One, no one and one hundred thousand firm risks: which are affected by the circular economy?

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Abstract

The paper studies for the first time in the literature the individual and interactive effects of circular economy practices, i.e., reducing, reusing, and recycling, on downside, idiosyncratic, and default risks from a risk-management perspective. We use a sample of 1,069 listed European non-financial companies over the period 2010-2022. We find that reducing, reusing, and recycling activities, implemented together, significantly decrease downside, idiosyncratic, and default risks. However, considering the three circular economy dimensions individually, only reduction and reusing mitigate these risks, while recycling does not. Moreover, reduction, reusing, and recycling, when applied pairwise, have a substitutive effect in decreasing idiosyncratic and default risks.

KEYWORDS: circular economy; downside risk; idiosyncratic risk; default risk; non-financial companies

JEL CODES: G11, G32, Q56

EFM classification codes: 210, 310, 330

Project funded under the National Recovery and Resilience Plan (NRRP), Mission 04 Component 2 Investment 1.5 – NextGenerationEU, Call for tender n. 3277 dated 30/12/2021, Award Number: 0001052 dated 23/06/2022

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1. Introduction

In the last decade, the European Union (EU) has increasingly focused on climate change and environmental issues, recognized as significant sources of uncertainties and risks potentially affecting firm resilience (Xue et al., 2020). To limit these risks, the EU has introduced, adopted, and promoted numerous environmental regulations, such as the Paris Agreement on Climate Change, the European Green Deal, and the Clean Energy for All Europeans Package[1]. Such initiatives underscore the European commitment to addressing the environmental issue comprehensively, aligning its policies toward sustainable development, and decoupling economic growth from environmental degradation (Palea et al., 2023). To achieve these objectives, circular economy (CE) emerges as a useful strategic tool. Unlike the traditional linear economy, characterized by sourcing, production, and disposal, the CE model represents a regenerative system in which raw materials, waste, pollution emissions, and energy consumption are drastically reduced throughout the entire life cycle of products (Korhonen et al., 2018). This is achieved by: (i) reducing the environmental impact of production, (ii) designing products that can be reused over time, and (iii) using recyclable materials. Recognizing the crucial role of CE in enhancing the green transition of European firms (Palea et al., 2024), the EU adopted its first Circular Economy Action Plan in 2015 (European Commission, 2015) and continued to enact further CE-related policies in the next years (European Commission, 2020; European Parliament, 2021).

In recent years, also financial policymakers have implemented numerous regulations aiming to achieve the Paris Agreement targets and other European environmental objectives. Among the various initiatives, a key role is played by the European Taxonomy Regulation (European Parliament and the Council, 2020). It requires financial companies to map their environmental risks, thus guiding non-financial firms toward more environmentally responsible practices and ensuring that financial flows support the transition to a more sustainable economy. In line with this approach, the European Banking Authority (EBA, 2023) aims to incorporate environmental risks across all pillars of its regulatory framework, recognizing that environmental factors significantly contribute to risks to individual institutions. Therefore, the EBA (2023) suggests financial companies accelerate the integration of environmental risks into the evaluation of their traditional financial risks, and especially of credit risk.

This increasing interest in environmental issues and their impact on corporate risks has involved not only policymakers but also some academic researchers. Although a great number of studies to date have focused on the linkage between environmental and economic outcomes in both financial and non-financial companies (Guenster et al., 2011; Tan et al., 2017; Miller et al., 2022), only a few authors have empirically explored, at the firm level, the impact of environmental performance on corporate risks (Xue et al., 2020; Maxfield and Wang, 2021; Zara and Ramkumar, 2022). Overall, extant literature does not provide unequivocal evidence regarding this relationship. Furthermore, to our knowledge, surprisingly the role played by CE in affecting different types of corporate risks has not yet been investigated. Specifically, except for Zara and Ramkumar (2022) and Zara et al. (2023), it seems nowadays almost completely unexplored whether and how CE practices, globally

[1] Specifically, the Paris Agreement on climate change, signed in 2015, aims to limit global warming to well below 2°C above pre-industrial levels, with efforts to keep it to 1.5°C. While the Agreement is not exclusive to Europe, the EU played a pivotal role in shaping this global accord. Another crucial initiative spearheaded by the EU is the European Green Deal, unveiled in 2019. This comprehensive roadmap commits the EU to becoming climate-neutral by 2050, emphasizing transformative actions across sectors like energy, transportation, and agriculture. Additionally, the Clean Energy for All Europeans Package aims to modernize the EU's energy system, promote renewable energy sources, and enhance energy efficiency.

and individually considered, impact firm risks. Investment in CE might, in fact, alternatively represent risk reduction opportunities or greater risk exposures for companies, making them more or less vulnerable to adverse shocks. Given the acknowledged importance of CE in fostering the green transition of firms, it is essential to understand not only which corporate risks can be affected by CE initiatives but also whether all the three main dimensions of the CE (reduction, reusing, and recycling), or only some of them, are related to these risks.

Our paper tries to fill these gaps. By adopting a firm-specific perspective, characterizing corporate financial risk managers, the study examines whether firm CE practices, both globally and individually considered, impact various corporate risks, specifically downside risk, idiosyncratic risk, and default risk. Furthermore, the paper aims to investigate the interactive effects of reduction, reusing, and recycling in affecting idiosyncratic and default risks.

The paper is based on a sample of 1,069 listed European non-financial companies analyzed in the period 2010-2022. Different reasons make Europe a valuable investigation site for the study of the impact of CE initiatives on different corporate risks. First, the EU is a pioneer in enacting regulations to promote the green transition and the adoption of CE practices by both financial and non-financial companies. Second, in Europe, there are both market-oriented and intermediary-oriented financial markets, making our study interesting for providers of both equity (investors) and debt (banks) capital. Our findings show that CE practices, globally implemented, significantly reduce downside risk, idiosyncratic risk, and default risk. However, when we consider the three CE dimensions separately, only reduction and reusing decrease all these risks, while recycling does not affect them. Furthermore, we find that reduction, reusing, and recycling, when implemented pairwise, have a substitutive effect in reducing idiosyncratic and default risks. Moreover, our additional analyses show that the de-risking effect of CE practices occurs both in the short and in the medium-long term.

The paper enhances existing academic research from different points of view. First, our study is related to the growing literature on CE. So far, most papers in this area have focused on the macroeconomic implications of CE (Panchal et al., 2021), and only a few authors have investigated its microeconomic implications (Mazzucchelli et al., 2022; Palea et al., 2023), and specifically its effects on corporate risks (Zara and Ramkumar, 2022; Zara et al., 2023). We extend this literature by analyzing for the first time the simultaneous impact of CE practices on different types of corporate risks, i.e., downside risk, idiosyncratic risk, and default risk. Second, the paper enriches previous research in the field of CE by employing comprehensive and coherent measurements of CE, that consider both its global evaluation (Palea et al., 2023) and the estimation of its three main dimensions, i.e., reducing, reusing, and recycling (Mazzucchelli et al., 2022). This makes our study very interesting because, as suggested by the stakeholder view, different stakeholders, such as investors and banks, may react variously to each dimension (Xue et al., 2020). Third, our analysis is related to the literature on the relationship between firm environmental performance and corporate risk. Although it is recognized that the effects of environmental management are mainly firm-specific in nature (Xue et al., 2020), existing studies in this area have mainly tested the impacts of firm environmental outcomes from a portfolio theory perspective (Maxfield and Wang, 2021; Hornuf and Yüksel, 2023), i.e., from the investor's point of view, rather than from a company perspective, i.e., from the risk manager's point of view (Cai et al., 2016). By adopting the risk management perspective, we extend previous literature by examining how different dimensions of CE affect different firm-specific risks, i.e., idiosyncratic risk and default risk. Fourth, the paper tests the interactive impacts of reduction, reusing, and recycling on these risks. More specifically, we investigate for the first time whether the three main CE practices, when implemented pairwise, produce a complementary or substitutive effect on idiosyncratic and default risks. Finally, our analysis enriches previous research on the relationship between firm environmental performance and corporate risks, so far particularly focused on the manufacturing sector, single countries, and limited time horizons (Palea et al., 2024), by using a multi-industry sample from 15 European countries in the period 2010-2022.

The remainder of the paper is structured as follows. Section 2 presents the existing literature and the research questions. Section 3 describes the data and the research methodology. Our main results are shown and discussed in Section 4. Section 5 reports robustness checks and additional analyses, and Section 6 the conclusions.

2. Literature review and research question development

The European Commission (2015) defines the CE as a system aiming to "*ensure that the resources used by the economy are kept in use for as long as possible, extracting their maximum value, and, when their use is no longer required, recovering and regenerating products and materials at the end of their life cycle*." In line with the regulatory approach, the academic literature (Nishitani et al., 2022; Palea et al., 2023; Palea et al., 2024) recognizes the multidimensional nature of CE and identifies its three main dimensions, known as the three Rs: reduction, reusing, and recycling. Reduction means creating goods and services while minimizing the use of natural resources, i.e., raw materials. Reusing involves extending the lifespan of products rather than disposing of them at the first sign of wear and tear. Recycling is related to the management of waste to transform it into new resources.

The CE approach applies to the production, consumption, and circulation of goods both at the micro (i.e., firms and consumers) and macro (i.e., regions, nations, and geographic areas in general) levels. Nowadays, although numerous studies have demonstrated the manifold benefits of CE at the macroeconomic level (Panchal et al., 2021), the research on the economic effects of CE at the firm level appears quite poor (Demirel, 2019). More specifically, the role played by different CE strategies in affecting firm risks has been, to date, only marginally investigated (Zara and Ramkumar, 2022; Zara et al., 2023).

From a theoretical point of view, the relationship between CE and corporate risk, considered as a whole, can be explained by two main perspectives: the risk mitigation view and the overinvestment view (Meles et al., 2023). The risk mitigation view suggests that CE can decrease firm risk by maintaining good relationships with corporate stakeholders, thus reducing regulatory fines, reputational damages, and stakeholder activism. This view is consistent with various theories, specifically the stakeholder theory, the legitimacy theory, the signaling theory, and the institutional theory. The stakeholder theory (Freeman, 1984) states that enterprises must fulfill the expectations not only of their shareholders but also of their other stakeholders (including the environment), which should legitimate the firms' green choices according to the legitimacy theory (Suchman, 1995). Moreover, the signaling theory (Spence, 1973) suggests that firms adopting CE strategies may use them as a signal to stakeholders about their quality, reliability, and commitment to environmental issues. Furthermore, the institutional theory (DiMaggio and Powell, 1983) emphasizes the role of institutions (i.e., regulations and norms) in shaping organizational behavior: in this context, enterprises may adopt CE practices to conform to institutional pressures, thereby reducing risks associated with non-compliance and gaining legitimacy in institutional environments. Conversely, the overinvestment view considers firm investments in CE as a waste of scarce resources, which threatens the stability of profits, increases cash flow volatility, and, therefore, corporate risk. This approach stems from the agency theory (Jensen and Meckling, 1976), which suggests that managers may overinvest in CE for their private benefit at the expense of shareholders. The overinvest in CE practices by managers might allow them to either improve their own reputation or increase the firm's environmental rating, thus deflecting the market's attention from their sub-optimal financial equilibrium (Anwer et al., 2023). The risk mitigation view and the overinvestment view provide conflicting explanations of the relationship between CE and corporate risk. Hence, the existing theoretical research supports both the idea of a positive and a negative impact of CE practices on firm risk.

From the empirical point of view, extant studies on the linkage between CE and corporate risk are very limited and can be traced back to the broader stream of literature investigating the relationship between the environmental performance of firms and their different risks.

By adopting a portfolio theory perspective, a first strand of research focuses on the risks that equity investors cannot reduce, or can only partially reduce, through portfolio diversification. Specifically, the studies in this area investigate the impact of corporate environmental outcomes on: (i) systematic risk, also known as market risk or undiversifiable risk (Muhammad et al., 2015; Cai et al., 2016; Sassen et al., 2016; Wamba et al., 2020)[2], (ii) total risk (Bouslah et al., 2013; Muhammad et al., 2015; Cai et al., 2016; Sassen et al., 2016; Xue et al., 2020) and (iii) downside risk (Muhammad et al., 2015; Cai et al., 2016). As regards market risk, it is shown to be negatively affected by environmental performance in the USA in the period 1991-2012 (Cai et al., 2016) but this linkage is unclear in the European and Australian markets. In fact, specifically focusing on European listed companies, a negative relationship between their environmental outcomes and systematic risk is displayed by Wamba et al. (2020) from 2007 to 2015, while Sassen et al. (2016) find this relationship statistically significant from 2002 to 2014, but only in environmentally sensitive industries. Furthermore, Muhammad et al. (2014) show no association between firm environmental performance and market risk in the Australian financial market over the period 2001-2010. As regards total risk, typically measured by stock return volatility, it is shown to be inversely associated with corporate environmental outcomes in the USA from 1991 to 2012 (Cai et al., 2016). However, Bouslah et al. (2013) find that this negative relationship does not characterize all US-listed companies in the period 1991-2007, but only non-S&P500 firms. Moreover, Muhammad et al. (2014) demonstrate a negative association between environmental performance and stock return volatility of 76 listed Australian companies from 2001 to 2010. This negative linkage is confirmed also in the European financial market (Sassen et al., 2016) from 2002 to 2014, but only for environmentally sensitive industries. Furthermore, Xue et al. (2019) disaggregate the environmental outcomes of 292 UK-listed companies over the period 2002-2013 into two dimensions, namely environmental management performance and environmental operational performance. The authors find that the first dimension significantly reduces total risk, while the second does not. Finally, as regards downside risk, it displays a significant negative association with the environmental performance of listed companies both in the USA (Cai et al., 2016) and in Australia (Muhammad et al., 2015). Overall, extant studies related to this first strand of research, conducted over various time horizons and in different geographical areas, do not allow the identification of a clear impact of corporate environmental outcomes on both market and total risks. However, previous research demonstrates the existence of a negative linkage between firm environmental performance and downside risk, thus partially supporting the risk mitigation view.

[2] In these studies, systematic risk is alternatively measured by the CAPM beta and the Fama-French market factor beta.

To the best of our knowledge, so far, only Zara et al. (2023) have examined the specific impact of CE on firm risks from a portfolio theory perspective. Specifically, the authors find that the degree of circularity of 644 European listed companies in the period 2019-2020 reduces both market and total risks. However, the analysis of Zara et al. (2023) suffers from different limitations. First, the authors use a unique and no-validated measure of CE, the circularity score, which globally reflects the firm compliance with 164 CE practices but does not allow to identify the specific role played by the three main determinants of CE, i.e., reduction, reusing, and recycling. This is a relevant limitation because, according to the stakeholder theory, different stakeholders, such as investors and banks, may react variously to each CE dimension, and the company could also enact different responses according to their capability (Xue et al., 2020; Wamba et al., 2020). Moreover, Zara et al. (2023) investigate a very short time horizon (2019-2020) and limit their study to the effect of CE on market and total risks without considering the downside risk that, in our opinion, should be the more sensitive to CE practices.

We believe, in fact, it is unreasonable to expect a significant relationship between CE and systematic risk, as CE is, by its nature, essentially firm-specific (Xue et al., 2020). As this risk measures the expected increase or decrease of an individual stock price in proportion to movements of the stock market as a whole, we suppose that undiversifiable risk may only marginally show a linkage with firm CE practices. This is consistent with previous studies on corporate environmental performance, that do not identify a clear impact of corporate environmental outcomes on systematic risk (Muhammad et al., 2015; Sassen et al., 2016). Moreover, we believe that CE practices may influence total and downside risks, which incorporate both (market) systematic and (firm-specific) idiosyncratic risks. Furthermore, by adopting a risk management perspective, we suppose that CE can impact downside risk more significantly than total risk. This assumption is based on the awareness that total risk captures both downside risk, i.e., the risk concerning the extent of losses, and upside risk, i.e., the risk concerning the extent of gains. However, firm shareholders generally consider only the downside to be a risk, while they favor the upside swing (Cai et al., 2016). Hence, we expect that reducing, reusing, and recycling, considered both globally (Palea et al., 2023) and individually (Mazzucchelli et al., 2022), affect firm downside risk. However, the multi-theoretical framework above mentioned, plus the lack of direct empirical evidence on the linkage between CE and downside risk, suggest that this relationship might be both negative and positive. Investments in CE could either serve as opportunities to reduce risks or expose companies to increased risks, thereby making them more or less vulnerable to negative shocks. Based on these considerations and prior literature, we pose our first research question as follows:

Research question 1 (RQ_1): *Reducing, reusing, and recycling practices adopted by non-financial companies, both globally and individually, affect their downside risk.*

By adopting a firm-specific perspective, typical of corporate financial risk managers aiming to reduce corporate risks, a second strand of empirical research investigates the relationship between corporate environmental performance and idiosyncratic risk (Bouslah et al., 2013; Sassen et al., 2016; Xue et al., 2020; Lin et al., 2020). This risk, also known as unsystematic or diversifiable risk, is associated with residual risk that cannot be explained by changes in average market portfolio returns (Sharpe, 1964) and is related to firm-specific characteristics (Sassen et al., 2016). Strong theoretical arguments (Fama and French, 2007) support the idea that also idiosyncratic risk is priced in financial markets because of the "neglect effect", i.e., the presence of investors with tastes for assets as consumption goods. This distortion of expected returns (i.e., deviations from the asset pricing model suggesting that rational investors price only systematic risk) is wide when investors with asset tastes account for substantial invested wealth or have tastes for a large range of assets

(Bouslah et al., 2013). Focusing on a sample of US-listed non-financial companies over the period 1991-2007, Bouslah et al. (2013) find that corporate environmental performance does not affect idiosyncratic risk. However, when the authors consider only S&P500 firms, their environmental outcomes are shown to increase unsystematic risk. Moreover, using a large European dataset analyzed over the time horizon 2002-2014, Sassen et al. (2016) demonstrate that corporate environmental performance generally decreases idiosyncratic risk. This finding is consistent with the evidence by Lin et al. (2020), showing that the green innovation strategy of 132 automotive companies from developed countries investigated from 2011 to 2017 reduces diversifiable risk. Furthermore, Xue et al. (2019) focus on the UK financial market in the period 2002-2013. They consider two distinct components of environmental outcomes, i.e., environmental management performance and environmental operational performance, and show that only the first dimension significantly decreases idiosyncratic risk, while the second does not. Overall, these studies do not provide us with unequivocal evidence regarding the relationship between environmental corporate performance and idiosyncratic risk.

So far, within this second strand of empirical research, to the best of our knowledge, no author has focused on the specific impact of CE on diversifiable risk. This is surprising considering that, from a theoretical point of view, the mitigation risk view and the overinvestment view support, respectively, the idea of a negative and positive relationship between CE and idiosyncratic risk. Based on these considerations and existing literature, and in an attempt to bridge the gap in this research area, we formulate our second research question as follows:

Research question 2 (RQ_2): *Reducing, reusing, and recycling practices adopted by non-financial companies, both globally and individually, affect their idiosyncratic risk.*

A third strand of empirical literature, further adopting a firm-specific perspective, analyses the relationship between corporate environmental performance and a particular type of idiosyncratic risk, namely default risk, also known as financial distress risk, insolvency risk, or bankruptcy risk (Boubaker et al., 2020; Capasso et al., 2020; Aslan et al., 2021; Aziz et al., 2021; Habermann and Fischer, 2021; Bannier et al., 2022; Dumitrescu et al., 2020; Shahrour et al., 2021; Zara and Ramkumar, 2022; Anwer et al., 2023; Brogi et al., 2022; Kanno, 2023; Meles et al., 2023; Palmieri et al., 2023; Vivel-Búa et al., 2023). This risk has been alternatively estimated by accounting-based measures, i.e., the Altman Z-score (Altman, 1968), the O-score (Ohlson, 1980), and the ZM-score (Zmijewski, 1984), and market-based measures, i.e., the probability to default based on the model of Black and Scholes (1973) and the distance to default based on the KMV model (Merton, 1974). Some studies focus on the US financial market over different periods (Boubaker et al., 2020; Aslan et al., 2021; Aziz et al., 2021; Habermann and Fischer, 2021; Dumitrescu et al., 2020). Some of them find that the environmental performance of US-listed companies significantly reduces their default risk (Boubaker et al., 2020; Aslan et al., 2021; Aziz et al., 2021), while other papers display no significant relationship between the two variables (Habermann and Fischer, 2021; Dumitrescu et al., 2020). Using a panel dataset of Japanese-listed firms between 2017 and 2020, Kanno (2023) shows that higher environmental scores are associated with higher levels of distress risk, thus indicating that environmental-related activities contribute to the increase rather than to the decrease of firm bankruptcy risk. In contrast with this result, Anwer et al. (2023), focusing on 158 energy companies from the Asian-Pacific area in the period 2010-2021, demonstrate that their carbon performance reduces default risk. Further studies concentrate on the European financial market (Shahrour et al., 2021; Meles et al., 2023; Palmieri et al., 2023; Vivel-Búa et al., 2023). Shahrour et al. (2021) show the mitigating effect of environmental outcomes on insolvency risk of 412 non-financial companies from the Eurozone in the period 2003-2017, and find that this effect is higher during a financial crisis. Consistent with this result, Meles et al. (2023) demonstrate that green innovation is negatively related to the default risk of 351 publicly listed firms from 35 European countries between 2003 and 2019. However, Palmieri et al. (2023) analyze a sample of 211 European listed firms from 2013 to 2022 and find that improvements in corporate environmental performance have a negative impact on bankruptcy risk. However, when controlling for industry and stock index, this impact becomes positive. This is confirmed by Vivel-Búa et al. (2023), who study 990 non-financial firms in the Eurozone over the period 2004-2020. They find that environmental performance increases default risk. Other studies in this area use international datasets (Capasso et al., 2020; Bannier et al., 2022; Brogi et al., 2022;). Capasso et al. (2020) analyze 458 companies included in the Bloomberg Barclays Agg Corporate Index from 2007 to 2017 and show that corporate solvency risk is negatively associated with firm carbon footprint. This evidence is consistent with Bannier et al. (2022), who study 1,703 US- and European-listed firms from 2003 to 2018 and find that environmental performance is negatively related to default risk both in the USA and in Europe. However, Brogi et al. (2022) show no statistically significant relationship between firm environmental outcomes and insolvency risk considering 3,331 listed companies all over the world between 2000 and 2016. Overall, once again, extant empirical literature on the relationship between corporate environmental performance and default risk provides mixed results.

So far, to our knowledge, only Zara and Ramkunar (2022) have analyzed the specific impact of CE on bankruptcy risk. Specifically, the authors estimate a global proxy of corporate CE practices, the circularity score, calculated using 164 indicators on a sample of 222 European listed companies in the period 2013-2018. The authors show that the higher the firm circularity, the lower the default risk. However, this study suffers from some limitations making the results not generalizable. Specifically, Zara and Ramkunar (2022) analyze a short time horizon (2013-2018) and estimate CE through a no-validated proxy, that measures the circularity level of companies only at a global level, without considering its main determinants. Therefore, we extend previous literature by investigating both the global and the specific impact of reducing, reusing, and recycling on insolvency risk. Considering the lack of empirical evidence in this area and the related multi-theoretical framework, supporting both the idea of a negative and positive relationship between CE and bankruptcy risk, we express our third research question as follows:

Research question 3 (RQ_3): *Reducing, reusing, and recycling practices adopted by non-financial companies, both globally and individually, affect their default risk.*

As the three Rs are conceptually distinct dimensions reflecting different perspectives of firm CE (Antonioli et al., 2022), we also analyze their possible interactions. Companies may, in fact, follow reducing, reusing, and recycling practices simultaneously in the form of environmental bundles. In this context, the level of a particular CE dimension is ideally dependent on the levels of other CE dimensions simultaneously in place at the firm level. Hence, we analyze the possible interactive effects of reducing, reusing, and recycling practices on idiosyncratic risk and default risk. We focus on firm-specific risks as the paper adopts a risk management perspective. Therefore, the study of the possible interactive effects of the three Rs on firm risks provides the companies with useful evidence in order to choose the better CE practices to implement. On the one hand, the adoption of one dimension could strengthen another, and therefore the three Rs might work jointly to affect idiosyncratic and default risks. On the other hand, different CE practices may act as substitutes if one dimension replaces another to affect these risks. Based on these issues, and considering the lack of specific empirical literature in this area, we formulate our fourth research question as follows:

Research question 4 (RQ_4): *Reducing, reusing, and recycling practices adopted by non-financial companies interactively affect their idiosyncratic and default risks.*

3. Data and Methods

3.1 Sample selection

Our data are collected from different sources: Thomson Reuters ASSET4, Refinitiv Eikon, World Bank, and Bloomberg databases. First, we identified in Thomson Reuters ASSET4 the 2,427 companies included in the Refinitiv ESG Europe Index in 2020. This index consists of European-listed companies adopting environmental, social, and governance (ESG) practices and providing information on ESG issues. Then we retrieved, over the period 2010-2022, company environmental data from Thomson Reuters ASSET4, firm economic and financial information from Refinitiv Eikon and Bloomberg, and macro-economic data from the World Bank database. At this stage, we collected 31,551 company-year observations from 2,427 financial and non-financial companies listed on the European financial market. After that, we removed from the initial sample the observations related to missing environmental and economic data, financial companies, and European firms not included in the UE-27. The final sample consists of an unbalanced panel dataset containing 6,888 firm-year observations for 1,069 non-financial companies from 15 EU countries. Tables 1 and 2 present, respectively, the composition of the sample by country and industry over the investigated period.

Table 1: Composition of the sample by country and year

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total	%
Austria	10	9	10	9	8	11	10	11	20	24	26	24	23	195	2.8
Belgium	11	11	12	13	10	11	16	15	31	31	32	25	23	241	3.5
Denmark	17	18	18	18	19	19	21	24	34	40	50	51	48	377	5.5
Finland	20	19	20	20	20	21	22	23	30	37	74	62	57	425	6.2
France	66	65	66	66	67	68	72	73	121	124	147	125	82	1,142	16.6
Germany	54	56	57	58	61	64	70	78	134	151	218	158	144	1,303	18.9
Greece	10	9	9	10	10	11	11	12	19	19	19	8	4	151	2.2
Ireland	9	9	11	11	11	11	11	11	15	17	16	15	17	164	2.4
Italy	18	18	19	18	16	17	20	30	60	62	96	65	65	504	7.3
Luxembourg	2	3	3	3	4	5	5	4	7	8	10	4	8	66	1.0
Netherlands	17	18	20	19	19	20	23	22	41	42	47	40	34	362	5.3
Poland	11	13	15	14	17	15	17	19	27	26	24	15	10	223	3.2
Portugal	6	4	6	5	4	5	6	5	13	13	12	5	7	91	1.3
Spain	24	28	29	29	29	30	30	33	51	53	52	40	25	453	6.6
Sweden	29	29	30	30	32	40	41	42	95	132	246	225	220	1,191	17.3
Total	304	309	325	323	327	348	375	402	698	779	1,069	862	767	6,888	100

This table reports the sample distribution by country for the whole sample period (2010-2022).

Table 2: Composition of the sample by industry and year

Industry group	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total	%
Aerospace*	1	1	1	1	1	4	4	5	7	9	11	10	10	65	0.9
Apparel*	2	4	4	5	5	5	6	5	9	9	12	10	10	86	1.2
Automotive*	9	9	9	9	11	11	11	12	22	24	27	21	20	195	2.8
Beverages*	4	5	5	5	5	5	5	6	6	7	8	8	7	76	1.1
Chemicals*	19	20	19	21	21	22	23	23	35	35	44	34	34	350	5.1
Construction*	28	29	29	28	28	28	28	25	56	60	75	60	50	524	7.6
Diversified	18	18	18	19	19	19	19	19	23	24	26	23	20	265	3.8
Drugs, Cosmetics & Health Care*	13	14	14	14	16	18	19	22	49	56	85	68	68	456	6.6
Electrical*	10	10	10	9	10	10	12	13	20	24	34	29	27	218	3.2
Electronics*	20	20	20	21	22	24	24	30	52	62	123	109	100	627	9.1
Food*	7	7	8	8	8	8	8	8	16	20	27	24	20	169	2.5
Machinery & Equipment*	15	16	17	17	17	21	23	30	54	58	79	65	47	459	6.7
Metal Producers*	11	12	12	12	11	11	12	12	17	16	18	14	12	170	2.5
Metal Product Manufacturers*	8	9	9	9	8	8	9	8	15	16	21	13	15	148	2.1
Miscellaneous	37	39	42	44	46	50	55	64	138	158	237	181	164	1,255	18.2
Oil, Gas, Coal & Related Services	14	16	16	17	17	16	16	17	23	25	28	21	13	239	3.5
Paper*	8	9	10	10	10	10	10	12	16	20	21	16	16	168	2.4
Printing & Publishing*	4	4	4	4	4	4	4	4	5	6	8	7	5	63	0.9
Recreation	10	10	10	11	10	10	12	10	23	29	36	30	29	230	3.3
Retailers	15	16	16	16	17	17	20	21	27	30	38	33	32	298	4.3
Textiles*	1	1	1	1	1	1	1	1	3	4	8	8	7	38	0.6
Tobacco*	1	0	0	0	0	1	0	0	1	1	1	1	1	7	0.1
Transportation	13	13	13	12	12	11	12	15	19	20	26	19	15	200	2.9
Utilities	36	27	38	30	28	34	42	40	62	66	76	58	45	582	8.4
Total	304	309	325	323	327	348	375	402	698	779	1,069	862	767	6,888	100

This table reports the sample distribution by industry for the whole sample period (2010-2022). The asterisk indicates the sectors that can be included in the manufacturing macro-group.

The most represented countries within the dataset are France, Germany, and Sweden, which together account for approximately 53% of the overall sample, as reported in Table 1. This Table shows that the number of companies included in our research sample increased from 2010 to 2020, while decreased in 2021 and 2022. This can be explained by the Covid-19 pandemic, which forced many listed firms into delisting (Al Amosh and Khatib, 2023). Moreover, Table 2 shows that the sample consists of firms from 24 different industries, 17 of which belong to the manufacturing macro-sector.

3.2 Measurement

In our empirical analyses, we estimate three different company risks: downside risk (DSR), idiosyncratic risk (IDIO), and default risk (PD). As previous literature shows that environmental practices provide benefits for firms, in terms of improvements in their economic and financial performance (Nguyen et al., 2020) and risk reduction (Bannier et al., 2022; Zara and Ramkunar, 2022), more in the long than in the short time horizon, we measure downside, idiosyncratic and default risk over a five-year period (Bannier et al., 2022; Zara and Ramkunar, 2022; Palmieri et al., 2023). In detail, we estimate company downside risk by the standard deviation of negative daily stock returns (Muhammad et al., 2015; Cai et al., 2016) and idiosyncratic risk by the standard deviation of residuals from the CAPM (Bouslah et al., 2013; Sassen et al., 2016; Xue et al., 2020; Lin et al., 2020). Specifically, we use the CAPM five-factor model (Fama and French, 2015) based on daily stock returns for the past five years[3]. Furthermore, we measure default risk by the five-year-ahead Bloomberg probability of default. We chose this market-based measure as it directly produces a default probability, while the accounting measures (i.e., the Altman Z-score, the O-score, and the ZM-score) produce a score, that is a less immediate proxy of insolvency risk (Anwer et al., 2023). Specifically, Bloomberg's corporate default risk model adopts a hybrid approach by fitting a structural model, applied to estimate the distance to default and considering differences not only between financial and non-financial companies but also within different regions and sectors, with a statistical method. This hybrid approach allows the direct calculation of term structures of real-world default probabilities through logistic regressions, recalculated daily. Considering the characteristics of our dataset, which consists of non-financial companies from different countries and industries, Bloomberg's probability of default results therefore the most appropriate measure of insolvency risk.

Furthermore, we calculate four independent variables related to corporate CE practices: a) reducing (RED), b) reusing (REU), c) recycling (RECY), and d) the circular economy score (CES), i.e., a global measure of firm circularity estimated as the sum of reducing, reusing and recycling. The circular economy score (CES) is a validated proxy of CE, as it is constructed considering the eight CE indicators tested by Palea et al. (2023). Specifically, these authors, by adopting the stringent definition of CE proposed by Nobre and Tavares (2021)[4], identify in the Thomson Reuters ASSET4 database the following eight environmental indicators strictly related to the CE approach: (i) e-waste reduction, (ii) waste reduction, (iii) resource reduction, (iv) renewable energy use, (v) water efficiency, (vi) energy efficiency, (vii) take-back and recycling and (viii) eco-design products. The indicators take value 1 if the firm adopts each CE practice, and 0 otherwise. Therefore, our circular economy score (CES) ranges from 0 (lowest level of circularity) to 8 (highest value of circularity). Moreover, we extend the analysis of Palea et al. (2023) by further aggregating the previous CE indicators into the three main CE dimensions: a) reducing (RED), a variable ranging from 0 to 3, as obtained by adding indicators (i), (ii) and (iii); b) reusing (REU), a variable ranging from 0 to 3, as obtained by adding indicators (iv), (v) and (vi); and c) recycling (RECY), a variable ranging from 0 to 2, as obtained by adding indicators (vii) and (viii). Table 3 reports the definitions of the eight indicators described above.

Table 3: CE indicator definitions

CE indicators	Description	CE dimensions
(i) E-waste reduction	A dummy variable that equals 1 if the company reports on initiatives to recycle, reduce, reuse, substitute, treat, or phase out any type of e-waste, 0 otherwise	REDUCING
(ii) Waste reduction	A dummy variable that equals 1 if the company reports on initiatives to recycle, reduce, reuse, substitute, treat, or phase out any type of waste, 0 otherwise	REDUCING

[3] The 5 factors have been retrieved from Professor French's website at: https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

[4] Nobre and Tavares (2021) describe CE as "*an economic system that targets zero waste and pollution through an efficient use and consumption of resources, materials that at their end-of-life return to either an industrial process or safely back to the environment, and the employment of renewable energy sources*."

(iii) Resource reduction	A dummy variable that equals 1 if the company sets specific objectives to be achieved on resource efficiency or comments on the results of the previously set objectives, 0 otherwise	REDUCING
(iv) Renewable energy use	A dummy variable that equals 1 if the company makes use of renewable energy, 0 otherwise	REUSING
(v) Water efficiency	A dummy variable that equals 1 if the company has a policy to improve its water efficiency, 0 otherwise	REUSING
(vi) Energy efficiency	A dummy variable that equals 1 if the company has a policy to improve its energy efficiency, 0 otherwise	REUSING
(vii) Take-back and recycling	A dummy variable that equals 1 if the company reports about take-back procedures and recycling programs to reduce the potential risks of products entering the environment, 0 otherwise	RECYCLING
(viii) Eco-design products	A dummy variable that equals 1 if the company reports on specific products that are designed for reuse, recycling, or the reduction of environmental impacts, 0 otherwise	RECYCLING

This table reports the definitions of the indicators constituting the circular economy score.

Following previous literature (Muhammad et al., 2015; Xue et al., 2020; Zara and Ramkunar, 2022; Zara et al., 2023), we also consider a set of control variables that may impact firm risks. First, we select some firm-specific control variables, extracted from the Refinitiv Eikon database, and including: (i) size (SIZE), measured by the natural logarithm of the total assets; (ii) profitability, proxied by both an accounting measure, the return on equity (ROE), and a market-based measure, the dividend yield (DY), calculated as dividend per share divided by the price per share; (iii) leverage (LEV), estimated by total liabilities to total assets; (iv) growth opportunities, proxied by the market to book value (MTBV), measured as the stock market capitalization divided by the total equity; (v) liquidity, proxied by the current ratio (CR), measured as current assets divided by current liabilities; and (vi) environmental management training (EMT), a dummy variable that equals 1 if the firm trains its employees on environmental issues, 0 otherwise. The analyses include firm size since larger companies tend to have lower risks, as they benefit from diversification in multiple markets, greater access to financial resources, strong brand recognition, and operational efficiency due to economies of scale (Muhammad et al., 2015; Xue et al., 2020; Zara and Ramkunar, 2022; Zara et al., 2023). Considering that higher firm profitability (Muhammad et al., 2015; Xue et al., 2020; Zara and Ramkunar, 2022; Zara et al., 2023) and growth forecasts (Muhammad et al., 2015; Xue et al., 2020; Zara et al., 2023) often decrease risks of non-financial companies, profitability and growth opportunities are also taken into account. Additionally, leverage and liquidity are included in our analyses, as firms with lower debt (Muhammad et al., 2015; Xue et al., 2020; Zara et al., 2023) and greater cash flow (Muhammad et al., 2015; Zara and Ramkunar, 2022) typically show lower risks. Furthermore, we consider an environmental control variable as a greater environmental engagement may decrease firm risks (Muhammad et al., 2015; Xue et al., 2020). Following previous studies, the control variables based on financial data (SIZE, ROE, DY, LEV, MTBV, and CR) are winsorized at 1% of each tail. Furthermore, the GDP growth rate (GDP), estimated as the annual percentage growth rate of GDP per capita based on constant local currencies and retrieved by the World Bank database, is included as a country control variable. Since the effect at the firm level of adopting CE practices is not immediate, we lagged both independent and control variables, as suggested by previous literature (Palea et al., 2023). This also allows to limit endogeneity/reverse causality concerns (Muhammad et al., 2015; Xue et al., 2020). Table A1 in the Appendix reports all the research variables described above.

3.3 Research methodology

In order to test the research questions 1 (RQ_1), 2 (RQ_2), and 3 (RQ_3), we run some regressions on panel data applying year and sector (industry group) fixed effects, as suggested by previous literature (Palmieri et al., 2023; Anwer et al., 2023). Specifically, we develop Model 1 (1):

$$Y_{i,t} = \alpha_i + \beta_1 X_{i,t-1} + \sum_i^n \beta_2 FIRM\_CONTR_{i,t-1} + \beta_3 GDP_{i,t-1} + \varepsilon_{i,t} \quad (1)$$

where $Y_{i,t}$ is firm risk at time *t*, alternatively measured by downside risk (DSR), idiosyncratic risk (IDIO), and default risk (PD), X_{t-1} are the firm CE practices at time *t*-1, alternatively estimated by the global circular economy score (CES), reducing (RED), reusing (REU), and recycling (RECY), $FIRM\_CONTR_{t-1}$ is a vector considering the firm characteristics at time *t*-1 described in Section 3.2 and used as control variables, and GDP_{t-1} is the annual percentage growth rate of Gross Domestic Product at the country-level at time *t*-1. Moreover, in order to test our fourth research question (RQ_4), we run further panel data regressions using year and sector (industry group) fixed effects. Specifically, we add to Model 1 the interactions between different CE practices adopted pairwise, as shown in Model 2 (2):

$$Y_{i,t} = \alpha_i + \beta_1 X_{i,t-1} + \beta_2 INTER_{i,t-1} + \sum_i^n \beta_2 FIRM\_CONTR_{i,t-1} + \beta_3 GDP_{i,t-1} + \varepsilon_{i,t} \quad (2)$$

where $INTER_{t-1}$ are, alternatively, the pairwise interactions between reducing (RED), reusing (REU), and recycling (RECY) at time *t*-1. In both Models 1 and 2 robust standard errors are clustered at the firm level in order to consider the serial correlation of the dependent variables for each company.

4. Empirical results and discussion

4.1 Descriptive statistics

Table 4 presents our descriptive statistics, while Table 5 reports the evolution over time of the dependent (downside risk, idiosyncratic risk, and default risk) and independent (circular economy score, reducing, reusing, and recycling) variables.

The mean (and the standard deviation) values of downside, idiosyncratic, and default risks are 0.021 (0.015), 0.022 (0.018), and 0.030 (0.038), respectively (Table 4). This suggests that listed European non-financial companies involved in ESG practices between 2010 and 2022 show quite stable total and firm-specific risks, as confirmed by their evolution over time reported in Table 5. Focusing on the CE variables, circular economy score, reducing, reusing, and recycling show, respectively, mean (standard deviation) values of 4.372 (1.927), 1.913 (0.806), 2.077 (1.046), and 0.382 (0.628) (Table 4). As reducing and reusing ranges from 0 to 3, while recycling from 0 to 2, this evidence suggests that, among the three Rs, recycling is the least implemented. This is reasonable if we consider that, according to the hierarchy of the three Rs (European Commission, 2015), waste and resources must initially be reduced, and if this is not possible, they should be firstly reused and secondly recycled. Furthermore, the evolution over time of our independent variables (Table 5 and Figure 1) shows that European-listed firms applying ESG strategies implemented CE practices quite steadily from 2010 to 2017. However, from 2018 to 2020, they reduced their involvement in CE activities, which has further increased since 2021. This mainly concerns reducing and reusing practices. These findings, consistent with data reported by the European Court of Auditors (2023) and the European Environment Agency[5] (2023), suggest that "*there is only limited evidence that the Circular Economy Action Plans published in 2015, and in particular the actions regarding the circular design of products and of production processes, had influenced circular-economy activities in the member states*" (European Court of Auditors, 2023, p. 4.). The hope is that the New Circular Economy Action Plan published in 2020 will yield better results.

Table 4: Descriptive statistics

Variable	N. Obs	Mean	Standard Deviation	Minimum	Maximum
DSR	6,888	0.021	0.015	0.007	0.123
IDIO	6,888	0.022	0.018	0.004	0.372
PD	6,888	0.030	0.038	0.000	0.364
CES	6,888	4.372	1.927	0.000	8.000
RED	6,888	1.913	0.806	0.000	3.000
REU	6,888	2.077	1.046	0.000	3.000
RECY	6,888	0.382	0.628	0.000	2.000
SIZE	6,888	15.358	1.791	10.216	19.269
ROE	6,888	8.476	24.794	-231.630	89.290
DY	6,888	2.248	2.305	0.000	15.150
LEV	6,888	25.494	15.672	0.000	86.880
MTB	6,888	3.164	3.660	-8.490	33.320
CR	6,888	1.741	1.560	0.310	19.690
EMT	6,888	0.610	0.488	0.000	1.000
GDP	6,888	1.324	3.559	-11.325	24.370

The table reports summary statistics (mean, standard deviation, minimum, and maximum). The variables are defined in Table A1 in the Appendix. The sample contains 6,888 firm-year observations about European-listed non-financial companies between 2010 and 2022. The financial variables are winsorized at 1 and 99 percentiles.

Table 5: Mean values of dependent and independent variables over time

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
DSR	0.025	0.024	0.022	0.019	0.018	0.018	0.018	0.018	0.019	0.019	0.021	0.022	0.024
IDIO	0.019	0.020	0.019	0.016	0.019	0.019	0.020	0.015	0.020	0.020	0.028	0.023	0.028
PD	0.023	0.044	0.030	0.020	0.025	0.028	0.024	0.014	0.029	0.022	0.044	0.024	0.041
CES	4.237	4.333	4.520	4.440	4.437	4.537	4.595	4.654	4.262	4.436	4.101	4.271	4.511
RED	1.865	1.877	1.954	1.910	1.884	1.940	1.960	2.000	1.898	1.963	1.833	1.891	1.960
REU	1.931	2.023	2.114	2.115	2.150	2.195	2.227	2.269	2.040	2.109	1.937	2.010	2.140
REC	0.441	0.434	0.452	0.415	0.404	0.402	0.408	0.386	0.324	0.365	0.331	0.370	0.412

This table reports the distribution of the mean values of dependent (DSR, IDIO, PD) and independent variables (CES, RED, REU, RECY). The variables are defined in Table A1 in the Appendix. The sample contains 6,888 firm-year observations about European-listed non-financial companies between 2010 and 2022. The financial variables are winsorized at 1 and 99 percentiles.

[5] The European Environment Agency reports data on the website: https://www.eea.europa.eu/en/analysis/indicators.

Figure 1: The evolution of the three Rs over time

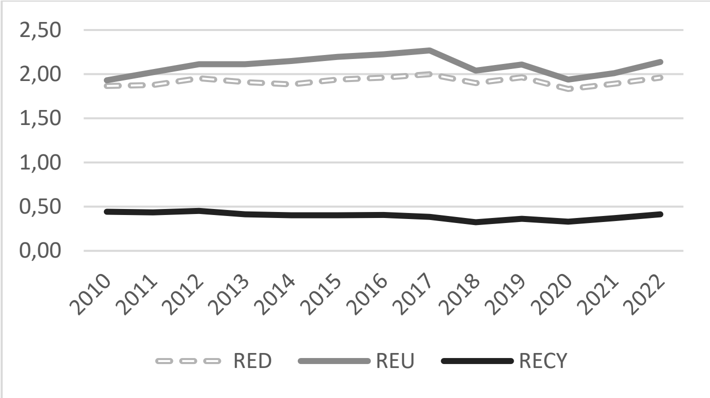


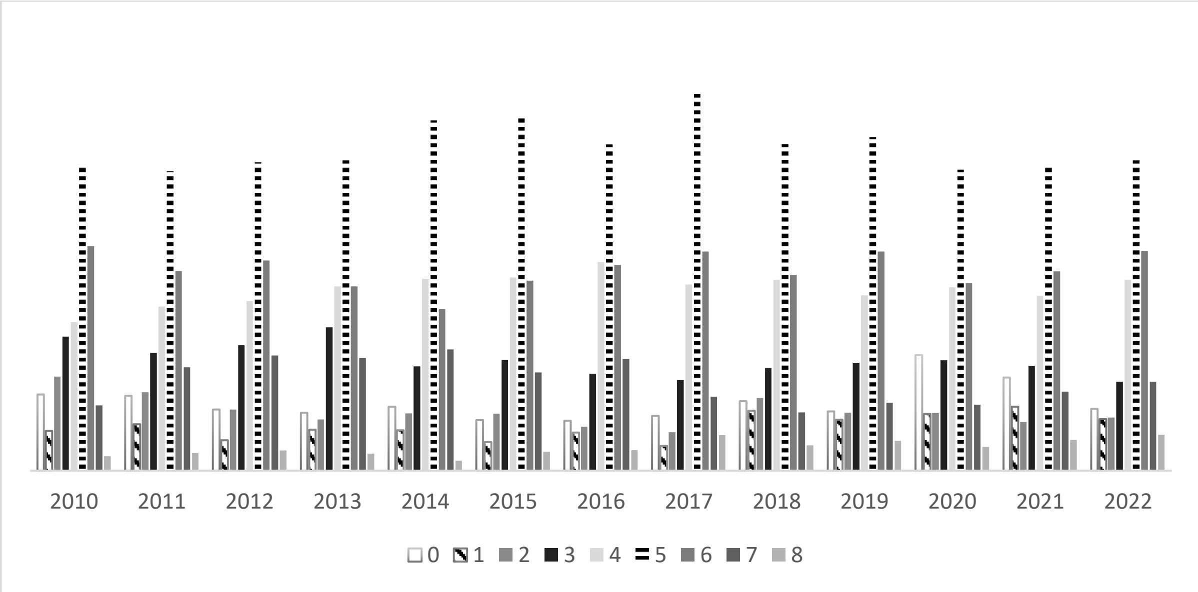
Table 6 details the number (from 1 to 8) of CE practices adopted by companies from 2010 to 2022. The involvement of firms in CE activities appears to be quite substantial. The companies adopting 5 and 6 practices are, in fact, 2,006 and 1,262, respectively, which together represent 47% of the sample. This dynamic is also stable over time, as shown in Figure 2.

Table 6: Number of CE practices adopted over time

Score	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
Circular economy score (CER)														
0	21	21	18	17	19	16	17	20	44	42	112	73	43	463
1	11	13	9	12	12	9	13	9	38	36	55	50	36	303
2	26	22	18	15	17	18	15	14	46	41	56	38	37	363
3	37	33	37	42	31	35	33	33	65	76	107	82	62	673
4	41	46	50	54	57	61	71	68	121	124	178	137	133	1,141
5	84	84	91	91	104	112	111	138	207	236	292	240	216	2,006
6	62	56	62	54	48	60	70	80	124	155	182	156	153	1,262
7	18	29	34	33	36	31	38	27	37	48	64	62	62	519
8	4	5	6	5	3	6	7	13	16	21	23	24	25	158
Total	304	309	325	323	327	348	375	402	698	779	1,069	862	767	6,888
Reducing (RED)														
0	23	23	19	19	22	16	20	21	48	48	121	82	49	511
1	49	56	52	56	55	58	58	50	119	103	146	119	108	1,029
2	178	166	179	183	189	205	214	239	387	458	593	472	435	3,898
3	54	64	75	65	61	69	83	92	144	170	209	189	175	1,450
Total	304	309	325	323	327	348	375	402	698	779	1,069	862	767	6,888
Reusing (REU)														
0	46	47	39	38	34	31	31	34	93	85	180	129	89	876
1	54	40	41	41	39	38	39	36	98	112	158	110	87	893
2	79	81	89	90	98	111	119	120	195	215	280	246	219	1,942
3	125	141	156	154	156	168	186	212	312	367	451	377	372	3,177
Total	304	309	325	323	327	348	375	402	698	779	1069	862	767	6,888
Recycling (RECY)														
0	202	208	212	219	226	242	257	280	512	548	780	603	518	4,807
1	70	68	79	74	70	72	83	89	146	178	224	199	182	1,534
2	32	33	34	30	31	34	35	33	40	53	65	60	67	547
Total	304	309	325	323	327	348	375	402	698	779	1069	862	767	6,888

The table shows the independent variables (CER, RED, REU, RECY) disaggregated in their constituents from 2010 to 2022.

Figure 2: The circular economy score disaggregated over time



We also calculate the correlation matrix and the variance inflation factor (VIF) value in order to detect any potential multicollinearity problem (Table 7). As no correlation coefficients exceed the threshold value of 0.60, no serious potential multicollinearity issues emerge in the analyses. This is confirmed by the VIF values, which are all between 1.04 and 1.51, therefore significantly above the threshold level of 10.

Table 7: Correlation matrix and VIF test

Variable	VIF	DSR	IDIO	PD	CES	RED	REU	RECY	SIZE	ROE	DY	LEV	MTBV	CR	EMT	GDP
DSR	-	1														
IDIO	-	0.497*	1													
PD	-	0.204*	0.401*	1												
CES	1.51	-0.137*	-0.204*	-0.111*	1											
RED	1.26	-0.113*	-0.161*	-0.104*	0.815*	1										
REU	1.44	-0.145*	-0.209*	-0.096*	0.867*	0.573*	1									
RECY	1.12	-0.033*	-0.072*	-0.047*	0.577*	0.263*	0.260*	1								
SIZE	1.39	-0.119*	-0.266*	-0.157*	0.454*	0.281*	0.434*	0.309*	1							
ROE	1.44	-0.104*	-0.231*	-0.513*	0.144*	0.134*	0.135*	0.046*	0.173*	1						
DY	1.14	-0.170*	-0.185*	-0.097*	0.183*	0.160*	0.177*	0.063*	0.248*	0.163*	1					
LEV	1.12	-0.075*	-0.037*	0.241*	0.150*	0.128*	0.166*	0.019	0.159*	-0.126*	0.069*	1				
MTBV	1.16	0.129*	0.107*	-0.128*	-0.152*	-0.124*	-0.144*	-0.065*	-0.204*	0.109*	-0.165*	-0.093*	1			
CR	1.14	0.068*	0.129*	-0.019	-0.263*	-0.231*	-0.250*	-0.093*	-0.286*	-0.110*	-0.150*	-0.314*	0.113*	1		
EMT	1.24	-0.072*	-0.151*	-0.060*	0.488*	0.406*	0.461*	0.209*	0.369*	0.092*	0.166*	0.131*	-0.166*	-0.218*	1	
GDP	1.04	0.015	-0.074*	-0.161*	-0.01	-0.023	-0.012	0.016	0.093*	0.090*	0.009	-0.067*	0.041*	-0.001	-0.030*	1

This table provides the correlation matrix for our dependent, independent, and control variables and the VIF test for multicollinearity. * Significant at 5% level. The variables are defined in Table A1 in the Appendix.

4.2 Baseline results

The paper analyses the effects of reducing, reusing, and recycling practices, both globally and individually considered (Model 1), on firm risks. Table 8 reports the results.

The circular economy score shows a negative relationship with downside risk (Table 7(A)). This is consistent with previous evidence on the linkage between firm environmental outcomes and this risk (Muhammad et al., 2015; Cai et al., 2016). Therefore, we demonstrate that corporate CE practices, globally implemented, significantly mitigate downside risk. Furthermore, the circular economy score displays a negative impact on idiosyncratic (Table 7(B)). This innovative result somehow supports previous findings proving a mitigating effect of firm environmental performance on diversifiable risk (Sassen et al., 2016; Lin et al., 2020). Moreover, the coefficient of the circular economy score in Table 7(C) is negative and statistically significant. This means that also insolvency risk is reduced when CE practices are implemented jointly, thus extending previous findings by Zara and Ramkunar (2022).

By considering the three Rs individually, reducing and reusing show a negative relationship with all the investigated risks, i.e., downside (Table 7(A)), idiosyncratic (Table 7(B)), and default (Table 7(C)) risks. However, recycling does not display any de-risking effect (Table 7(A-B-C)). Therefore, we demonstrate that reducing and reusing practices mitigate the downside, the idiosyncratic and the insolvency risks of non-financial companies, while recycling does not.

Some firm-specific characteristics are included in the Models as control variables. Size and profitability have a negative and significant effect on all the investigated risks, as suggested by previous literature (Xue et al., 2020; Zara et al., 2023). This evidence suggests that larger and more profitable non-financial companies are characterized by lower risks. Leverage displays instead a negative relationship with the downside risk, as suggested by Muhammad et al. (2015), but a positive linkage with the default risk, as shown by Li et al. (2022) and Meles et al. (2023). This means that firm indebtedness increases insolvency risk of firms but reduces their downside risk. Moreover, on the one hand, the higher the firm growth opportunities, the higher the downside and idiosyncratic risks, consistent with Muhammad et al. (2015) and Sassen et al. (2016). On the other hand, the higher the firm growth opportunities, the lower the default risk. This evidence suggests that growth opportunities increase total and unsystematic risks but mitigate the insolvency risk. Furthermore, company liquidity and country GDP reduce default risk, as shown by Vivel-Búa et al. (2023).

The results shown in Table 7 allow us to answer our research questions 1, 2, and 3. Our evidence demonstrates that reducing, reusing, and recycling practices, globally implemented, decrease the downside risk whereas, when they are individually considered, only reducing and reusing mitigate this risk (RQ_1). The same occurs for the other firm-specific risks. The three Rs, jointly, have a de-risking effect on idiosyncratic risk but, individually applied, only reducing and reusing activities decrease the unsystematic risk (RQ_2). The default risk is also lowered by reducing, reusing, and recycling practices globally implemented whereas, when they are individually considered, only reducing and reusing mitigate this risk (RQ_3).

Table 8: The relationship between CE and downside, idiosyncratic, and default risks

	Panel A: Downside risk				*Panel B: Idiosyncratic risk*				*Panel C: Default risk*			
Variables	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
CE_{t-1}	-0.000785***				-0.000973***				-0.00140***			
	(0.000116)				(0.000146)				(0.000299)			
RED_{t-1}		-0.00107***				-0.00154***				-0.00290***		
		(0.000257)				(0.000338)				(0.000613)		
REU_{t-1}			-0.00149***				-0.00190***				-0.00193***	
			(0.000226)				(0.000254)				(0.000570)	
$RECY_{t-1}$				-0.000647				-0.000318				-0.00122
				(0.000319)				(0.000376)				(0.000721)
$SIZE_{t-1}$	-9.78e-05	-0.000312**	-0.000108	-0.000296**	-0.00114***	-0.00140***	-0.00115***	-0.00145***	-0.00175***	-0.00208***	-0.00190***	-0.00210***
	(0.000142)	(0.000137)	(0.000142)	(0.000144)	(0.000206)	(0.000201)	(0.000206)	(0.000204)	(0.000302)	(0.000294)	(0.000301)	(0.000305)
ROE_{t-1}	-5.53e-05***	-5.54e-05***	-5.53e-05***	-5.96e-05***	-0.000120***	-0.000119***	-0.000120***	-0.000125***	-0.000583***	-0.000580***	-0.000585***	-0.000591***
	(1.09e-05)	(1.10e-05)	(1.09e-05)	(1.11e-05)	(1.84e-05)	(1.84e-05)	(1.83e-05)	(1.85e-05)	(4.22e-05)	(4.21e-05)	(4.24e-05)	(4.26e-05)
DY_{t-1}	-0.000835***	-0.000849***	-0.000837***	-0.000863***	-0.000675***	-0.000689***	-0.000677***	-0.000712***	-0.000660**	-0.000669***	-0.000677***	-0.000710***
	(8.20e-05)	(8.27e-05)	(8.20e-05)	(8.26e-05)	(9.55e-05)	(9.63e-05)	(9.57e-05)	(9.76e-05)	(0.000259)	(0.000259)	(0.000260)	(0.000260)
LEV_{t-1}	-4.07e-05***	-4.18e-05***	-3.88e-05***	-4.39e-05***	3.42e-06	2.25e-06	5.93e-06	-7.28e-08	0.000423***	0.000423***	0.000425***	0.000418***
	(1.37e-05)	(1.38e-05)	(1.37e-05)	(1.38e-05)	(1.69e-05)	(1.69e-05)	(1.67e-05)	(1.70e-05)	(3.39e-05)	(3.39e-05)	(3.39e-05)	(3.39e-05)
$MTBV_{t-1}$	0.000553***	0.000555***	0.000562***	0.000564***	0.000300***	0.000301***	0.000311***	0.000316***	-0.000627***	-0.000633***	-0.000608***	-0.000607***
	(8.93e-05)	(8.95e-05)	(8.96e-05)	(8.98e-05)	(0.000104)	(0.000104)	(0.000103)	(0.000104)	(0.000180)	(0.000180)	(0.000180)	(0.000180)
CR_{t-1}	-0.000124	-8.53e-05	-0.000119	-2.77e-05	-0.000102	-6.67e-05	-0.000101	1.92e-05	-0.00104***	-0.00102***	-0.000982***	-0.000865***
	(0.000117)	(0.000117)	(0.000117)	(0.000117)	(0.000153)	(0.000152)	(0.000153)	(0.000150)	(0.000307)	(0.000308)	(0.000306)	(0.000304)
EMT_{t-1}	0.00111**	0.000624	0.00106**	0.000123	0.000424	-6.03e-05	0.000410	-0.000856	0.000607	0.000291	3.46e-05	-0.00113
	(0.000473)	(0.000460)	(0.000481)	(0.000457)	(0.000538)	(0.000534)	(0.000553)	(0.000559)	(0.00106)	(0.00101)	(0.00107)	(0.000999)
GDP_{t-1}	-1.96e-06	1.64e-05	-5.88e-06	4.06e-05	0.000278	0.000296	0.000271	0.000331	-0.000580***	-0.000570***	-0.000564***	-0.000504**
	(0.000103)	(0.000103)	(0.000103)	(0.000103)	(0.000331)	(0.000331)	(0.000330)	(0.000330)	(0.000207)	(0.000208)	(0.000207)	(0.000207)
Constant	0.0289***	0.0313***	0.0284***	0.0301***	0.0445***	0.0476***	0.0439***	0.0466***	0.0873***	0.0920***	0.0877***	0.0893***
	(0.00304)	(0.00305)	(0.00304)	(0.00312)	(0.00355)	(0.00360)	(0.00354)	(0.00365)	(0.00682)	(0.00684)	(0.00684)	(0.00689)
Observations	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533
R-squared	0.108	0.105	0.109	0.102	0.156	0.153	0.158	0.149	0.290	0.289	0.288	0.287
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

This table shows the estimates of the panel data fixed effect for the period 2010-2022. The dependent variables are downside risk (Panel A), idiosyncratic risk (Panel B), and default risk (Panel C). The independent variables are the circular economy score (CES), reducing (RED), reusing (REU), and recycling (RECY). All the variables are defined in Table A1 in the Appendix. Time- and industry-fixed effects are included. The control variables based on accounting data are winsorized at the 1% of each tail. Firms clustered standard errors (SE) are reported in parentheses. *** $p<0.01$, ** $p<0.05$.

Furthermore, in order to answer our fourth research question (RQ_4), we investigate whether and how different CE dimensions act as complements or substitutes in affecting firm idiosyncratic and default risks. Table 8 reports our results. They show that when reducing, reusing, and recycling are implemented pairwise, one of the two CE dimensions loses its negative influence on both unsystematic (Table 8(A)) and insolvency (Table 8(B)) risks. The only exception is the joint implementation of reducing and reusing (Table 8(A,1)), where these variables both maintain their negative impact on idiosyncratic risk. None of the coefficients of interacted variables reported in Table 8 are statistically significant. Overall, this evidence indicates that reducing, reusing, and recycling practices, when implemented pairwise, have a substitutive effect in reducing firm-specific risks (RQ_4).

Moreover, Table 8 suggests the existence of a hierarchy among the three Rs. Reducing, when implemented together with reusing or recycling, always maintains its explanatory power of the dependent variables. The same occurs with reusing when applied jointly with recycling, which, instead, always shows no statistically significant coefficient. This indicates that when the three CE dimensions are adopted pairwise, reducing is more effective than reusing and recycling in mitigating idiosyncratic and default risks, and, in turn, reusing is more effective than recycling.

Table 9: The interactive effect of the three Rs on firm-specific risks

	Panel A: Idiosyncratic risk			*Panel B: Default risk*		
Variables	(1)	(2)	(3)	(1)	(2)	(3)
RED_{t-1}	-0.00128**	-0.00146***		-0.00255**	-0.00276***	
	(0.000614)	(0.000373)		(0.00116)	(0.000687)	
REU_{t-1}	-0.00238***		-0.00176***	-0.00129		-0.00193***
	(0.000603)		(0.000261)	(0.00119)		(0.000609)
$RECY_{t-1}$		0.000866	0.00174		7.20e-05	-0.00167
		(0.00175)	(0.00204)		(0.00237)	(0.00239)
RED_{t-1}#$RECY_{t-1}$		-0.000380			-0.000301	
		(0.000687)			(0.000955)	
$RECY_{t-1}$#REU_{t-1}			-0.000702			0.000322
			(0.000747)			(0.000896)
RED_{t-1}#REU_{t-1}	0.000433			0.000143		
	(0.000294)			(0.000569)		
Constant	0.0453***	0.0475***	0.0434***	0.0903***	0.0911***	0.0869***
	(0.00372)	(0.00368)	(0.00360)	(0.00701)	(0.00695)	(0.00697)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,533	5,533	5,533	5,533	5,533	5,533
R-squared	0.159	0.153	0.158	0.290	0.289	0.289
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Industry f.e.	Yes	Yes	Yes	Yes	Yes	Yes

This table shows the estimates of the panel data fixed effect for the period 2010-2022. The dependent variables are idiosyncratic risk (Panel A) and default risk (Panel B). The independent variables are reducing (RED), reusing (REU), and recycling (RECY) and their interacted variables (RED_{t-1}#$RECY_{t-1}$, $RECY_{t-1}$#REU_{t-1}, RED_{t-1}#REU_{t-1}). All the variables are defined in Table A1 in the Appendix. Time- and industry-fixed effects are included. The control variables based on accounting data are winsorized at the 1% of each tail. Firms clustered standard errors (SE) are reported in parentheses. *** $p<0.01$, ** $p<0.05$.

4.3 Discussion

The results reported in Section 4.2 suggest some important considerations and provide novel evidence compared to previous studies.

First, two of the three dimensions of CE, specifically reducing and reusing, are shown to be effective in mitigating default risk, the broader idiosyncratic risk, and the further broader downside risk. This is a very innovative finding as, to our knowledge, no previous literature has focused on this issue. Our results provide strong empirical support for the risk mitigation view, stating that CE initiatives may decrease the risk of listed non-financial companies both from the equity (investors) and debt (banks) perspectives. From the first point of view, the de-risking effect exerted on downside risk and, even more, on idiosyncratic risk (supposed to be priced in financial markets because of the "neglect effect") by reducing and reusing practices suggests that they are viewed by investors as providing an insurance-like effect in non-financial companies. This can be explained by considering that firms adopting these CE practices tend to have good relationships with their stakeholders, which grant to limit regulatory fines and reputational damages. This also allows listed companies to anticipate stakeholder concerns and thus undertake processes of environmental management to reduce the negative volatility of their financial results, which, in turn, reduces the downside volatility of stock returns. From the banking perspective, our evidence indicates that reducing and reusing practices mitigate firm default risk, suggesting that these CE dimensions make non-financial companies more creditworthy and, therefore, less exposed to financial defaults.

Second, our results show, for the first time in the literature, that while reducing and reusing practices are effective in mitigating default, idiosyncratic, and downside risks, recycling practices are not. This can be explained considering, on the one hand, that recycling, when compared to reducing and reusing, often involves not only more stages and complexities (including collection, sorting, processing, and then manufacturing, each with its challenges and potential risks), but also more external factors influencing its effectiveness (like market demand for recycled goods, technological advancements in recycling processes, and infrastructure availability). On the other hand, as shown in our descriptive statistics, among the three Rs, recycling has been so far the least implemented. This is reasonable if we consider that it is at the bottom of the hierarchy of the three Rs (European Commission, 2015). Therefore, since recycling is nowadays less implemented in the EU compared to the other CE practices, it is possible that some technologies related to recycling of goods that could mitigate company risk have not been adopted yet.

Third, this study tests whether and how different CE dimensions, implemented pairwise, are substitutes or complementary in affecting firm-specific risks. Our findings demonstrate that reducing, reusing, and recycling practices have a substitutive effect in reducing idiosyncratic and default risks. Furthermore, among the three Rs, reducing emerges as the more effective in mitigating these risks. This suggests that investors and banks are not homogenous with respect to their beliefs about the definition of each CE dimension and its effect on idiosyncratic risk and default risk, respectively. Reducing is, in fact, viewed by both equity and debt capital providers as granting a stronger insurance-like effect than reusing, which, in turn, is seen as allowing a higher insurance-like effect than recycling. Therefore, in terms of CE practices, one is not as good as the other. By adopting a risk management perspective, our results suggest to listed non-financial companies to implement firstly reducing practices, followed by reusing, and only subsequently, recycling.

5. Robustness checks and additional analyses

We test the robustness of our findings by running several checks.

First, we run Model 1 by using alternative risk measures as dependent variables. Specifically, we replace: (i) downside risk (DSR) with total risk, measured by the standard deviation of daily stock returns for the past five years (STDEV); (ii) idiosyncratic risk estimated by the CAPM five-factor model (IDIO) with idiosyncratic risk estimated by the CAPM three-factor model (IDIO3); and (iii) default risk proxied by the five-year-ahead Bloomberg probability of default (PD) with default risk proxied by the Odds ratio of default over a five-year period (ODD), calculated as the logarithm of the proportion of the physical probability of default to the physical probability of survival (1 - probability of default), as suggested by Kanno (2023) (3):

$$Odds\_ratio = ln\frac{Probability\ of\ Default_{i,t}}{1-Probability\ of\ Default_{i,t}} \quad (3)$$

The results, reported in Table 9, strongly support previous evidence shown in Table 7.

Second, we run Model 1 by using an instrumental variable (IV) regression analysis. Previous studies (Xue et al., 2020; Anwar et al., 2023) show, in fact, that the relationship between corporate environmental performance and firm risk can suffer from endogeneity. Hence, the instrumental variable (IV) regression approach allows us to control for possible endogeneity problems related to the CE variables. For each CE variable, i.e., CES, RED, REU, and RECY, we identify two instruments. The first instrument is the annual average of each CE variable by country and sector (Xue et al., 2020; Anwar et al., 2023). The idea is that the context in which companies operate, both in terms of industry and country, may substantially impact the firm decision to embrace CE practices. The second instrument is a further CE variable extracted from the Thomson Reuters ASSET4 database. Specifically, we instrument the CE score (CES) with the variable "environmental products" (EP). EP is a dummy variable that equals 1 if the company reports on at least one product line or service designed to have positive effects on the environment or which is environmentally labeled and marketed, and 0 otherwise. The idea is that firms adopting CE strategies typically report on services or products having positive effects on the environment (Palea et al., 2023). Moreover, we instrument reducing (RED) with the variable "policy emissions reduction" (PER). PER is a dummy variable that equals 1 if the firm has a policy to improve emission reduction in its operations and system or a set of formal, documented processes for controlling emissions and driving continuous improvement, and 0 otherwise. We suppose that having a policy for reducing emissions demonstrates the firm involvement in reducing practices. Furthermore, we instrument reusing with the variable "renewable energy use ratio" (RENEW). RENEW is calculated by Thomson Reuters ASSET4 as the total energy purchased from primary renewable energy sources divided by total energy use. We suppose that the level of renewable energy used by the company expresses its efforts toward reusing practices. Finally, we instrument recycling (RECY) with the variable "environmental supply chain monitoring" (ESCM). This is a dummy variable that equals 1 if the company monitors the environmental performance of its suppliers through surveys, audits, supplier site visits, and questionnaires, and 0 otherwise. The idea is that effective environmental supply chain monitoring requires firms to collect data on various aspects of their supply chain (including suppliers' environmental practices, material sourcing, and transportation methods) that are required for assessing and improving recycling practices within the firm. The instruments are correlated with the possible endogenous variable and not correlated with the error term. However, this does not guarantee that the instrumental variables are good instruments within Model 1. Therefore, the F-test and the Sargan-Hansen (over-identification) test are run to detect, respectively, the presence of weak instruments and the validity of instrumental variables. The results of the second step of the IV regression analysis are reported in Table 10. They confirm that the circular economy score (CES), reducing (RED), and reusing (REU) significantly decrease downside, idiosyncratic, and default risks, while recycling (RECY) does not. The high values of the F-test provide evidence that our instrumental variables are strong. Furthermore, the p-value of the Sargan-Hansen test is always large, and this means that the overidentifying restrictions are valid. Hence, our instrumental variables appear to be valid instruments in Model 1. Overall, the evidence of the IV regression analysis highly confirms our baseline results.

Third, we perform the analyses by considering different fixed effects. Specifically, we run Model 1 by applying the interaction between time and industry- (Time#Industry) and country-fixed effects. The evidence reported in Table A2 in the Appendix strongly supports the main findings.

Fourth, we further check the robustness of our baseline results by splitting the sample between manufacturing (3,918 firms) and non-manufacturing (3,069 firms) companies. Previous literature (Xue et al., 2019; Li et al., 2022; Zara et al., 2023) suggests in fact that in the manufacturing industry, where processes are often resource-intensive and generate negative externalities, the adoption of CE and, more generally, of green practices is likely to produce significant effects, as this sector is highly exposed to supply chain disruption, price volatility, availability of raw materials, and environmental regulation. The results, reported in Table 11, confirm our baseline finding both in the manufacturing and the non-manufacturing subsamples.

Table 9: Robustness tests using alternative risk measures

	Panel A: Total risk				*Panel B: Idiosyncratic risk – CAPM 3 factors*				*Panel C: Odds_ratio*			
Variables	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
CES $_{t-1}$	-0.0285***				-0.000975***				-0.0475***			
	(0.00370)				(0.000146)				(0.00860)			
RED $_{t-1}$		-0.0470***				-0.00154***				-0.0853***		
		(0.00819)				(0.000338)				(0.0180)		
REU $_{t-1}$			-0.0587***				-0.00190***				-0.101***	
			(0.00696)				(0.000254)				(0.0157)	
RECY $_{t-1}$				0.000657				-0.000320				0.0214
				(0.00937)				(0.000377)				(0.0215)
Constant	1.656***	1.748***	1.632***	1.731***	0.0445***	0.0476***	0.0438***	0.0466***	-2.310***	-2.154***	-2.356***	-2.159***
	(0.0809)	(0.0819)	(0.0813)	(0.0843)	(0.00355)	(0.00360)	(0.00354)	(0.00366)	(0.216)	(0.215)	(0.217)	(0.219)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533
R-squared	0.224	0.220	0.226	0.215	0.156	0.153	0.158	0.149	0.433	0.432	0.434	0.429
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

This table shows the estimates of the panel data fixed effect for the period 2010-2022. The dependent variables are total risk (Panel A), idiosyncratic risk - CAPM 3 factors (Panel B), and Odds_ratio (Panel C). The independent variables are the circular economy score (CES), reducing (RED), reusing (REU), and recycling (RECY). All the variables are defined in Table A1 in the Appendix. Time- and industry-fixed effects are included. The control variables based on accounting data are winsorized at the 1% of each tail. Firms clustered standard errors (SE) are reported in parentheses. *** p<0.01, ** p<0.05.

Table 10: Robustness test running instrumental variable regressions 2sls

	Panel A: Downside risk				*Panel B: Idiosyncratic risk*				*Panel C: Default risk*			
Variables	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
CES_{t-1}	-0.00125***				-0.00173***				-0.00315***			
	(0.000191)				(0.000248)				(0.000543)			
RED_{t-1}		-0.00242***				-0.00320***				-0.00458***		
		(0.000392)				(0.000574)				(0.00105)		
REU_{t-1}			-0.00573***				-0.00373***				-0.00764**	
			(0.00164)				(0.00103)				(0.00328)	
$RECY_{t-1}$				-0.000702				9.43e-05				-0.00155
				(0.000758)				(0.000918)				(0.00143)
Constant	0.0256***	0.0292***	0.0267***	0.0244***	0.0425***	0.0482***	0.0446***	0.0415***	0.0827***	0.0927***	0.0887***	0.0828***
	(0.00293)	(0.00295)	(0.00536)	(0.00514)	(0.00354)	(0.00359)	(0.00482)	(0.00590)	(0.00680)	(0.00685)	(0.0134)	(0.00944)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,533	5,533	1,473	3,027	5,533	5,533	1,473	3,027	5,533	5,533	1,473	3,027
R-squared	0.106	0.100	0.130	0.099	0.152	0.148	0.172	0.141	0.285	0.288	0.342	0.312
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sargan p-value	0.5084	0.4793	0.4598	0.9533	0.9634	0.3389	0.3236	0.7517	0.3221	0.7277	0.4227	0.2600
F-test	1487.46	1974.17	170.199	605.524	1487.46	1974.17	170.199	605.524	1487.46	1974.17	170.199	605.524

This table shows the results of the second step of the 2sls regressions. The following CE variables are instrumented: circular economy score (CES), reducing (RED), reusing (REU) and recycling (RECY). Two instruments are identified for each CE variable and inserted in the first-stage regressions. The first instrument is the annual average of each CE variable by country and sector. The second instrument is an environmental variable related, respectively, to the circular economy score (CES), reducing (RED), reusing (REU) and recycling (RECY). Specifically, we instrument, respectively, CES with the variable "environmental products" (EP), reducing (RED) with the variable "policy emissions reduction" (PER), reusing (REU) with the variable "renewable energy use ratio" (RENEW), AND recycling (RECY) with the variable "environmental supply chain monitoring" (ESCM). The dependent variables are downside risk (Panel A), idiosyncratic risk (Panel B) and default risk (Panel C). The independent variables of interest are circular economy score (CES), reducing (RED), reusing (REU) and recycling (RECY). All the variables are defined in Table A1 in the Appendix. Time- and industry-fixed effects are included. The control variables based on accounting data are winsorized at the 1% of each tail. Firms clustered standard errors (SE) are reported in parentheses. *** $p<0.01$, ** $p<0.05$.

Table 11: Robustness test disaggregating manufacturing and non-manufacturing firms

	Panel A: Downside risk				*Panel B: Idiosyncratic risk*				*Panel C: Default risk*			
Variables	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	Manufacturing firms											
CES $_{t-1}$	-0.000812***				-0.000825***				-0.00128***			
	(0.000180)				(0.000239)				(0.000397)			
RED $_{t-1}$		-0.00189***				-0.00192***				-0.00392***		
		(0.000400)				(0.000593)				(0.000870)		
REU $_{t-1}$			-0.00131***				-0.00164***				-0.00161**	
			(0.000342)				(0.000415)				(0.000757)	
RECY $_{t-1}$				-0.000192				0.000441				5.69e-05
				(0.000479)				(0.000616)				(0.000947)
Constant	0.0280***	0.0313***	0.0284***	0.0307***	0.0461***	0.0494***	0.0459***	0.0501***	0.0947***	0.0999***	0.0963***	0.0996***
	(0.00382)	(0.00375)	(0.00377)	(0.00394)	(0.00481)	(0.00486)	(0.00477)	(0.00510)	(0.00830)	(0.00830)	(0.00833)	(0.00854)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,642	2,642	2,642	2,642	2,642	2,642	2,642	2,642	2,642	2,642	2,642	2,642
R-squared	0.110	0.111	0.109	0.104	0.155	0.156	0.156	0.151	0.342	0.345	0.340	0.339
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Non-manufacturing firms											
CES $_{t-1}$	-0.000729***				-0.00109***				-0.00148***			
	(0.000150)				(0.000166)				(0.000456)			
RED $_{t-1}$		-0.000373				-0.00130***				-0.00226***		
		(0.000340)				(0.000368)				(0.000865)		
REU $_{t-1}$			-0.00161***				-0.00211***				-0.00230***	
			(0.000303)				(0.000300)				(0.000855)	
RECY $_{t-1}$				-0.00114***				-0.00102***				-0.00195
				(0.000401)				(0.000321)				(0.00118)
Constant	0.0314***	0.0325***	0.0305***	0.0311***	0.0419***	0.0442***	0.0410***	0.0422***	0.0862***	0.0897***	0.0855***	0.0861***
	(0.00322)	(0.00335)	(0.00325)	(0.00329)	(0.00301)	(0.00322)	(0.00300)	(0.00311)	(0.00810)	(0.00828)	(0.00808)	(0.00820)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,891	2,891	2,891	2,891	2,891	2,891	2,891	2,891	2,891	2,891	2,891	2,891
R-squared	0.106	0.100	0.110	0.101	0.178	0.168	0.180	0.165	0.257	0.255	0.256	0.254
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

This table shows the estimates of the panel data fixed effect for 2010-2022 for two sub-samples: manufacturing firms and non-manufactoring firms. The dependent variables are downside risk (Panel A), idiosyncratic risk (Panel B) and default risk (Panel C). The independent variables are the circular economy score (CES), reducing (RED), reusing (REU), and recycling (RECY). All the variables are defined in Table A1 in the Appendix. Time- and industry-fixed effects are included. The control variables based on accounting data are winsorized at the 1% of each tail. Firms clustered standard errors (SE) are reported in parentheses. *** $p<0.01$, ** $p<0.05$.

We also run some additional analyses.

First, we run Model 1 using a short-time horizon. Although previous literature suggests that investments in green practices offer mainly long-term benefits (Nguyen et al., 2020), some studies show that corporate environmental initiatives produce de-risking effects also in the short-term (Bannier et al., 2022; Zara and Ramkunar, 2022). Hence, we suppose that CE may affect downside, idiosyncratic, and default risks not only in the long, but also in the short time. We study the impact of our CE variables, i.e., circular economy score, reducing, reusing, and recycling, on firm risks calculated over a 1-year period. Specifically, we estimate company downside risk by the standard deviation of negative daily stock returns at 1 year, idiosyncratic risk by the standard deviation of residuals from the CAPM five-factor model based on daily stock returns for the past year, and default risk by the one-year-ahead Bloomberg probability of default. The results are reported in Table 12.

They show that CE practices, globally implemented, reduce downside, idiosyncratic, and default risks. These de-risking effects also occur when individually considering reduction and reusing initiatives. However, recycling decreases default risk, while does not affect downside and idiosyncratic risks. Table 12 demonstrates that CE practices, globally implemented, and reduction and reusing, individually adopted, mitigate downside, idiosyncratic, and default risks not only in the long term, as shown in our main analyses (Table 8), but also in the short term. These findings, specifically focused on CE practices, thus extend previous evidence on the de-risking effect of corporate environmental initiatives on default risk (Bannier et al., 2022; Palmieri et al., 2023).

Second, we test whether the mitigating effect of CE practices increased after 2015, when the Paris Agreement was signed and the Action Plan on Circular Economy was issued by the European Commission. For these reasons, 2015 may mark a turning point around which both investors and creditors would have increased their awareness about the policy commitment toward climate change, thus starting to look differently at the CE. Hence, as suggested by Palea et al. (2023), we run Model 1 by adding the dummy variable PARIS (that takes value 1 after 2014, and 0 otherwise) and the interactions between PARIS and our CE variables ($PARIS\#CES_{t-1}$, $PARIS\#RED_{t-1}$, $PARIS\#REU_{t-1}$ and $PARIS\#RECY_{t-1}$). The results are reported in Table 13.

The signs and meanings of CES, RED, REU, and RECY persist. However, the PARIS coefficient and the coefficients of its interactions with the CE variables are not statistically significant. This evidence suggests that neither the Paris Agreement nor the Action Plan on Circular Economy of 2015 played a crucial role in making investors incorporate CE risks into their investment decisions. In other words, surprisingly, after 2015, the financial market did not perceive listed companies involved in CE practices as less risky, thus confirming the evidence shown by the European Court of Auditors (2023).

Table 12: Additional analyses over a 1-year time horizon

	Panel A: Downside risk at 1 year				*Panel B: Idiosyncratic risk at 1 year*				*Panel C: Default risk at 1 year*			
Variables	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
CES_{t-1}	-0.000688***				-0.000892***				-0.000302***			
	(0.000130)				(0.000115)				(9.33e-05)			
RED_{t-1}		-0.000912***				-0.00136***				-0.000587***		
		(0.000297)				(0.000253)				(0.000190)		
REU_{t-1}			-0.00132***				-0.00172***				-0.000356**	
			(0.000233)				(0.000202)				(0.000174)	
$RECY_{t-1}$				-0.000577				-0.000427				-0.000477**
				(0.000349)				(0.000284)				(0.000220)
Constant	0.0265***	0.0287***	0.0261***	0.0276***	0.0419***	0.0448***	0.0414***	0.0437***	0.0128***	0.0138***	0.0130***	0.0130***
	(0.00415)	(0.00415)	(0.00413)	(0.00422)	(0.00318)	(0.00320)	(0.00317)	(0.00326)	(0.00182)	(0.00186)	(0.00182)	(0.00184)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533
R-squared	0.103	0.100	0.104	0.099	0.207	0.202	0.208	0.197	0.142	0.142	0.141	0.141
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

This table shows the estimates of the panel data fixed effect for 2010-2022. The dependent variables are the 1-year downside risk (Panel A), the 1-year idiosyncratic risk (Panel B), and default risk at the 1-year-ahead (Panel C). The independent variables are circular economy score (CES), reducing (RED), reusing (REU), and recycling (RECY). All the variables are defined in Table A1 in the Appendix. Time- and industry-fixed effects are included. The control variables based on accounting data are winsorized at the 1% of each tail. Firms clustered standard errors (SE) are reported in parentheses. *** $p<0.01$, ** $p<0.05$.

Table 13: Additional analyses on the effect of the Paris Agreement and the Circular Economy Act

	Panel A: Downside risk				*Panel B: Idiosyncratic risk*				*Panel C: Default risk*			
Variables	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
PARIS	-0.00326**	-0.00441***	-0.00270*	-0.00324***	0.00564**	0.00528**	0.00552**	0.00310**	-0.00510	-0.00655	-0.00516	-0.00537*
	(0.00162)	(0.00170)	(0.00153)	(0.00116)	(0.00224)	(0.00237)	(0.00225)	(0.00142)	(0.00409)	(0.00415)	(0.00376)	(0.00291)
PARIS#CES$_{t-1}$	0.000149				-0.000381				0.000168			
	(0.000228)				(0.000264)				(0.000608)			
PARIS#RED$_{t-1}$		0.000715				-0.000947				0.000906		
		(0.000569)				(0.000731)				(0.00146)		
PARIS#REU$_{t-1}$			8.69e-05				-0.000693				0.000249	
			(0.000451)				(0.000563)				(0.00112)	
PARIS#RECY$_{t-1}$				-0.000246				-0.000253				-0.000698
				(0.000601)				(0.000783)				(0.00134)
CES$_{t-1}$	-0.000897***				-0.000684***				-0.00152***			
	(0.000205)				(0.000200)				(0.000549)			
RED$_{t-1}$		-0.00162***				-0.000804				-0.00360***		
		(0.000500)				(0.000607)				(0.00128)		
REU$_{t-1}$			-0.00155***				-0.00139***				-0.00211**	
			(0.000417)				(0.000458)				(0.000978)	
RECY$_{t-1}$				-0.000462				-0.000127				-0.000690
				(0.000533)				(0.000751)				(0.00121)
Constant	0.0294***	0.0325***	0.0286***	0.0300***	0.0431***	0.0461***	0.0427***	0.0465***	0.0879***	0.0935***	0.0881***	0.0891***
	(0.00318)	(0.00323)	(0.00314)	(0.00313)	(0.00371)	(0.00377)	(0.00370)	(0.00365)	(0.00727)	(0.00728)	(0.00721)	(0.00693)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533
R-squared	0.109	0.105	0.109	0.102	0.156	0.153	0.158	0.149	0.290	0.289	0.288	0.287
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

This table shows the estimates of the regressions aimed at verifying the possible effect of the Paris Agreement and the Circular Economy Act after 2014. The dependent variables are downside risk (Panel A), idiosyncratic risk (Panel B), and default risk (Panel C). The independent variables are the circular economy score (CES), reducing (RED), reusing (REU), and recycling (RECY). In addition to the main independent variables, we include the variable PARIS - that takes value 1 after 2014, and 0 otherwise – and the interactions between PARIS and the CE variables (PARIS#CES$_{t-1}$, PARIS#RED$_{t-1}$, PARIS#REU$_{t-1}$ and PARIS#RECY$_{t-1}$). All the variables are defined in Table A1 in the Appendix. Time- and industry-fixed effects are included. The control variables based on accounting data are winsorized at the 1% of each tail. Firms clustered standard errors (SE) are reported in parentheses. *** $p<0.01$, ** $p<0.05$.

6. Conclusions

The paper tests the impact of CE on corporate risks from a risk management perspective. The study specifically investigates whether reduction, reusing, and recycling practices, implemented both globally and individually by 1,069 European non-financial companies, affect downside risk, idiosyncratic risk, and default risk. In addition, the paper explores the interactive effects of reduction, reusing, and recycling in affecting firm-specific risks.

We find that non-financial companies benefit from globally adopting CE practices, allowing them to reduce default risk, broader idiosyncratic risk, and even broader downside risk. However, reduction, reusing, and recycling practices, individually implemented, do not produce the same effects. Specifically, reduction and reusing decrease all considered risks, while recycling does not affect any of these risks. Moreover, our results show that when reuse, reduction, and recycling are implemented pairwise, their interactive effect in mitigating firm-specific risks is mainly substitutive. Furthermore, our additional analysis demonstrates that the de-risking effect of CE practices occurs both in the long term (5 years) and in the short term (1 year).

Our paper has important implications for both academics and practitioners.

From the academic perspective, the study enriches previous literature by demonstrating that CE practices, globally implemented, are effective in mitigating downside, idiosyncratic, and default risks of European non-financial companies. However, reduction, reusing, and recycling do not disclose the same de-risking effect: reduction and reusing decrease all the investigated risks, while recycling does not affect them. The paper shows for the first time in the literature that when reduction, reusing, or recycling operates pairwise, one of them replaces the other in mitigating firm-specific risks. Among the three Rs, reducing emerges as the more effective in decreasing both idiosyncratic and default risks.

From the practitioners' perspective, our results are interesting for managers, investors, banks, and regulators. First, our evidence is useful for managers as it shows that CE practices, globally implemented, are key factors for reducing downside, idiosyncratic, and default risks. Therefore, strategic CE management and improvements of CE processes should be included in firms' risk management agendas. However, in terms of CE dimensions, one is not as good as the other in mitigating firm risks. As companies mainly follow different CE practices simultaneously in the form of environmental bundles, from a risk management perspective our results suggest that listed non-financial companies should implement first reducing, followed by reusing, and only subsequently, recycling. Second, our results may help investors, who mainly cannot thoroughly examine the company's real commitment toward CE, clarify confusion about the linkage between CE and downside and idiosyncratic risks. Because of the mitigation effect of CE initiatives on these risks, the stocks of circular firms, and specifically of those implementing reducing and reusing practices, might be attractive for investors with a low-medium risk profile. Third, our evidence is useful for debt capital providers, such as banks. As non-financial companies implementing reducing and reusing strategies show a lower default risk, banks are encouraged to finance these firms (thus supporting the transition to a more sustainable economy) and integrate CE scores into their lending practices. This is particularly important for European banks that from 2024 are required to disclose the green asset ratio (GAR), i.e., an indicator related to the assets that finance and are invested in EU Taxonomy-aligned economic activities, among which the CE practices fall. Fourth, our results should persuade policymakers to continue supporting firms to adopt CE practices, and specifically the reducing and reusing ones, since they mitigate the probability of financial distress. Although in the period 2014-2020, the EU planned more than €10 billion in funding for the transition to a CE, they were mainly used for waste management, which has a low potential to reduce environmental impact, rather than on waste prevention through circular design (European Court of Auditors, 2023). Consistent with the EU program for the 2021-2027 period, which shows more emphasis on the CE, our results suggest policy makers to provide more incentives for the adoption by firms of reducing and reusing activities. Moreover, our findings should encourage financial regulators in supporting the widespread use of environmental metrics incorporating CE indicators in assessing credit risk.

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Appendix

Table A1: Variable measurement description

Variable	Label	Description	Source
Dependent variables			
Downside risk	DSR	Standard deviation of negative daily stock returns for the past five years	Own calculation on Refinitiv Eikon data
Idiosyncratic risk	IDIO	Standard deviation of residuals from CAPM five-factor model, based on daily stock returns for the past five years	Own calculation on Refinitiv Eikon data
Probability of default	PD	Probability of default of the issuer over the next five years	Bloomberg
Independent variables			
Circular Economy Score	CES	Score of the firm adoption of CE practices. The score ranges from 0 (no practices) to 8 (all practices).	Own calculation on Thomson Reuters ASSET4 data
Reducing	RED	Score of the firm adoption of reduction practices. The score ranges from 0 (no strategy) to 3 (all practices).	Own calculation on Thomson Reuters ASSET4 data
Reusing	REU	Score of the firm adoption of reuse practices. The score ranges from 0 (no strategy) to 3 (all practices).	Own calculation on Thomson Reuters ASSET4 data
Recycling	RECY	Score of the firm adoption of recycling practices. The score ranges from 0 (no strategy) to 2 (all practices).	Own calculation on Thomson Reuters ASSET4 data
Control variables			
Environmental management training	EMT	Dummy variable that equals 1 if the firm trains its employees on environmental issues, 0 otherwise.	Thomson Reuters ASSET4 data
Size	SIZE	Natural logarithm of firm total asset	Refinitiv Eikon
Return On Equity	ROE	Net income by shareholder equity	Refinitiv Eikon
Dividend yield	DY	Dividend per share divided by price per share	Refinitiv Eikon
Leverage	LEV	Total liabilities to total assets	Refinitiv Eikon
Market to book value	MTBV	Stock market capitalization divided by the total equity	Refinitiv Eikon
Current ratio	CR	Current assets divided by current liabilities	Refinitiv Eikon
GDP growth	GDP	Growth rate of gross domestic product	World Bank

This table describes the variables, their definitions, and data sources

Table A2: Robustness checks using different fixed effects

	Panel A: Downside risk				*Panel B: Idiosyncratic risk*				*Panel C: Default risk*			
Variables	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
CES_{t-1}	-0.000440***				-0.000468***				-0.00158***			
	(0.000119)				(0.000136)				(0.000295)			
RED_{t-1}		-0.000512**				-0.000866***				-0.00337***		
		(0.000261)				(0.000308)				(0.000624)		
REU_{t-1}			-0.000876***				-0.00100***				-0.00227***	
			(0.000240)				(0.000234)				(0.000563)	
$RECY_{t-1}$				-0.000358				0.000287				-0.00161**
				(0.000324)				(0.000358)				(0.000709)
Constant	0.0360***	0.0374***	0.0359***	0.0370***	0.0550***	0.0564***	0.0549***	0.0570***	0.0340***	0.0314***	0.0323***	0.0277***
	(0.00271)	(0.00272)	(0.00274)	(0.00275)	(0.00337)	(0.00344)	(0.00341)	(0.00349)	(0.00321)	(0.00310)	(0.00318)	(0.00292)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533	5,533
R-squared	0.178	0.177	0.178	0.176	0.240	0.240	0.241	0.239	0.350	0.350	0.349	0.347
Year*industry f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country f.e.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

This table shows the estimates of the panel data fixed effect for 2010-2022. The dependent variables are downside risk (Panel A), idiosyncratic risk (Panel B) and probability of default (Panel C). The independent variables of interest are circular economy score (CES), reducing (RED), reusing (REU) and recycling (RECY). All the variables are defined in Table A1 in the Appendix. Time- and industry-fixed effects are included. The control variables based on accounting data are winsorized at the 1% of each tail. Firms clustered standard errors (SE) are reported in parentheses. *** p<0.01, ** p<0.05.