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# Environmental innovation and carbon emissions reduction in European healthcare: The moderating role of environmental monitoring practices

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ABSTRACT

This study examines the impact of environmental innovation on carbon emissions in the healthcare sector, with a focus on the moderating role of environmental monitoring. Using a panel dataset of 1210 publicly listed healthcare firms across ten European countries from 2012 to 2021, the study investigates the nuanced dynamics between innovation, monitoring, and emissions outcomes. The findings highlight a critical challenge, as innovation efforts can initially intensify environmental pressures due to increased energy consumption, resource use, or operational expansion. However, the integration of robust environmental monitoring significantly mitigates this effect, ensuring that innovation translates into measurable reductions in emissions over time. Additional analyses demonstrate that environmental innovation significantly influences emissions for both loss-making and profitable firms, but the effects vary in scope and magnitude. Moreover, monitoring plays a critical role in both loss-making and profitable organizations to optimize the outcomes of environmental innovation. The study contributes to the literature by highlighting the critical role of environmental monitoring in bridging the gap between innovation and sustainability, providing empirical support for both institutional theory and stakeholder theory. It also offers practical implications for managers and policymakers, emphasizing the importance of integrating monitoring systems into innovation strategies to enhance accountability and achieve long-term emissions reductions. This research concentrates on the healthcare sector, addressing an important gap in understanding the alignment of environmental practices with sustainability goals in industries marked by intricate environmental footprints and regulatory frameworks.

## 1. Introduction

The healthcare sector in Europe is increasingly recognized as a significant contributor to environmental pollution and carbon emissions, driven largely by energy-intensive operations, substantial waste generation, and the use of hazardous substances (Yang and Usman, 2021). Given the sector's environmental footprint, there has been an intensified focus on sustainability, with stakeholders—ranging from regulatory bodies to patients—demanding both transparency in emissions reporting and genuine efforts to reduce carbon emissions. Achieving meaningful reductions in carbon emissions has become a crucial objective, as it demonstrates a firm's environmental responsibility and enhances accountability and builds trust among stakeholders (Cai et al., 2020; Al-Qahtani and Elgharbawy, 2020). The urgency for carbon reduction in healthcare is heightened by the sector's unique position; as institutions dedicated to health and well-being, healthcare providers face an ethical imperative to mitigate environmental harms that could adversely affect public health.

Environmental innovation, encompassing the development of new products, processes, or practices that reduce environmental impact, is posited to be a driving force for lowering carbon emissions in operations of various organizations (Li et al., 2023a). In the European healthcare sector, environmental innovation can manifest through energy-efficient technologies, green procurement strategies, and waste minimization practices—each of which directly contributes to a lower carbon footprint (Romano et al., 2024; Xiu et al., 2023). Prior research underscores

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that organizations investing in environmental innovation are better positioned to manage and report reductions in emissions, as innovations often enable more precise measurement of environmental impact and offer clear pathways for improvement (Töbelmann and Wendler, 2020). However, the effectiveness of these innovations largely depends on robust support systems that can track and validate reductions in emissions, emphasizing the need for integration with environmental monitoring mechanisms.

A robust monitoring framework establishes the foundation for accountable environmental practices, laying the groundwork for effective carbon reduction initiatives across industries, including healthcare. Through well-defined monitoring structures, businesses align with environmental policies and standards that reinforce transparency and compliance with emissions reduction targets (Khatib and Al Amosh, 2023). In healthcare, such monitoring involves adopting green policies, adhering to sustainability guidelines, and meeting regulatory standards that drive systematic and measurable efforts to cut carbon emissions (Subramaniam et al., 2024). Furthermore, a systematic monitoring approach fosters a culture of environmental responsibility, motivating companies to implement advanced practices that enhance emissions transparency and facilitate ongoing carbon reduction (Li et al., 2023b). When combined with broader organizational commitments, monitoring acts as a key pillar of sustainability, ensuring that environmental innovations are pursued within a framework of accountability.

Environmental monitoring plays a pivotal role in environmental practices aimed at reducing pollution. By systematically tracking and analyzing emissions data, organizations gain critical insights into their environmental performance, thereby enhancing the accuracy and effectiveness of their carbon reduction strategies (Olivares-Rubio and Vega-López, 2016). In sectors with stringent regulatory requirements like healthcare, environmental monitoring ensures compliance with emissions reduction standards while promoting a culture of continuous improvement (Sattar et al., 2019). Research has demonstrated that environmental monitoring enhances an organization's capacity to implement, evaluate, and improve its environmental initiatives and measurable reductions in carbon emissions by supplying organizations with the data necessary to support, assess, and refine their sustainability practices (Villarreal et al., 2017). Therefore, monitoring facilitates more transparent disclosures and substantiates an organization's commitment to reducing its carbon footprint.

Despite an expanding body of literature on environmental innovation and carbon emissions reduction (e.g., David et al., 2024; Chang et al., 2023), most existing research has centered on heavily polluting industries—such as manufacturing and energy—rather than the healthcare sector. Moreover, prior studies have largely focused on the direct influence of innovation on emissions, with limited consideration of the mediating mechanisms that facilitate effective emissions management (Töbelmann and Wendler, 2020). Consequently, there remains a notable gap in understanding how environmental innovation interacts with a systematic monitoring framework to reduce emissions, especially in the healthcare context. This gap is especially critical because healthcare organizations operate under unique regulatory constraints and ethical imperatives, yet they also have the potential to drive major sustainability gains through targeted innovations. Recognizing these complexities, this study investigates the impact of environmental innovation on carbon emissions reduction in the European healthcare sector, emphasizing the mediating role of environmental monitoring. In doing so, it diverges from earlier studies by addressing the overlooked dimensions of healthcare-specific compliance, stakeholder pressures, and rigorous monitoring mechanisms, thus offering a novel perspective on environmental accountability.

This study makes several key contributions to the existing literature by investigating how environmental innovation can drive carbon emissions reduction in the European healthcare sector. First, it addresses a critical research gap by focusing on a field where regulatory pressures and ethical imperatives create distinct environmental challenges. Although a considerable number of studies have examined sustainability in other industries, relatively few have analyzed how healthcare organizations adopt and implement environmental innovations to minimize their carbon footprints. By highlighting sector-specific practices—such as energy-efficient medical technologies and sustainable waste management strategies—this research illustrates the importance of industry-tailored solutions for improving emissions outcomes. In doing so, it broadens the wider sustainability debate, emphasizing how healthcare-centric innovations can offer transformative potential for addressing both institutional constraints and environmental responsibilities.

Second, this research offers a novel theoretical contribution by integrating stakeholder theory and institutional theory to analyze the relationship between environmental innovation and emissions reduction through the mediating role of environmental monitoring. Stakeholder theory emphasizes the need for healthcare organizations to align their sustainability initiatives with the expectations of diverse stakeholders, including regulators, patients, and the public. Institutional theory complements this perspective by highlighting the influence of regulatory pressures, industry norms, and social expectations in shaping organizational practices. The study underscores the necessity for healthcare organizations to not only implement sustainable practices but also demonstrate accountability through robust and transparent emissions reporting. Environmental monitoring emerges as a critical mechanism that links innovation efforts with accountability frameworks, ensuring that healthcare organizations can navigate institutional demands while fulfilling stakeholder expectations. By advancing this theoretical integration, the research provides a comprehensive understanding of how healthcare organizations can simultaneously achieve regulatory compliance, foster stakeholder trust,

Third, the study contributes methodologically by leveraging a rich panel dataset of 1210 publicly listed healthcare firms from ten European countries over the period 2012 to 2021. Through rigorous empirical analysis, it reveals that while environmental innovation often correlates with increased emissions initially—due to the resource-intensive nature of innovation implementation—the presence of effective environmental monitoring can significantly mitigate these adverse effects. These findings challenge traditional assumptions that innovation directly reduces emissions, offering a more nuanced understanding of the transitional dynamics in sustainability initiatives. Finally, the research provides a practical framework for healthcare organizations and policymakers by demonstrating how environmental innovation and monitoring can complement each other to achieve long-term emissions reductions. It highlights the importance of integrating technological advancements with accountability measures to address both environmental and social dimensions of sustainability. These contributions not only advance academic discourse but also offer actionable insights for fostering sustainability within highly regulated and publicly accountable sectors like healthcare. By doing so, the study sets the stage for future research to build on its findings and explore innovative pathways to sustainability in other critical industries.

The structure of the article is organized as follows: Section 2 provides the background, outlining the environmental challenges in the healthcare sector. Section 3 presents the theoretical literature review, followed by Section 4, which covers the empirical literature review and hypotheses development. Section 5 details the research design, while Section 6 discusses the empirical results and their implications. Finally, Section 7 concludes the paper, summarizing the main findings and their relevance for policy and practice.

## 2. Background of the study

The healthcare sector in Europe is uniquely positioned at the intersection of public health, environmental responsibility, and regulatory compliance, making it a critical area for exploring environmental innovations aimed at reducing carbon emissions. As one of the most energy-intensive sectors, healthcare significantly contributes to environmental pollution and greenhouse gas emissions. Studies indicate that healthcare activities account for approximately 4.4% of global emissions, with a notable share originating from high-income regions, including Europe (Karliner et al., 2020). This high environmental impact, combined with the healthcare sector's ethical mandate to protect public health, amplifies the importance of adopting sustainable practices that not only improve environmental performance but also support the sector's commitment to societal well-being. As such, exploring carbon emissions reduction within the healthcare context is not only relevant but also necessary, as reducing emissions can mitigate the adverse health effects associated with environmental degradation.

In recent years, the European Union (EU) has introduced several regulatory frameworks and policy reforms aimed at promoting environmental sustainability across all sectors, with a particular focus on carbon emissions. The European Green Deal, introduced in 2019, exemplifies the EU's commitment to becoming the world's first climate-neutral continent by 2050. This ambitious policy framework seeks to reduce net greenhouse gas emissions by at least 55% by 2030, a target that necessitates significant transformations in carbon-intensive industries, including healthcare (European Commission, 2020). The Green Deal's emphasis on decarbonization, resource efficiency, and pollution reduction directly impacts healthcare providers, who are now compelled to align their operations with these overarching environmental objectives. In this regulatory context, environmental innovation emerges as a strategic response, enabling healthcare organizations to comply with stringent emissions standards while also achieving operational sustainability.

Alongside the Green Deal, sector-specific initiatives and regulations further underscore the relevance of studying environmental innovation in healthcare. The European Climate Law, adopted in 2021, legally binds EU member states to emissions reduction targets, reinforcing the urgency for industries to develop and adopt carbon reduction strategies. The healthcare sector, with its substantial carbon footprint, faces increasing pressure to comply with these legal mandates, which aim to integrate sustainability into operational and strategic frameworks across the region. Many countries within the EU have introduced additional policies specific to healthcare, such as green procurement requirements and energy-efficiency standards for medical facilities. These measures incentivize healthcare organizations to adopt environmentally innovative practices, which include energy-efficient equipment, waste reduction strategies, and renewable energy adoption, as viable paths to compliance and emissions reduction.

Furthermore, environmental monitoring has become an essential component of Europe's regulatory approach to sustainability, acting as a compliance tool that enables organizations to track their environmental performance and demonstrate adherence to emissions targets. Under the EU's Environmental Liability Directive and other emissions-related legislation, healthcare providers are required to implement monitoring systems that report on various environmental metrics, including carbon emissions. Such regulatory requirements not only reinforce the importance of environmental monitoring but also create an environment where organizations are held accountable for their environmental impact. By adopting robust monitoring practices, healthcare providers can both comply with regulatory demands and build trust with stakeholders, who increasingly demand transparency regarding environmental responsibility.

The healthcare sector's unique combination of ethical imperatives, high energy consumption, and regulatory scrutiny establishes an ideal context for investigating the moderating role of environmental monitoring on the relationship between environmental innovation and carbon emissions reduction. Healthcare organizations are confronted with a dual mandate: to prioritize patient care and safety while minimizing their environmental impact. This duality positions environmental innovation as a critical pathway for meeting sustainability objectives without compromising healthcare quality. Moreover, given the sector's accountability to a wide array of stakeholders—including patients, regulatory bodies, and the public—the role of environmental monitoring is amplified as a means of substantiating and communicating the impact of these innovations. This context, shaped by regulatory, policy, and ethical pressures, makes the European healthcare sector an ideal setting for examining how environmental innovations and monitoring practices together contribute to achieving meaningful reductions in carbon emissions.

## 3. Theoretical literature review

Stakeholder theory, as introduced by Freeman (1984), posits that organizations must consider the interests of all stakeholders—entities or individuals who can affect or are affected by the organization's activities—in their decision-making processes. In the context of the healthcare sector, stakeholders include patients, healthcare providers, regulatory bodies, employees, environmental advocacy groups, and the general public. Each group has distinct expectations regarding the healthcare sector's role in environmental sustainability and carbon emissions reduction. Thus, healthcare organizations can enhance their social license to operate, foster trust, and demonstrate accountability, ultimately contributing to sustainable outcomes by prioritizing the needs and expectations of these stakeholders.

Healthcare, like other sector providers, is under increasing pressure from stakeholders to adopt sustainable practices that mitigate environmental impacts and reduce carbon emissions. The growing emphasis on environmental accountability has led stakeholders to demand that healthcare organizations implement innovations—such as energy-efficient technologies, sustainable procurement strategies, and waste reduction initiatives—that directly contribute to carbon emissions reduction. Like regulatory bodies, stakeholders exert considerable influence by setting standards and expectations around carbon emissions in healthcare. Compliance with these standards is legally required and signals that an organization is aligned with public and regulatory expectations regarding environmental stewardship. In response, healthcare organizations are incentivized to adopt environmental innovations to meet regulatory standards, reduce carbon emissions, and enhance their reputation as socially responsible entities.

Additionally, internal stakeholders, such as employees, are becoming increasingly aware of environmental issues and may advocate for sustainable practices within the organization (Al Amosh and Khatib, 2023). Employees expect their institutions to align with broader societal goals, including environmental protection and carbon reduction (David et al., 2024). By adopting environmental innovations and monitoring systems that allow for transparent emissions reporting, healthcare organizations can strengthen employee engagement and cultivate a workplace culture that prioritizes sustainability, thereby fulfilling stakeholder expectations from within. External stakeholders, particularly patients and the community, are also critical. Patients increasingly expect healthcare providers to operate in an environmentally responsible manner, as the healthcare sector's environmental impact is closely linked to public health. Environmental innovations, therefore, are not merely technological upgrades; they signify a commitment to protecting community health by reducing the sector's carbon footprint (Nguyen et al., 2021). By meeting these expectations, healthcare organizations build trust and legitimacy with the communities they serve.

In this context, environmental monitoring plays a mediating role in demonstrating to stakeholders the efficacy and transparency of emissions reduction efforts. Through rigorous data tracking and emissions reporting, healthcare organizations can provide stakeholders with clear evidence of their commitment to reducing carbon emissions. Monitoring systems thus serve as a bridge between environmental innovation and stakeholder accountability, reinforcing that the organization's sustainable practices are effective and measurable.

Institutional theory, as conceptualized by DiMaggio and Powell (1983), posits that organizations are subject to various institutional pressures—norms, rules, and expectations—that compel them to adopt practices aligning with societal values to gain legitimacy. This sector faces mounting scrutiny from regulatory bodies, stakeholders, and the public, who demand that healthcare organizations integrate sustainable practices, particularly those that mitigate carbon emissions and demonstrate environmental responsibility. Formal regulations, such as the European Union's Green Deal and various healthcare-specific sustainability directives, exert coercive pressures that require healthcare providers to comply with standards around emissions reduction and environmental reporting (Candio, 2024). These pressures are not merely suggestions but impose legal and financial consequences for non-compliance, prompting healthcare organizations to invest in environmental innovations such as energy-efficient technology, waste reduction strategies, and renewable energy sourcing.

Alongside regulatory requirements, normative pressures arise from professional standards, industry best practices, and environmental expectations within the healthcare community. For healthcare organizations, adopting sustainable practices has become an ethical obligation aligned with their mission of promoting health and well-being. By reducing carbon emissions, these organizations demonstrate a commitment to minimizing the negative environmental impacts that can adversely affect public health. Moreover, as industry leaders adopt innovative environmental practices, other healthcare providers feel compelled to follow suit to maintain reputational parity and stakeholder trust. This normative pressure encourages healthcare providers to adopt practices that are both environmentally responsible and expected within their professional sphere.

Mimetic pressures also play a significant role as organizations respond to uncertainty about the best ways to reduce emissions by emulating successful practices from industry leaders (Liao, 2018). As leading healthcare providers invest in environmental innovations and adopt advanced monitoring systems to track and report emissions reductions, other organizations follow suit, perceiving these practices as effective and legitimate. This imitation helps standardize carbon reduction practices within the sector, creating a normative benchmark for environmental responsibility that aligns with public and regulatory expectations.

## 4. Empirical literature review and hypotheses development

### *4.1. Environmental innovation and carbon emissions reduction*

Environmental innovation, encompassing the development and implementation of new technologies, processes, and practices aimed at reducing environmental impact, has gained significant attention as a strategic approach to mitigate climate change. Drawing on Stakeholder theory, environmental innovation is not only a response to increasing regulatory pressures but also an ethical commitment to stakeholders who expect organizations to minimize their ecological footprint (Freeman, 1984). In the healthcare sector, where the environmental impact is substantial, stakeholders—including regulatory bodies, patients, employees, and the community—exert considerable influence over organizations' environmental strategies. The adoption of environmental innovations, such as energy-efficient technologies, green procurement practices, and advanced waste reduction measures, aligns with the expectations of these diverse stakeholders by demonstrating a commitment to sustainable practices and reducing carbon emissions (Clarkson et al., 2008). Stakeholder Theory thus provides a foundation for understanding how healthcare organizations can simultaneously achieve environmental sustainability and maintain their social license to operate.

Scholars have consistently demonstrated that environmental innovation is closely linked to improved corporate social responsibility (CSR), sustainability, and environmental, social, and governance (ESG) performance (Marie et al., 2024; Ntim and Soobaroyen, 2013; Xiu et al., 2023). Studies indicate that organizations that integrate environmental innovations, such as sustainable production processes, energy-efficient technologies, and resource optimization strategies, report stronger CSR and ESG performance outcomes (Shahab et al., 2018; Nguyen et al., 2021). This alignment with CSR and sustainability goals is particularly pronounced in industries where public scrutiny and regulatory standards are high, driving organizations to adopt practices that enhance their social and environmental responsibility (Elmagrhi et al., 2019). Thus, organizations can reduce operational risks and create value through improved stakeholder trust, reputational gains, and compliance with ESG expectations (Al Amosh, 2024). Furthermore, the integration of environmental innovation within CSR and sustainability strategies is shown to strengthen an organization's overall ESG performance, as it enables more robust environmental management practices that align with stakeholder values and regulatory demands (Haque and Ntim, 2018). Research suggests that proactive environmental initiatives often extend beyond regulatory compliance, leading to innovations that support long-term sustainability by minimizing environmental impact and promoting resource efficiency (Khatib and Al Amosh, 2023). The cumulative effect of such innovations is reflected in an organization's ESG performance, where strong environmental scores are often accompanied by enhanced governance and social performance, indicating a holistic commitment to sustainable and responsible business practices.

Environmental innovations are integral to overall sustainability and ESG outcomes and also critical for achieving measurable reductions in carbon footprints. Empirical research supports the positive impact of environmental innovation on carbon emissions reduction across various sectors (Li et al., 2023a). Studies show that organizations investing in energy-efficient technologies and cleaner production methods consistently report lower levels of greenhouse gas emissions and enhanced environmental performance (Horbach, 2008; Rennings, 2000). In the European context, regulatory frameworks such as the EU's Green Deal and other sector-specific sustainability mandates have catalyzed the adoption of environmental innovations across industries, including healthcare (European Commission, 2020). These regulatory pressures not only mandate emissions reductions but also incentivize innovations that meet specific environmental standards, creating an environment conducive to sustainable transformation. The healthcare sector, characterized by high energy consumption and stringent regulatory oversight, offers a unique context to examine how environmental innovations contribute to emissions reduction in a highly regulated, public-facing industry.

Within the European healthcare sector, contextual factors such as regulatory compliance, stakeholder expectations, and operational complexities make environmental innovation both necessary and challenging. Healthcare providers, committed to enhancing patient health, face an ethical imperative to minimize environmental risks associated with pollution and carbon emissions, which have direct implications for public health. As stakeholders increasingly hold healthcare providers accountable for environmental stewardship, the adoption of environmental innovations becomes a vital strategy to address emissions. Additionally, environmental monitoring systems are integral in this context, enabling healthcare providers to track emissions reduction outcomes effectively and provide transparent reports to stakeholders. This alignment between innovation and accountability reinforces the notion that environmental innovation can lead to measurable reductions in carbon emissions when supported by systematic monitoring efforts. Given the theoretical basis, empirical evidence, and unique contextual challenges of the healthcare sector, the following hypothesis is proposed.

**Hypothesis 1**. Environmental innovation is positively associated with carbon emissions reduction in the European healthcare sector.

### *4.2. The moderator role of environmental monitoring*

Environmental monitoring is essential for advancing sustainability as it provides organizations with the data needed to track, evaluate, and improve their environmental impact (Ahmed et al., 2020). By systematically collecting and analyzing data on emissions, resource use, and waste, monitoring enables firms to identify inefficiencies, set measurable sustainability goals, and demonstrate progress toward environmental targets. This transparency meets regulatory requirements and strengthens accountability to stakeholders, who increasingly demand evidence of sustainable practices (Haque and Ntim, 2018). In sectors like healthcare, where environmental impacts can have direct implications on public health, monitoring allows organizations to adopt proactive, data-driven approaches to minimize their carbon footprint and align with broader sustainability frameworks. Furthermore, environmental monitoring supports continuous improvement by providing actionable insights that can inform and refine future sustainability strategies, ensuring that firms stay adaptive and responsive to evolving environmental standards and societal expectations.

Environmental innovations are pivotal to advancing sustainability efforts, particularly in combating climate change and reducing carbon emissions (Xiu et al., 2023; Li et al., 2023b). By developing and implementing new technologies, processes, and practices, organizations can significantly decrease their environmental footprint and contribute to global efforts to mitigate climate impacts (Hadj, 2020). Innovations such as energy-efficient systems, waste reduction technologies, and renewable energy solutions enable firms to operate with lower emissions and reduced resource consumption, directly addressing the root causes of climate change. Environmental innovations also support the transition to a circular economy, where resources are used more efficiently and waste is minimized, thereby conserving natural resources and reducing pollution (Romano et al., 2024). In healthcare, where regulatory standards and stakeholder expectations demand accountability, environmental monitoring allows organizations to rigorously measure the effectiveness of innovations like energy-efficient technology, green procurement, and waste minimization in reducing carbon outputs. Moreover, these innovations enhance an organization's resilience to environmental regulations and societal pressures, aligning their operations with international sustainability targets, such as those outlined in the Paris Agreement (Huang and Zhai, 2021). By integrating environmental innovations into their core practices, firms not only meet stakeholder expectations for sustainability but also position themselves as leaders in environmental stewardship, which can further enhance brand reputation and long-term financial viability in an increasingly eco-conscious market.

As environmental concerns increasingly shape public and institutional expectations, healthcare organizations are motivated to adopt both innovative practices and monitoring systems to legitimize their environmental efforts (Adjei-Mensah et al., 2024). The institutional pressure to demonstrate transparency in emissions reduction aligns with the healthcare sector's ethical obligations to public health, where carbon reduction efforts are increasingly viewed as essential for social legitimacy. Environmental monitoring, therefore, becomes a practical tool and a response to these institutional pressures, allowing healthcare organizations to substantiate their commitment to environmental innovation with credible data. This role is critical within sectors, like healthcare, that face high stakeholder scrutiny, reinforcing that the adoption of environmental innovations is supported and validated through rigorous, institutionally driven monitoring frameworks.

By generating reliable, real-time data, environmental monitoring facilitates continuous improvement, enabling healthcare organizations to adapt and refine their strategies in response to emissions data. This dynamic role supports transparency, as healthcare providers can share validated emissions data with stakeholders, reinforcing trust and accountability (Delmas et al., 2013). Monitoring also provides a feedback mechanism that helps organizations meet compliance standards more effectively, as they can proactively address discrepancies and ensure that innovations are aligned with environmental targets. Thus, environmental monitoring strengthens the direct impact of environmental innovation on emissions reduction and amplifies its efficacy by ensuring that innovations are accurately implemented, assessed, and reported. This leads to the following hypothesis.

**Hypothesis 2.** Environmental monitoring moderates the relationship between environmental innovation and carbon emissions reduction, such that the positive impact of innovation on emissions reduction is stronger with more rigorous environmental monitoring practices.

### *4.3. Research design*

This study examines data from publicly listed healthcare companies across ten European countries over a ten-year period, from 2012 to 2021. The countries included in the analysis are Sweden, the United Kingdom, France, Germany, Switzerland, Denmark, Spain, Belgium, Italy, and the Netherlands. In total, data from 1210 healthcare companies were analyzed (see Table 1). This sample includes all companies within the healthcare industry with available data, ensuring a comprehensive representation of the sector in these regions. Data collection was carried out using multiple reliable sources, including company annual reports, the Eikon database, and macroeconomic databases from the World Bank. Annual reports provided detailed financial and operational data directly from the companies, while the Eikon database offered specific information on key environmental indicators, including carbon emissions, environmental innovation scores, and environmental monitoring practices. Additionally, the World Bank database was used to incorporate relevant macroeconomic indicators, such as gross domestic product (GDP), the corruption index, and the human development index (HDI), which helped provide context and control variables for the analysis. This multi-source approach ensured that the data were robust, accurate, and suitable for evaluating the relationships under investigation.

$$\begin{aligned}\text{EmissionsScore}_{it} = {} & \beta_0 + \beta_1\ \text{EnvInnScore}_{it} + \beta_2\text{age}_{it} + \beta_3\text{Size}_{it} \\ & + \beta_4\text{Leverage}_{it} + \beta_5\ \text{ROA}_{it} + \beta_6\text{CurrentRatio}_{it} + \beta_7\text{Beta}_{it} \\ & + \beta_8\text{BoardSize}_{it} + \beta_9\ \text{Loss}_{it} + \beta_{10}\ \text{GDP}_{it} + \beta_{11}\ \text{Corruption}_{it} + \beta_{12}\ \text{HDI}_{it} \\ & + \text{Year} + \text{Count} + \varepsilon_{it}\end{aligned}$$

$$\begin{aligned}\text{EmissionsScore}_{it} = {} & \beta_0 + \beta_1\ \text{EnvInnScore}_{it}\ \text{X EM} + \beta_2\text{age}_{it} + \beta_3\text{Size}_{it} \\ & + \beta_4\text{Leverage}_{it} + \beta_5\ \text{ROA}_{it} + \beta_6\text{CurrentRatio}_{it} + \beta_7\text{Beta}_{it} \\ & + \beta_8\text{BoardSize}_{it} + \beta_9\ \text{Loss}_{it} + \beta_{10}\ \text{GDP}_{it} + \beta_{11}\ \text{Corruption}_{it} + \beta_{12}\ \text{HDI}_{it} \\ & + \text{Year} + \text{Count} + \varepsilon_{it}\end{aligned}$$

We utilized two primary measures for greenhouse gas (GHG) emissions: Log(GHG) and Log(GHG)/SIZE. Log(GHG) represents the natural logarithm of GHG emissions, with data sourced from the EPA website. This measure reflects the total CO2 emissions generated by a sample firm and its subsidiaries over the course of a year. To account for firm size as a variable affecting emissions, we also used a size-adjusted measure, calculated by dividing Log(GHG) by the firm's size (SIZE). This size-adjusted measure serves as an "efficiency" proxy, recognizing

**Table 1**
Tabulation of countries.

| Country | Obs. | Percent | Cum. |
|---|---|---|---|
| Sweden | 210 | 17.36 | 17.36 |
| United Kingdom | 180 | 14.88 | 32.24 |
| France | 150 | 12.40 | 44.64 |
| Germany | 160 | 13.22 | 57.86 |
| Switzerland | 200 | 16.53 | 74.39 |
| Denmark | 120 | 9.92 | 84.31 |
| Spain | 50 | 4.13 | 88.44 |
| Belgium | 70 | 5.79 | 94.23 |
| Italy | 40 | 3.31 | 97.54 |
| Netherlands | 30 | 2.48 | 100.00 |
| Total | 1210 | 100.00 | |

that larger firms tend to have higher total emissions. The literature shows mixed findings regarding the relationship between environmental disclosure and environmental performance, so the expected effect of Log (GHG) or Log(GHG)/SIZE varies depending on the theoretical perspective taken (Cong et al., 2020). In addition, in order to control for the possible endogeneity of the variables, which could bias the coefficients obtained, the estimation is carried out with panel data using two-stage least squares (2SLS) estimation. Table 2 provides a detailed summary of the variable measurements.

## 5. Empirical results and discussion

### 5.1. Descriptive findings

Table 3 provides descriptive statistical results. The EmissionsScore, which reflects the overall emissions performance of firms, has a mean value of 49.243 with a standard deviation of 31.742, indicating substantial variability in emissions practices among firms. The minimum value of 0 and a maximum close to 100 suggest that while some firms report no emissions, others have high emissions scores, capturing a broad spectrum of environmental responsibility across firms. This spread implies that companies within the healthcare sector are at different stages of emissions management and reporting, influenced by varying levels of regulatory pressure and stakeholder expectations. For CO2Direct and CO2Indirect emissions, the means are 11.601 and 12.805, respectively, with both metrics displaying high positive skewness (2.486 for direct emissions and 3.714 for indirect emissions). This skewness suggests that while most firms maintain lower CO2 levels, a few report substantially higher emissions, representing possible outliers with greater carbon footprints. EnvInnScore, measuring firms' investment in environmental innovation, has a mean of 20.329 and a positive skew (0.91), indicating that although some firms are highly innovative in their environmental practices, many score lower, possibly due to differences in resource availability or prioritization of environmental initiatives (Romano et al., 2024). This high variability across EmissionsScore, CO2Direct, CO2Indirect, and EnvInnScore emphasizes the diversity in environmental performance and innovation in the sample, making it a rich context for analyzing the impact of environmental practices on emissions reduction within the healthcare sector.

Regarding the remaining variables, Age shows a high mean (293.653) and positive skew, indicating a mix of newer and exceptionally old firms. Size has a consistent mean (9.002) with low skewness, reflecting similar firm sizes, while Leverage has moderate levels (mean of 0.207) but positive skew, suggesting some firms carry notably high debt (Al Amosh, 2024). ROA and Current Ratio vary considerably, with ROA showing extreme skewness due to outliers where firms report large losses, and Current Ratio displaying high kurtosis, indicating diverse liquidity profiles. Beta (mean 0.782) reflects lower-than-market systematic risk, though some outliers exist. BoardSize averages 9.4 members, with a slight positive skew toward larger boards. Lastly, GDP, Corruption, and HDI highlight diverse economic settings, with GDP showing high variability, while Corruption and HDI indicate generally low corruption and high development across countries.

**Table 2**
The Variables measurements.

| Variable | Label | Description |
|---|---|---|
| Carbon emission | EmissionsScore | Emission scores received from Eikon database |
| Environmental innovation score | EnvInnScore | Environmental innovation scores received from Eikon database |
| Environmental Monitoring | EM | We use developed a composite index based on six items measuring the rigor of environmental monitoring practices. Input variables include: 1) frequency of emissions data collection; 2) use of digital monitoring systems; 3) compliance with regulatory standards; 4) transparency in emissions reporting; 5) regularity of emissions audits; and 6) advanced monitoring technology adoption. |
| Age | age | The number of years since the firm's founding. |
| Size | Size | The natural logarithm of the firm's total assets at the end of the fiscal year, representing firm size. |
| Leverage | Leverage | The ratio of the firm's long-term debt to its total assets, indicating financial leverage. |
| ROA | ROA | Calculated as profit after tax divided by total assets, measuring the firm's profitability. |
| Current Ratio | CurrentRatio | The ratio of current assets to current liabilities |
| Systematic risk | Beta | Systematic risk, estimated as the slope coefficient from a market-model regression of daily stock returns against the NYSE, AMEX, and NASDAQ market index returns over the fiscal year |
| Board Size | BoardSize | The total number of directors on the board at the end of the financial year. |
| Loss | Loss | A binary variable indicating whether the firm reported a net loss for the fiscal year. |
| Gross domestic product | GDP | The log value of the gross domestic product at the end of the year, sourced from the World Bank database. |
| Corruption index | Corruption | The value of the corruption index at the end of the year, sourced from the World Bank database. |
| Human development index | HDI | The value of the human development index at the end of the year, sourced from the World Bank database. |

### 5.2. Matrix of correlations

Table 4 shows the correlation matrix results between the study variables, particularly those central to environmental performance, such as EmissionsScore, CO2Direct, CO2Indirect, and EnvInnScore. Notably, EmissionsScore shows a moderate positive correlation with EnvInnScore (0.322), suggesting that firms investing in environmental innovation are more likely to achieve better emissions performance, aligning with stakeholder expectations for sustainable practices. EmissionsScore also correlates positively with CO2Direct (0.169) and CO2Indirect (0.143), indicating that firms with higher emissions scores often report substantial levels of both direct and indirect CO2 emissions. This correlation pattern could reflect firms' comprehensive disclosure practices, where firms active in environmental monitoring and innovation (as seen with EM, correlation of 0.418 with EmissionsScore) may be more transparent, reflecting institutional pressures to transparently report and manage their environmental impact. thereby capturing both direct and indirect CO2 data.

On other hand, Size shows a robust positive correlation with EmissionsScore (0.49), CO2Direct (0.537), and CO2Indirect (0.647), consistent with prior literature that links larger firms with higher emissions due to their broader operational scope and resource intensity. This connection emphasizes the need for size-adjusted measures in emissions analysis to more accurately assess emissions efficiency across firms. BoardSize also correlates positively with both CO2Direct (0.5) and CO2Indirect (0.511), which may indicate that larger boards, potentially influenced by stakeholder diversity, support broader emissions disclosure practices. Moreover, Age and CurrentRatio show negative correlations with emissions and innovation variables, suggesting that older firms and those with higher liquidity may be less actively involved in emissions innovations, possibly due to established processes that are less flexible in adopting new sustainability practices. Additionally, macroeconomic factors like GDP and governance indicators such as Corruption and HDI reveal mixed correlations with the primary variables,

**Table 3**
Descriptive Statistics of the variables.

| Variables | Obs | Mean | Std. Dev. | Min | Max | Skew. | Kurt. |
|---|---|---|---|---|---|---|---|
| EmissionsScore | 742 | 49.243 | 31.742 | 0 | 99.782 | −0.248 | 1.852 |
| CO2Direct | 742 | 11.601 | 3.571 | 0 | 31.612 | 2.486 | 8.64 |
| CO2Indirect | 742 | 12.805 | 2.661 | 0 | 18.632 | 3.714 | 9.771 |
| EnvInnScore | 742 | 20.329 | 28.182 | 0 | 98.498 | 0.91 | 2.347 |
| EM | 1210 | 3.590 | 4.122 | 0 | 8 | 0.429 | 1.84 |
| age | 1210 | 293.653 | 675.645 | 3 | 2023 | 2.168 | 5.706 |
| Size | 1179 | 9.002 | 0.936 | 4.113 | 11.163 | −0.014 | 3.634 |
| Leverage | 1179 | 0.207 | 0.187 | 0 | 1.145 | 1.074 | 4.657 |
| ROA | 1160 | 0.004 | 0.307 | −6.087 | 1.088 | −9.502 | 159.941 |
| CurrentRatio | 1178 | 2.861 | 2.97 | 0.082 | 24.384 | 3.101 | 14.994 |
| Beta | 803 | 0.782 | 0.505 | −2.876 | 2.984 | −0.36 | 7.808 |
| BoardSize | 742 | 9.4 | 3.287 | 2 | 21 | 0.868 | 4.186 |
| Loss | 726 | 0.241 | 0.428 | 0 | 1 | 1.211 | 2.466 |
| GDP | 1210 | 292.334 | 307.255 | 1.02 | 914.04 | 0.34 | 1.463 |
| Corruption | 1210 | 79.374 | 9.329 | 42 | 92 | −1.568 | 5.904 |
| HDI | 1210 | 0.93 | 0.021 | 0.874 | 0.962 | −0.757 | 2.638 |

suggesting that national economic and governance contexts exert nuanced effects on environmental practices. Lastly, the variance inflation factors (VIFs) are below critical thresholds, indicating no concerning multicollinearity, supporting the robustness of these correlations for subsequent regression analyses.

### 5.3. Regression findings

The results presented in Table 5 reveal a significant positive relationship between environmental innovation score (EnvInnScore) and carbon emissions, with a coefficient of 0.278 ($p < 0.01$). This finding in model 1 suggests that environmental innovation, contrary to expectations, can initially contribute to higher carbon emissions. This outcome may occur because innovative practices often lead to increased energy consumption or operational expansions, particularly during the early stages of implementation. These innovations, while aimed at enhancing sustainability, can require substantial resource inputs or operational adjustments that inadvertently elevate emissions. Moreover, innovation can sometimes lead to increased production or changes in supply chains, amplifying emissions outputs in the short term. Additionally, the process of integrating new technologies and practices may involve transitional inefficiencies, such as resource-intensive implementation phases or increased operational scope, temporarily elevating emissions levels (Li et al., 2023a; Cai et al., 2020).

Theoretically, the positive relationship between environmental innovation and carbon emissions highlights the interplay between transparency, institutional pressures, and stakeholder expectations. Institutional theory provides a lens to interpret this result, suggesting that firms adopting environmental innovations are responding to external pressures to demonstrate environmental responsibility. These firms may prioritize compliance and legitimacy by improving the accuracy and breadth of their emissions reporting, even if their actual environmental performance has not yet improved. This alignment with institutional norms can lead to a scenario where reported emissions increase due to enhanced measurement and disclosure, rather than a failure of innovation itself (Xiu et al., 2023). Additionally, stakeholder theory suggests that firms introducing environmental innovations are often under scrutiny from regulators, investors, and the public to disclose comprehensive environmental data (Haque and Ntim, 2018). Stakeholders value transparency as a sign of commitment to sustainability, even if immediate reductions in emissions are not achieved. The observed increase in emissions may also be attributable to the expanded operational activities that often accompany innovation, such as scaling up production or adopting new technologies that require initial resource inputs. These findings imply that environmental innovation alone is insufficient to achieve emissions reductions without complementary mechanisms like monitoring and efficiency optimization.

From a practical perspective, the results of Model 1 underscore the importance of understanding the transitional dynamics of environmental innovation. Organizations adopting new environmental technologies or practices may initially experience higher emissions due to the resource-intensive nature of implementation or the need for enhanced emissions tracking (Li et al., 2023b). This highlights the necessity for firms to manage stakeholder expectations effectively, communicating that short-term increases in emissions do not undermine their long-term sustainability goals (Shahab et al., 2018). Clear reporting and transparency can mitigate potential reputational risks associated with temporary emissions spikes, ensuring that stakeholders recognize the broader benefits of innovation. Furthermore, managers should view environmental innovation as part of a larger strategy that includes robust monitoring systems and operational efficiency measures to ensure that innovations deliver the intended environmental benefits. Policymakers and industry leaders should also consider supporting firms through this transition by providing incentives or resources to offset the short-term costs and inefficiencies associated with innovation adoption. By acknowledging the complexities revealed in Model 1, firms can better integrate innovation into their sustainability strategies, ensuring that long-term reductions in carbon emissions are achieved alongside enhanced reporting and stakeholder engagement.

The control variables in Model 1 provide additional insights into factors influencing carbon emissions. Firm Size exhibits a strong positive relationship with emissions (coefficient = 4.739, $p < 0.01$), consistent with the understanding that larger firms tend to have higher operational scales and, consequently, greater emissions. Similarly, Leverage and ROA are positively associated with emissions, suggesting that more leveraged and profitable firms might have resource-intensive operations that contribute to higher emissions levels. In contrast, Current Ratio is negatively associated with emissions (coefficient = −2.272, $p < 0.01$), implying that firms with better liquidity management may be more efficient in resource utilization and environmental practices.

Macroeconomic variables also play a significant role. GDP shows a positive association with emissions, indicating that firms in economically advanced regions may have larger operations and higher emissions, despite potentially better access to sustainability resources. Conversely, HDI is negatively associated with emissions, suggesting that firms operating in countries with higher human development tend to adopt more sustainable practices, aligning with institutional and societal expectations. Other variables, such as BoardSize, show a small but significant positive effect, potentially reflecting the influence of diverse board perspectives on emissions strategies. Overall, the control variables highlight the multifaceted nature of emissions determinants, with organizational, financial, and macroeconomic factors jointly influencing carbon performance.

**Table 4**
Matrix of correlations between variables.

| Variables | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) | (15) | (16) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) EmissionsScore | 1 | | | | | | | | | | | | | | | |
| (2) CO2Direct | 0.169 | 1 | | | | | | | | | | | | | | |
| (3) CO2Indirect | 0.143 | 0.855 | 1 | | | | | | | | | | | | | |
| (4) EnvInnScore | 0.322 | 0.289 | 0.322 | 1 | | | | | | | | | | | | |
| (5) EM | 0.418 | 0.194 | 0.301 | 0.296 | 1 | | | | | | | | | | | |
| (7) Age | −0.168 | −0.11 | −0.16 | −0.232 | −0.019 | 1 | | | | | | | | | | |
| (8) Size | 0.49 | 0.537 | 0.647 | 0.276 | 0.433 | −0.171 | 1 | | | | | | | | | |
| (9) Leverage | 0.097 | 0.062 | 0.076 | −0.005 | 0.008 | −0.128 | 0.215 | 1 | | | | | | | | |
| (10) ROA | 0.028 | −0.1 | −0.118 | 0.219 | 0.066 | 0.101 | −0.082 | −0.323 | 1 | | | | | | | |
| (11) CurrentRatio | −0.208 | −0.134 | −0.168 | −0.107 | −0.019 | 0.05 | −0.347 | −0.363 | 0.069 | 1 | | | | | | |
| (12) Beta | 0.072 | 0.122 | 0.162 | −0.006 | 0.131 | −0.133 | 0.105 | 0.032 | −0.117 | −0.099 | 1 | | | | | |
| (13) BoardSize | 0.296 | 0.5 | 0.511 | 0.194 | 0.288 | 0.027 | 0.563 | 0.014 | −0.046 | −0.28 | −0.038 | 1 | | | | |
| (14) Loss | −0.047 | −0.044 | −0.055 | −0.157 | −0.04 | −0.05 | −0.191 | 0.093 | −0.504 | 0.06 | 0.145 | −0.02 | 1 | | | |
| (15) GDP | 0.233 | −0.113 | −0.137 | −0.009 | 0.121 | −0.029 | −0.026 | −0.142 | 0.153 | −0.001 | 0.385 | −0.229 | −0.123 | 1 | | |
| (16) Corruption | 0.008 | 0.041 | 0.043 | 0.05 | −0.035 | −0.483 | −0.004 | −0.078 | 0.039 | −0.001 | 0.362 | −0.186 | −0.033 | 0.523 | 1 | |
| (17) HDI | 0.121 | 0.087 | 0.07 | 0.046 | 0.037 | −0.34 | −0.005 | −0.081 | 0.041 | 0.046 | 0.332 | −0.203 | −0.042 | 0.631 | 0.876 | 1 |
| **Variance inflation factor** | | | | 1.267 | 1.807 | 2.503 | 1.273 | 1.359 | 1.344 | 1.138 | 1.834 | 1.978 | 1.399 | 2.269 | 3.883 | 1.431 |

**Table 5**
The effect of environmental innovation score and environmental monitoring on carbon emission.

| Variables | Model 1 | Model 2 | Model 1 (2SLS) | Model 2 (2SLS) |
|---|---|---|---|---|
| **EnvInnScore** | 0.278*** (5.99) | 1.06*** (4.67) | 0.012*** (6.21) | 2.031*** (4.75) |
| **EM** | | 10.175*** (9.07) | – | 2.458*** (1.31) |
| **EnvInnScore × EM** | | −0.209*** (−4.18) | – | −0.201*** (−4.25) |
| **Age** | −0.031 (−0.60) | −0.023* (−1.77) | −0.029 (−0.65) | −0.03402 (−1.62) |
| **Size** | 4.739*** (8.11) | 9.758*** (5.59) | 2.815*** (8.47) | 6.925*** (5.78) |
| **Leverage** | 14.068** (2.20) | 8.558* (1.48) | 9.879** (2.31) | 4.467* (1.51) |
| **ROA** | 22.074*** (3.99) | 4.85** (0.90) | 12.455*** (4.02) | 4.92** (0.85) |
| **CurrentRatio** | −2.272*** (−5.16) | −1.552*** (−3.86) | −2.367*** (−5.28) | −2.197*** (−3.71) |
| **Beta** | −2.504 (−1.12) | −2.211 (−1.10) | −2.564 (−1.14) | −1.195 (−1.07) |
| **BoardSize** | 0.577** (1.30) | 0.096** (0.24) | 0.615** (1.38) | 0.089** (0.21) |
| **Loss** | −1.066 (1.34) | −0.896 (1.52) | −1.112 (1.40) | −0.924 (1.45) |
| **GDP** | 0.027*** (5.60) | 0.026*** (6.12) | 0.038*** (4.77) | 0.067*** (6.98) |
| **Corruption** | 0.288 (1.01) | 0.141 (0.55) | 0.305 (1.84) | 0.138 (1.03) |
| **HDI** | −4.442*** (−3.18) | −3.329*** (−3.35) | −2.582*** (−3.93) | −2.128*** (−2.49) |
| **Constant** | 23.18*** (2.53) | 22.6*** (2.91) | 11.452*** (2.60) | 12.847*** (1.98) |
| **Year** | Yes | Yes | Yes | Yes |
| **Prob > F** | 43.299*** | 51.594*** | 15.213*** | 12.731*** |
| **R-squared** | 0.522 | 0.619 | 0.438 | 0.627 |
| **Number of Obs.** | 742 | 742 | 742 | 742 |

Note: All variables are defined in Table 2. Models 1 and 2 use OLS estimation, while models 1 (2SLS) and 2 (2SLS) are estimated using Two-Stage Least Squares. The table reports the coefficient values and t-values (in parentheses). ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

### *5.4. Environmental monitoring as a moderator*

Model 2 in Table 5 reveals the moderating role of environmental monitoring (EM) on the relationship between environmental innovation (EnvInnScore) and carbon emissions. The interaction term (EnvInnScore * EM) shows a significant negative coefficient (−0.209, $p < 0.01$), indicating that environmental monitoring enhances the effectiveness of environmental innovations in reducing carbon emissions. This finding underscores that while environmental innovation contributes to better environmental performance, the presence of robust monitoring systems is critical in translating these innovations into tangible emissions reductions. The substantial increase in the model's explanatory power (R-squared improves from 0.522 in Model 1 to 0.619 in Model 2) further emphasizes the importance of integrating monitoring mechanisms into environmental management strategies.

The results highlight the intricate interplay between institutional structures and stakeholder pressures in shaping the efficacy of environmental practices. While environmental innovations often emerge from institutional demands for legitimacy, their true impact on carbon emissions is contingent on the presence of systems that ensure accountability and continuous evaluation (Xiu et al., 2023; Ahmed et al., 2020). Environmental monitoring serves as a mechanism that bridges the gap between innovation and measurable outcomes, addressing a fundamental challenge in sustainability: the disconnect between intentions and tangible results. This underscores the importance of institutional alignment, where firms integrate monitoring systems to comply with regulatory expectations and to embed a culture of accountability that amplifies the practical benefits of innovation. From a theoretical perspective, the significant moderating effect of environmental monitoring demonstrates how stakeholder expectations are operationalized within institutional frameworks. Stakeholders demand not only innovative solutions but also clear evidence of their impact, making monitoring a critical element in the process of institutionalization. Without robust monitoring, environmental innovations may remain symbolic gestures, undermining their credibility. The interaction effect in Model 2, therefore, provides empirical evidence that monitoring mechanisms are not just tools for compliance but are integral to ensuring that institutional demands translate into real environmental progress. This finding advances the theoretical understanding of how organizations navigate the dual pressures of achieving legitimacy and delivering performance, positioning environmental monitoring as a strategic enabler that harmonizes these objectives.

Practically, the moderating effect of environmental monitoring in Model 2 highlights its indispensable role in achieving sustainability goals (Villarreal et al., 2017). Firms that invest in environmental innovation must complement these efforts with monitoring systems to ensure that innovations lead to tangible emissions reductions. Monitoring provides the data necessary to evaluate and refine innovative practices, enabling firms to identify gaps, address inefficiencies, and optimize their environmental strategies. For industries like healthcare, where emissions are linked to operational complexity and resource intensity, monitoring systems can guide targeted interventions that align innovation efforts with broader sustainability objectives. The practical implications extend to policy and governance as well. Regulators and industry bodies should emphasize not only the adoption of environmental innovations but also the implementation of rigorous monitoring frameworks to track their outcomes. Firms with robust monitoring systems are better positioned to meet regulatory requirements, enhance stakeholder trust, and achieve long-term sustainability. The interaction effect underscores that monitoring is not a passive reporting tool but an active component of effective environmental management, enabling organizations to transition from compliance to leadership in sustainability. For managers, this means prioritizing investments in monitoring infrastructure alongside innovation initiatives to maximize their environmental and strategic benefits.

On the other hand, these 2SLS estimates (Models 1 and 2 in Table 5) help address potential endogeneity concerns by offering consistent parameter estimates for the relationship between environmental innovation, monitoring, and carbon emissions. The results align closely with those of the OLS models, indicating that the observed positive effect of environmental innovation on emissions, as well as the significant moderating influence of environmental monitoring, remains robust even when accounting for endogeneity. Notably, the coefficients for EnvInnScore and EnvInnScore × EM retain their expected signs and statistical significance, underscoring that environmental monitoring continues to mitigate the initial increase in emissions associated with innovation. This consistency across estimation techniques strengthens confidence in the study's main findings and highlights the importance of monitoring as a strategic mechanism for ensuring that innovation efforts ultimately lead to lower carbon emissions.

### 5.5. Additional analysis

#### 5.5.1. Alternative measures for carbon emissions

In the additional analysis shown in Table 6, the study uses CO2 equivalent emissions directly (Scope 1) and indirectly (Scope 2) as alternative measures for carbon emissions to validate the robustness of the primary findings. This approach extends the analysis by disaggregating emissions into their direct and indirect components, offering a more granular view of the relationship between environmental innovation, environmental monitoring, and emissions outcomes. The regression models incorporate Scope 1 (direct emissions from firm operations) and Scope 2 (indirect emissions from energy consumption) as dependent variables to assess how innovation and monitoring impact different types of emissions. This disaggregation allows for a nuanced understanding of whether the dynamics observed in the overall emissions score are consistent across specific emissions categories.

**Table 6**
The regression results using CO2 equivalent emissions direct (Scope 1 and 2) as an alternative for emission score.

| Variables | Scope 1 | Scope 2 | Scope 1 | Scope 2 |
|---|---|---|---|---|
| **EnvInnScore** | 2.912*** (3.25) | 1.185*** (3.23) | 1.529*** (0.63) | 3.911*** (1.22) |
| **EM** | – | 0.019*** (1.58) | – | 1.398*** (1.89) |
| **EnvInnScore × EM** | – | −1.213*** (−0.12) | – | −1.081*** (1.62) |
| **Age** | −2.319 (−1.15) | −0.873 (−0.53) | −3.125 (−1.17) | −0.795 (−0.49) |
| **Size** | 1.489*** (3.28) | 1.901*** (1.73) | 11.528*** (6.72) | 11.401*** (2.38) |
| **Leverage** | 2.651** (0.25) | 0.042* (1.08) | 1.483** (0.19) | 0.128* (0.95) |
| **ROA** | 2.782** (1.52) | 5.311** (1.41) | 2.234*** (1.33) | 2.754** (1.61) |
| **CurrentRatio** | −12.723*** (−1.47) | −10.347** (−1.49) | −7.342*** (−2.19) | −10.452** (−1.48) |
| **Beta** | −0.621 (−2.34) | −1.067 (−3.69) | −15.732 (−2.71) | −1.291 (−3.41) |
| **BoardSize** | 6.347*** (4.83) | 6.892*** (3.58) | 10.152*** (5.11) | 12.678*** (3.64) |
| **Loss** | −1.577 (2.27) | −1.428 (4.51) | −3.744 (5.22) | −2.195 (3.03) |
| **GDP** | 2.881*** (3.97) | 2.964*** (5.42) | 2.902*** (3.43) | 2.521*** (4.51) |
| **Corruption** | 7.623 (1.91) | 5.214 (1.79) | 4.521 (2.34) | 5.517 (2.10) |
| **HDI** | −8.203*** (−4.31) | −5.654*** (−4.01) | −8.711*** (−4.72) | −5.849*** (−4.07) |
| **Constant** | 8.231*** (5.72) | 6.127*** (6.21) | 8.642*** (6.25) | 6.235*** (6.03) |
| **Year** | Yes | Yes | Yes | Yes |
| **R-squared** | 0.467 | 0.562 | 0.478 | 0.561 |
| **Number of Obs.** | 607 | 607 | 607 | 607 |
| **F-test** | 22.143*** | 32.417*** | 19.287*** | 27.812*** |

Note: All variables are explained in Table 2. The models are estimated using 2SLS. The table reports the Coefficient value and t-value (in parenthesis). ***, ** and * indicate statistical significance at the 1, 5 and 10 percent level, respectively.

The results indicate a positive and significant relationship between EnvInnScore and both Scope 1 and Scope 2 emissions across the models, reinforcing the earlier finding that environmental innovation is associated with increased emissions in the short term. For Scope 1 emissions, the coefficient for EnvInnScore is 2.872 ($p < 0.01$) in the first model, highlighting that firms with higher innovation scores tend to report higher direct emissions. Similarly, the coefficient for Scope 2 emissions is 1.063 ($p < 0.01$), suggesting that indirect emissions also increase with environmental innovation. These findings are consistent with the idea that firms adopting environmental innovations often improve their emissions tracking and reporting systems, leading to higher disclosed emissions. This is particularly evident in indirect emissions (Scope 2), where enhanced monitoring technologies can capture previously underreported emissions from energy use. From a theoretical perspective, these results align with Institutional Theory, which posits that firms respond to regulatory and societal pressures by improving transparency and reporting practices. As firms adopt environmental innovations, they may not immediately reduce emissions but instead enhance their ability to measure and disclose emissions more accurately. The increased emissions reported in the short term could also reflect transitional inefficiencies as firms integrate new technologies and practices into their operations.

On the other hand, the moderating role of environmental monitoring

(EM) is evident in the interaction term (EnvInnScore * EM), which shows significant negative coefficients for both Scope 1 (−1.205, $p < 0.01$) and Scope 2 (−1.048, $p < 0.01$) emissions. These results suggest that environmental monitoring mitigates the short-term increase in emissions associated with environmental innovation. In practical terms, this finding highlights the critical role of monitoring systems in ensuring that environmental innovations lead to meaningful reductions in emissions over time. By providing real-time data and feedback, environmental monitoring enables firms to identify inefficiencies, optimize processes, and accelerate the transition to lower emissions. Moreover, environmental monitoring serves as a mechanism to bridge the gap between innovation and performance by ensuring that firms' sustainability efforts align with stakeholder expectations. The significant interaction effect underscores that monitoring amplifies the effectiveness of innovation, transforming intentions into tangible environmental outcomes. Practically, the results highlight the importance of integrating environmental monitoring into innovation strategies to achieve sustainability goals. While environmental innovation drives improvements in emissions tracking and transparency, the presence of robust monitoring systems ensures that these innovations translate into actual emissions reductions. For policymakers, these findings suggest the need to incentivize the adoption of both environmental innovations and monitoring technologies. Regulations should emphasize not only innovation but also the implementation of systems to track and verify emissions data.

### 5.5.2. Examining emissions and financial context

In Table 7 we used the additional analysis examines the moderating effect of environmental monitoring (EM) on the relationship between environmental innovation (EnvInnScore) and emissions, disaggregating the sample into loss-making and profitable firms. This segmentation provides deeper insights into how financial performance influences the effectiveness of environmental innovation and monitoring in addressing emissions. The analysis evaluates Scope 1 (direct emissions) and Scope 2 (indirect emissions) emissions separately for both groups, highlighting variations in the innovation-emissions nexus across financial contexts. The results underscore the nuanced dynamics of environmental management, where financial health plays a critical role in shaping the outcomes of sustainability efforts.

The results reveal that EnvInnScore significantly influences emissions across both loss-making and profitable firms, albeit with differing magnitudes. For loss-making firms, the effect of EnvInnScore on Scope 1 emissions is positive and significant (coefficient = 0.523, $p < 0.01$), reflecting that environmental innovations are associated with increased direct emissions. Similarly, profitable firms show a positive relationship between EnvInnScore and Scope 2 emissions (coefficient = 1.041, $p < 0.01$), suggesting that innovations in this group also lead to higher indirect emissions. These results align with the broader observation that environmental innovation often enhances emissions reporting and transparency, particularly for firms under financial or stakeholder pressure to improve their environmental accountability. Loss-making firms may prioritize cost-saving innovations, which inadvertently increase emissions during implementation, while profitable firms might adopt ambitious innovations that initially expand operational activities, increasing indirect emissions.

The disparity in outcomes between loss-making and profitable firms can be theoretically explained. Loss-making firms might lack the financial capacity to fully integrate innovations into their operations, resulting in transitional inefficiencies and incomplete emissions reductions. In contrast, profitable firms, with greater resources, may adopt comprehensive solutions that impact indirect emissions (e.g., energy consumption), yet require time to achieve meaningful reductions. These findings emphasize the importance of financial health in determining the immediate effectiveness of environmental innovations.

The moderating role of EM is evident in both groups but varies in intensity. For loss-making firms, the interaction term (EnvInnScore * EM) is significant and negative for Scope 1 emissions (−0.099, $p < 0.01$), suggesting that monitoring helps mitigate the emissions increases associated with innovation. Similarly, for profitable firms, EM significantly moderates the effect of innovation on Scope 2 emissions (−0.205, $p < 0.01$), indicating that monitoring enhances the efficiency and accountability of innovation processes. These findings highlight the critical role of monitoring in ensuring that innovations translate into measurable sustainability outcomes, regardless of financial performance. Theoretically, these results demonstrate the interplay between financial resources and institutional pressures. For loss-making firms, environmental monitoring serves as a compensatory mechanism, ensuring compliance with institutional demands even when resources are constrained. For profitable firms, monitoring amplifies the effectiveness of innovations, aligning with Stakeholder Theory, as stakeholders expect not only transparency but also demonstrable outcomes. The moderating effect reflects the dual role of monitoring as both a compliance tool for financially constrained firms and a performance-enhancement tool for resource-abundant firms.

**Table 7**
The regression results between profitable and loss firms.

| | Loss firms | | Profitable firms | |
|---|---|---|---|---|
| | Scope 1 | Scope 1 | Scope 2 | Scope 2 |
| EnvInnScore | 0.523*** (3.07) | 0.583*** (1.91) | 0.22*** (4.75) | 1.041*** (3.35) |
| EM | | 10.742*** (4.01) | | 9.032*** (5.99) |
| EnvInnScore × EM | | −0.099 *** (−1.19) | | −0.205*** (−3.04) |
| Age | −0.008 (−1.34) | −0.001 (−0.12) | −0.004** (−2.00) | −0.004** (−2.07) |
| Size | 9.654*** (3.63) | 11.314** (2.22) | 13.589*** (6.94) | 9.92*** (5.12) |
| Leverage | 37.721*** (3.28) | 21.727** (2.11) | 0.506 (0.06) | 1.43 (0.18) |
| ROA | 9.811 (1.09) | 12.798 (1.69) | 15.511** (0.93) | 14.138** (0.90) |
| CurrentRatio | −1.015 (−1.15) | 0.086 (0.11) | −2.035*** (−3.93) | −1.763*** (−3.52) |
| Beta | −3.433 (−0.92) | −2.374 (−0.76) | −8.874*** (−2.86) | −5.216** (−1.67) |
| BoardSize | 0.968** (0.67) | 0.646*** (0.53) | 0.501** (1.14) | 0.029* (0.07) |
| Loss | −0.754* (0.23) | −0.519* (0.48) | −0.459 (1.63) | −0.068 (1.24) |
| GDP | 0.011 (0.91) | 0.004 (0.33) | 0.041*** (7.96) | 0.034*** (6.92) |
| Corruption | 0.079 (0.10) | 1.42 (1.85) | 0.343 (1.18) | 0.376 (1.37) |
| HDI | −8.965 (−0.25) | −2.434 (−0.87) | −4.433*** (−3.94) | −5.251*** (−4.23) |
| Constant | 21.439*** (0.29) | 28.31*** (1.01) | 35.347*** (3.57) | 36.006*** (3.84) |
| Year | Yes | Yes | Yes | Yes |
| R-squared | 0.542 | 0.691 | 0.464 | 0.531 |
| Number of obs | 270 | 270 | 337 | 337 |
| F-test | 9.092*** | 12.702*** | 26.535*** | 28.201*** |

Note: The table reports the coefficient value and t-value (in parenthesis). ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

## 6. Summary and conclusion

This study sets out to explore the relationship between environmental innovation and carbon emissions within the European healthcare sector, with a specific focus on the moderating role of environmental monitoring. By examining a sample of 1210 publicly listed healthcare firms over a ten-year period, the research aimed to address the complex dynamics between innovation, transparency, and sustainability outcomes in a sector that is both environmentally impactful and highly regulated. The analysis incorporated disaggregated measures of carbon emissions, including Scope 1 (direct) and Scope 2 (indirect) emissions, as well as firm-specific and contextual variables, providing a comprehensive understanding of the innovation-emissions nexus.

The findings reveal several key insights. First, environmental innovation is positively associated with reported emissions, suggesting initial implementation can lead to increased emissions due to several factors. For instance, the adoption of innovative technologies often requires significant energy inputs, resource allocation, or operational adjustments during the transition phase, which can temporarily elevate emissions. Moreover, innovation may expand a firm's operational scope or production capacity, inadvertently increasing its environmental footprint. These unintended consequences highlight that innovation, in isolation, is not a guaranteed pathway to emissions reduction. Instead, its effectiveness depends on complementary mechanisms, such as environmental monitoring, to track and optimize the impact of these innovations. This dynamic emphasizes the need for a more nuanced understanding of innovation's role in sustainability, recognizing its potential to both challenge and contribute to emissions reduction efforts in the short and long term. However, the integration of environmental monitoring significantly mitigates this effect, ensuring that innovation leads to measurable reductions in emissions over time. This moderating effect was consistent across both Scope 1 and Scope 2 emissions, underscoring the critical role of monitoring in translating innovation into tangible environmental benefits. Additional analyses highlighted the influence of financial performance, with loss-making and profitable firms exhibiting distinct patterns in the innovation-emissions relationship. Loss-making firms, constrained by limited resources, benefit significantly from basic monitoring systems to ensure compliance and efficiency, while profitable firms leverage advanced monitoring to optimize innovation outcomes. Together, these results provide a nuanced understanding of the interplay between innovation, monitoring, and emissions in the healthcare sector.

Theoretical implications of this study extend existing frameworks by highlighting the dual role of environmental monitoring as both a compliance tool and a performance-enhancement mechanism. Within the context of Institutional Theory, the findings suggest that firms respond to regulatory and societal pressures not only by adopting innovations but also by integrating monitoring systems that enhance accountability and legitimacy. Environmental monitoring bridges the gap between institutional demands and practical outcomes, ensuring that innovations align with stakeholder expectations and regulatory norms. The study also advances Stakeholder Theory by demonstrating that stakeholders value measurable progress and transparency, particularly in industries like healthcare, where environmental sustainability directly impacts public health. By empirically validating the moderating role of monitoring, this research provides a theoretical foundation for understanding how firms operationalize environmental accountability within institutional and stakeholder-driven contexts.

From a practical perspective, the findings offer actionable insights for managers, policymakers, and industry leaders. For firms, the results underscore the importance of integrating environmental monitoring into innovation strategies to achieve long-term emissions reductions. Managers should prioritize investments in monitoring systems to optimize resource use, identify inefficiencies, and demonstrate measurable progress to stakeholders. For loss-making firms, policymakers could provide incentives or subsidies to support the adoption of basic monitoring technologies, ensuring compliance without overburdening financial resources. Profitable firms, on the other hand, are better positioned to adopt advanced systems that enhance both innovation outcomes and reputational gains. At a broader level, industry standards and regulations should emphasize the dual importance of innovation and monitoring, creating an ecosystem where sustainability efforts are transparent, accountable, and impactful.

Although the study provides valuable insights, it is not without limitations, which offers opportunities for future research. Future research could expand this study by examining other sectors beyond healthcare to determine if the observed relationships hold across industries with varying environmental impacts and regulatory pressures. Such an approach could provide a more generalized understanding of the innovation-emissions nexus. Additionally, the geographical scope of this study, focused on the European healthcare sector, could be broadened to include non-European regions or emerging economies. Exploring how differing institutional and cultural contexts influence the dynamics between environmental innovation, monitoring, and emissions could yield valuable insights. The study's short-to medium-term focus could be complemented by future research adopting longitudinal designs to assess the long-term effects of environmental innovation and monitoring on emissions reductions, operational efficiency, and stakeholder trust. Investigating alternative moderators, such as corporate governance quality, stakeholder engagement levels, or the presence of Chief Sustainability Officers, could also enrich the understanding of factors that enhance the effectiveness of environmental innovation. Differentiating between types of environmental innovations, such as process, product, or organizational innovations, would allow for a more granular exploration of their respective impacts on emissions performance. Moreover, future studies could refine measurement approaches by incorporating Scope 3 emissions, which account for upstream and downstream emissions, to provide a more comprehensive assessment of a firm's environmental footprint. While this study addressed potential endogeneity concerns, future research could explore additional causal inference methods, such as difference-in-differences analysis or propensity score matching, to further strengthen the validity of results. These avenues for future research would deepen the theoretical and practical understanding of the innovation-emissions relationship and its implications for achieving sustainability goals.

## CRediT authorship contribution statement

**Hamzeh Al Amosh:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Saleh F.A. Khatib:** Writing – review & editing, Visualization, Software, Resources, Project administration, Methodology, Formal analysis, Conceptualization.

## Ethics approval statement

This article does not contain any studies with human participants or animals performed by any of the authors.

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## Declaration of competing interest

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

## Data availability

Data will be made available on request.

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