic literature has extensively examined the effects, in terms of financial performance and credit risk reduction, generated by sustainability and corporate social responsibility practices. However, although circularity practices (e.g. waste recycling, emission reduction, renewable energy use) have been increasing also spurred by regulation, few researches have explored the financial implications of circularity and only one study

(Zara and Ramkumar, 2022) has investigated the effect of circularity on companies' probability of default.

The aim of this paper is to gauge the role of circularity and its main determinants in explaining firms’ PD in the short-term (1 year) and in the medium-term (5 years). To this end, in order to compute a circularity measure, we combine the most commonly used CE classification system that relates to the 3R principle (Reduce, Reuse, Recycle) with a measurement approach as the one represented by the three environmental indicators of the Eco-Efficiency Indicator (Park & Behera, 2014).

We identify three main dimensions of circularity whose mean represents what can be considered an overall circularity score. The first, Reduce, represents the degree of reduction in GHG emissions with respect to the previous year, the second, Reuse, measures the share of renewable energy used and the third, Recycle, represents the share of waste recycled or recovered. Our estimates of the relationship of the 3R with the PD are based on an OLS regression with company and year fixed effects, which is performed over a sample of 108 companies that were part of the STOXX Europe 600 Index, observed over the period 2017-2021. Both financials and circularity data are retrieved from Bloomberg database.

Three main results emerge from our analysis, which are qualitatively the same.

First, circularity practices as measured by the overall circularity score are associated to a lower companies’ PD both in the short and medium term, even after controlling for the main economic-financial indicators. Specifically, a 1 percentage point increase in the circularity score is associated with a 2.664% decrease in 1-year PD and a 0.896% decrease in 5-year PD. Second, when we focus on each of the 3 circularity dimensions, only Reduce has a significant negative association with PD, while Reuse and Recycle alone do not have a significant contribution in explaining the PD. By contrast, a 1 percentage point increase in the Reduce score is associated to a reduction in the 1-year PD and 5-year PD by 1.094% and 0.300% respectively. In sum, while the two individual components Reuse and Recycle do not have a significant relationship with the PD, Reduce is negatively and significantly associated with the risk of default, although such an association is quantitatively lower than the one captured by the overall circularity score. This suggests that a holistic consideration of all CE determinants and dimensions is preferable to gauge companies’ financial health.

Third, when comparing the effect of circularity in the short term versus the medium term, it emerges that the negative relationship is more pronounced in the short term, whether considering the overall Circular Economy score or its individual dimensions. This result is suggestive of short-term benefits of circularity in terms of default risk measurement, which can in principle offset implementation costs, which instead can be amortized over years. Further, circularity activities can improve access to sustainable financing and attract sustainability-conscious investors.

Finally, efforts to reduce emissions and waste of resources can rapidly improve the company's reputation with customers, partners, and investors, reducing PD through increased trust and improved corporate image.

On the other hand, in the medium term these benefits may stabilize and become less pronounced as production processes become optimized and the advantages of circularity become more standardized within industries.

In summary, CE practices can serve as an effective strategy for the sustainable development of companies (e.g. Chen & Dagestani, 2023) also in terms of measurement of the company probability of default and, according to our results, GHG emission reduction activities appear to be the most relevant.

Amidst growing interest in CE from both individual companies and supranational institutions, this study can offer a twofold implication. First, from the firms' viewpoint, the negative empirical association between the probability of default and circularity actions, particularly GHG emission reduction, can represent useful information in their decision-making processes. Second, from the policymakers' viewpoint, regulation should actively promote circular economy practices among companies (e..g. via fiscal incentives) since the negative relation of circularity issues with probability of default could contribute to financial stability.

Future research work may focus on the differences between CE and ESG scores in explaining PD, in order to investigate two main issues: first, whether CE is able to capture further features with respect to the environmental pillar of ESG, second, what are the effect of the social and governance pillars (if any) in explaining PD.

Chapter II: MITIGATING SUPPLY CHAIN EMISSIONS THROUGH STRATEGIC SUPPLIER ASSESSMENT

1. Introduction. – 2. Literature review: supply chain emissions management. – 3. Hypotheses Development. – 3.1. The effect of economic performance on emissions in the ceramic tiles supply chain. – 3.2. The effect of social sustainability on mitigating emissions in the ceramic supply chain. – 3.3. The governance sustainability on mitigating emissions in the ceramic tiles supply chain. – 4. Material and methods. – 4.1. Context of analysis. – 4.2. Parameter notions and data sources. – 4.3. Data analysis. – 5. Results. – 5.1. Exploratory Factor Analysis Results. – 5.2. Regression results. – 6. Discussion and conclusions.

Abstract: Companies are required to diminish and disclose emissions within their supply chains. Implementing strategic supplier assessment, that includes emissions performance as a criterion, enables the identification of sustainable supply chains. Acquiring emissions performance data often presents challenges and incurs considerable expenses, necessitating the identification of proxies for suppliers' emissions data. To address this issue, the study analyses a dataset comprising economic, social, governance and emissions metrics from 374 suppliers of an Italian ceramic company. Utilising dimensionality reduction techniques and a linear regression model, the research uncovers that emissions proxies are different within different phases of the supply chain. The analysis shows that for suppliers belonging to the material-processing sector, economic performance can be a significant proxy of emissions, with higher economic achievements closely tied to increased emissions. In contrast, social sustainability practices toward employees' impact on emissions within the logistics sector. Meanwhile, for suppliers in the services sector, implementing sustainable governance practices positively impacts emissions mitigation.

The research indicates that the effectiveness of emissions proxies is contingent upon the suppliers' sector within the ceramic supply chain. This evidence brings contributions and implications to understanding how companies can respond to the recent pressure to assess and disclose supply chain emissions.

1. Introduction

Companies are increasingly subject to escalating pressures from both stakeholders and regulatory entities to assume accountability for the emissions attributable to their supply chains (CSRD, 2022; Gimenez and Tachizawa, 2012; Mani and Gunasekaran, 2018; Riccaboni and Luisa Leone, 2010). These pressures mandate that firms augment their existing measurement and management frameworks to encompass the emissions performance across their entire supply chains (Foroozesh et al., 2022).

The suppliers' assessment strategy (Sancha et al., 2016) can be implemented to select suppliers also based on their emissions performance, facilitating their identification based on lower emissions outputs such as: carbon dioxide, methane and ammonia, and thereby reducing the footprint of the overall supply chain (Foroozesh et al., 2022; Gimenez and Tachizawa, 2012).

However, the literature exploring the implementation of suppliers' assessment strategy (Liu et al., 2021; Mani and Gunasekaran, 2018; Pagell and Gobeli, 2009) partially consider the existing variability in emissions across different industrial sectors (Burritt et al., 2011; Kazemian et al., 2022) as well as the challenges and costs associated with acquiring accurate quantitative emissions data (Huang et al., 2024; Ratnatunga et al., 2011). This gap underscores the critical need for identifying reliable and sector-specific proxies for suppliers' emissions. In response, this paper investigates potential proxies for emissions across various industrial sectors of suppliers.

Previous studies have highlighted the interconnections among sustainability dimensions, including economic, social, governance and environmental aspects (Huang et al., 2024; ESRS, 2022; Sancha et al., 2016; Sutherland et al., 2016).

Given the general availability of economic, social, and governance data related to employees' practices, this paper examines the potential of sustainability indicators to serve as proxies for emissions in various suppliers' sectors.

The research empirics include economic, social, and governance sustainability and emissions performance data collected for 374 suppliers of a large Italian ceramic company. The ceramic supply chain is increasingly focused on the issue of emissions, driven by the regulatory framework established by the European Union's Climate Change and other Sustainability initiatives (CSRD, 2022). The Italian case is relevant as Italy and Spain are the most significant EU ceramic tile producers (Ros-Dosdá et al., 2018).

The ceramic supply chain was mapped, and the suppliers were segmented into three main industrial sectors: material-processing, logistics and services (Nasir et al. 2021; Sun et al. 2021).

An exploratory factor analysis (Byrne, 2005) was performed to identify composite indicators for economic, social, and governance dimensions. Subsequently, a linear regression model was implemented to understand the effect of economic, social, and governance dimensions on the emissions of each sector, such as logistics, material-processing and services.

Findings reveal that economic performance increases emissions in the material-processing sector. While social sustainability practices toward employees impact on emissions within the logistics sector. Conversely, sustainable governance practices mitigate emissions in the services sector.

Given the evidence emerged from these findings, this research contributes to the literature on supply chain emissions (Liu et al., 2021; Qian and Schaltegger, 2017; Schaltegger and Csutora, 2012) in two main ways.

First, the paper responds to the open call for emissions data proxies (Kazemian et al., 2022; Nasir et al. 2021; Pagell and Gobeli, 2009) that are necessary for the implementation of suppliers' sustainability assessment strategy as a means to reduce corporate supply chain emissions (Gimenez and Tachizawa, 2012; Sancha et al., 2016). It is shown that economic, social, and governance performances affect the emissions levels of suppliers and, consequently, can be implemented as proxies when emissions data are unavailable.

Second, the paper confirms the relevance of considering the sector when implementing suppliers' assessment (Burritt et al., 2011; Kazemian et al., 2022). The findings indicate that emissions proxies are dependent on suppliers' sector and, therefore, considering suppliers' sector is crucial when implementing sustainability assessment strategies to mitigate supply chain emissions.

Finally, the analysis advances practical implications for companies to implement a sustainability assessment strategy to select suppliers based also on their emissions. In particular, it provides the manufacturing sector (Mazzucchelli et al., 2022) with guidance on evaluating and selecting suppliers based on their performances in economic, social, and governance sustainability, which serve as proxies for supply chain emissions.

The rest of the paper is structured as follows. In the second section, the literature on supply chain emissions management is introduced. The third section welcomes hypothesis development. Subsequently, the fourth section illustrated the materials and methods of the paper. The fifth section illustrates the results of the analysis, while the last section collects the discussion and the conclusions.

2. Literature review: supply chain emissions management

Sustainable Supply Chain Management (SSCM) has become a critical aspect of modern business practices, integrating sustainable development goals into supply chain management (Sajjad et al., 2020). According to Alzubi and Akkerman (2022), SSCM encompasses enhancing a company's industrial processes and activities towards sustainability. Within this context, the process of selecting sustainable suppliers has emerged as a key strategy in SSCM. This approach involves evaluating potential suppliers not only on their economic performance but also on their ability to pursue environmental and social sustainability (Govindan et al., 2021).

Among various factors considered in SSCM, emissions (especially carbon dioxide CO2, methane CH4 and ammonia NH3) significantly impact the environment (Gan et al., 2022; Karim et al., 2021) and assessing tools are crucial (Zhang et al., 2024).

Emissions, which include carbon dioxide (CO2), methane (CH4) and ammonia (NH3) particulate matter produced by human activities, are a significant contributor to the deterioration of the atmospheric ecosystem, leading to climate change and global warming (Thomas et al., 2004). Moreover, emissions are linked to serious health issues, including cancer, threatening human well-being (Kheirbek et al., 2016).

The growing recognition of emissions' detrimental effects on both human health and the environment has increasingly brought this issue to the forefront of public discourse. There is an urgent call for significant alterations in human activities to mitigate these emissions, as emphasised by Tang and Luo (2014).

The pressure of reducing emissions also extends to companies (Adhikari and Zhou, 2022; Solomon and Solomon, 2006) since they are the main responsible for emissions worldwide (Montiel, 2008).

In addition, in recent years, the public and stakeholders' pressure has extended to companies' supply chains' emissions reduction (Gimenez and Tachizawa, 2012; Mani and Gunasekaran, 2018; Riccaboni and Luisa Leone, 2010).

The recently formulated regulation mandates the reporting of sustainability information across supply chains, encompassing emissions data from both relevant companies and suppliers (CSRD, 2022). In particular, the Corporate Sustainability Reporting Directive of the

European Union (CSRD, 2022) requires companies to activate due diligence processes to identify and resolve adverse impacts on the human and the environment of their worldwide suppliers.

The literature has shown possible strategies companies can implement to reduce their supply chain's emissions (Gimenez and Tachizawa, 2012; Sancha et al., 2016). One strategy suggests reducing supply chain emissions through the assessment of suppliers (Gimenez and Tachizawa, 2012). In this view, single companies can respond to the pressure of reducing their supply chain's emissions by selecting suppliers with lower environmental impacts, such as emissions (Foroozesh et al., 2022; Gimenez and Tachizawa, 2012).

The implementation of an assessment strategy, however, requires reliable and updated data on suppliers' emissions performance. These data are not always available nor effortless to achieve due to technical and regulatory issues (Ratnatunga et al., 2011). For example, Ratnatunga et al. (2011) have discovered that collecting and analysing emissions data can be very expensive, and extending emissions data collection to suppliers could be even more expensive.

To address the problem of a lack of suppliers' emissions data (Ratnatunga et al., 2011), there remains a need to find proper and usable proxies for suppliers' emissions data (Kazemian et al., 2022; Pagell and Gobeli, 2009; Sancha et al., 2016).

In this sense, few authors have advanced evidence on the interconnections among sustainability dimensions, suggesting that economic, social, governance and environmental sustainability may influence each other (Pullman et al., 2009; Sancha et al., 2016; Sutherland et al., 2016). Furthermore, the literature calls for quantitative data that may help the implementation of sustainable supply chain practices when adopting a triple bottom line perspective (Huang et al., 2024).

The notion that various dimensions of sustainability may exert mutual influence underscores the necessity of exploring the extent to which emissions within the supply chain can be approximated by alternative dimensions of sustainability, including economic, social, and governance aspects. Exploring the effects of economic, social, and governance dimensions on suppliers' emissions could provide usable proxies of emissions data.

In addition, Burritt et al. (2011) suggest that various industries may approach the issue of managing emissions differently. For this reason, it is essential to consider suppliers' industrial sectors (Nasir et al. 2021; Sun et al. 2021) when developing emissions' proxies.

Taking these insights together, the urgency of exploring suppliers' emissions indirect indicators emerges, considering that they operate within diverse industrial sectors and can be influenced differently by their economic, social, and governance sustainability.

3. Hypotheses Development

The study explores further the idea that supply chain emissions proxies can differ within various suppliers' industrial sectors (Burritt et al., 2011; Kazemian et al., 2022). The analysis concentrates on the ceramic industry and proposes a segmentation of the ceramic supply chain included sectors such as material-processing (Gusmerotti et al., 2019; Lucianetti et al., 2018), logistics and services (Gusmerotti et al., 2019).

Nevertheless, the issue of emissions should be approached with a holistic perspective (Lee et al., 2017) considering not only the relevance of carbon dioxide, but also of methane (CH4) and ammonia (NH3).

As a matter of fact, CH4 combustion, which occurs during the firing process of ceramic tiles, contributes substantially to emissions (Ma et al., 2022). Moreover, NH3, is used as a chemical reagent in various stages of ceramic production, including the synthesis of ceramic materials and the application of coatings. The use of ammonia in such chemical processes can lead to higher levels of emissions (Valera-Medina et al., 2024).

3.1 The effect of the economic performance on emissions in the ceramic tiles supply chain

The existing research indicates a correlation between increased economic activity and high levels of emissions (Chen et al., 2020; Karim et al., 2021). The relationship between firms' economic sustainability dimension and emissions levels strongly depends on the sector to which firms belong (Burritt et al., 2011; Kazemian et al., 2022).

Based on these studies, we expect that economic sustainability is decoupled from emissions levels in those sectors where the value added is not connected with producing or processing materials. In the services and logistics sector, for example, the delivered output is intangible and based on transports and knowledge.

Differently, in the material-processing sector, it can be expected that economic performance and emissions are aligned (Azam et al., 2021; Mazzucchelli et al., 2022; Tseng and Hung, 2014). Therefore, we hypothesise that the economic sustainability dimension is positively related to emissions levels for suppliers operating in the material-processing sector of the ceramic tiles supply chain. On the contrary, the economic sustainability will not impact emissions levels in the services and logistics sectors.

Drawing on the presented arguments, the following research questions are developed:

H1: Economic sustainability increases emissions for material-processing suppliers within the supply chain.

3.2 The effect of social sustainability on mitigating emissions in the ceramic tiles supply chain

The significance of social sustainability in contemporary supply chains is a prominent theme in academic research (Chouhan et al., 2022; Cohen et al., 2018; Sancha et al., 2016; Spence and Bourlakis, 2009).

Industries such as fashion and food have faced demands to disclose the social conditions of workers within their extensive global production and logistics networks (Pullman et al., 2009; Wu et al., 2012). However there remains a limited understanding of the social factors affecting sustainable supply chain management practices (Hahn et al., 2021; Oelze et al., 2016).

Amid heightened awareness of the social impacts of logistics operations (Cook et al., 2011; Leung et al., 2023; Welford, 2016), stakeholders within and outside organisations advocate for logistics practices that adhere to a socially sustainable development (Richey et al., 2022).

The current market pressure to reduce shipping prices has been imposed on delivery companies, causing great stress on their employees (Kumar, 2022). Thus, the logistics industry has recently been concentrating more on social aspects than on the issue of emissions reduction (Dey et al., 2022).

For this reason, we hypothesise that social sustainability in the logistics sector impacts the emissions levels in the logistics sector:

H2: Social sustainability practices mitigate emissions of logistic suppliers within the supply chain.

3.3 The effect of governance sustainability on mitigating emissions in the ceramic tiles supply chain

The services sector, often regarded as having relatively low emissions, demonstrates significant responsiveness to environmental challenges, notably in emissions mitigation (Albitar et al., 2023; Ng et al., 2023).

For example, Microsoft Corporation’s sustained efforts to quantify and manage its carbon footprint (Mishra, 2020). Indeed, some authors advance the idea that the “decoupling relationship between emissions and the economic development in the services sector is conducive to promoting sustainable development” (Gan et al., 2022, p. 63).

The current attention of the services sector on emissions-related issues is connected with top managers’ accumulated knowledge, attitudes and culture regarding the relevance of these issues (Alsaleh et al., 2021; Karim et al., 2021; Zhang and Cheng, 2021).

Studies investigating this relationship include various aspects of corporate governance, including the size and independence of the board (Gerged et al., 2023) and gender diversity (Aguilera et al., 2021).

Adequate governance fosters improved decision-making processes (Husted and Sousa-Filho, 2019), encompassing deliberations on capital expenditure and the disclosure of carbon emissions (Karim et al., 2021). Since governance choices and strategies are undertaken by top management, we can hypothesise that governance sustainability practices will mitigate emissions in the services sector:

H3: Governance sustainability practices negatively impact emissions levels for services suppliers within the supply chain.

Finally, figure 1 summarises the research hypothesis.

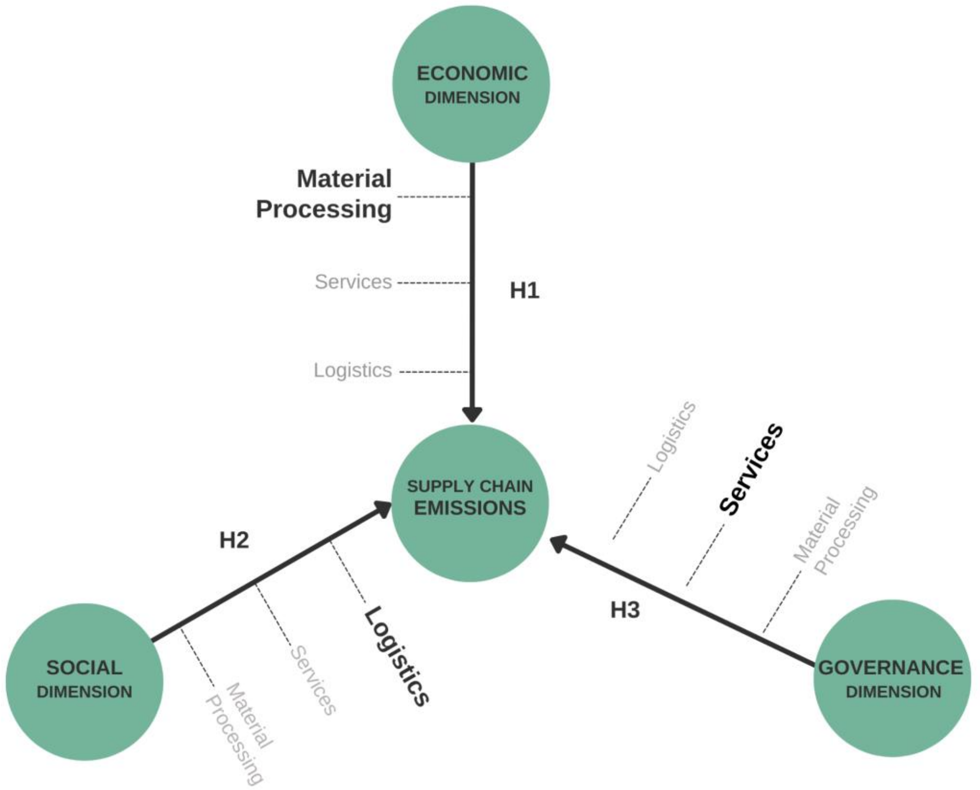


Figure 1. Summary of the research hypotheses.

4. Material and methods

4.1 Context of analysis

The empirical data of this research were collected from the supply chain of a large ceramic tiles company based in the ceramic district of Italy (Emilia Romagna).

The choice of concentrating on the ceramic supply chain was driven by the fact that the ceramic industry is considered a high-carbon industry (Sangwan et al., 2018), and companies are increasingly under pressure from stakeholders, such as clients, to extend emissions measurement and management to all their suppliers.

The ceramic supply chain is currently pressured to reduce emissions by the regulatory framework established by the European Union's Climate Change and other Sustainability initiatives (CSRD, 2022). This regulatory landscape includes specific mandates and objectives outlined in different Directives (2003/87/EC, 2009/29/EC, and 2012/27/EU), which set forth goals related to emissions and set a targeted reduction in CO2 emissions for industrial sectors by the year 2050. The specific Italian case is relevant as Italy together with Spain represent the largest European producers of ceramic tiles (Ros-Dosdá et al., 2018).

The choice to consider the entire ceramic supply chain is driven by the ambition of having a holistic view of the production process and considering the entire life cycle (Thabrew et al., 2009) from a cradle-to-grave approach (Mazzi, 2020).

The specific identification of each supplier was obtained through the ceramic production company management system (System Applications and Products in Data Processing - SAP). Once the overall list of all suppliers had been extracted, only those with whom the focal company had a trade–exchange were considered, resulting in a final sample of 374 suppliers.

In order to test our hypothesis and perform the empirical analysis, we have collected economic, social, governance and environmental performance data from the financial year 2019. The choice of the year was made to avoid any COVID-19-related exogenous shocks that might impact the considered variables.

As shown in Table 1 descriptive statistics, suppliers analysed in this study are represented by companies characterised by broad heterogeneity in terms of economic results.

Table 1. Summary of the suppliers

	Obs.	**Mean**	**Standard Deviation**
Employees_2019	374	749,90	6.923,80
Total Assets_2019 (thousands of euros)	374	564.432,08	5.971.805,30
Total Value of Production_2019 (thousands of euros)	374	139.259,42	887.601,05
Profit / Loss for the year_2019 (thousands of euros)	374	8.876,38	66.705,20

The ceramic production chain involves several suppliers due to the complexity of the process, which includes specialised stages. The first stage is the one in which the raw materials such as clay and minerals are extracted and processed.

Most of these suppliers focus on transforming raw materials into ceramics through specific processing techniques. In addition, other suppliers in a second phase provide services such as such as planning/management activities, assisting with tile-lying projects and marketing. Finally, distribution involves logistics companies that handle the transportation of the final products.

As shown in Figure 2, the ceramic supply chain examines the entire process of creating ceramic products, from raw materials processing to the final product’s distribution and disposal.

In order to answer the research question and empirically verify the research hypothesis, we aggregated homogeneous suppliers within three different industrial sectors. Specifically, suppliers involved in the material extraction and processing are identified as “MATERIAL PROCESSING”, suppliers involved in planning, financial accounting, personnel recruitment, product promotion and after-sales activities as “SERVICES”, and suppliers involved in inbound and outbound logistics as “LOGISTICS”.

We opted to split our sample in this way since the manufacturing suppliers play a pivotal role in natural resource transformation (Zarei et al., 2020; Zhu et al., 2010). Conversely, services suppliers have a supporting role in manufacturing activities (Martinez et al., 2017). Lastly, logistics suppliers (such as companies directly or indirectly involved in delivery) provide shipping and customs clearances (Saebi and Foss, 2015).

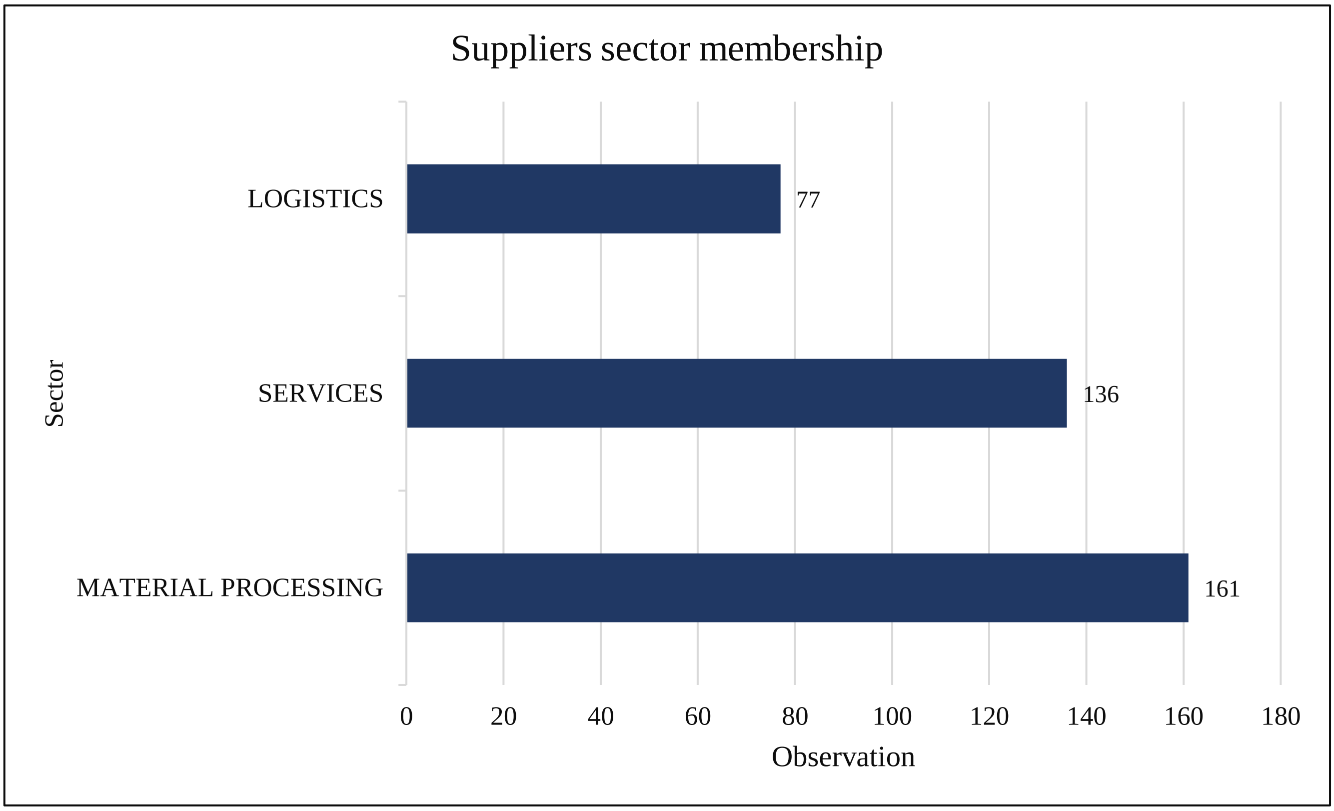


Figure 2. Suppliers of the sample divided by sector.

4.2 Parameter notations and data sources

Given the research hypothesis, for each supplier we have collected data on economic (ECO), employees' social sustainability practices (SOC), governance data (GOV), sustainability and carbon dioxide (CO2), methane (CH4) and ammonia (NH3) emissions (EM) as detailed in Table 2.

Table 2. Variables summary, description and theory-related features

Variables	Computation	Type	Reference(s)
Explanatory variables			
Revenue [ECO1] *continuous variable.*	Revenues	ECO	Braccini and Margherita, 2019; Rossi et al., 2020; Xu and Liu, 2021
EBITDA [ECO2] *continuous variable.*	EBITDA	ECO	Braccini and Margherita, 2019; Rossi et al., 2020; Xu and Liu, 2021
Net Financial Position [ECO3] *continuous variable.*	Financial Position	ECO	Braccini and Margherita, 2019; Rossi et al., 2020; Xu and Liu, 2021
Value Added [ECO4] *continuous variable.*	Value Added	ECO	Braccini and Margherita, 2019; Rossi et al., 2020; Xu and Liu, 2021
Total Production Costs [ECO5] *continuous variable.*	Total Production Costs	ECO	Braccini and Margherita, 2019; Rossi et al., 2020; Xu and Liu, 2021
Company Seniority [GOV1] *continuous variable that measures the longevity of firm's.*	LOG (2019 - Year of company foundation)	GOV	Bianchini et al., 2018
Gender Equality Index [GOV2] *continuous variable.*	LOG Women in BOD/Tot.position BoD	GOV	Safari, 2022; Karim et al., 2021

Number of Managers [GOV3] *continuous variable.*	LOG Number of company managers	GOV	Lin and Hwang, 2010
Employee Turnover [SOC1] *continuous variable.*	LOG (Total $Employee_n$- Total Employee $_{n-1}$)	SOC	Govindan et al., 2021
Total Labour Cost [SOC2] *continuous variable.*	LOG (Total Labour Cost $_n$ - Total Labour Cost $_{n-1}$)	SOC	Zhang, 2016
Labour productivity ratio [SOC3] *continuous variable.*	LOG [(Total Revenue + Other Revenue) / Total Labour Cost]	SOC	Zhang, 2016
Dependent Variables			
CO2 Emissions [EM1] *continuous variable.*	LOG CO2	EM	Wang et al., 2014; Delmas et al. 2015
CH4 Emissions [EM2] *continuous variable.*	LOG CH4	EM	Ma et al., 2018
NH3 Emissions [EM3] *continuous variable.*	LOG NH3	EM	Ramirez-Contreras et al., 2020
Control Variables			
Size *continuous variable.*	LOG Total assets		Li et al., 2014; Matsumura et al., 2014
Logistic_dummy	0 = Not belonging to the logistics sector ; 1 = Belonging to the logistics sector.		
Service_dummy	0 = Not belonging to the services sector; 1 = Belonging to the services sector.		
MaterialProcessing_dummy	0 = Not belonging to the material-processing sector; 1 = Belonging to the material processing sector.		

From the economic perspective (ECO), the above–mentioned measures are widely established in the literature since they employ published accounting data (Rossi et al., 2020). Rossi et al. (2020) advanced a set of indicators concerning the economic dimension; the variables adopted can be divided into four main blocks: cost reduction, revenue generation, profitability and investment in technological innovation.

Similarly, Braccini and Margherita (2018) examined a manufacturing company's economic sustainability by considering EBITDA, sales and net profit. Kwarteng et al. (2022) conducted a cross-sector analysis among various manufacturing industries to verify the effect of sustainability initiatives on financial performance, intended as the principal measure of profitability.

On the social dimension side (SOC), the systematic literature review of Luthin et al. (2023) identifies variables related to employees among six human-centred sub-categories of social impact. Previous studies (Poponi et al., 2022; Walker et al., 2021; Govindan et al., 2021) have focused on social responsibility and wealth distribution.

The presented social measures (Table 2) are designed as a higher level of these variables, which corresponds to a decrease in the social responsibility of companies (Frishammar and Parida, 2018). For example, higher employee turnover [SOC1] is generally associated with lower corporate social sustainability (Bocken et al., 2021). A low difference in the cost of labour [SOC2] generally indicates that the social practices toward employees are considered unsustainable. While a higher ratio of labour productivity [SOC3] indicates a higher utilisation of the labour force.

Establishing robust corporate governance (GOV) is related to some critical central aspects. Gender diversity [GOV2] and inclusion reflect the relevance of greater diversity in corporate decision-making, acknowledging that diverse perspectives can lead to better outcomes and higher sustainability (Safari, 2022). Similarly, managers' presence on the board of directors [GOV3] is also a critical aspect since they are not involved in the day-to-day management of the company; they can provide an objective perspective and monitor the executives' actions (Lin and Hwang, 2010). Simultaneously, company longevity [GOV1] indicates its resilience and long-term perspective (Bianchini et al., 2018).

Emissions are among the most relevant aspects of the air pollution emergency (Qian et al., 2018; Hsiao et al., 2022; Afolabi et al., 2023). However, according to the United States Environmental Protection Agency (EPA), although CO2 emissions [EM1] are the leading cause of climate change, methane [EM2] and ammonia [EM3] play a crucial role in environmental pollution and human health. Methane was considered since, although disappearing after about ten years in the atmosphere (European Commission, 2021), has an harmful effect on nature and humans. Similarly, Ammonia has a role in the nitrogen cycle that can potentially influence the emissions of other greenhouse gases (Boggia et al., 2019).

As indicated in Table 2, we welcomed the insights coming from the literature (Zhang et al., 2015), advancing the need to perform logarithmic transformation only for social governance and environmental variables to reduce their skewness.

Suppliers' industrial sectors were included as a dichotomous variable. For example, the variable material-processing was labelled "0" for no membership and "1" for the material-processing group membership. The same procedure has been implemented for services and logistics.

Given the empirical design of this research, two databases were used: Aida - Bureau van Dijk, which provides information on Italian enterprises for economic, social, and governance data, and I. STAT for the environmental emissions data. Both databases provided information on both large companies and small and medium-sized companies.

Concerning emissions data, the computational methodology adopted is called NAMEA (National Accounting Matrix including Environmental Accounts), which estimates the amount of emissions for various pollutants directly caused by each Sector Industrial Classification (SIC) activities. As a result, this estimation does not include emissions caused by natural phenomena and not car pollution, but only emissions directly associated with a specific production process of each SIC activity. Subsequently, the emission allocation for each supplier was performed by using each of their revenues as a criterion, consistent with European Environmental Economic Accounts (EEEA) (EUR-Lex, 2011).

4.3 Data analysis

Two statistical methodologies characterise the analysis:

- Exploratory Factor Analysis (EFA): a statistical technique used in the field of multivariate analysis to uncover underlying patterns in a dataset (Byrne, 2005). Given the objective of this study, EFA was performed to simplify the complexity of data by identifying common factors that explain the correlations or covariances among observed variables. Once the dimensions had been extracted and their reliability verified, we moved on to the next stage.
- Ordinary least square regression (OLS regression) is a statistical technique used to analyse the relationship between a dependent variable and one or more independent

variables. Consequently, it provides a valuable framework for modelling and understanding relationships between single variables or multidimensional constructs. (see Eq. (1))

$$y = \beta_0 + \sum \beta_i x_i + \varepsilon \qquad (1)$$

where y is the dependent variable, β_0 is the intercept, x_i is the ith independent variable, β_i is the ith regression coefficient, ε is the error term, and p is the number of independent variables.

Using factors as variables in a regression analysis requires adherence to the assumptions of linear regression. These assumptions include linearity and the absence of multicollinearity among the independent variables (Spanos, 1995). Given that factors are derived from a correlation matrix in EFA, multicollinearity can be a concern. These assumptions were checked in Table 4, Table 5 and Table 6.

H1 was tested through the following model:

$Emissions_t = \beta_0 + \beta_1\, Size_t + \beta_2\, Logistic\_dummy_t + \beta_3\, Services\_dummy_t + \beta_4\, ECO_t + \beta_5\, ECO * Logistics_t + \beta_6\, ECO * Material\ processing_t + \varepsilon_t$

H2 was tested through the following model:

$Emissions_t = \beta_0 + \beta_1\, Size_t + \beta_2\, Logistic\_dummy_t + \beta_3\, Services\_dummy_t + \beta_4\, SOC_t + \beta_5\, SOC * Logistics_t + \beta_6\, SOC * Services_t + \varepsilon_t$

H3 was tested through the following model:

$Emissions_t = \beta_0 + \beta_1\, Size_t + \beta_2\, Logistic\_dummy_t + \beta_3\, Services\_dummy_t + \beta_4\, GOV_t + \beta_5 GOV * Logistics_t + \beta_6\, GOV * Services_t + \varepsilon_t$

5. Results

5.1 Exploratory Factor Analysis Results

The Exploratory Factor Analysis (EFA) showed that all the constructs were formed by a single factor with an explained variance higher than 0.45, as recommended by a previous study (Bagozzi and Yi, 1988). In addition, for all scales the KMO index and Bartlett's test sphericity tests provided good results.

The output of EFA shows that the ECO dimension is represented by a single construct: ECO = 82,79 per cent (*KMO* = 0.597). Concerning the SOC and GOV dimensions, the EFA underlines that two constructs explain 46 percent of the total variance overall (*KMO* = 0.614). Finally, for the ENV dimension (emissions), the output of the EFA indicates that we can extract one construct that explains almost 95 per cent of the total variance (*KMO* = 0.767) overall.

Overall, for all scales, the KMO index and Bartlett's sphericity tests provided reliable results, confirming the suitability of the three constructs (Table 3).

Table 3. Components' variables

Variables	Factor 1 [ECO]	Factor 2 [GOV]	Factor 3 [SOC]	Factor 4 [EM]
Revenue	0,985			
EBITDA	0,864			
Net Financial Position	0,698			
Value Added	0,979			
Production Costs	0,989			
Gender Equality Index		0,744		
Number of Managers		0,598		
Firm Seniority		0,610		

Employee Turnover			0,787	
Total Labour Cost			-0,768	
Labour productivity ratio			0,369	
CO2 Emissions				0,979
CH4 Emissions				0,963
NH3 Emissions				0,982

Note: Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Four extracted dimensions.

The results of EFA reported in Table 3 indicate that the Economic (ECO) dimension encompasses five economic variables - revenues, EBITDA, NFP, value added and production costs - associated with higher levels of financial performance.

The Governance (GOV) dimension encompasses three variables - gender equality, number of managers and firm seniority - that can contribute positively to sustainable governance practices.

Within the Social (SOC) factor, two variables - turnover and labour productivity ratio - are synthesised, reflecting unsustainable practices concerning employees (Govindan et al., 2021). The difference from one year to another of the total cost of labour [SOC2] displays a negative sign, suggesting that labour costs are not effectively managed to maintain fair compensation for employees. It can be affirmed that the factor of the social dimension represents unsustainable practices.

Lastly, the Emissions dimension (EM) encompasses three distinct emissions measures - Carbon Dioxide, Methane and Ammonia - indicating their contribution to general pollution.

5.2 Regression results

In this section, the results of the OLS analysis are presented. The OLS analysis served to test our hypotheses H1, H2 and H3. The effect of every sustainability dimension (ECO, GOV, SOC) on supply chain emissions level (EM) was tested within the three different suppliers' industrial sectors.

To ensure the reliability of the results, multicollinearity was checked with Variance Inflation Factor (VIF) and Tolerance (1/VIF). The commonly accepted threshold level of VIF is 10 (O'Brien, 2007), while the Tolerance is recommended to be higher than 0.2 (Kim, 2019). For all the variables of this paper, VIF is less than 10, and the tolerance level is less than 1.

H1 states that economic sustainability exhibits a positive impact on emissions for material-processing suppliers within the supply chain. Table 4 shows the regression result used to estimate the effect of economic sustainability on supply chain emissions for each of the three suppliers' categories. One of three dummies of suppliers' industrial sectors in this case was excluded from the regression equation to avoid perfect multicollinearity (Park, 2011).

The OLS output demonstrates that, within the material-processing sector, the economic dimension positively impacts emissions (β = 0,429 p < 0,003). This result confirms our H1, suggesting that economic performance is a possible proxy for supplier emissions levels for material-processing suppliers.

Table 4. Effects of economic performance on emissions in the supplier's industrial sectors

Relations	Coef.	Std. Error	t	Sign.	Tolerance	VIF
(Constant)	-2,999	0,175	-17,168	0,000		
Size	0,817 ***	0,041	19,756	0,000	0,767	1,303
Logistic_dummy	0,356 ***	0,095	3,755	0,000	0,869	1,151
Service_dummy	-0,163 **	0,076	-2,154	0,032	0,856	1,168
ECO	-0,109 ***	0,041	-2,619	0,009	0,543	1,841
ECO * Logistics	-0,058 n.s.	0,065	-0,401	0,371	0,633	1,580
ECO * Material processing	**0,429*** **	**0,144**	**2,968**	**0,003**	**0,821**	**1,218**

F = 91,291; Adj. R2 = 0,592; S.E. of estimate = 0,651
Predictors: (Constant), Size, Logistic_dummy, Service_dummy, ECO, ECO * Logistics, ECO * Material Processing
Dependent variable: Emissions
Note: *, **, ***, n.s. a significance level of 0.01, 0.05, 0,1 and not significant, respectively.

H2 states that social sustainability practices mitigate emissions of logistic suppliers within the supply chain. We can affirm that (Table 5) in the logistics sector, compared to the other sector, the social dimension has a positive impact on mitigating emissions (β = 0,148 p < 0,091).

Considering the aforementioned converse impacts of the social variables on social practices, the affirmative outcomes indicate that emissions are positively impacted by the implementation of unsustainable initiatives targeted toward employees (such as turnover, labour cost and productivity) within the logistics suppliers sector.

This result confirms our H2 and shows that social sustainability can be a possible proxy for emissions levels for logistic suppliers. Logistic suppliers investing in social sustainability for their employees present a lower emissions impact.

Table 5. Effects of Social Dimension on emissions in the supplier's industrial sectors

Relations	Coef.	Std. Error	t	Sign.	Tolerance	VIF
(Constant)	-2,959	0,143	-20,760	0,000		
Size	0,799 ***	0,035	22,769	0,000	0,868	1,152
Logistic_dummy	0,366 ***	0,091	4,008	0,000	0,876	1,142
Service_dummy	-0,133 **	0,067	-1,971	0,049	0,862	1,160
SOC	-0,069 n.s.	0,052	-1,340	0,181	0,656	1,523
SOC*Logistics	**0,148***	**0,088**	**1,972**	**0,091**	**0,764**	**1,309**
SOC * Services	-0,020 n.s.	0,071	0,860	0,073	0,600	1,666

F = 111,542; Adj. R2 = 0,585; S.E. of estimate = 0,666
Predictors: (Constant), Size, Logistic_dummy, Service_dummy, SOC, SOC * Logistics, SOC * Services
Dependent variable: Emissions
Note: *, **, ***, n.s. a significance level of 0.01, 0.05, 0,1 and not significant, respectively.

Finally, H3 states that governance sustainability practices negatively impact on higher emissions levels for services suppliers within the supply chain. The regression model reported in Table 6 shows that, within the services sector, the governance dimension negatively impacts emissions (β = - 0,115 p < 0,09).

This result confirms our H3. It can be affirmed that governance sustainability is a possible proxy for emissions levels for service suppliers. For service suppliers’ assessment, higher governance sustainability can be used to select suppliers with lower emissions and enhance SSCM.

Table 6. Effects of Governance Dimension on emissions in the supplier's industrial sectors

Relations	Coef.	Std. Error	t	Sign.	Tolerance	VIF
(Constant)	-3,049	0,143	-21,295	0,000		
Size	0,821 ***	0,036	23,034	0,000	0,873	1,145
Logistic_dummy	0,371 ***	0,091	4,072	0,000	0,873	1,145
Service_dummy	-0,127 *	0,067	-1,897	0,058	0,867	1,153
GOV	0,047 n.s.	0,048	0,993	0,321	0,731	1,368
GOV * Logistics	-0,011 n.s.	0,095	-0,610	0,909	0,772	1,296
GOV * Services	**-0,115 ***	**0,069**	**-2,282**	**0,090**	**0,570**	**1,754**

F = 112,206; Adj. R2 = 0,587; S.E. of estimate = 0,665
Predictors: (Constant), Size, Logistic_dummy, Service_dummy, GOV, GOV * Logistics, GOV * Services
Dependent variable: Emissions
Note: *, **, ***, n.s. a significance level of 0.01, 0.05, 0,1 and not significant, respectively.

6. Discussion and conclusions

The paper explores the issue of extending corporate responsibility to suppliers' emissions (CSRD, 2022; Gimenez and Tachizawa, 2012; Mani and Gunasekaran, 2018; Riccaboni and Luisa Leone, 2010).

The objective of the study is to identify potential proxies for supply chain emissions (Ratnatunga et al., 2011) to assess whether suppliers' sectors have any influence on these proxies (Burritt et al., 2011; ESRS, 2022; Nasir et al., 2021; Sun et al. 2021). We explored these issues in the specific case of an Italian ceramic supply chain. All 374 company's suppliers were analysed, and data on their economic, social, governance and emissions were collected.

Our factor analysis confirmed the literature-based aggregation of sustainability variables into four factors (economic, social and governance sustainability and emissions).

Subsequently, we performed linear regressions for investigating the effects of economic, social, and governance sustainability on emissions levels of suppliers operating in material-processing, logistics and service stages of the ceramic supply chain.

By assessing the sustainability factors related to economic, social, and governance dimensions and testing their influence for each sector, we can accurately account for the emissions across the entire supply chain. This approach provides a complete overview for

SSCM and identifies targeted strategies for mitigating emissions in different suppliers' sectors.

In particular, the analysis revealed that economic performance positively impacts emissions levels in the material-processing sector. This suggests that economic performance can be considered emissions' proxy for assessing material-processing suppliers. The findings highlight that choosing suppliers with strong economic performance could increase company's supply chain emissions.

Conversely, in the logistics sector, the implementation of socially unsustainable practices appears to positively influence higher emissions. This reveals that the efforts of logistics companies in fulfilling social sustainability expectations (Kumar, 2022) can optimise their emissions performance. Therefore, to diminish emissions within the supply chain, logistics suppliers should be evaluated based on their social sustainability endeavours.

Finally, the study finds that governance sustainability practices may contribute to lowering emissions in the services sector, endorsing governance sustainability as a criterion for assessing service suppliers' emissions. This underscores the importance of incorporating governance sustainability as a proxy for the emissions assessment of services suppliers.

The insights that emerged from the analysis of the results contribute to the call for usable proxies for suppliers' emissions assessment (Kazemian et al., 2022; Gimenez and Tachizawa, 2012; Pagell and Gobeli, 2009) and contribute to the literature (Foroozesh et al. 2022; Liu et al., 2021; Mani and Gunasekaran, 2018) in two main ways.

First, it shows that emissions levels depend on other sustainability dimensions such as economic, social, and governance. Given the availability of many economic, social, and governance sustainability data in available databases, leveraging these sources as proxies for emissions levels presents a valuable and promising approach. Furthermore, the research extends the existing literature (Gimenez and Tachizawa, 2012; Kazemian et al., 2022; Pagell and Gobeli, 2009) by exploring the social and governance factors influencing the implementation of SSCM practices through suppliers' assessment strategies.

Secondly, the paper highlights that suppliers operate across various industrial sectors (Burritt et al., 2011; Kazemian et al., 2022) and that proxies for emissions may vary across different phases of the supply chain. To the best of our knowledge, this paper represents the first attempt to evaluate supply chain emissions proxies by considering suppliers as entities operating in distinct sectors. It provides more targeted recommendations in particular for manufacturing companies seeking to reduce their supply chain emissions through suppliers' strategic assessment.

Finally, the paper advances practical implications for the manufacturing companies (Gusmerotti et al., 2019; Lucianetti et al., 2018).

Our study aims at contributing to the growing necessity of SSCM empirical assessment, (Khan et al., 2021) in the manufacturing sector, as most of the existing literature focuses on the agrifood supply chain (Kamble et al., 2019; Nematollahi and Tajbakhsh, 2020; Mehmood et al., 2021). Furthermore, the analysis highlights the impact of economic, social, and governance sustainability on emissions within different suppliers' industrial sectors and recommends that companies operating in the ceramic industry assess their suppliers' emissions by categorising them into services, logistics, and material-processing sectors.

Specifically, in the material-processing sector, suppliers should be assessed on the basis of their economic performance as it significantly impacts their emission levels. Within the logistics sector, it is recommended that companies prioritise selecting suppliers who demonstrate significant social sustainability efforts towards employees, as this has been shown to reduce emissions. Finally, emission assessment in the service sector can be implemented by analysing governance sustainability measures.

Moreover, our study shows that a strategic evaluation of all sustainability dimensions at various supply chain phases can identify measurable and comparative indicators that primarily influence emissions, which can then be addressed in setting different scenarios and sustainability optimisation strategies.

Nowadays, researchers are starting to investigate how to create sustainable supply chains, and most of them tend to use optimisation algorithms for route optimisation (Khan et al., 2021). However, our study contributes to a more comprehensive understanding regarding the full spectrum of sustainability dimensions—economic, social, and governance —that significantly influence emissions throughout the supply chain.

The study also acknowledges some limitations. Firstly, the data were collected from a single supply chain perspective - the ceramic tiles supply chain. Therefore, there remains the need for further investigation that extends the analysis to other manufacturing supply chains. Second, the research was conducted on data from a single year. To enhance the analysis, it would be beneficial to collect data from additional years (Huang et al. 2024), allowing for more comprehensive panel studies.

Chapter III: GOVERNANCE TRAITS AND SUSTAINABILITY DISCLOSURE: AN EMPIRICAL ANALYSIS ACROSS SMES

1. Introduction. – 2. Theoretical Background. – 3. Hypotheses Development. – 3.1. CEO Duality. – 3.2.BoD Independence. – 3.3 BoD Size. – 3.4. BoD Age and Gender. – 4. Methodology. – 4.1. Sample and data collection. – 4.2. Statistical methods. – 5. Results. – 6. Discussion and conclusions.

Abstract: Through the lens of agency theory, the paper aspires to understand to what extent sustainable corporate governance can mitigate agency problems in small and medium enterprises (SMEs). Despite the growing recognition of the significance of Sustainability Disclosure (SD) practices, predominantly in large companies, there remains a dearth of comprehensive empirical studies investigating the interconnectedness between governance and sustainability in the SME frame. This paper aims to examine the extent to which governance traits (CEO duality, board of directors' size, board independence, board average age, and board gender diversity) influence the amount of SD. The analysis was performed by mapping an Italian ceramic company's upstream and downstream supply chain composed of 197 companies. The analysis led to the calculation of an SD indicator for each company based on the European Sustainability Reporting Standards (ESRS). After conducting a fractional logistic regression, preliminary findings suggest that the board of directors' size, board independence, and board average age can leverage SD. In contrast, no significant relationship was found with CEO duality and board gender diversity. This study contributes to the literature on SMEs by offering empirical evidence on the fallout from the organizational implications of companies' governance on SD practices. Moreover, to the best of our knowledge, this is the first paper to examine the association between governance traits in explaining SD, according to the novel sustainability reporting standard ESRS.

1. Introduction

In recent years, the debate on the implications on Sustainability Disclosure (SD) of the corporate governance traits has gained prominence in both academic and business communities. The significance of reporting these issues is further underscored when focusing on Small and Medium-sized Enterprises (SMEs). While SMEs are not presently required to implement SD practices directly, they are subject to a "trickle-down" effect (Ortiz-Martínez et al., 2023). This effect indirectly obliges them to adopt SD practices as part of their involvement in supply chains or response to stakeholder expectations.

A large body of previous research has focused on board governance characteristics as a crucial determinant of SD (Tran et al., 2021; Aureli et al., 2020; Tibiletti et al., 2020). This proves an ongoing dialogue exists on whether internal governance factors influence the SD system (Helfaya & Moussa, 2017; Gray et al., 2001). Furthermore, in conformity with agency theory, the SD sheds light on companies' higher commitment to sustainability (Hassan et al., 2020) and informs stakeholders of the appropriateness of the companies' actions (Matinheikki et al., 2022; Clarkson et al., 2011).

In this vein, informing stakeholders is closely tied to agency costs arising from potential conflicts of interest between economic actors. Clear and effective communication reduces information asymmetry, a significant source of these costs, by equipping shareholders with the information needed to oversee management's actions (Jensen & Meckling, 1976).

While the impact of governance traits on SD has received more consideration in the context of listed companies (Beretta et al., 2023; Lu et al., 2022; Campanella et al., 2020), we have much to learn about governance traits in SMEs (Somoza, 2023). Seow (2023), in a systematic literature review on the determinants of environmental, social, and governance (ESG) disclosure, has highlighted the growing significance of ESG practices among SMEs, emphasizing the need for more investigations into their participation in ESG initiatives. Further research must consider the SMEs' unique challenges and opportunities in their SD initiatives.

The prevailing corpus of literature predominantly focuses on specific facets of sustainability: reporting framework employed (Pizzi et al., 2022; Jonsdottir, 2022; Miras - Rodriguez & Di Pietra, 2018), policies implemented (Ofori et al., 2023; Haque & Ntim, 2017) and ESG ratings (Umar et al., 2023; Albitar et al., 2022; Clerc, 2021).

However, the recent regulatory developments also address a novel nuance of SD, proposed by the Corporate Sustainability Reporting Directive (CSRD, 2022), as the companies that fall under the scope of this directive must report sustainability information on their supply chain. Due to the recent approval of the CSRD and its specific standard included in the European Sustainability Reporting Standard (ESRS), many SMEs are facing growing demands for sustainability information from external sources such as banks and large companies they supply. This new regulation creates a spill-over effect, influencing SMEs as they are part of the companies' supply chain and are directly impacted by the new regulation. Analyzing these changes and requirements in this realm is crucial, as the CSRD significantly impacts SMEs' operational and compliance landscape across Europe (European Commission, 2021).

Drawing on these issues, the paper aims to answer the following research question:

RQ: How do the governance traits of SMEs influence SD coverage under the implementation of ESRS standards?

Specifically, this paper's main aim is to analyze the effect of board composition on SMEs' SD. We claim that effective governance traits and SD can be seen as two phenomena moving in the same direction. Notably, we argue that effective managerial practices in governance bodies may be an underlying element of an increased propensity to communicate and disseminate positions on sustainability issues, mitigating the information asymmetry inherent in the SME-stakeholder relationship (Vitolla et al., 2020).

The study examines the governance traits and their effect on the SD of 197 SMEs involved in the supply chain of a ceramic company in Italy. Given its wide range of industries, from mining and processing materials to logistics and industrial planning activities, there is one specific underlying reason for choosing this supply chain.

Consequently, this paper examines agency problems between different SMEs and their stakeholders. Among these stakeholders, an accountable SD is demanded by the “focal company” of the supply chain (Fayezi et al., 2012).

The paper contributes to the existing literature by focusing on SMEs’ governance and SD differently from most contributions that refer to large companies (Yadav & Jain, 2023; Eng et al., 2022). In analyzing this relationship, the study contributes to developing SME research in three ways.

First, the examination extends beyond the traditional focus on agency issues within singular companies. Instead, it adopts a broader perspective, recognizing that such challenges pervade the interactions among economic actors throughout the supply chain. In this context, the systematic literature review of Matinheikki et al. (2022) emphasizes the importance of considering agency costs within the complex dynamics of the supply chain network.

Second, the debates on agency issues within SMEs often focus on family dynamics (Minola et al., 2021; Songini & Gnan, 2015) rather than governance composition. However, delving into governance dynamics is essential for several reasons. It facilitates nurturing a professional environment within the organization (Sacchetti & Catturani, 2021), where decisions are based on expertise and experience rather than family affiliations.

In addition, it promotes adopting a long-term vision geared towards value creation for all stakeholders (Yar Hamidi & Machold, 2011), not considering the interests of a single-family or a select group.

Lastly, the discussion concerns the recent reporting framework introduced by the CSRD. Although SMEs are not directly required to provide such information in the immediate future, they may be subject to a “trickle-down” effect, i.e., an indirect reporting obligation arising from the fact that they might be included in the supply chains of large companies. This peculiarity is emphasized in paragraph 5 of the ESRS 1, which outlines the general requirements.

This paper's reminder is structured as follows: Section 2 reviews the literature on SD to address agency problems and identifies the enabling traits of governance within it. This review will be conducted concerning the context of SMEs. Section 3 formulates the hypotheses based on the literature review. Section 4 describes the dataset, and the main variables used in the analysis. Section 5 illustrates the empirical model used and reports the results. Section 6 presents conclusions and main implications.

2. Theoretical Background

SD is pivotal in analyzing board governance traits to mitigate agency problems and information asymmetry between principal and agent (Kavadis et al., 2022). Agency theory posits that conflicts of interest arise between principals and agents, leading to agency problems, such as moral hazard and adverse selection (Jensen & Meckling, 1976). Rossi & Harjoto (2020), within the Italian context, stated that the legislative changes over the past two decades on the responsibility of the organizations, along with the growth in relevance of the independent rating agencies, positively impact performance, risk, and agency costs of Italian listed firms.

A systematic literature review by Zamil et al. (2021) confirms that agency issues related to SD, despite structural differences across countries, are universally relevant. Vitolla et al. (2020) compare agency issues to an aspect that can be part of a formal contract between individuals or companies, asserting that non-financial disclosure is a potential mechanism to align the interests of various stakeholders.

Appropriate oversight is essential to address information asymmetry through disclosure effectively. The Board of Directors (BoD) serves as a primary control aspect and supervises management, especially regarding disclosure matters (Donnelly & Mulcahy, 2008). In this vein, CEO duality, where one individual hold both the CEO and chairperson positions (Goergen et al., 2020), concentrates power and can hinder transparency.

Most empirical and theoretical evidence suggests that separating the roles of CEO and chairperson promotes greater board independence and oversight, thus facilitating more transparent SD practices (Lu et al., 2022). Further, this separation can lead to more rigorous SD, reflecting a broader consideration of stakeholder interests, including environmental impact, social responsibility, and ethical governance (Yadav & Jain, 2023).

Board independence is crucial for effective board governance, as independent directors are more likely to act in the best interests of diverse stakeholders (Zahid et al., 2020). Independent directors are more likely to advocate for the interests of external stakeholders, such as the community, customers, and the environment, as they are not closely involved in the company's financial performance (Rashid, 2021). Indeed, companies with a higher rate of independent directors could be more inclined to engage in SD (Masulis & Zhang, 2019).

Similarly, the board’s breadth may offer different perspectives and expertise to grasp a broad and multifaceted concept, such as sustainability issues (Dey, 2008; Vitolla et al., 2020). Larger boards may be beneficial because they bring a more comprehensive range of perspectives, experiences, and expertise, which can enhance the board’s ability to address the diverse concerns of stakeholders (Islam et al., 2022).

Another important aspect is related to the demographic characteristics of BoD; in this discourse, aspects such as age and gender come into the big picture of governance mechanisms.

A governance structure that ensures the participation of young members in its decision-making processes can effectively tackle the agency's problems by fostering a responsive and active BoD (Chams & García-Blandón, 2019). The average age of board members - often overlooked in governance discussions - could impact non-financial disclosure (Gerged, 2021).

First, younger board members can introduce innovative perspectives, improving the board's ability to address emerging sustainability and social responsibility issues.

Further elements of interest concern diversity, especially gender issues, of the board members. Although the results from research in this field do not appear to be entirely convergent (Amorelli & Garcia-Sanchez, 2021), a diverse board could favor the development activities and look for ways of reducing conflicts (Nielsen & Huse, 2010).

Consequently, considering a broader range of perspectives can lead to decisions that align more closely with the company's social and environmental responsibilities, often key stakeholder concerns (Rao & Tilt, 2016). Even though mimetic regulatory and coercive pressures often drive the inclusion of women on boards, it can reduce agency costs by enhancing the board's oversight capabilities (Rigolini & Huse, 2021).

Considering average age and board diversity together, with a focus on socio-demographic aspects instead of structural governance mechanisms, an inclusive board, in terms of age and gender, may be more aware of contemporary issues, such as climate change, social justice, and technological innovation, which are increasingly crucial to stakeholders (Khatib et al., 2020). Likewise, diverse boards are more inclined to consider not only the economic and financial implications of company actions, which aligns with the broader stakeholder focus of SD (Wu et al., 2022).

In this frame, the main focus of SD in the academic literature refers to listed companies. However, applying this perspective could also be helpful to the SME context because SMEs could benefit significantly from transparent reporting practices (Ortiz-Martínez et al., 2023). However, the literature on SMEs predominantly emphasizes family dynamics as determinants of governance traits and disclosure practices (Minola et al., 2021; Songini & Gnan, 2015; Gnan et al., 2013), while the elements that determine the characteristics and composition of BoD have so far been given little consideration.

Agency problems are amplified when extending beyond the "micro" context that characterizes the traditional company boundaries, particularly in supply chains. The buyer-supplier relationship is inherently prone to information asymmetry, potentially leading to unconscious supplier selection and moral hazard threats (Matinheikki et al., 2022; Zu & Kaynak, 2012).

An adequate supply chain governance requires transparent communication and mutual trust between principals and agents. In this context, SD is essential in enhancing transparency and accountability along the upstream and downstream supply chain. Even though SMEs are not always directly mandated to follow stringent sustainability regulations, they are significantly influenced by the trickle-down effects from larger companies within the supply chain and by the demands of their stakeholders (Ortiz-Martinez et al., 2023).

3. Hypotheses Development

We define governance as "*the combination of mechanisms which ensure that the management (the agent) runs the firm for the benefit of one or several stakeholders (principals)*" (Goergen & Renneboog, 2006, p. 100). In line with the above citation, Selznick (1992: 290) asserts that "*governance takes account of all the interests that affect the viability, competence, and moral character of an enterprise*". Moreover, as suggested by Cucari et al. (2017), we have focused on BoD structure since it ensures an integral role in driving sustainability into a company's business strategy. Its decisions, oversight, and guidance are crucial for embedding sustainability into the company's culture and ensuring that it becomes a core element of its success and competitiveness.

From an agency theory perspective, the BoD in SMEs functions as a pivotal information system for stakeholders, allowing for monitoring executive behavior and assessing firm performance (Gabrielsson & Winlund, 2000). In the case of sustainability specifically, they deliberate on strategies directly or indirectly to the company's stance on social and environmental responsibility (Orzalin, 2019; Jizzi, 2017; Galbreath, 2016; Michelon & Parbonetti, 2012).

The research hypotheses we intend to investigate with this contribution are outlined in the following paragraphs.

3.1. CEO Duality

Examining board composition, Machold et al. (2011) highlight the essential elements that influence team performance in SMEs, with a particular focus on the role of the CEO. An important aspect to consider when analyzing board structure is the occurrence of CEO duality, where the same individual holds the roles of the chairperson and chief executive officer. Prior literature has acknowledged that the type of board leadership and the role of the CEO can influence firm performance. However, empirical evidence on CEO duality remains inconclusive, with some studies finding no significant effect on firm performance (Braun & Sharma, 2007).

In SMEs, CEO duality is more common due to concentrated ownership structures and role integration, with the CEO often also serving as the board chairperson (Machold et al., 2011). However, as previously stated, agency theory arguments advocate for separating these two positions (Coles & Hesterly, 2000; Fama & Jensen, 1983). Centralized leadership authority may result in management's domination of the board, leading to poor performance (Jensen & Meckling, 1976; Fama & Jensen, 1983; Shleifer & Vishny, 1997). Separating the CEO and chairperson roles enhances the quality of reporting, prevents ambiguity, and improves the company's public profile and transparency (Sundarasen et al., 2016). Considering the CEO-chair dual role in terms of decision-making on SMEs' disclosure, we hypothesize the following:

H1: The dual role of the CEO as chairperson of the board negatively affects sustainability disclosure coverage in SMEs.

3.2. BoD Independence

Independent directors reduce agency conflicts, ensure effective monitoring, and enhance management quality. According to Adams & Ferreira (2009), their presence addresses attendance issues on board.

The higher the independence of company board directors, the more influential the board's decisions and the greater its encouragement for ESG disclosure (Melis & Rombi, 2021; Holtz & Sarlo Neto, 2014). A significant number of independent directors indicate that the board is likely less controlled by management, minimizing direct or indirect relationships with the firm that could influence their decisions.

Independent directors function as a controlling mechanism to reduce agency conflicts and information asymmetry (Sundarasen et al., 2016; Roberts et al., 2005). Furthermore, independent directors are often employee-oriented, come from diverse backgrounds, and exhibit higher concerns regarding environmental issues (Williams, 2003; Johnson & Greening, 1999).

For instance, de Villiers et al. (2011) argue that boards with more independent directors are likelier to possess the information and knowledge necessary to monitor environmental performance effectively. This leads us to state the second hypothesis:

H2: The percentage of independent directors in the BoD is positively associated with higher coverage of sustainability disclosure in SMEs.

3.3. BoD Size

The firm's size significantly impacts board oversight effectiveness (Beji et al., 2020). From the agency theory perspective, larger boards may face coordination and communication difficulties, potentially reducing efficiency (Andrés et al., 2005; Bushman & Smith, 2001). In contrast, larger boards better represent diverse interests, which can enhance the firm’s non-financial disclosures (Frias-Aceituno et al., 2012; Kock et al., 2011).

Large boards have the potential to foster the creation of social capital, which can, in turn, enhance more balanced and inclusive decision-making processes (Beji et al., 2020). Such inclusivity is crucial for improving non-financial disclosure (Frias-Aceituno et al., 2012). By integrating a broad spectrum of perspectives and expertise, larger boards are more adept at tackling complex sustainability issues (Hafsi & Turgut, 2012), resulting in more effective and comprehensive sustainability actions and encouraging the communication of ESG information (Jizzi, 2017). Hence, we propose the third hypothesis:

H3: The larger the size of the board, the higher the sustainability disclosure coverage in SMEs.

3.4. BoD Age and Gender

Other traits of boards are represented by their diversity, which refers to the variations in directors' attributes, emphasizing the range of differences within a given board (Beji et al., 2020; Hafsi & Turgut, 2012). Research on board diversity often distinguishes between demographic dimensions (Hillman et al., 2007) and cognitive dimensions (Forbes & Milliken, 1999).

However, much of the existing empirical literature predominantly focuses on readily measurable attributes of directors, particularly demographic aspects such as gender and age (Jizzi, 2017). Age and gender diversity within the board of directors can significantly improve the board's ability to respond to these requirements, thus fostering greater SD (Gallego-Álvarez & Rodriguez-Dominguez, 2023; Islam et al., 2022).

In line with this stream of literature (Beji et al., 2020; Ferrero-Ferrero et al., 2013), we can formulate the fourth hypothesis specifically focused on board average age:

H4: Boards with younger members positively influence sustainability disclosure coverage in SMEs.

The empirical corporate governance literature investigating the relationship between gender diversity and SD has yielded mixed results. For instance, some studies found a positive relationship between gender diversity in boards and the quality of voluntary sustainability reporting (Bravo et al., 2018) or the level of ESG disclosure (Arayssi et al., 2020). Conversely, other studies observed a negative relationship between the percentage of female directors and ESG disclosure (Husted & Sousa-Filho, 2019; Cucari et al., 2017). Manita et al. (2018) also found no significant relationship between board gender diversity and SD.

According to De Masi et al. (2021), these conflicting results are due to the measures failing to capture female directors' nuanced influence. Neither approach considers the impact of having multiple women on the board and reaching the critical mass (De Masi et al., 2021). Considering that the numerical representation of women in SMEs is meager and that the mere presence of women on boards cannot effectively influence board decisions, their influence may remain limited. Therefore, concerning board gender diversity, we hypothesize that:

H5: The presence of women on the board of directors has no effect on sustainability disclosure coverage in SMEs.

4. Methodology

4.1. Sample and data collection

The study relies on primary data collected from online sources. Our final sample comprises a total of 197 organizations operating in Italy. Of these, 180 organizations (91.37%) are in northern Italy, while the remaining 17 organizations (8.63%) are in the country's central and southern regions.

Specifically, we focused on SMEs following the European Commission's definition, understood as enterprises with fewer than 250 employees, an annual turnover of up to EUR 50 million, or a balance sheet total not exceeding EUR 43 million (EU Recommendation 2003/361). This definition is consistent with most researchers' criteria, which include initial capital/investment, number of employees, and annual turnover (Zahoor et al., 2020). This perspective provides a systemic view of the production process, monitoring raw materials extraction and processing, direct or indirect associated services, logistics activities, and before- and after-sales marketing activities. In other words, we base our assumption on the life cycle thinking, considering the production process from cradle to grave (Mazzi, 2020).

As mentioned in the introduction paragraph, even in the composition of the sample under study, we have taken as reference the draft ESRS 1, specifically paragraph 5 concerning the supply chain, in which it is clearly stated that: "The information about the reporting undertaking provided in the sustainability statements shall be extended to include information on the material impacts, risks and opportunities connected to the undertaking through its direct and indirect business relationships in the upstream and/or downstream supply chain" (EFRAG, 2022).

The specific identification of each ceramic focal company supplier is referred to in 2022. The sample spans three primary industries: services, which includes brokerage, consulting, and research and development; distribution, encompassing transport and sales; and manufacturing, which covers machinery and finished products.

The average age of the companies in this sample is 32.6 years, reflecting a diverse range of establishment periods. In addition, 19.29% of these companies actively compile and publish sustainability reports, indicating a growing emphasis on corporate responsibility within the sample. Financially, the average Earnings Before Interest, Taxes, Depreciation, and Amortization (EBITDA) across these organizations is € 3,021,811.68.

The independent variables include the average age of the board (X1), which provides insights into the demographic composition of the board and is critical for understanding diversity and experience within leadership structures. The percentage of independent directors (X2) quantifies the proportion of independent board members, serving as a measure of the board's objectivity and capacity for oversight. The number of board members (X3) offers an understanding of the size of the board. CEO duality (X4), a dummy variable, indicates whether the CEO concurrently holds the position of the chairperson of the board. Gender equality on the board (X5) reflects the gender composition among board members. In addition to these primary variables, control variables were included, such as revenue (X6), total assets (X7), the number of employees within each organization (X8), and the industry sector in which the company operates (X9).

In this respect, five different industries that characterize the ceramic supply chain were included: manufacturing (Industry 1), including companies involved in the processing of raw materials and semi-finished products; chemical (Industry 2) including companies involved in the production of glazes and organic agents, technology (Industry 3) including companies dealing with robots and industrial software, logistics (Industry 4) including companies involved in the inbound of raw materials and outbound of finished products, and services (Industry 5) including companies dealing with consulting and after-sales management.

A comprehensive list of all variables is presented in Table 1.

Table 1. Study variables.

Variable description	Type	Mean (St. Dev.)	Count (%)	Source
Disclosure rate (Y)	Numeric [0–1]	0.27 (0.29)		EFRAG, 2022
Average age of the board (X_1)	Numeric	57.61 (6.32)		Beji et al., 2020
Percentage of independent directors on the total board members (X_2)	Numeric	0.64 (0.41)		Valls Martinez et al., 2019; Chen and Moers, 2018
Number of board members (X_3)	Numeric	4.19 (2.52)		Rubino et al., 2017; Ntim et al., 2014; Tanna et al., 2011
CEO Duality (X_4)	Binary			Voinea et al., 2022; Oware and Awunyo-Vitor, 2021; Muttakin and Subramaniam, 2015
1 = The CEO is also the chairperson of the board			68 (34.52)	
0 = otherwise.			129 (65.48)	
Gender equality on the board (X_5)	Numeric	0.18 (0.24)		Alodat et al., 2023; Halliday et al., 2020
Revenues (X_6)	Numeric	€ 33,849,655.65 (74,878,862.91)		Alodat et al., 2023; Halliday et al., 2020
Total assets (X_7)	Numeric	€ 47,096,561.58 (174,929,197.63)		Atan et al., 2018
N. employees (X_8)	Numeric	61.62 (63.90)		Lamm et al., 2015
Industry (X_9)	Categorical			
1 = Manufacturing			50 (25.38)	Michelon & Parbonetti, 2012
2 = Chemicals			27 (13.71)	
3 = Technology			32 (16.24)	

4 = Logistics	17 (8.63)
5 = Services	71 (36.04)
N=197	

The dependent variable, defined as the disclosure rate (SD), is established using thematic content analysis, a technique widely used since it allows the analysis of written text (Cole, 1988; Krippendorf, 1980) from online public documents. This allows one to explore how a company handles its intangible assets (Castilla-Polo & Ruiz-Rodríguez, 2017).

The most significant developments arising from the ESRS 1, which defines the General Requirements, concern the analysis perspective and the information to be disclosed. The perspective of analysis impacts not only the focal – company that has to report its sustainability information but also its entire supply chain, from downstream to upstream activities.

The urgency of this issue is also underlined in paragraph 5.2 of ESRS 1 on General Requirements, stating: "*Obtaining value chain information could also be challenging in the case of SMEs and other value chain entities that are not in the scope of the CSRD*" (EFRAG, 2022)[12]. On the other hand, the information to be disclosed must observe the double–materiality requirement for the focal company, except for two topics considered by the European Financial Reporting Advisory Group (EFRAG) transversally material for every company: Climate Change (ESRS – E1) and Own Workforce (ESRS – S1). In this regard, EFRAG uses the term 'industry agnostic metrics' to denote the impartial relevance of these metrics, irrespective of the specific contextual factors that may influence a company's characteristics and operations. A comprehensive ESRS E1 and ESRS S1 was constructed (see Appendix).

The stages of thematic content analysis are explained in the following text.

First, the metrics related to the ESRS E1 (Climate Change) and ESRS S1 (Own Workforce) standards were taken as a reference in the Appendix section. Second, the disclosure or non-disclosure of the specific information in the Appendix tables was carried out. In doing this, since the companies in the sample are mainly SMEs, we take into account their web pages, given their central role in communicating information (Du & Vieira, 2012).

[12] Draft European Sustainability Reporting Standards, ESRS 1 General Requirements, November 2022, p. 16. https://www.efrag.org/lab6

Then, we analyzed the various areas on the web content (such as the sustainability area on the company website) and any available documents (mainly the code of ethics and sustainability report). According to Michelon et al. (2015), examining different sources helps the researcher overcome the limitations posed by analyzing a unique document, the sustainability report.

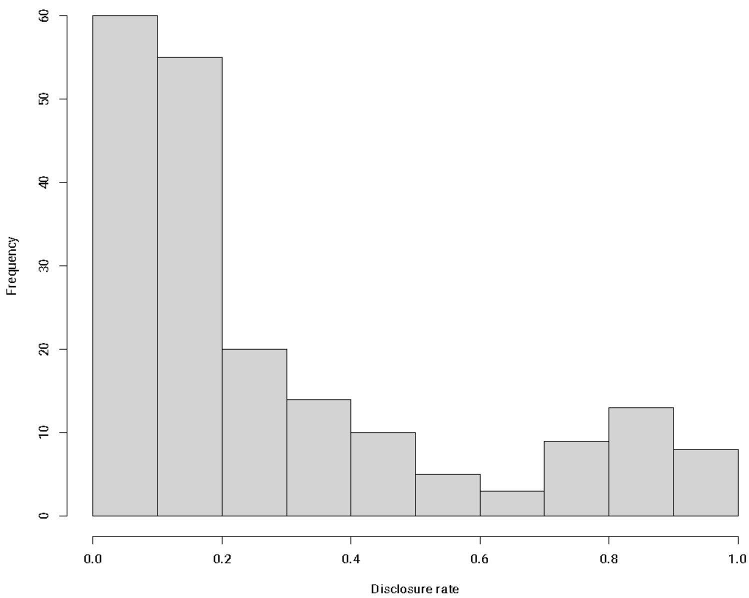
The presence or absence of a specific data point of one of the two standards was coded as 1 if present and 0 if not mentioned. No penalty was imposed if a data point was not mentioned. For instance, if the company stated its policy on ESRS - E1 - V1, it received a score of 1 for this specific variable.

The disclosure rate is computed as a fraction ranging from 0 to 1, representing the overall disclosure of a company regarding social and environmental ESRS. The disclosure rate (D_i) for each observation i is calculated as the sum of the Environmental disclosure (E_i) and the Social disclosure (S_i). This sum is then normalized by dividing it by the maximum possible disclosure rate (D_{max}), ensuring the disclosure rate falls within the interval [0,1].

$$D_i = \frac{E_i + S_i}{D_{max}}$$

The resulting disclosure variable is defined in [0,1]; thus, the fractional logistic model is appropriate. Figure 1 shows a graphical representation of the dependent variable distribution.

Figure 1. Disclosure rate distribution.



4.2. Statistical methods

Before data analysis, KNN imputation (k=5) was employed to address missing values. To predict the disclosure rate of a company, we employed fractional logistic regression, a nonlinear regression model designed for fractional response variables [0,1]. Given a sample of n observations, let y be the dependent variable and x the explanatory variable. For each i^{th} observation ($i = 1, \ldots, n$), the fractional model is specified as follows:

$$E(x_i) = G(x_i\beta)$$

where $G(\cdot)$ is the logistic function satisfying $0 < G(z) < 1$ for each $z \in R$. The unknown parameters are estimated using Quasi-Maximum Likelihood Estimation (QMLE), an efficient method under the Generalized Linear Model assumptions (Papke and Wooldridge, 1996).

5. Results

Regarding the model specification, we employed the RESET test to evaluate the appropriateness of the fractional logistic framework for modeling the data. The results (test statistic = 0.2115, df1 = 1, df2 = 190, p-value = 0.6461) indicate that non-linear combinations of the fitted values do not provide significant additional explanatory power to the model.

Given that the p-value (0.6461) exceeds any conventional significance level (e.g., 0.05), we fail to reject the null hypothesis. This finding suggests no evidence of model misspecification, concluding that the fractional model is adequately specified. The baseline equation of the fractional model takes the following form:

$$E(Disclosure|x_k) = G(\beta_0 + \beta_1 Avgerage_{age} + \beta_2 \%\_Indep.\_directors + \beta_3 Board\_members + \beta_4 CEO\_duality + \beta_5 Gender\_equality)$$

where x_k is the k^{th} predictor ($k = 1, \ldots, p$) and $G(.)$ is the logistic function ensuring predictions to be within the unit interval. We estimate nonlinear models using the logit link function and Quasi Maximum Likelihood Estimation (QMLE). Table 2 reports the coefficient estimates from the hierarchical logistic regressions, including a set of controls.

Table 2. Fractional logistic regression

	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	–0.817	–0.788	–0.790	–0.794	–1.018
	(0.875)	(0.868)	(0.868)	(0.827)	(0.873)
Average age BoD (X_1)	–0.028**	–0.025*	–0.025*	–0.025*	–0.024*
	(0.014)	(0.014)	(0.014)	(0.013)	(0.014)
% of independent directors BoD (X_2)	1.038***	0.776***	0.776***	0.789***	0.845***
	(0.305)	(0.299)	(0.299)	(0.283)	(0.290)
N. board members (X_3)	0.180***	0.141***	0.141***	0.119**	0.122**
	(0.055)	(0.055)	(0.057)	(0.057)	(0.058)
CEO Duality_1 (X_4)	–0.223	–0.214	–0.216	–0.201	–0.154
	(0.211)	(0.200)	(0.202)	(0.201)	(0.210)
Gender equality BoD (X_5)	–0.042	–0.099	–0.097	–0.085	–0.093
	(0.128)	(0.132)	(0.127)	(0.114)	(0.115)
Revenues (X_6)		0.000**	0.000**	0.000	0.000
		(0.000)	(0.000)	(0.000)	(0.000)
Total assets (X_7)			0.000	0.000	0.000
			(0.000)	(0.000)	(0.000)
N. employees (X_8)				0.000	0.000
				(0.000)	(0.001)
Industry (X_9)					
Industry_2					0.045
					(0.307)
Industry_3					0.069
					(0.310)
Industry_4					0.224
					(0.375)
Industry_5					0.260
					(0.276)
Observations	197	197	197	197	197
Pseudo R^2	18.609	26.324	26.764	30.319	31.738

Note(s): CEO Duality: 1 = if the CEO is also the board's chairperson; 0 = otherwise. Value Chain: 1 = Manufacturing; 2 = Chemicals; 3 = Technology; 4 = Logistics; 5 = Services.

Robust standard errors are in parentheses. * $p < .1$; ** $p < .05$; *** $p < .01$.

Since the Breusch-Pagan test underlined heteroscedastic disturbances in the model (BP = 13.551, df = 5, p-value = 0.018), robust standard errors are computed based on a heteroskedasticity-consistent covariance. The complete model (3), including control variables, has a pseudo R^2=30.303, which is generally regarded as a good fit (McFadden, 1979).

Figure 2. Homoscedasticity test

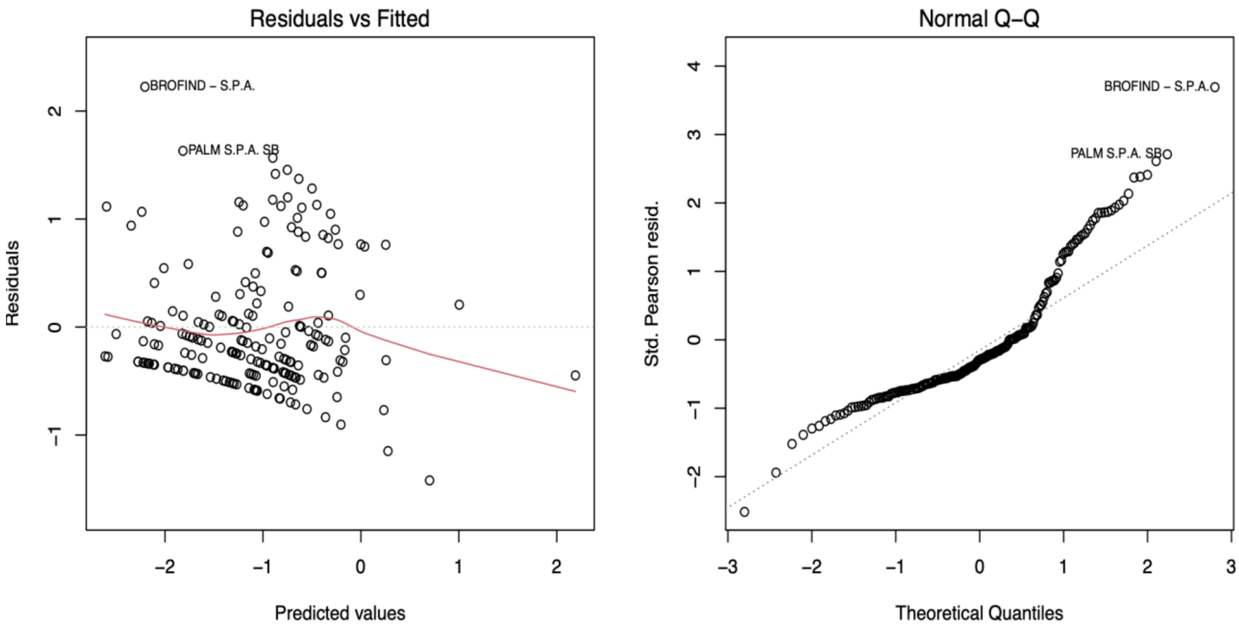


Table 2 provides a summary of the models used to perform the analysis. The results underline that four of the five hypotheses are confirmed. No empirical evidence suggests a relationship between CEO_Duality and SD (β = - 0.223), even after accounting for the economic-financial indicator and industry (β = - 0.154).

This is proposed because the duality of the CEO on boards may not significantly impact the SD in SMEs due to limited resources, the prioritization of short-term goals, and the centralized decision-making processes of CEOs or owners (Eggers, 2020). Additionally, limited awareness of the benefits of SD may reduce the influence of this governance trait (Johnson, 2013). Thus, we reject H1.

Conversely, our results indicate that different governance traits can impact the SD rate in the case of SMEs. Indeed, the percentage of independent directors BoD (X_2) and the number of board members (X_3) reveal a positive relationship (respectively β = 1.038***; β = 0.180***), even after including the control variable in Model 4 (respectively β = 0.845 ***; β = 0.122 ***).

They demonstrate that the autonomy of top bodies and a large board regarding skills and experience play a crucial role in enhancing SD practices. Among the demographic traits of governance, BoD, such as the average age of the BoD (X_1) and SD rate, suggests that the existence of an adverse relationship is advanced in all the models.

This result advances the assumption that older members may lack clear awareness of sustainability's significance, preferring conservative approaches and prioritizing personal returns over long-term sustainability initiatives (Lee et al., 2024).

Ultimately, as hypothesized, the presence of women in the BoD does not influence the SD rate. This implies that the presence of women, per se, on boards of directors is not sufficient to influence board decisions effectively. Therefore, it is possible to state that H2, H3, H4, and H5 are confirmed.

6. Discussion and conclusions

This study advances our understanding of how board governance traits impact sustainability disclosure in SMEs, particularly within the regulatory framework set by the CSRD and ESRS. By examining a sample of 197 SMEs in a ceramic company’s supply chain, the study analyzes the influence of governance characteristics—including board independence, board size, CEO duality, board age, and gender diversity—on SD practices.

Our findings underscore the importance of specific governance traits in influencing SD in SMEs, contributing to existing literature that examines governance structures as essential drivers of organizational transparency and sustainability, particularly within supply chains.

The results demonstrate that board independence and size positively impact SD. Independent directors, known for enhancing oversight and aligning company practices with stakeholder interests (Adams & Ferreira, 2009; Zahid et al., 2020), appear to strengthen SD by reducing agency conflicts and information asymmetry within SMEs, thereby improving transparency.

Larger boards also contribute positively by bringing diverse expertise to sustainability-related decision-making (Frias-Aceituno et al., 2012; Hafsi & Turgut, 2012), which supports the organization’s ability to address varied stakeholder demands. This aligns with agency theory, as these governance traits reflect mechanisms for mitigating agency problems (Kavadis et al., 2022), thus enhancing organizational and supply chain transparency.

Conversely, CEO duality showed no significant association with SD, which may be attributed to the centralized decision-making and limited resources characteristic of SMEs (Eggers, 2020).

Additionally, a negative association was observed between the average age of board members and SD, aligning with findings suggesting younger board members are more inclined to promote and report sustainability initiatives than their older counterparts (Lee et al., 2024). Finally, gender diversity was found to have no significant effect on SD, highlighting an area for further research better to understand its role within the context of SMEs.

The findings also illustrate the "trickle-down" effect (Ortiz-Martínez et al., 2023), where SMEs experience indirect pressures to improve SD due to their relationships with larger companies that must comply with CSRD. This effect emphasizes the importance of governance traits within SMEs, which are crucial for meeting heightened transparency expectations in downstream supply chains (Fayezi et al., 2012).

These dynamics are in line with recent studies highlighting that SMEs are increasingly influenced by regulatory frameworks that impact their more significant supply chain partners, underscoring the need for robust governance structures to support compliance and sustainability (Matinheikki et al., 2022; Pizzi et al., 2022).

As larger companies increasingly depend on SD from their supply chain partners to fulfill their compliance requirements under evolving European sustainability standards, SMEs must adapt by implementing governance structures that enhance disclosure practices, thereby meeting the escalating transparency expectations of downstream stakeholders.

In conclusion, this study provides empirical evidence on the importance of governance traits in enhancing SD in SMEs, contributing to the literature on SME governance and sustainability (Somoza, 2023; Seow, 2023). Practically, it offers SMEs insights into prioritizing effective governance traits for improved SD and provides policymakers with guidelines that promote SD practices in SMEs, bolstering transparency across supply chains.

Future research could extend these findings by examining the quality of SD content within the ESRS framework, thus refining our understanding of the role of governance in SD practices in SMEs and supply chains.

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Appendix A [Chapter II]

Table A1. Kmo and Bartlett Test for ECO variables

Kmo & Bartlett Test		
Kaiser-Meyer-Olkin measure of sampling adequacy.		0,597
Bartlett's test of sphericity		
	Appross. Chi-square	5.267,678
	gl.	10
	Sign.	0,000

Table A2. Economic component cumulative variance

Initial Eigenvalues				**Extraction Sums of Squared Loadings**		
Component	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	4,140	82,796	82,796	4,140	82,796	82,796
2	0,726	14,510	97,306			
3	0,122	2,445	99,750			
4	0,011	0,226	99,976			
5	0,001	0,024	100,00			

Note: Total Variance Explained by Economic component

Table A3. Kmo and Bartlett Test for SOC and GOV variables

Kmo & Bartlett Test		
Kaiser-Meyer-Olkin measure of sampling adequacy.		0,614
Bartlett's test of sphericity		
	Appross. Chi-square	170,076
	gl.	15
	Sign.	0,000

Table A4. Social and Governance components cumulative variance

Initial Eigenvalues				**Extraction Sums of Squared Loadings**		
Component	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	1,703	28,379	28,379	1,703	28,379	28,379
2	1,058	17,638	46,017	1,058	17,638	46,017
3	0,971	16,182	62,199			
4	0,855	14,251	76,450			
5	0,825	13,756	90,206			
6	0,588	9,794	100,000			

Note: Total Variance Explained by Social and Governance components

Table A5. Kmo and Bartlett Test for ENVIRONMENTAL EMISSIONS variables

Kmo & Bartlett Test		
Kaiser-Meyer-Olkin measure of sampling adequacy.		0,767
Bartlett's test of sphericity		
	Appross. Chi-square	2.032,85
	gl.	3
	Sign.	0,000

Table A6. Environmental emissions component cumulative variance

Initial Eigenvalues				**Extraction Sums of Squared Loadings**		
Component	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	2,850	94,994	94,994	2,850	94,994	94,994
2	0,107	3,574	97,306			
3	0,043	1,432	100,00			

Note: Total Variance Explained by Environmental emissions component

Appendix B [Chapter III]

Table B1. ESRS – E1 Disclosure Requirements

ESRS E1 – Climate Change		
ESRS – E1 – V1	Gross Scope 1 GHG emissions	0 = Absence 1 = Presence
ESRS – E1 – V2	Gross Scope 2 GHG emission	0 = Absence 1 = Presence
ESRS – E1 – V3	Gross Scope 3 GHG emissions	0 = Absence 1 = Presence
ESRS – E1 – V4	Total GHG emissions per net revenue	0 = Absence 1 = Presence
ESRS – E1 – V5	Total energy consumption from non–renewable sources	0 = Absence 1 = Presence
ESRS – E1 – V6	Total energy consumption from renewable sources	0 = Absence 1 = Presence

Table B2. ESRS – S1 Disclosure Requirements

ESRS S1 – Own Workforce		
ESRS – S1 – V1	The undertaking shall disclose its approaches and actions on negative impacts	0 = Absence 1 = Presence
ESRS – S1 – V2	The undertaking shall disclose its approaches and actions on positive impacts	0 = Absence 1 = Presence
ESRS – S1 – V3	The undertaking shall manage material risks and opportunities related to its own workforce.	0 = Absence 1 = Presence
ESRS – S1 – V4	The undertaking shall disclose key characteristics of employees, in terms of contractual characteristics, in its own workforce	0 = Absence 1 = Presence
ESRS – S1 – V5	The undertaking shall disclose key characteristics of non-employee workers in its own workforce.	0 = Absence 1 = Presence
ESRS – S1 – V6	The undertaking shall disclose information on the extent to which the working conditions and terms of employment of its own workforce are determined or influenced by collective bargaining agreements and to the extent to which its employees are covered in social dialogue in the EEA at the establishment and European level.	0 = Absence 1 = Presence
ESRS – S1 – V7	The undertaking shall disclose the gender distribution at top management amongst its employees	0 = Absence 1 = Presence
ESRS – S1 – V8	The undertaking shall disclose the age distribution at top management amongst its employees	0 = Absence 1 = Presence
ESRS – S1 – V9	The undertaking shall disclose whether or not all workers in its own workforce are paid an adequate wage, in line with applicable benchmarks	0 = Absence 1 = Presence
ESRS – S1 – V10	The undertaking shall disclose whether its own workers are covered by social protection against loss of income due to major life events	0 = Absence 1 = Presence
ESRS – S1 – V11	The undertaking shall disclose the percentage of persons with disabilities in its own workforce.	0 = Absence 1 = Presence
ESRS – S1 – V12	The undertaking shall disclose the extent to which training and skills development is provided to its employees	0 = Absence 1 = Presence
ESRS – S1 – V13	The undertaking shall disclose information on the number of incidents associated with work-related injuries, ill health and fatalities of its own workers	0 = Absence 1 = Presence

ESRS – S1 – V14	The undertaking shall disclose information on the extent to which its own workforce is covered by its health and safety management system	0 = Absence 1 = Presence
ESRS – S1 – V15	The undertaking shall disclose the extent to which employees are entitled to and make use of family-related leave	0 = Absence 1 = Presence
ESRS – S1 – V16	The undertaking shall disclose the percentage gap in pay between women and men	0 = Absence 1 = Presence