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ORIGINAL RESEARCH

Eco-innovation and corporate waste management: The moderating role of ESG performance

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Abstract

Based on a sample of companies from G7 countries, we investigate the effect of eco-innovation on waste management as well as the moderating role of firms' environmental, social, and governance (ESG) on this relationship. Our findings indicate that a higher level of eco-innovation might lead to a decline in firms' total waste produced and an increase in firms' magnitude of reusing and recycling waste. Likewise, our findings are associative with a moderating effect of ESG on the eco-innovation-waste management nexus. We argue that eco-innovation, along with better ESG performance, leads to a reduction in waste produced and thus better business waste management. Our study has several implications on micro- and macroeconomic levels. Countries should revisit their national strategies and domestic policies about circular economies to form international alliances and embrace more technological development.

Keywords Eco-innovation · Waste management · Waste recycling · ESG performance · G7 countries

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1 Introduction

Today, the economic model 'take-make-dispose' proved wasteful and unsustainable. The acclamation of globalization, the waves of corporate hegemony, and expansionary urbanism led to an increase in the quantities of waste. Waste is defined as 'anything that is unwanted or unusable and is generally classified as hazardous or non-hazardous and includes, among others, plastic, garbage, chemical waste, organic waste, nuclear waste' (EPA 2016). From a universal lens, waste poses a significant cost to society, and the growing volumes of materials embedded in trade result in significant environmental pressures, including land degradation, greenhouse gas emissions, and the dispersion of toxic substances in the environment (Verhoef et al. 2006; Zaman et al. 2021; Bilal et al., 2022). To alleviate the harm of this existential threat, global efforts were put into exploring ways to reuse products or their components and recover more precious materials and energy.

Several countries arduously rushed to develop national strategies and mainstream domestic policies for sustainable materials management, resource productivity, or the circular economy (Benjamin et al. 2020). G7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) account for around 40% of the global economy, 30% of energy demand, and 25% of energy system CO2 emissions[1]. The report "Achieving Net Zero Heavy Industry Sectors in G7 Members" lays out a series of recommendations to advance the transition towards near zero emission. G7 countries' economic heft, technology leadership, and international alliances present them with a special role in leading the way and inspiring successful energy. For instance, a low-impact scenario of a 40% reduction in G7 food waste from retail and citizens would yield an estimated saving of 60 million tons of CO2e per year, while a central scenario to meet SDG 12.3 would save 76 million tons of CO2e per year and a transformative scenario would save 370 million tons CO2e per year[2].

Concomitantly, waste can cease to be waste if it can become a secondary raw material. Waste management can cover a large share of the economic loss and contribute considerably to sustainability (Verhoef et al. 2006). This can be further achieved by speeding up technology development in the high waste reduction costs decoupling economic growth from environmental impacts. A clear rationale is to further advance the transition to a more resource-efficient and circular economy whereby discarded materials representing a valuable resource, can be retained with benefits in environmental, economic, and social domains (Gull et al. 2022). The directive of the EU foundation "Waste Framework Directive" has established a five-step hierarchy for managing and disposing of waste: prevention; preparing for re-use; recycling; recovery; and disposal. It has also provided additional labelling, record keeping, monitoring, and control obligations from the "cradle to the grave", and banned the mixing of hazardous waste with other categories of hazardous and non-hazardous waste.

Eco-innovation is mainly related to the benefits to the environment and contributes to environmental sustainability (Rennings, 2000; Horbach et al., 2012; Triguero et al., 2013; Huang et al., 2023; Qi et al., 2023). Eco-innovation can improve energy efficiency and consequently reduce waste and carbon emissions in the production process (Lin and Zhu, 2019; Albitar et al. 2023a). However, there is a lack of literature that analyses the impacts

[1] https://www.iea.org/reports/achieving-net-zero-heavy-industry-sectors-in-g7-members.

[2] https://www.iea.org/reports/achieving-net-zero-heavy-industry-sectors-in-g7-members.

of eco-innovations on areas such as recycling, waste, and water management (Kammerer, 2009; Horbach et al., 2012).

From a scientific perspective, the effect of economic development on CO2 emissions was extensively investigated. Specifically, the enormous carbon footprint of food production contributes to 37% of global greenhouse gas emissions. In this area, findings pointed out that there are three ways to reduce its level: cutting emissions from food production (regenerative agriculture), changing the types of food we produce and eat, and reducing food waste (Adnouni et al. 2022; Giannakis and Bruggeman 2017; Hübler and Löschel 2013). Notwithstanding, many national and regional decision-making endeavoured to find optimal solutions, but the topic remains complex because of the many stakeholders, the fuzzy, often conflicting objectives, perspectives, and interests, and the size and ambiguity of the systems (Akter and Simonovic 2005).

Several studies investigate sustainability and eco-innovation from a macroeconomic view (Du et al. 2019; Duygan et al. 2021; Moors and Dijkema 2006). Yet, the analysis appears more complicated when narrowed down to waste reduction and the needed infrastructure to manage it. On a microeconomic level, the literature is dispersed. Benjamin et al. (2020) explore the effect of voluntary waste disclosure on corporate cash holdings using a sample of S&P 500 firms, while Shahab et al. (2022) examine the effect of corporate governance mechanisms on the level of waste produced on a global sample of firms. Gull et al. (2022) test the effect of waste management on corporate performance. They find a significantly negative (positive) relationship between waste generation (recycling) and financial performance. Ahsan et al. (2023) investigate how the enhancement of climate governance influences companies' disclosure of waste by focusing on both hazardous and non-hazardous waste disclosures. Uyar et al. (2023) study the impact of foreign directors on firms' waste management. Yet, to our knowledge, the effect of corporate eco-innovation on waste management remains relatively unexplored. This study attempts to answer the following research question: How can corporate eco-innovation affect waste management? Moreover, our study posits that ESG performance serves as a crucial moderating factor in the relationship between environmental innovation and waste management, as it incentivizes firms to prioritize waste reduction efforts and fosters a positive ecosystem that supports effective waste management practices. ESG performance-based compensation policies can mitigate the negative impact of waste on financial performance which is consistent with the principles of shared value creation and validation advocated by Porter and Kramer (2019). This emphasizes the growing importance of ESG practices in enhancing green innovation and driving sustainable business practices (Albitar et al. 2020; Hao et al. 2023; Yang et al. 2024). Thus, the present study is an attempt to fill the gap in the previous literature as it delves into eco-innovative corporate strategies to deal with waste problems. It reflects on the social and ethical corporate attitudes to deal with the harmful impact of waste. In this regard, organizational capabilities are considered essential drivers of eco-innovation (Cuerva et al. 2014). In addition, as corporations voluntarily provide environmental information (Braam et al. 2016), it becomes important to study the impact from a corporate perspective and in G7 countries.

The contributions of this paper are manifold. First, unlike existing studies that focused on environmental management by considering mainly corporate environmental practices such as CO2 emissions score or carbon disclosure as proxies for environmental practices (e.g., Afrifa et al., 2020; Albitar et al. 2023a), we contribute to knowledge around business environmental management practices and performance by focusing specifically on waste management which is considered an important issue to stakeholders, including management, employees, and policymakers (Hill and Jones, 1992), and may change the way businesses operate and their cost structure (Shahab et al. 2022). Second, to the best of our knowledge, this paper is the first in this domain to examine the effect of corporate eco-innovation on business waste management. As shown, prior studies focused either on the general determinants of waste management, such as corporate governance (Shahab et al. 2022; Ahsan et al. 2023), or on the consequences of waste management, such as corporate cash holdings (Benjamin et al. 2020) and financial performance (Gull et al. 2022). We differ from prior studies by providing novel evidence that corporate eco-innovation is positively associated with business waste management. Firms with eco-innovation can help to efficiently control pollution and resource use to reduce their environmental impact. Third, our paper contributes to the existing findings by providing new evidence on the moderating effect of eco-innovation and ESG towards less waste production, efficient resource use, and innovative recycling techniques, which is still missing in the literature. We provide insights that eco-innovation along with better ESG performance leads to a reduction in corporate waste produced and thus better waste management. Fourth, we dissect waste components into hazardous and non-hazardous to pinpoint the significance of each component. Fifth, we then go beyond the prior literature (Benjamin et al. 2020) and consider more proxies for waste management, namely, waste recycling, the ratio of waste to total assets, and a dummy variable to account if the firm has a waste reduction policy.

Our findings indicate that eco-innovation and waste levels are negatively associated, implying that a higher level could lead to a decline in the total waste produced in firms operating in G7 countries. When dissecting waste components into hazardous and non-hazardous, we deduce that the eco-innovation effect is more pronounced with the non-hazardous waste, which explains the importance of sophisticated technology and firms' pursuit and vigilance to cope with the dangerous component of waste. We also find a positive and statistically significant association between eco-innovation waste reduction and recycling. Our results remained the same after applying several robustness tests. Our results are supported by the mitigation effect of the ESG moderating role. Our research highlights the vital role of corporate green technology innovations in waste management to foster economic growth and maintain a positive corporate image. Large companies must lead by example to preserve their reputation. At the macroeconomic level, nations should revise national strategies, form global alliances, and prioritize technological development for sustainable materials management and the circular economy.

The rest of the paper is organized as follows. In Sect. 2, we review the literature and develop research hypotheses, Sect. 3 shows the econometric methodology. Section 4 shows the main findings and Sect. 5 discusses the results. Section 6 concludes the paper.

2 Literature review and hypotheses development

2.1 Theoretical framework

In light of the emergence of the waste management debate and the importance of embracing new technologies and eco-innovation solutions, it becomes apparent that this economic conjecture is found at the heart of corporate decisions. Global initiatives and green directives have been undertaken at the macro level, yet the bulk effect is attributed to companies' main activities. Recently, there has been increasing stakeholder pressure and consumer awareness around the impact of firms' business operations on the environment. The relationship between a firm's resources and sustained competition is possible if the resources are valuable, rare, inimitable, non-sustainable, and organized (VRIN-O) (Barney et al. 2021; Bhandari et al. 2022). Thus, we propose the resource-based view (RBV) as the theoretical framework for our work as it focuses on the internal strengths and weaknesses of the firm in contrast to the external environmental model of competitive advantage, where the focus is on opportunities and threats.

2.2 Hypotheses development

Environmental innovation has become a forefront agenda item for many countries. It is argued that social and environmental concerns and the "triple bottom line" have been regarded as the main responsibility of corporate boards (Elkington 2006). Arguably, it has positive impacts on a firm's competitive position as by minimizing waste and reducing pollution and emissions, profitability tends to increase through the adoption of innovative ways of production and efficient use of resources.

Empirically, it was evidenced that pollution intensity and green technology innovation are negatively associated. Nonetheless, the measurement of embedded technology is complex and trivial as it cannot be observable on the macroeconomic level. Du and Li (2019) find two indicators from the extended version of production-theory decomposition analysis: energy technological advancement and energy utilization efficiency improvement. Moreover, many metrics were used to proxy technology, such as expenditure on research and development (R&D) (Cole et al. 2005), the ratio of R&D to GDP (Li-Ying and Wang 2015; Liu and Hao 2018), afforestation expanse from the environmental technology input (Song et al. 2018), energy patents count (Ghisetti and Quatraro 2017; Zhou et al. 2012), and industrial agglomeration (Liu et al. 2017). On the other side, many studies innovated their methodological approaches to account for the impact of technological progress. For example, Shao et al. (2016) measure the technological progress of Shanghai's industrial sector using the SFA approach, while Yu et al. (2017) quantify the technological innovations of coal-fired power plants in China based on the DEA approach. In the context of 71 countries, Du et al. (2019) find that the relationship between per capita CO2 emissions and per capita GDP is inverted U-shaped, and urbanization level, industrial structure, trade openness, and energy consumption structure significantly affect CO2 emissions. Several studies focus on ways to improve carbon productivity in terms of energy price (Yuan and Zuo 2011), industrial structure (Meng and Niu 2012; Wang et al. 2019; Zhang et al. 2019), technological progress (Wesseh Jr et al. 2013), FDI and international trade (Zheng et al. 2011); intercountry comparisons (He et al. 2009) and the convergence effect and decoupling from economic growth (Zhang and Wang 2013).

From a microeconomic perspective, a stream of contemporary research claims green technology innovations might overcome potential climate adversity and environmental calamities. Prior evidence suggests that firms that voluntarily disclose environmental information, such as their waste output or carbon emissions, are usually more proactive in terms of being environmentally friendly, through initiatives such as pollution control, usage of renewable energy, and recycling of waste materials (Matsumura et al. 2014). A central focus arises on renewable energy supply and efficient end-use (Wilson et al. 2012). These studies show that eco-innovation enhances firms' financial performance (Song et al. 2017), generates higher stock return (Szutowski 2021), mitigates financial constraints (Zhang et al. 2020), reduces information asymmetry (Vieira and Radonjič 2020) and results in flexible credit terms (Liao 2020). In the context of performance, many indicators were applied. For example, Eiadat et al. (2008) examine the relationship between eco-innovation and firm performance and report a positive link between both variables. Similarly, Przychodzen and Przychodzen (2015) analyze the relationship between eco-innovation and firm performance and report that eco-innovation positively impacts return on assets. A recent study by Uyar et al. (2023) explores the moderating effect of Eco-innovation on the foreign directorship-waste management nexus. They mention that Eco-innovation has the potential to encourage the efficient adoption of recycling methods and contribute to the decrease in waste generation.

Thus, we derive our first hypothesis.

H1 *Eco-innovation is associated with waste management.*

As our central question is highly entangled with ecological and environmental corporate attitudes, managerial and strategic corporate actions are important to account for. More and more, ecology and sociology are embedded into business and economics under the aegis of corporate boards and top-management teams. Bhandari et al. (2022) explore if firms' objectives are economic, societal, and environmental under the shared value creation. They argue that the impact on a society with a proper ethical governance mechanism must be assessed, and this assessment must drive the objective of the firm, rather than the orthodox measure of a single unit of profit maximization. However, as environmentalism is costly and requires strong top management commitments, certain attributes of boards of directors make them more likely to devote attention to eco-innovation. Prior studies (He and Jiang 2019; Nadeem et al. 2020) argue that diversity on boards brings different perspectives to decisions under consideration, which ultimately enhances boards' sensitivity to sustainability and environmentalism. Nadeem et al. (2020) study the effect of board gender diversity on eco-innovation and find a significant positive association. Firms with better environmental performance will reduce companies' environmental risks as well as show a commitment to green and sustainable development, and therefore corporate environmental responsibility has a positive impact on green innovation (Hao et al. 2023). In the same context, firm-level initiatives toward environment, social, and governance (ESG) performance-based compensation that aim to shape management behaviour might influence firms' environmental orientation (Velte 2016). The engagement of firms' discretionary citizenship toward society (e.g., waste reduction and recycling) can positively influence stakeholders, including consumers and employees (Mishra and Suar 2010). In contemporary society, consumers are becoming more aware of firms' manufacturing operations and their effects (Nadeem et al. 2020). They usually assign a higher value to products from companies with good citizenship (Maignan and Ferrell 2001). Moreover, firms' environmental commitment can contribute to employees' job satisfaction, reduce turnover, and invoke positive reactions (Riordan et al. 1997). This implies that ESG performance-based incentives may enhance management focus on environmental orientation and motivate employees to work more efficiently and effectively, thereby contributing to firms' operations and resulting in better performance (Huselid 1995). Furthermore, firms' initiatives to tackle social challenges can increase their products' value through customer loyalty, resilience, internal strength, and positive brand information (Sen et al. 2006). Gull et al. (2022) document that the negative impact of waste on financial performance was mitigated by the introduction of ESG performance-based compensation policies. The survival and sustainable financial development of a company rely on its environmental, social, and governance (ESG) practices (Aliani et al. 2024). For instance, investors may consider ESG practices as either an opportunity or a risk, which shows the significant role ESG plays in their investment choices (Sciarelli et al. 2021). Also, Yang et al. (2024) discuss that as companies enhance their ESG ratings, they increasingly perceive green innovation as a pivotal domain for growth. Yang et al. (2024) highlight the significant role of ESG in promoting green innovation. Porter and Kramer (2019) argue for the shared value creation, measurement, and validation which furthered the stream of research related to ESG. Thus, the essential question of the study is whether ESG strengthens the integration of eco-innovation that is supposed to affect the level of waste production negatively.

H2 *ESG moderates the relationship between Eco-innovation and waste management.*

3 Research methodology

3.1 Sample and data

This study is based on a sample of companies from G7 countries over the period from 2016 to 2020. These countries are considered as in the advanced stage of development in environmental management practices. Also, the G7 countries remarkably have achieved high economic development, in part, due to improvements in the degree of technical innovation (Meng et al. 2022). Further, companies in G7 countries are well positioned to guide companies in developing countries within the path towards sustainability because they are claimed to have a unique potential to take decisive steps towards sustainability and ability to climate change adaptation than developing countries. We extract data about G7 countries from Refinitiv Reuters. We get 6093 firms with available environmental technology and waste data. The 2016–2020 period represents a crucial time in global economic dynamics and environmental awareness, which includes significant events such as international climate agreements, regulatory shifts, and heightened societal focus on sustainability. Further, advancements in environmental technologies and evolving industry practices during this period shed light on how firms adapted to changing environmental concerns. We excluded post-2020 years not only due to data availability but also to mitigate potential effects related to the COVID-19 period, ensuring that the study's focus is on pre-pandemic dynamics. Table 1 shows the sample distribution by country. The USA has the highest number of firms (1,485) that apply environmental technology, followed by Japan (1,477). Japanese firms appear to have the highest average waste reduction.

Table 1 Sample distribution by country

Country		WM	w_Hazw	w_nonHazw	Waste_R	WRdummy	ENVINOV
Canada	N	402	295	295	402	402	402
	Mean	21.361	0.529	36.074	0.366	0.978	24.722
France	N	444	349	350	444	444	444
	Mean	0.203	0.039	0.187	0.68	0.984	50.425
Germany	N	369	293	293	369	369	369
	Mean	1.051	0.07	0.81	0.675	0.951	50.719
Italy	N	314	302	304	314	314	314
	Mean	0.541	0.025	0.514	0.643	0.981	39.772
Japan	N	1477	395	396	1477	1477	1477
	Mean	0.507	0.021	0.43	0.808	0.963	57.736
UK	N	669	330	330	669	669	669
	Mean	3.5	0.199	8.8	0.67	0.982	38.985
US	N	1485	984	987	1485	1485	1485
	Mean	2.216	0.087	5.416	0.56	0.972	41.056

Where: w_Hazw: Natural log of the total hazardous waste produced in tons; w_nonHazw: Natural log of the total non-hazardous waste produced in tons; WM: Total Waste, Natural log of the total waste produced in tons; *Waste_R*: the waste recycled variable measured as the ratio of the recycled waste to total waste generated; ENVINOV: Environmental innovation score reflects a company's capacity to reduce environmental costs. Appendix 1 provides a complete definition of the study variables

3.2 Dependent variable

The dependent variable is the firm's level of waste (WM) measured as the natural logarithm of the total waste (both hazardous and non-hazardous) generated in tons following (Benjamin et al. 2020; Gull et al. 2022; Shahab et al. 2022). As an alternative to our primary measure of waste, we separately focus on each component of waste, that is, hazardous and non-hazardous waste. Hazardous waste (w_Hazw) and non-hazardous waste (w_nonHazw) are measured as the natural logarithm of their respective levels of generated waste in tons. We then go beyond the prior literature (Benjamin et al. 2020) and consider another aspect of waste management, namely, waste recycling (R_WASTE), which is measured as the ratio of the recycled waste to total waste generated and, WM2 which is the ratio of waste to total assets. We also use a dummy variable (WRdummy) to account if the firm has a waste reduction policy (a dummy of 1 if there is a waste reduction policy and 0 otherwise). Appendix 1 provides a complete definition of the study variables.

3.3 Independent variable

The independent variable is eco-innovation (ENVINOV) in line with prior studies (Nadeem et al. 2020; Zaman et al. 2021; Albitar et al. 2023a, b). ENVINOV scores reflect a company's capacity to reduce environmental costs and burdens for its customers, thereby creating new market opportunities through further improvement in existing environmental technologies and processes or eco-designed products or processes. This eco-innovation score ranges between 0 and 100.

3.4 Control variables

We control for a number of firm's financial variables as follows.

- Liquidity (LIQ) is defined as the ratio of current assets to current liabilities. A higher current ratio implicates a higher magnitude to conduct daily operations and apply innovative ways to reduce waste and/or recycle it (Lim and Tsutsui 2012).
- Return on assets (ROA) is defined as the ratio of net income to total assets. The ROA effect on waste production was heavily investigated in the prior literature (Gull et al. 2022). Yet, the relationship might be positive or negative based on the company's life cycle, industry, and other internal managerial characteristics.
- Leverage (LEV) is measured as debt divided by total assets and is included since the capital structure influences financial performance (Zeitun and Tian 2007).
- Size (SIZE) is measured as the natural logarithm of total assets. Larger companies generally have a greater capability of implementing sustainable business models. Moreover, size affects economies of scale, environmental technology applications, and waste management strategies (Robaina and Madaleno 2020).

  Loss indicator (LOSS) is a dummy variable equal to 1 if net income is negative, and zero otherwise. It is included since there is an association between FP and financial loss faced by a firm (Byard et al. 2006).

Board characteristics were utilized by many scholars in the context of corporate social and environmental responsibility (see for example: Alfi et al. 2024; Al-Shaer et al. 2024; Rahman et al. 2024). We, therefore, also control for corporate governance variables. These include Bsize (the number of directors on the board), INDP (proportion of independent directors on the board), GD (the proportion of female directors on the board), and CSRcomm (an indicator that equals 1 if a board-level sustainability committee exists and 0 otherwise).

3.5 Moderator variable

We test the moderating effect of ESG while testing the relationship between environmental innovation and waste practices. The firm's ESG scores are extracted from Eikon Refinitiv. They reflect the companies' performance over the environmental, social, and governance factors. We believe that ESG performance may lead to better investment in environmental technology and better waste management.

3.6 Model specification

To investigate the effect of eco-innovation (*ENVINOV*) on companies' waste, this study uses two equations. The first includes the association between the dependent variable proxied by waste management, waste reduction, and recycling while controlling for the firm financial and governance characteristics (H1). We control for two sets of firms' variables: financial and governance factors. The series are transformed into their natural logarithms to ensure they conform to normal distribution. Appendix 1 provides a complete definition of the study variables.

$$WASTEit = \beta 0 + \beta 1ENVINOVit + \beta 2LiQit + \beta 3INDPit \\ + \beta 4ROAit + \beta 5LEVit + \beta 6Bsizeit + \beta 7GDit \\ + \beta 8FSit + \beta 9CSRcommit + \beta 10LOSSit \\ + \beta 11Countrydummies + \beta 12Industrydummies \\ + \beta 13Yeardummies + \varepsilon \tag{1}$$

Where: WASTE refers to the different measures of waste used in our analysis (WM; w_Hazw; w_nonHazw; Waste_R; WRdummy). t specifies the considered period for this study (2016–2020); i depicts company I; β denotes the coefficient's series; ε is the error term. All variables are explained in Appendix 1. We expect a negative relationship between ENVINOV and WM.

The second model includes the interaction term between the eco-innovation ENVINOV and the company ESG score to investigate the moderating impact of ESG on the relationship between WM and ENVINOV (H2). Appendix 1 provides a complete definition of the study variables.

$$WASTE_{it} = \beta_0 + \beta_1 ENVINOV_{it} + \beta_2 ENVINOVit * ESG_{it} \\ + \beta_3 LiQ_{it} + \beta_4 INDP_{it} + \beta_5 ROA_{it} + \beta_6 LEV_{it} + \beta_7 Bsize_{it} \\ + \beta_8 GD_{it} + \beta_9 FS_{it} + \beta_{10} CSRcomm_{it} + \beta_{11} LOSS_{it} \\ + \beta_{12} Countrydummies + \beta_{13} Industrydummies \\ + \beta_{14} Yeardummies + \varepsilon \tag{2}$$

4 Research results

4.1 Descriptive analysis

Table 2 shows the descriptive analysis. It shows that the mean of ENVINOV, 45.72, lies between a minimum of 0 and a maximum of 99.83, indicating variability in the firm's eco-innovation scores. WM has a mean of 7.19 while the maximum figure is 1570 indicating the huge level of waste produced by most of the firms' sample. This is apparent through the non-hazardous component that touches a maximum of 1510 with a high standard deviation of 82.72. The mean of the firm's waste reduction policy, 0.654, indicates that most of the studied firms tend to adopt a clear strategy to reduce waste. Table 3 presents the pair-wise Pearson correlations between all variables. There is a negative correlation (-0.179***) between WM and ENVINOV which supports our first hypothesis. Overall, there is no significant correlation above 0.70 among our control variables which means our sample is free from multicollinearity issues.

4.2 Regression results

4.2.1 The effect of ENVINOV on WM

Table 4 shows the results of regressing ENVINOV on WM (Model 1) after controlling for governance characteristics, firms' financial conditions, country, industry, and year-fixed

Table 2 Descriptive Statistics

Variable	N	Mean	p50	SD	Min	Max
Dependent Variable						
WM	5160	7.196	0.0460	65.37	0	1570
W_Hazw	2948	0.571	0.00200	6.575	0	144
W_nonHazw	2955	10.88	0.0410	82.72	0	1510
Waste R	5160	0.654	0.727	0.297	0	1.609
WRdummy	5160	0.971	1	0.167	0	1
WM2	5160	0.00100	0	0.00400	0	0.0900
Independent Variable						
ENVINOV	5160	45.72	50	31.72	0	99.83
Moderating Variable						
ESGscore	5160	63.84	65.60	15.48	5.280	94.75
Control Variables						
Bsize	5160	11.14	11	3.831	1	138
CSRcomm	5160	0.873	1	0.333	0	1
FS	5160	24.23	23.67	2.708	17.55	31.85
GD	5160	23.18	25	14.67	0	66.67
INDP	5160	58.07	60	26.98	0	100
LEV	5160	0.277	0.263	0.176	0	2.115
LiQ	5160	1.825	1.500	1.917	0.0680	57.14
LOSS	5160	0.145	0	0.352	0	1
ROA	5160	0.0390	0.0380	0.0810	-1.517	0.907

This table provides a summary statistic of variables included in our estimation models. Obs denotes the total number of observations, Std. Dev. denotes standard deviation, Min, and Max denote the minimum and maximum values for each variable used. Appendix 1 provides a complete definition of the study variables

effects. Based on the Hausman test we decided to use the fixed effect (FE) model to empirically investigate the effect of ENVINOV on WM in G7 countries. ENVINOV is negatively associated with WM and is statistically significant at the 1% level. A higher level of eco-innovation leads to a decline in the total waste produced in firms operating in G7 countries. Thus, H1 is supported. To gauge the amplitude of hazardous versus non-hazardous waste, we further our analysis by regressing ENVINOV on each waste category while controlling for governance characteristics, firms' financial conditions, and country, industry, and year-fixed effects. Table 4 (models 2 and 3) shows that ENVINOV is negatively associated with both components of waste and is statistically significant at the 1% level. Yet, the eco-innovation effect is more pronounced with the non-hazardous waste. Non-hazardous waste includes any rubbish or recycling that causes no harm, while Hazardous waste poses a severe threat to human or environmental health if improperly disposed of. This explains the importance of environmental technology and firms' pursuit and vigilance to cope with the dangerous component of waste.

4.2.2 The effect of ENVINOV on waste recycling and waste reduction

Furthermore, we complement our analysis by regressing ENVINOV on Waste Recycling (Waste_R) (Table 4, model 4) and Waste Reduction (WRdummy) (Table 4, model 5), while controlling for governance characteristics, firms' financial conditions, and country, industry,

Table 3 Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) WM	1.000										
(2) ENVINOV	-0.179***	1.000									
(3) Bsize	-0.030**	0.234***	1.000								
(4) CSRcomm	0.047***	0.157***	0.121***	1.000							
(5) FS	-0.033**	0.363***	0.282***	0.171***	1.000						
(6) GD	0.008	-0.092***	0.070***	0.079***	-0.520***	1.000					
(7) INDP	0.104***	-0.131***	-0.164***	0.036***	-0.460***	0.435***	1.000				
(8) LEV	-0.056***	-0.006	0.112***	0.055***	-0.038***	0.156***	0.194***	1.000			
(9) LiQ	0.078***	-0.101***	-0.187***	-0.134***	-0.081***	-0.182***	-0.065***	-0.365***	1.000		
(10) LOSS	0.059***	-0.094***	-0.026*	-0.004	-0.139***	0.048***	0.084***	0.141***	-0.021	1.000	
(11) ROA	-0.010	0.010	-0.056***	-0.044***	-0.016	0.019	0.044***	-0.252***	0.168***	-0.652***	1.000

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Appendix 1 provides a complete definition of the study variables and year fixed effects. This would shed light on the efforts put in by companies to reduce and recycle their levels of waste. Logit has been used when using WRdumm. Table 4 models 4 and 5 show that ENVINOV is positively associated with Waste_R and WRdummy and is statistically significant at the 1% level. This is evidence of the firm's competitive position in minimizing waste and reducing pollution and emissions through the adoption of innovative ways of production and efficient use of resources.

4.3 Robustness tests

The potential problem of reverse causality implies a possibility that WM influences ENVINOV causing a correlation between the explanatory variables and the regression's error term. We use an instrumental variable (IV) approach. Our identification of instrumental variables is informed by prior studies on environmental disclosure and performance and wider sustainability and CSR-related studies (Al-Hadi et al. 2019; Ghaly et al. 2015). The most common instrumental variables are the one-year lagged values of waste measures (L.WM, L.w_Hazw, L.w_nonHazw, L.Waste_R, & L.WRdummy) and the industry average (defined by a two-digit SIC code). More specifically, we apply an IV method using the 2SLS estimator in Table 5 (Models 1–5). To address potential bidirectional causality issues in our research, we employ the lagged one-year dependent variable (L1WM) and the industry-year average of eco-innovation as instrumental variables. This approach enhances the robustness of our analysis by considering the lagged dependent variable as a means to mitigate potential endogeneity concerns. Previous literature used lag one-year eco-innovation, industry-year average eco-innovation, or region-year average eco-innovation (Liang et al. 2022; Yu et al. 2023). We rely on several post-estimation test statistics (under-identification, weak identification, and overidentification). Our model is not under-identified as the Kleibergen-Paap rk LM statistic (Kleibergen and Paap 2006) is highly significant ($p < 0.001$).

To further verify our findings, and to address the endogeneity that arises when the dependent variable is affected by its past value, the study employs lagged regression. We lagged the independent variable (L. ENVINOV). Hence, Table 6, shows 5 models (1 to 5) by lagging 1 period for the main independent variable. This is to potentially correct endogeneity issues and provide more consistent estimates of the parameters. The endogeneity of several right-hand side variables causes trouble in multivariate analysis. We also proceed to apply two additional robustness tests. In Table 7 we use an alternative measure of WASTE which is the ratio of waste to total assets (WM2). We apply our regressions OLS with FE (model 1), lagged independent variable (model 2), 2SLS (model 3), and GMM (model 4). Through the four different tests, ENVINOV remains significant in affecting WASTE.

4.4 The moderating effect of ESG

To test H2 on the moderating impact of ESG on the relationships between ENVINOV and WASTE, we run Eq. (2) by including the interaction term between ESG and ENVINOV and using the FE regression Hausman test. Table 8 shows the findings for WM and both components of waste (hazardous and non-hazardous). The interaction effect of ENVINOV and ESG supports the importance of embracing innovation and ESG policies to reduce the level of firms' waste levels. However, the effect is negative on WM in the regression model 1. The findings in Table 8 models 2 and 3 also support our previous findings, where the

Table 4 Regression analysis of ENVINOV on WM

VARIABLES	(1)	(2)	(3)	(4)	(5)
	WM	w_Hazw	w_nonHazw	Waste_R	WRdummy
ENVINOV	-0.09***	-0.00***	-0.19***	0.00***	0.02***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Bsize	-0.17	0.00	-0.81**	0.00***	0.04
	(0.12)	(0.96)	(0.02)	(0.00)	(0.30)
CSRcomm	0.67	-0.04	-2.31	-0.02	1.89***
	(0.30)	(0.15)	(0.27)	(0.16)	(0.00)
FS	4.15***	0.12***	9.96***	-0.01	0.32***
	(0.00)	(0.00)	(0.00)	(0.10)	(0.01)
GD	-0.06*	0.00**	-0.02	0.00	0.03**
	(0.10)	(0.04)	(0.87)	(0.31)	(0.01)
INDP	-0.04***	0.00	-0.16***	-0.00***	0.00
	(0.00)	(0.42)	(0.00)	(0.00)	(0.73)
LEV	-2.33	-0.31***	-6.37	0.03	0.02
	(0.22)	(0.00)	(0.14)	(0.29)	(0.98)
LiQ	0.44	0.01	-0.26	-0.01***	0.15
	(0.16)	(0.58)	(0.75)	(0.01)	(0.13)
LOSS	1.29	-0.09	2.42	0.01	-0.08
	(0.34)	(0.20)	(0.48)	(0.57)	(0.85)
ROA	2.60	-0.22	3.16	0.16*	-1.22
	(0.77)	(0.57)	(0.87)	(0.06)	(0.63)
Constant	-88.00***	-2.75***	-195.79***	0.76***	-8.73***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	5,159	2,948	2,955	5,159	3,752
R-squared	0.330	0.165	0.323	0.397	0.372
Industry FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Appendix 1 provides a complete definition of the study variables

non-hazardous waste component is more intensively affected than the hazardous one by the combination of eco-innovation and ESG practices. On the other hand, the effect of the interaction term on WRdummy turns out to be the opposite of our previous results. In this regard, it might be possible that G7 firms have reached high ESG scores and they need to commit to sustainable waste management practices by heavily relying on environmental innovation. This sheds light on the importance of this later variable and its preponderant role in the interplay of ESG and waste management. To conclude, our results corroborate with (Mishra and Suar 2010; Nadeem et al. 2020; Velte 2016), who state that firms' environmental orientation and engagement toward society (e.g., waste reduction and recycling) can positively influence stakeholders, including consumers who usually assign a higher value to products from companies with good citizenship. In addition, our results are in line with Gull et al. (2022), who document that the negative impact of waste on financial performance was mitigated by the introduction of ESG performance-based compensation policies.

To enhance the robustness of our conclusions, we conducted a re-analysis, introducing each dimension of Environmental, Social, and Governance (ESG) as a separate moderator. Table 9 presents the outcomes, illustrating the direct influence of environmental, social, and

Table 5 2SLS Regression analysis of ENVINOV on WM

VARIABLES	(1)	(2)	(3)	(4)	(5)
	WM	w_Hazw	w_nonHazw	Waste_R	WRdummy
ENVINOV	-0.08***	-0.00	-0.17***	0.00***	0.02***
	(0.00)	(0.71)	(0.00)	(0.00)	(0.00)
Bsize	-0.08	-0.00	-0.64**	0.01***	0.05
	(0.35)	(0.83)	(0.02)	(0.00)	(0.22)
CSRcomm	0.56	-0.03*	-1.61	-0.01	1.93***
	(0.38)	(0.09)	(0.45)	(0.36)	(0.00)
FS	3.10***	0.05***	8.44***	-0.01**	0.34***
	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)
GD	-0.05**	0.00*	-0.02	0.00	0.03***
	(0.03)	(0.09)	(0.78)	(0.20)	(0.01)
INDP	-0.03**	0.00	-0.13***	-0.00***	0.01
	(0.04)	(0.20)	(0.00)	(0.00)	(0.43)
LEV	-2.17	-0.10***	-4.00	0.01	-0.17
	(0.11)	(0.00)	(0.35)	(0.76)	(0.82)
LiQ	-0.20	-0.00	-0.92**	-0.01***	0.16*
	(0.14)	(0.74)	(0.02)	(0.00)	(0.06)
LOSS	1.14*	-0.02	3.31	-0.00	-0.08
	(0.10)	(0.21)	(0.11)	(0.67)	(0.83)
ROA	2.79	-0.00	5.72	0.04	-0.65
	(0.37)	(0.96)	(0.54)	(0.45)	(0.67)
Constant	-55.84***	-1.09***	-157.52***	0.65***	-9.60***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	5,248	2,964	2,969	5,248	2,906
R-squared	0.350	0.194	0.332	0.389	
Industry FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Appendix 1 provides a complete definition of the study variables

governance scores on WM, w_Hazw, and w_nonHazw. Furthermore, the moderating impact of each dimension on the relationship between ENVINOV and waste management was assessed individually, aligning with our main findings. Consistent with our results, these findings reinforce the significant role of environmental, social, and governance factors in shaping the ENVINOV and WM relationship. To ensure the robustness of our results, we conducted an additional analysis by excluding governance variables as controls. Remarkably, Table 10 shows that the outcomes remained consistent, underscoring the reliability of our findings in this supplementary analysis.

5 Discussion

Our findings suggest that companies in G7 intensively investing in eco-innovation are more adept at decreasing their waste levels by integrating eco-friendly practices that account for waste recyclability. Furthermore, the baseline model indicates that eco-innovation and waste levels are negatively associated, which implies that a higher level of eco-innovation

Table 6 Regression analysis of ENVINOV on WASTE (lagged independent variable)

VARIABLES	(1)	(2)	(3)	(4)	(5)
	WM	w_Hazw	w_nonHazw	Waste_R	WRdummy
L.ENVINOV	-0.09***	-0.00***	-0.18***	0.00***	0.02***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Bsize	-0.17	0.00	-0.83**	0.01***	0.05
	(0.14)	(0.73)	(0.02)	(0.00)	(0.23)
CSRcomm	0.75	-0.03	-2.59	-0.01	2.00***
	(0.28)	(0.27)	(0.27)	(0.31)	(0.00)
FS	4.29***	0.13***	10.24***	-0.01*	0.35***
	(0.00)	(0.00)	(0.00)	(0.08)	(0.01)
GD	-0.07*	0.00**	-0.02	0.00	0.04**
	(0.09)	(0.03)	(0.86)	(0.28)	(0.01)
INDP	-0.05***	0.00	-0.17***	-0.00***	0.00
	(0.00)	(0.34)	(0.00)	(0.00)	(0.67)
LEV	-2.30	-0.31***	-5.36	0.03	-0.10
	(0.25)	(0.00)	(0.23)	(0.35)	(0.91)
LiQ	0.55*	0.01	-0.08	-0.01***	0.15
	(0.09)	(0.43)	(0.93)	(0.00)	(0.16)
LOSS	1.46	-0.09	3.01	0.01	0.05
	(0.31)	(0.21)	(0.41)	(0.61)	(0.92)
ROA	2.04	-0.24	3.66	0.17*	-1.04
	(0.82)	(0.55)	(0.85)	(0.05)	(0.70)
Constant	-91.88***	-2.89***	-202.81***	0.77***	-9.74***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	4,977	2,829	2,834	4,977	2,812
R-squared	0.340	0.170	0.332	0.403	0.345
Industry FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Appendix 1 provides a complete definition of the study variables

could lead to a decline in the total waste produced in firms operating in G7 countries, in line with Elkington (2006) and Gull et al. (2022). This finding is accentuated by the economic heft, technology leadership, and international alliances in G7. As a result, such countries are assigned a special role in leading the way, inspiring successful energy schemes, and initiating food waste reduction to meet SDGs. In the same vein, our results reflect how G7 countries strive to embrace the policy of "*Achieving Net Zero Heavy Industry Sectors* " and the transition circular economy.

On a narrower level, as waste is generally classified as hazardous or non-hazardous, we analyze the effect of eco-innovation on each component and deduce that the effect is more pronounced with non-hazardous waste. This explains the importance of sophisticated technology and firms' pursuit and vigilance to cope with the dangerous component of waste. Our findings are in line with Benjamin et al. (2020), Shahab et al. (2022), and Gull et al. (2022). So far, our first hypothesis is well supported. The negative effect between our main dependent/independent variables is expected. Yet, the most intriguing part resides in depicting firms' magnitude of reusing and recycling waste. Indeed, waste can cease to be waste if it can become a secondary raw material. In this sense, waste management can cover a large

Table 7 Regression analysis of ENVINOV on alternative measure of WASTE

VARIABLES	(1)	(2)	(3)	(4)
	WM2	WM2	WM2	WM2
L.WM2				0.31***
				(0.00)
ENVINOV	-0.00***		-0.00***	0.00
	(0.00)		(0.00)	(0.78)
L1ENVINOV		-0.00***		
		(0.00)		
Bsize	-0.00	-0.00	0.00***	-0.00
	(0.28)	(0.37)	(0.00)	(0.56)
CSRcomm	0.00*	0.00**	0.00***	0.00
	(0.08)	(0.02)	(0.00)	(0.26)
FS	0.00***	0.00***	0.00***	-0.00**
	(0.00)	(0.00)	(0.00)	(0.03)
GD	-0.00**	-0.00**	-0.00	-0.00
	(0.01)	(0.01)	(0.56)	(0.53)
INDP	-0.00	-0.00	0.00***	0.00**
	(0.55)	(0.50)	(0.00)	(0.03)
LEV	-0.00***	-0.00***	-0.00**	0.00***
	(0.00)	(0.00)	(0.02)	(0.00)
LiQ	0.00	0.00*	-0.00***	-0.00
	(0.17)	(0.06)	(0.00)	(0.79)
LOSS	0.00	0.00	-0.00	0.00
	(0.86)	(0.69)	(0.59)	(0.62)
ROA	-0.00	-0.00	-0.00	-0.00
	(0.86)	(0.88)	(0.30)	(0.14)
Constant	-0.01***	-0.01***	-0.04***	0.00
	(0.00)	(0.00)	(0.00)	(.)
Observations	5,159	4,977	4,523	3,988
R-squared	0.364	0.380	0.498	
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Appendix 1 provides a complete definition of the study variables

share of the economic loss and can contribute considerably to sustainability (Verhoef et al. 2006). Accordingly, we re-run our regressions to test the effect of eco-innovation on waste recycling and reduction policies. We found a positive and statistically significant association between ENVINOV and Waste_R and WRdummy. This is evidence of the firm's competitive position in minimizing waste and reducing pollution and emissions through the adoption of innovative ways of production and efficient use of resources. Our findings are in line with Adnouni et al. (2022); Giannakis and Bruggeman (2017); and Hübler and Löschel (2013). In this context, it would be worth segregating the analysis from two distinct points of view. On a macroeconomic level, it is very important to analyze how to synchronize strategies that can speed up technology development to overcome the high costs of waste reduction and decouple economic growth from environmental impacts. In a circular economy, discarded materials represent a valuable resource that can be retained with benefits

Table 8 Regression analysis of ENVINOV on WM with the moderating effect of ESG

VARIABLES	(1)	(2)	(3)	(4)	(5)
	WM	w_Hazw	w_nonHazw	Waste_R	WRdummy
ENVINOV	0.23***	0.01***	0.71***	0.00***	0.01
	(0.00)	(0.00)	(0.00)	(0.00)	(0.54)
ESGscore	0.43***	0.01***	1.07***	-0.00	0.10***
	(0.00)	(0.00)	(0.00)	(0.98)	(0.00)
ENVINOV*ESGscore	-0.01***	-0.00***	-0.01***	-0.00***	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.68)
Bsize	-0.18*	0.00	-0.72**	0.00***	0.08*
	(0.09)	(0.85)	(0.03)	(0.00)	(0.07)
CSRcomm	-2.38***	-0.10***	-8.27***	-0.01	1.07***
	(0.00)	(0.00)	(0.00)	(0.47)	(0.00)
FS	3.44***	0.11***	8.12***	-0.00	-0.06
	(0.00)	(0.00)	(0.00)	(0.71)	(0.64)
GD	-0.11***	0.00	-0.14	0.00	0.00
	(0.00)	(0.10)	(0.15)	(0.14)	(0.86)
INDP	-0.07***	-0.00	-0.22***	-0.00**	-0.01*
	(0.00)	(0.99)	(0.00)	(0.03)	(0.08)
LEV	-2.11	-0.29***	-5.21	0.03	0.67
	(0.26)	(0.00)	(0.21)	(0.33)	(0.44)
LiQ	0.52*	0.01	-0.14	-0.01***	0.15
	(0.10)	(0.52)	(0.86)	(0.01)	(0.17)
LOSS	1.62	-0.08	3.43	0.01	0.10
	(0.23)	(0.26)	(0.31)	(0.60)	(0.82)
ROA	3.58	-0.24	0.89	0.16*	-0.83
	(0.68)	(0.53)	(0.96)	(0.06)	(0.76)
Constant	-91.11***	-2.99***	-206.50***	0.63***	-2.62
	(0.00)	(0.00)	(0.00)	(0.00)	(0.36)
Observations	5,159	2,948	2,955	5,159	3,752
R-squared	0.350	0.176	0.350	0.400	0.449
Industry FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Appendix 1 provides a complete definition of the study variables

in environmental, economic, and social domains (Gull et al. 2022). On a microeconomic level, companies tend to find the optimal scenario between investments in environmental technology and resource efficiency plans (value of waste prevention; preparing for re-use; recycling; recovery; and disposal).

Furthermore, it becomes very challenging to derive firms' positive attributes and main drivers to embrace eco-innovations. For instance, cash holdings, debt level, corporate governance, and financial performance might be the main determinants. Yet, as our central question is highly entangled with the ecological and environmental corporate attitudes, managerial and strategic corporate actions are important points to account for. Ecology and sociology are embedded into business and economics under the aegis of corporate boards and top-management teams. More centrally, ethical governance mechanisms, board diversity, female directors, and firm-level initiatives toward ESG performance-based compensa-

Table 9 Regression analysis of ENVINOV on WASTE with the moderating effect of component ESG

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	WM	w_Hazw	w_nonHazw	WM	w_Hazw	w_nonHazw	WM	w_Hazw	w_nonHazw
ENVINOV	0.02	0.00**	0.14**	0.11***	0.01***	0.44***	0.04	0.00**	0.15*
	(0.39)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.18)	(0.04)	(0.09)
E	0.25***	0.01***	0.71***						
	(0.00)	(0.01)	(0.00)						
S				0.22***	0.01***	0.61***			
				(0.00)	(0.00)	(0.00)			
G							0.11***	0.00**	0.30***
							(0.00)	(0.04)	(0.00)
ENVINOV*E	-0.00***	-0.00***	-0.01***						
	(0.00)	(0.00)	(0.00)						
ENVINOV*S				-0.00***	-0.00***	-0.01***			
				(0.00)	(0.00)	(0.00)			
ENVINOV*G							-0.00***	-0.00***	-0.01***
							(0.00)	(0.00)	(0.00)
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Constant	-69.77***	-2.76***	-167.90***	-75.07***	-2.89***	-185.84***	-77.35***	-2.91***	-184.34***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	5,157	2,947	2,954	5,157	2,947	2,954	5,157	2,947	2,954
R-squared	0.360	0.169	0.353	0.360	0.175	0.350	0.351	0.169	0.337
Industry FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES	YES	YES	YES	YES

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Appendix 1 provides a complete definition of the study variables tion might influence firms' environmental orientation (Velte 2016). Thus, we integrate the moderating effect of ESG and test the effect on our baseline model. We deduce that firms' environmental orientation and engagement toward society (e.g., waste reduction and recycling) can positively influence all stakeholders.

6 Conclusion

As most of the existing studies have extensively emphasized the effect of technological advancement on CO2 emissions from the macroeconomic level and some of them have investigated the effect of technology on corporate performance, the present study aims to ponder the effect of the magnitude of green or environmental technology on waste management from microeconomic perspectives. To emphasize, previous studies treated environmental technology and firm characteristics as general explanatory variables of performance, while we attempted to explore the effect of the technological environment on waste management. Our sample is composed of companies from G7 countries for 2016–2020. Data is extracted from Eikon Refinitiv. We apply panel data regressions while controlling for firms' financial and governance characteristics. We proxied the dependent variable in different measures to shed light on companies' waste production as a standalone variable and as a ratio to weigh the relative effect on total assets, efficient resource use, and innovative recycling policies and techniques. We also perform robustness tests and account for the interaction between firms' environmental, social, and governance (ESG) scores and eco-innovation.

Findings indicated that eco-innovation and waste levels are negatively associated, implying that a higher level of eco-innovation could lead to a decline in the total waste produced in firms operating in G7 countries. When dissecting waste components into hazardous and non-hazardous, we deduced that the eco-innovation effect is more pronounced with the non-hazardous waste. Non-hazardous waste includes any rubbish or recycling that causes no harm, while Hazardous waste poses a severe threat to human or environmental health if improperly disposed of. This explains the importance of sophisticated technology and firms' pursuit and vigilance to cope with the dangerous component of waste. Intrinsically, it became important to gauge firms' magnitude of reusing and recycling waste and uncover the economic benefits of such green practices. Accordingly, we re-ran our regressions to test the effect of eco-innovation on waste recycling and reduction policies. We found a positive and statistically significant association between ENVINOV and Waste_R and WRdummy. This is evidence of the firm's competitive position in minimizing waste and reducing pollution and emissions through the adoption of innovative production and efficient use of resources. Our findings are in line with Albitar et al. (2023a). Our results remained the same after applying several robustness tests. Finally, we use ESG in our model as a moderator. We got the same results except with WRdummy, which turned out to be the opposite of our previous results.

Furthermore, the study has many implications on micro- and macroeconomic levels. On a microeconomic level, it elucidates the strategic role of companies towards environmental preservation and waste management. Our findings pinpoint the importance of corporate green technology innovations as they are the drivers to mitigate the devastating effects of pollution and environmental calamities while boosting economic growth. Nowadays, big

Table 10 Regression analysis of ENVINOV on WASTE with the moderating effect of ESG, without governance variables

VARIABLES	(1)	(2)	(3)	(4)	(5)
	WM	w_Hazw	w_nonHazw	Waste_R	WRdummy
ENVINOV	0.24***	0.01***	0.71***	0.00***	0.01
	(0.00)	(0.00)	(0.00)	(0.00)	(0.27)
ESGscore	0.39***	0.01***	0.97***	-0.00	0.10***
	(0.00)	(0.00)	(0.00)	(0.78)	(0.00)
ENVINOV*ESGscore	-0.01***	-0.00***	-0.01***	-0.00***	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.47)
CSRcomm	-2.22***	-0.10***	-8.29***	-0.01	1.08***
	(0.00)	(0.00)	(0.00)	(0.61)	(0.00)
FS	3.11***	0.11***	7.24***	0.00	-0.01
	(0.00)	(0.00)	(0.00)	(0.50)	(0.92)
LEV	-2.09	-0.29***	-6.40	0.03	0.56
	(0.27)	(0.00)	(0.12)	(0.28)	(0.52)
LiQ	0.57*	0.01	0.06	-0.01**	0.13
	(0.07)	(0.59)	(0.94)	(0.01)	(0.22)
LOSS	1.42	-0.07	3.05	0.01	-0.02
	(0.29)	(0.28)	(0.37)	(0.55)	(0.96)
ROA	2.47	-0.22	-0.37	0.16*	-1.61
	(0.78)	(0.55)	(0.98)	(0.06)	(0.55)
Constant	-89.41***	-3.00***	-205.16***	0.57***	-3.57
	(0.00)	(0.00)	(0.00)	(0.00)	(0.21)
Observations	5,159	2,948	2,955	5,159	3,752
R-squared	0.346	0.175	0.344	0.397	0.443
Industry FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES

*** $p<0.01$, ** $p<0.05$, * $p<0.1$. Appendix 1 provides a complete definition of the study variables

companies struggle to take the lead and act as role models towards their surrounding partners. Failure to do so can substantially deteriorate firms' glamorous image and eradicate its reputation. On a macroeconomic level, countries should revisit their national strategies and domestic policies to form international alliances and embrace more technological development towards more sustainable materials management, resource productivity, or the circular economy. Future research would account for national environmental policies, labelling, and public financial support. Examples of approaches that can generate environmentally effective and economically efficient outcomes include Extended Producer Responsibility (EPR), Green Public Procurement (GPP), integrated lifecycle analysis, or partnerships with businesses and stakeholders across the value chain to support industrial symbiosis and innovation for improved eco-design. Another research stream would also address the level of municipal waste within the same country to instil creative and innovative solutions vested on the level of each municipality and the degree of innovation intensity. Also, while our study excluded post-2020 years, there is an opportunity for future research to explore the impact of eco-innovation on waste management during the COVID-19 period or after.

Appendix 1: variables definitions

WM	Total Waste, Natural log of the total waste produced in tons.
ENVINOV	ENVINOV scores reflect a company's capacity to reduce environmental costs and burdens for its customers. Eco-innovation score ranges between 0 and 100.
LiQ	Liquidity measured by current ratio.
LEV	Debt to total asset ratio
ROE	Return on equity ratio measured by net income to total equity
FS	Natural log of total assets
INDP	The proportion of independent directors on the board.
Bsize	The number of directors on the board.
GD	The proportion of female directors on the board.
CSRcomm	An indicator variable that equals 1 if a board-level sustainability committee exists, and 0 otherwise.
LOSS	An indicator variable equal to one when the current year's net income is negative, and zero otherwise
Country	Country dummies (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States)
Industry	A set of industry indicators based on RSN classification.
t	Year dummies, 2016, 2017, 2018, 2019 and 2020
Alternate measures	
w_Hazw	Natural log of the total hazardous waste produced in tons.
w_nonHazw	Natural log of the total non-hazardous waste produced in a ton
Waste_R	The ratio of the recycled waste to total waste generated
waste reduction	Dummy, waste reduction policy
WM2	Waste to total assets
Moderator variable	
ESG	Eikon Refinitiv ESG scores measure a company's relative ESG performance.

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