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Environmental performance and financial performance in the European steel industry

A firm-level analysis

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ABSTRACT

This thesis investigates the relationship between environmental performance and financial performance in the European steel industry, focusing on the challenges and opportunities associated with sustainability transition in a hard-to-abate sector.

The study is motivated by the growing relevance of environmental issues in corporate strategy, investment decisions and public policy, as well as by the mixed empirical evidence concerning the economic implications of sustainability initiatives. Particular attention is devoted to the limitations of aggregate ESG scores and to the potential advantages of intensity-based environmental indicators in capturing firms' operational environmental performance.

The analysis combines a review of the main theoretical and empirical literature with a firm-level empirical investigation conducted on a sample of ten European companies observed between 2017 and 2024. The sample includes firms characterised by different production models, ranging from electric arc furnace (EAF) producers to hybrid and blast furnace-basic oxygen furnace (BF–BOF) producers, with Feralpi Group serving as the central case study. Environmental performance is measured through intensity-based indicators, including emission intensity, energy intensity, recycling rate and water intensity, while financial performance is analysed through profitability and investment indicators.

The empirical analysis is based on preliminary descriptive analysis, correlation analysis and panel fixed-effects regression models including year dummies and lagged environmental variables. The results suggest that the relationship between environmental and financial performance in the European steel industry is complex and heterogeneous. In particular, stronger environmental performance does not appear to be systematically associated with higher short-term profitability. At the same time, some evidence emerges that firms characterised by relatively stronger environmental performance may also display more structured sustainability-related investment dynamics, while more environmentally intensive firms do not appear to invest proportionally more in transition-related activities.

Overall, the findings suggest that the environmental transition of the European steel industry remains uneven and influenced by structural, technological and financial constraints. The study contributes to the literature by providing sector-specific

evidence from a hard-to-abate industry and by highlighting the importance of intensity-based environmental indicators for analysing the economic implications of sustainability strategies.

INTRODUCTION

In recent years, the relationship between environmental sustainability and corporate financial performance has become one of the most debated topics in both academic research and managerial practice. Increasing regulatory pressure, growing investor attention toward ESG-related risks, and the progressive transition toward low-carbon economic systems have significantly transformed the strategic environment in which firms operate. In this context, environmental performance is no longer considered exclusively as a compliance issue or as a reputational dimension, but increasingly as a factor potentially capable of influencing competitiveness, operational efficiency, access to capital and long-term value creation.

At the same time, the empirical literature has not reached fully homogeneous conclusions regarding the actual economic implications of environmental performance. While several studies suggest the existence of positive relationships between sustainability and financial performance, other contributions underline the presence of weak, heterogeneous or context-dependent effects. These differences emerge particularly clearly in environmentally intensive and hard-to-abate sectors, where decarbonisation requires substantial technological investments, long transition periods and significant financial resources.

Among these sectors, the steel industry represents one of the most relevant and complex cases. Steel production remains fundamental for industrial development and for many strategic value chains, but it is also characterised by high levels of emissions, energy consumption and exposure to environmental regulation. The European steel industry is currently facing increasing pressure related to climate targets, carbon pricing mechanisms and decarbonisation policies, while simultaneously maintaining competitiveness in a highly internationalised market, a combination that makes the sector particularly suitable for analysing whether stronger environmental performance may be associated with different financial outcomes and investment dynamics.

The objective of this dissertation is therefore to analyse the relationship between environmental and financial performance in the European steel industry through a firm-level empirical analysis. Particular attention is devoted to the use of intensity-based environmental indicators, such as emission intensity, energy intensity, recycling rate and water intensity, in order to partially overcome some of the limitations associated

with aggregate ESG scores and to better capture operational environmental efficiency in a hard-to-abate industry.

The analysis focuses on a sample of ten European companies observed between 2017 and 2024 and includes Feralpi Group as the central case study due to its electric arc furnace-based production model and its strategic positioning within the sustainability transition.

The dissertation is structured into three main chapters. The first one reviews the principal theoretical and empirical literature concerning the relationship between environmental and financial performance, focusing in particular on the Natural-Resource-Based View, the Porter Hypothesis, Stakeholder Theory, ESG measurement issues and the methodological challenges related to causality and endogeneity. The chapter also highlights the increasing importance of industry-specific and intensity-based indicators in sustainability research.

The second chapter focuses on the steel industry and on the specific characteristics that make it a hard-to-abate sector, analysing the environmental intensity of steel production, the main decarbonisation pathways currently available and the strategic implications of environmental investments, while also introducing Feralpi Group and explaining the rationale behind the selection of the companies included in the empirical analysis.

Finally, the third chapter presents the empirical analysis. After a preliminary descriptive analysis and a correlation analysis, the study performs panel fixed-effects regression models with year dummies and lagged environmental variables in order to analyse the relationship between environmental performance and financial outcomes while controlling for firm-specific heterogeneity and common temporal shocks.

The empirical results suggest that the relationship between environmental performance and financial performance in the European steel industry is complex and not always aligned with the more optimistic expectations frequently associated with ESG strategies. In particular, the analysis does not identify a systematic positive relationship between stronger environmental performance and higher short-term profitability. However, results indicate that firms characterised by relatively stronger environmental efficiency tend to display more structured and proportionally higher investment dynamics related to sustainability and transition processes. At the same time, more environmentally intensive firms do not appear to invest proportionally more

in transition-related activities, suggesting the existence of financial, technological and organisational constraints that may slow down the decarbonisation process.

These findings are particularly relevant not only from an academic perspective, but also in managerial and policy terms. From a managerial perspective, the results suggest that environmental transition strategies may require long-term investment horizons and organisational capabilities that are not immediately reflected in short-term profitability indicators. From a policy perspective, the evidence highlights the importance of designing regulatory and financial support mechanisms capable of facilitating the transition of hard-to-abate industries, especially for firms facing greater structural and technological difficulties.

Finally, the dissertation also opens several possible directions for future research. Further studies could extend the analysis to larger international samples, incorporate longer time horizons, analyse non-linear relationships more explicitly or investigate the role of additional variables such as carbon pricing exposure, green financing conditions or technological innovation. Moreover, future research could explore the long-term financial effects of decarbonisation investments and compare different hard-to-abate industries in order to better understand how environmental transition dynamics vary across sectors.

CHAPTER 1 - LITERATURE REVIEW

This first chapter reviews the main theoretical and empirical studies that investigate the relationship between environmental performance and corporate economic and financial performance.

A progressive structure is followed: the first section covers the main theoretical frameworks that explain why environmental performance may affect firm outcomes; the following ones examine existing empirical evidence, highlighting differences in results across studies, also addressing measurement issues and methodological challenges, before focusing on sector-specific research and, finally, concluding with the identification of research gaps and positioning the present study within the existing literature.

1.1 Conceptual foundations of the environmental–financial performance relationship

This section introduces the key theoretical frameworks that explain how and why environmental performance may influence firms' economic and financial outcomes. These theories provide a conceptual basis that helps interpret the empirical findings discussed later in the chapter.

1.1.1 From shareholder primacy to sustainability-oriented theories of the firm

The shareholder primacy model has traditionally provided the dominant framework for defining corporate purpose.

In his most influential contribution, Friedman (1970) argues that the sole social responsibility of business is to increase its profits, provided that firms operate within legal and ethical constraints, the so called "rules of the game". According to this interpretation, corporate executives are agents of the owners and have a fiduciary duty to manage resources in their sole interest; therefore, any diversion of corporate funds toward broader social objectives—unless it ultimately enhances profitability—represents an unjustified spending of shareholders' money (Friedman, 1970). This approach has an undeniable analytical strength: it offers a single, measurable objective, with profit maximisation functioning as a clear performance benchmark and

limiting managerial discretion. Within this logic, environmental performance is economically relevant only when it affects financial outcomes, through cost reductions, risk mitigation, regulatory compliance or reputational gains, while environmental initiatives that do not contribute to long-term profitability are difficult to justify, and are therefore interpreted as costs borne for societal purposes rather than as intrinsic components of corporate strategy.

However, the assumption that shareholder value can be pursued in isolation has been widely challenged. Freeman (1984) proposes a broader conception of the firm, where a stakeholder is defined as any group or individual who can affect or is affected by the achievement of organisational objectives. This conceptual change shifts the analytical focus, with the firm no longer being viewed as a vehicle for shareholders alone, but as a network of relationships embedded in a complex social environment. Freeman's argument emerged in response to increasingly turbulent competitive and regulatory conditions. Managers, he suggests, cannot effectively pursue strategic objectives without accounting for employees, customers, suppliers, regulators, communities and other actors whose cooperation is essential. Environmental performance, in this perspective, becomes part of stakeholder management, by reflecting how firms respond to claims related to pollution, resource use or ecological risk. Ignoring these relationships may therefore undermine long-term viability, even if short-term financial indicators remain satisfactory.

Later developments further refine and consolidate this view. Freeman et al. (2010) argue that stakeholder theory is not simply a normative critique of shareholder capitalism but a reinterpretation of how value is actually created. In fact, firms generate value through cooperative processes that involve multiple constituencies: sustainable wealth creation requires maintaining and aligning these relationships over time and, in this sense, stakeholder theory does not reject value creation but expands the mechanisms through which it is understood.

Donaldson and Preston (1995) introduce a useful conceptual clarification by distinguishing descriptive, instrumental and normative dimensions of stakeholder theory: descriptively, the theory portrays the firm as a combination of interdependent interests; instrumentally, it investigates whether attention to stakeholder relationships contributes to traditional performance outcomes and, normatively, it asserts that stakeholders possess intrinsic value and legitimate claims, independently of their economic contribution. This distinction is central to the debate, since much empirical

research linking environmental or social performance to financial outcomes operates within the instrumental dimension. However, Donaldson and Preston (1995) emphasise that the normative base is fundamental, indeed, as stakeholders have legitimate claims grounded in ethical reasoning and modern property rights theory, managerial responsibility cannot be reduced entirely to shareholder wealth. Environmental performance, in this context, may express obligations toward affected parties even when financial returns are uncertain or delayed. The broadening of corporate objectives raises concerns about coherence.

Jensen (2001) argues that organisations require a single-valued objective function in order to make consistent trade-offs: because it is logically impossible to maximise several objectives simultaneously, abandoning profit maximisation may generate ambiguity and weaken accountability. Jensen therefore proposes long-term value maximisation as the ultimate corporate objective, defined broadly to include the market value of all financial claims. Importantly, this position does not dismiss stakeholder considerations, but, instead, it reframes them instrumentally, with effective stakeholder management becoming a necessary condition for maximising long-term value. Environmental investments are, in this sense, justified when they reduce risk, preserve the firm's licence to operate, or foster innovation.

Not all scholars accept this reconciliation. For example, Margolis and Walsh (2003) observe that even though organisational research has frequently sought to legitimize corporate social initiatives by demonstrating their compatibility with economic logic, empirical findings on the social–financial performance relationship are still mixed and context-dependent. They suggest that the tension between economic and social objectives should not be prematurely resolved and, instead of assuming that "doing good" must always pay financially, scholars should acknowledge that firms operate within moral and institutional environments that shape behaviour beyond immediate profit considerations.

A further development concerns how managers prioritise competing claims in practice. Mitchell, Agle and Wood (1997) propose a theory of stakeholder identification and salience based on three attributes: power, legitimacy and urgency, with stakeholders possessing these attributes to a high degree are more likely to influence managerial decisions. The framework highlights that stakeholder relevance is dynamic, as changes in regulation, public opinion or perceived risk can alter which actors are considered salient. Environmental stakeholders often derive legitimacy from widely

shared sustainability norms, power from regulatory or collective action mechanisms, and urgency from the perceived severity of ecological risks. As climate-related concerns intensify, environmental issues may become more salient independently of short-term financial incentives. Firms may therefore strengthen environmental commitments not solely for profit-related reasons, but in response to evolving stakeholder pressures.

In conclusion, the shift away from a strictly shareholder-first approach reflects a profound change in the perceived purpose of the firm. This transition moves from Friedman's (1970) focus on clear fiduciary mandates and financial returns to Freeman's (1984, 2010) broader vision of mutual value creation. The theoretical landscape is anchored by the conceptual frameworks of Donaldson and Preston (1995) and Jensen's (2001) objective of long-term sustainability. Finally, the details of this shift are then captured by Margolis and Walsh (2003) and Mitchell et al. (1997), who highlight the dynamic nature of stakeholder influence and the inherent conflicts within corporate governance. Together, these contributions establish the theoretical foundation for analysing environmental performance not merely as a cost imposed on profit-seeking firms, but as the outcome of strategic choices embedded in relational, institutional and normative contexts. Environmental performance, therefore, can be understood and analyzed as part of the broader question of how firms define their objectives, manage stakeholder relationships and pursue long-term value creation under conditions of increasing societal scrutiny.

1.1.2 The Natural-Resource-Based View of the firm

The Natural-Resource-Based View (NRBV) represents one of the most important theoretical extensions of the traditional resource-based view (RBV) in the analysis of environmental performance. While the RBV identifies firm-specific resources and capabilities as the primary sources of sustained competitive advantage, it originally paid limited attention to ecological constraints.

Hart (1995) explicitly addresses this gap by arguing that the natural environment must be incorporated into strategic analysis, as environmental challenges increasingly shape both risks and opportunities for firms. The NRBV therefore reframes environmental issues not as peripheral constraints but as central determinants of long-term competitiveness (Hart, 1995).

Building on RBV logic, Hart (1995) maintains that competitive advantage arises from valuable, rare, inimitable and organisationally embedded resources; however, he argues that environmental challenges create new domains in which such capabilities can emerge. In particular, he identifies three interrelated strategic capabilities: pollution prevention, product stewardship and sustainable development. Pollution prevention emphasises continuous improvement and waste reduction within production processes, often leading to cost savings through greater resource efficiency; product stewardship extends environmental responsibility across the value chain, integrating suppliers and customers into life-cycle management, and sustainable development, the most far-reaching dimension, requires firms to align economic activity with ecological limits and broader societal expectations. These capabilities are path-dependent and socially complex, which makes them difficult to replicate and therefore potentially sources of sustained advantage (Hart, 1995).

Subsequent research has provided empirical support and theoretical refinement to this perspective. Russo and Fouts (1997) explicitly adopt a resource-based framework to examine the relationship between corporate environmental performance and profitability but, rather than interpreting environmental performance as a cost imposed by regulation or stakeholder pressure, they conceptualise it as an indicator of underlying organisational capabilities such as innovation, learning and effective coordination. Their empirical findings suggest a positive association between environmental performance and profitability, particularly in high-growth industries where intangible assets and dynamic capabilities are more critical (Russo and Fouts, 1997). This result reinforces the idea that environmental performance may reflect deeper strategic competencies rather than short-term compliance behaviour. At the same time, the NRBV does not imply that environmental initiatives automatically generate superior financial outcomes.

Christmann (2000) provides an important refinement by demonstrating that the economic benefits of environmental “best practices” depend on the presence of complementary assets within the firm, highlighting the heterogeneous and contingent nature of environmental capabilities. Drawing on RBV reasoning, she shows that process innovation capabilities and implementation routines moderate the relationship between environmental management practices and cost advantage. Firms lacking such complementary capabilities may incur additional costs without realising efficiency

gains, while firms with stronger organisational integration can convert environmental initiatives into measurable economic benefits (Christmann, 2000).

The contingent dimension of environmental strategy is further developed by Aragón-Correa and Sharma (2003), who integrate the NRBV with contingency theory and the dynamic capabilities perspective, arguing that the competitive value of proactive environmental strategies depends not only on internal resources but also on characteristics of the external business environment, such as uncertainty and complexity. In dynamic contexts, proactive environmental strategies may function as dynamic capabilities that enable firms to sense, seize and reconfigure resources in response to emerging environmental challenges. In more stable environments, similar strategies may yield weaker advantages (Aragón-Correa and Sharma, 2003). This contribution further reinforces the idea that environmental performance must be analysed in relation to both internal competencies and external conditions.

Fifteen years after its original formulation, Hart and Dowell (2011) revisit the NRBV and assess its evolution. They note that much empirical research has concentrated on pollution prevention, given the relative ease of measuring efficiency outcomes; however, they argue that the broader dimensions of product stewardship and sustainable development are increasingly relevant in light of global sustainability challenges. Moreover, they emphasise the importance of integrating the NRBV with dynamic capabilities theory, as environmental competencies must continuously evolve in response to regulatory, technological and market changes (Hart and Dowell, 2011). The NRBV, therefore, is not a static framework but one that highlights adaptive capability development.

Complementing these firm-level analyses, Ambec and Lanoie (2008) provide a systematic overview of the economic mechanisms through which improved environmental performance can enhance financial performance. Although not explicitly framed as an NRBV contribution, their analysis is consistent with its logic. They identify multiple channels linking environmental initiatives to economic outcomes, including lower material and energy costs, improved risk management, enhanced reputation, better access to capital and increased employee productivity. Importantly, they stress that such “win–win” outcomes are not automatic: indeed, the economic impact of environmental strategies depends on firm characteristics, industry structure and the nature of the environmental investment (Ambec and Lanoie, 2008), reinforcing the NRBV’s emphasis on heterogeneity and firm-specific capability configurations.

Taken together, these contributions position the NRBV as a central framework for understanding the relationship between environmental performance and competitive advantage. By embedding ecological constraints within the RBV, Hart (1995) shifts the focus from external pressure to internal capability development. Subsequent empirical studies, such as Russo and Fouts (1997) and Christmann (2000), demonstrate that environmental performance may generate economic benefits under specific organisational conditions. Further refinements by Aragón-Correa and Sharma (2003) and Hart and Dowell (2011) highlight the dynamic and contingent nature of environmental capabilities, while Ambec and Lanoie (2008) clarify the mechanisms through which environmental strategies may affect financial performance.

Overall, the NRBV provides a robust conceptual foundation for analysing environmental performance as a potential source of sustained competitive advantage. Environmental outcomes are not merely by-products of regulation but may reflect deeper strategic capabilities embedded in organisational routines and learning processes. In environmentally intensive sectors, where resource efficiency and technological innovation are central to competitiveness, intensity-based environmental indicators may serve as proxies for these underlying capabilities. Understanding this linkage is crucial for evaluating whether environmental performance is associated with long-term value creation rather than short-term compliance costs.

1.1.3 The Porter Hypothesis and environmental innovation

The Porter Hypothesis represents a major turning point in the debate on the relationship between environmental regulation and firm competitiveness, challenging the conventional economic view that regulation necessarily imposes additional costs and therefore weakens productivity and profitability.

In the traditional framework, pollution is treated as an unavoidable by-product of production, and regulatory intervention forces firms to allocate resources to compliance rather than to productive investment, following the logic that, if profitable pollution-reducing opportunities existed, profit-maximising firms would already have adopted them, making regulation redundant (Porter and van der Linde, 1995). Porter and van der Linde (1995) argue that this reasoning relies on unrealistic assumptions about firm behaviour, as it presumes that firms operate on their production possibility frontier, possess full information, and continuously exploit all efficiency-enhancing

opportunities. In practice, however, firms face organisational inertia, bounded rationality and coordination failures and inefficiencies—such as excessive material inputs, energy waste or outdated technologies—may persist simply because they are not systematically identified.

From this more dynamic perspective, environmental regulation can function as a catalyst element, stimulating innovation, rather than merely imposing costs, by drawing attention to inefficiencies and creating incentives to rethink processes (Porter and van der Linde, 1995). At the core of the Porter Hypothesis lies the idea of "innovation offsets". Well-designed environmental regulation, particularly when it is stringent but flexible, can induce firms to develop innovations that partially or even fully compensate for compliance costs, with efforts to reduce emissions or waste often coinciding with improvements in resource productivity and process efficiency. Regulation, in this view, shifts technological trajectories and encourages experimentation and learning. Importantly, Porter and van der Linde (1995) do not claim that all forms of regulation are beneficial, as prescriptive and rigid standards are less likely to foster innovation than market-based or performance-based instruments. Subsequent literature has clarified and refined the hypothesis.

Jaffe and Palmer (1997) distinguish between different versions that have become a standard in empirical research. The "weak" version points out that environmental regulation stimulates innovation, without making claims about net economic effects, while the "strong" version states that regulation-induced innovation improves competitiveness by more than offsetting compliance costs. A "narrow" version suggests that certain regulatory instruments—especially market-based tools such as taxes or tradable permits—are more conducive to innovation than command-and-control approaches (Jaffe and Palmer, 1997). Empirical evidence tends to support the weak version. Using panel data, Jaffe and Palmer (1997) find out that environmental regulation is associated with increased research and development expenditures, confirming that regulatory pressure appears to stimulate innovative effort. However, higher R&D spending does not automatically translate into measurable gains in productivity or profitability. This distinction between innovation inputs and economic outcomes is crucial, as it warns against interpreting any observed increase in innovative activity as proof that regulation enhances competitiveness.

Ambec et al. (2013), in a comprehensive review conducted twenty years after the original formulation, emphasise that much of the controversy surrounding the

Porter Hypothesis arises from misunderstandings about its scope. The hypothesis does not assert that environmental regulation is universally beneficial, nor that innovation offsets are guaranteed. Rather, it proposes that under specific conditions—such as regulatory flexibility, technological opportunity and learning effects—regulation *may* trigger innovations that enhance both environmental and economic performance. Ambec et al. (2013) also stress the importance of timing: compliance costs often arise in the short term, whereas innovation benefits may materialise only gradually.

The role of technological dynamics is explored more explicitly in the literature on directed technical change. Aghion et al. (2016), in particular, analyze how environmental policies, including carbon taxes, influence not only the level but also the direction of innovation. As firms typically build on existing technological capabilities, which can create path dependency and lock-in to carbon-intensive trajectories, altering relative incentives across technologies, environmental policies can redirect innovative effort toward cleaner alternatives. Empirical evidence from the automotive industry shows that higher fuel prices and carbon-related regulations stimulate innovation in low-emission technologies while discouraging innovation in polluting ones (Aghion et al., 2016). This perspective complements the Porter Hypothesis by highlighting how regulation shapes long-term technological pathways rather than merely short-term efficiency improvements.

Another relevant dimension concerns knowledge spillovers Dechezleprêtre, Martin and Mohnen (2017) compare spillovers from clean and dirty technologies using patent citation data, finding that clean technologies generate significantly larger knowledge spillovers than polluting technologies. In other words, innovation in environmentally friendly sectors creates broader external benefits for the economy. This provides an additional rationale for environmental regulation: if clean innovation produces greater positive externalities, regulatory policies that encourage its development might enhance aggregate productivity, even if individual firms cannot fully appropriate the gains (Dechezleprêtre et al., 2016). In this sense, regulation may address not only environmental externalities but also innovation-related market failures.

Overall, these contributions underscore that the relationship between environmental regulation and competitiveness is inherently dynamic. The Porter Hypothesis shifts attention away from static cost comparisons toward a more complex interaction between regulation, organisational capabilities and technological change,

suggesting that environmental policy can act as a stimulus for innovation, but only under specific institutional and technological conditions. At the same time, important limitations remain. Not all firms possess the absorptive capacity or financial resources required to respond effectively to regulatory pressure, therefore innovation offsets may be partial, delayed or unevenly distributed across sectors. In capital-intensive industries, for example, characterised by long investment cycles, compliance costs may precede productivity gains by several years. Ambec et al. (2013) explicitly warn against interpreting the hypothesis as a broad “all-encompassing” justification for stricter regulation, since its validity depends on regulatory design, technological opportunities and firm capabilities.

In general, the Porter Hypothesis provides a crucial conceptual bridge between environmental performance and competitiveness by placing innovation at the centre of the analysis. By challenging the traditional trade-off view, it legitimises the study of environmental regulation as a potential driver of technological transformation and long-term value creation. When combined with insights from directed technical change and knowledge spillover research, in fact, it offers a nuanced framework for understanding how environmental policies may reshape both firm-level performance and broader technological trajectories.

1.2 Empirical evidence on ESG-environmental performance and financial performance

This second section reviews the empirical literature that has tested the relationship between environmental or ESG performance and corporate financial performance, with the aim of highlighting the main findings of previous studies and the reasons behind the mixed and sometimes contradictory results observed in the literature.

1.2.1 Early empirical studies and mixed evidence

Early empirical research on the relationship between corporate social performance (CSP) and corporate financial performance (CFP) is marked by fragmentation and inconsistent findings, with studies from the late 1970s through the 1990s reporting positive, negative, and statistically insignificant relationships, often within similar time periods and samples. Rather than converging toward a shared conclusion, this first

wave of research exposed deep conceptual and methodological weaknesses that have shaped the subsequent evolution of the field.

A foundational critique is offered by Ullmann (1985), who famously described the literature as “data in search of a theory.” According to Ullmann (1985), the absence of a clear theoretical framework linking social and financial performance explains much of the empirical inconsistency.

Many early studies tested correlations between CSP and CFP without specifying causal mechanisms. Competing explanations—such as the trade-off hypothesis, the slack resources argument, and managerial quality interpretations—were frequently examined within the same empirical models, often without clear conceptual differentiation, and, as a result, statistical associations were reported but their interpretation remained ambiguous.

One prominent early perspective was grounded in neoclassical economics and assumed a trade-off between social responsibility and profitability. From this viewpoint, social initiatives—investments in environmental protection, employee welfare, or community engagement—represent discretionary costs that reduce short-term shareholder value. Empirical tests inspired by this logic often sought negative relationships between CSP and accounting or market-based indicators of financial performance.

McGuire, Sundgren and Schneeweis (1988), for example, examined corporate social responsibility ratings alongside measures of profitability and risk. While they did not find strong evidence that CSP consistently predicts future financial performance, they showed that prior financial performance is positively associated with subsequent CSP. This finding lends support to the slack resources’ hypothesis, stating that financially successful firms possess discretionary resources that allow them to invest in social initiatives (McGuire et al., 1988). The slack resources explanation implies a direction of causality from financial to social performance. In contrast, the “good management” hypothesis suggests that socially responsible behaviour enhances financial outcomes by improving stakeholder relationships, reputation, and organisational effectiveness. Rather than viewing CSP as a luxury afforded by profitable firms, this perspective treats it as an indicator of superior management quality.

The difficulty, however, lies in disentangling these two mechanisms empirically: as Preston and O’Bannon (1997) argue, the CSP–CFP relationship cannot be fully

understood without explicitly considering both the sign of the association and the direction of causality. Their analysis highlights that positive correlations may reflect multiple underlying processes operating simultaneously, reinforcing the need for more rigorous modelling strategies.

A major empirical contribution addressing this issue is provided by Waddock and Graves (1997). Using improved data on corporate social performance, they test both the slack resources and good management hypotheses within a single framework. Their results indicate that CSP is positively associated with both prior and future financial performance, suggesting a potentially virtuous cycle: stronger financial results enable greater social engagement, which in turn contributes to improved subsequent performance (Waddock and Graves, 1997). Although influential, this finding does not eliminate ambiguity, but instead reinforces the idea that the relationship is complex, dynamic, and potentially bidirectional.

Methodological heterogeneity further complicates interpretation. Griffin and Mahon (1997), in their review of twenty-five years of research, conclude that inconsistency is a defining feature of the CSP–CFP debate, as differences in operationalisation, data sources, and performance metrics substantially affect empirical outcomes. Perceptual measures of social performance—such as reputation indices or third-party ratings—often yield different results compared to objective indicators like pollution emissions or philanthropic expenditures. Similarly, accounting-based financial measures may produce conclusions that diverge from those based on stock market performance (Griffin and Mahon, 1997). In some cases, the choice of measurement appears to predetermine the direction of the observed relationship.

The use of social disclosure as a proxy for actual social performance constitutes another source of inconsistency. Ullmann (1985) questions the validity of equating disclosure with substantive performance, noting that reporting practices may be driven by strategic communication concerns rather than genuine responsibility: firms may, in fact, overstate social engagement to enhance legitimacy or underreport it to avoid scrutiny and, consequently, empirical studies relying on disclosure measures may capture reputational strategies rather than operational behaviour, leading to biased or unstable results.

Additional problems arise from sample selection and model specification. Many early studies relied on large, cross-industry samples, implicitly assuming homogeneity in the CSP–CFP relationship; however, as industries actually differ in regulatory

exposure, stakeholder pressure, technological intensity, and environmental impact, aggregating firms across heterogeneous sectors may obscure context-specific dynamics. Griffin and Mahon (1997) emphasise that industry effects, measurement sensitivity, and time horizons all influence empirical outcomes. In particular, short-term market reactions may differ substantially from long-term accounting performance, yet early research often treated these measures interchangeably.

Risk adjustment also plays a crucial role. McGuire et al. (1988) show that firms with higher social performance tend to exhibit lower total risk, suggesting that CSP may function as a risk management mechanism. However, many earlier studies did not control adequately for risk, potentially conflating higher returns with higher volatility. Without incorporating appropriate controls, observed associations between CSP and CFP may therefore be misleading.

In general, early empirical research does not provide a definitive answer regarding the existence, sign, or direction of the CSP–CFP relationship; instead, it reveals struggle with theoretical under-specification, measurement limitations, and methodological diversity. While some studies report positive associations and others identify negative or null effects, these discrepancies often reflect differences in conceptual framing and operational choices rather than fundamentally contradictory economic realities. This phase of the literature was nonetheless relevant as, by exposing weaknesses in theory and measurement, it laid the groundwork for more refined approaches in later decades. The identification of slack resources, good management mechanisms, bidirectionality, measurement sensitivity, and contextual heterogeneity provided the analytical foundations for subsequent meta-analyses and more sophisticated empirical designs. In this sense, the mixed evidence of early research should be interpreted as an exploratory stage in the development of a more mature understanding of the relationship between social and financial performance.

1.2.2 Meta-analyses and systematic reviews of the ESG–financial performance relationship

As the empirical literature on ESG and financial performance rapidly expanded over the past three decades, individual studies began to produce heterogeneous and sometimes conflicting findings, leading scholars to adopt meta-analytic and systematic

review approaches in order to synthesize accumulated evidence and assess whether a consistent pattern could be identified.

Overall, while methodological diversity remains substantial, the majority of large-scale meta-analyses converge toward a positive average association between ESG (or CSP) and corporate financial performance, although with significant contextual variation.

A foundational contribution is represented by the meta-analysis by Orlitzky, Schmidt and Rynes (2003). Applying meta-analytic techniques, correcting for measurement error, to 52 primary studies (33,878 observations), the authors challenge the widespread claim that the CSP–CFP relationship was “inconclusive” and report a statistically significant and positive association between corporate social performance and financial performance, demonstrating that the magnitude of the relationship depends on operationalization. In fact, CSP is more strongly correlated with accounting-based indicators (e.g., ROA, ROE) than with market-based measures, and reputation-based proxies of CSP exhibit stronger correlations than other indicators. This early meta-analysis already highlights a central issue that continues to characterize the literature, being that measurement choices substantially shape empirical outcomes.

Building on this foundation, Friede, Busch and Bassen (2015) provide the most comprehensive aggregation of ESG–CFP evidence to date. Synthesizing more than 2,000 empirical studies through a second-order approach that integrates vote-count studies and prior meta-analyses, they find out that roughly 90% of studies report a non-negative relationship between ESG criteria and financial performance, with a clear majority indicating positive effects. Moreover, the positive association appears stable over time and across regions, including emerging markets and newer asset classes. While this study strongly supports the economic rationale for ESG, it also emphasizes heterogeneity in effect sizes, suggesting that the ESG–financial performance relationship is neither uniform nor unconditional.

The robustness of these findings is further reinforced by the second-order meta-analysis of Busch and Friede (2018), which combines 25 previous meta-analyses and approximately one million observations. Their results confirm a highly significant, positive, and bilateral CSP–CFP relationship, as the positive association holds for both environmental and social dimensions, though corporate reputation emerges as a particularly influential driver. Notably, the relationship is stronger for operational

financial performance than for market-based indicators. By explicitly addressing concerns regarding publication bias and journal orientation, the authors conclude that the positive association is not a product of selective reporting; however, they also acknowledge variability across CSP dimensions and financial metrics, reinforcing the diverse nature of the relationship.

More recent contributions have refined the debate by incorporating broader datasets, alternative methodologies, and cross-country comparisons. Bai et al. (2024), combining bibliometric analysis and meta-analysis across English, Chinese and Korean publications, identify a low but positive overall correlation between ESG and financial performance. Interestingly, while English-language studies show statistically weaker effects, Chinese and Korean papers report moderate positive correlations, suggesting that institutional and regional factors may influence observed outcomes. This cross-linguistic comparison underlines the importance of contextual embeddedness in ESG research.

Similarly, Ke Wang et al. (2025) examine the heterogeneous impact of ESG disclosure on corporate performance: their meta-analysis indicates that the relationship varies significantly depending on disclosure quality, governance structures, and industry characteristics. Indeed, rather than a uniform ESG effect, the evidence points toward conditional relationships shaped by transparency, regulatory environment, and firm-specific attributes.

From a financial stability perspective, Zheng et al. (2025) extend the scope of research by investigating the ESG–financial stability nexus through bibliometric and meta-analytic techniques. Synthesizing 140 studies, they highlight that ESG performance is frequently associated with lower risk exposure, enhanced resilience, and improved financial stability, although individual ESG components (E, S, and G) exert distinct effects: environmental performance may reduce regulatory and transition risks, while governance quality can lower financing costs. This micro-level approach suggests that aggregating ESG into a single composite score may hide important mechanisms.

A complementary systematic review by Da Cunha et al. (2025) maps ESG indicators and corporate performance through a structured literature synthesis. Their analysis confirms the predominance of positive or neutral findings but stresses the persistent lack of standardization in ESG measurement and the underexplored role of mediating and moderating variables.

Similarly, Parra-Domínguez (2026), focusing on emerging markets, finds that while the CSR–financial performance relationship is predominantly positive, its magnitude is strongly shaped by institutional quality, sector sensitivity, and governance maturity.

Overall, meta-analyses and systematic reviews converge toward three core conclusions. First, the average relationship between ESG (or CSP) and financial performance is positive and statistically significant; second, negative trade-offs appear relatively rare in aggregate evidence; and third, heterogeneity is substantial and cannot be ignored. Measurement choices, regional context, industry characteristics, disclosure quality, and financial metrics all influence the magnitude and, occasionally, the direction, of the relationship. Therefore, while the cumulative evidence provides strong support for the existence of a financial benefit for ESG, it also underscores that the latter is conditional rather than universal: ESG performance does not mechanically translate into superior financial outcomes; instead, it interacts with institutional environments, firm capabilities, and strategic integration. Meta-analytic research thus shifts the research focus beyond the simplistic question of whether ESG "pays" toward an understanding of when, how, and under which conditions ESG performance might contribute to economic value creation.

1.2.3 Non-linearities, thresholds effects and contingency factors

A growing body of research questions the implicit assumption that the relationship between environmental (or broader ESG) performance and financial performance is linear. Rather than assuming a constant marginal effect, these studies argue that the impact of sustainability engagement varies across performance levels, sectors and institutional environments. This different perspective offers a plausible explanation for the heterogeneous and sometimes contradictory results documented in earlier empirical research: by explicitly modelling curvilinear patterns, thresholds and regime shifts, this stream of research reframes the ESG–financial performance nexus as structurally contingent rather than uniformly positive or negative.

One of the most influential contributions is by Barnett and Salomon (2012), who examine the shape of the corporate social performance (CSP)–corporate financial performance (CFP) relationship, building their argument on the concept of stakeholder influence capacity (SIC), defined as a firm's ability to leverage stakeholder

relationships for competitive advantage. At low levels of CSP, social investments may impose costs without generating sufficient stakeholder support, leading to weak or even negative financial effects; however, once firms accumulate adequate stakeholder influence capacity, they are better positioned to extract reputational and relational benefits. Empirical evidence based on panel data from 1,214 firms (1998–2006) reveals a U-shaped relationship: firms with moderate CSP underperform, while those with very high CSP achieve superior financial performance. The implication is not that sustainability automatically pays, but that "it pays to be really good" once a critical threshold is reached (Barnett and Salomon, 2012).

A similar logic is applied to environmental performance by Trumpp and Guenther (2017), who draw on the "*too-little-of-a-good-thing*" (TLGT) framework, which, using measures of carbon performance and waste intensity for an international sample, also identify a U-shaped relationship between corporate environmental performance (CEP) and financial outcomes. At low levels of environmental engagement, costs dominate; beyond a certain point, however, efficiency gains, reputational benefits and innovation effects become more pronounced. Importantly, the relationship varies across industries, with stronger curvilinear effects in manufacturing sectors. This suggests that environmental intensity and technological characteristics shape the payoff structure of sustainability strategies (Trumpp and Guenther, 2017).

Nollet, Filis and Mitrokostas (2016) further extend the non-linear perspective by estimating both linear and quadratic models for S&P 500 firms. Notably, their analysis relies on Bloomberg ESG disclosure scores, which measure the extent of corporate transparency rather than actual sustainability performance. While linear specifications often indicate a negative association with certain accounting-based indicators, quadratic models reveal U-shaped patterns. Disaggregating ESG into environmental, social and governance components, the authors find that the non-linearity is primarily driven by the governance pillar. This result highlights two important points: first, aggregate ESG scores may mask heterogeneous dynamics across dimensions, and second, only sufficiently high levels of transparency and governance commitment appear to generate measurable financial benefits (Nollet et al., 2016).

Beyond individual studies, Endrikat, Guenther and Hoppe (2014) provide a meta-analytic synthesis of the corporate environmental performance–financial performance literature. Although their primary focus is not exclusively on non-linear

modelling, they demonstrate that effect sizes vary systematically depending on methodological choices, industry characteristics and measurement approaches. In particular, the presence of moderators helps explain conflicting findings and supports the view that the CEP–CFP relationship is context-dependent rather than structurally uniform (Endrikat et al., 2014).

The importance of internal mechanisms is explored by Hussain, Rigoni and Cavezzali (2018), who investigate the “black box” linking sustainability performance and financial performance. Their results suggest that the impact of ESG depends on how sustainability practices are integrated within organisational processes and governance structures. Rather than producing immediate linear effects, ESG investments interact with firm capabilities and strategic orientation, reinforcing the argument that thresholds and complementarities matter, and, therefore, that the financial payoff of sustainability is mediated by internal alignment and implementation depth (Hussain et al., 2018).

More recent contributions apply advanced econometric techniques to capture regime-switching and distributional effects. Bouattour, Kalai and Helali (2024), using a regime-switching approach in the banking sector, show that the ESG–stability relationship differs across digital and non-digital contexts. ESG engagement enhances bank stability primarily in certain regimes, indicating that institutional and technological environments condition the benefits of sustainability.

Similarly, Bagh et al. (2024) identify inverse U-shaped patterns between ESG performance and sustainable growth, suggesting that excessive ESG investment may eventually generate diminishing returns.

Several studies further develop this perspective. Kweh, Ting and Lu (2025), employing non-linear efficiency models, document threshold effects in the ESG–efficiency relationship, with marginal gains declining beyond intermediate levels of ESG engagement.

Ke Wang et al. (2025), analysing ESG investment dynamics, find time-varying and sector-dependent non-linearities. Ke Wang (2025), focusing on stock returns, reports a U-shaped association between ESG scores and abnormal returns, alongside inverted U-shaped effects for certain risk-adjusted performance measures.

Complementing these findings, Yang (2025) demonstrates that the ESG premium itself exhibits non-linear characteristics in asset pricing models, particularly when extreme ESG scores are considered. Taken together, these studies confirm that

linear specifications may underestimate the complexity of ESG-related performance effects.

Overall, the evidence suggests that the ESG–financial performance relationship is shaped by thresholds, sectoral conditions and organisational capabilities. Low levels of ESG engagement may generate costs without sufficient strategic benefits, while very high levels, if not supported by complementary resources, may also entail inefficiencies. Between these extremes, firms may experience varying payoffs depending on industry structure, regulatory pressure and internal governance, implying that linear models risk oversimplifying a fundamentally dynamic and contingent relationship. By explicitly modelling U-shaped patterns and regime dependence, this literature reconciles previously conflicting findings and deepens our understanding of how and when sustainability translates into financial value. For environmentally intensive sectors in particular, where capital intensity and regulatory exposure are high, recognising non-linearities is essential to interpret empirical results accurately and to avoid misleading generalisations.

1.3 Measurement issues in ESG and environmental performance research

This third section addresses the main measurement challenges that affect ESG and environmental performance research, focusing in particular on how different measurement choices may influence empirical results and their interpretation.

1.3.1 Limitations of aggregate ESG scores and rating divergence

The rapid growth of sustainable finance has led to widespread reliance on third-party ESG ratings as synthetic measures of firms' sustainability performance. Aggregate ESG scores— constructed by combining environmental (E), social (S), and governance (G) dimensions into a single composite indicator—are now employed in portfolio allocation, benchmarking, engagement strategies, and academic research.

Despite their diffusion, a growing literature questions their conceptual coherence, measurement validity, and empirical reliability. These concerns are particularly visible in the phenomenon of rating divergence, historical instability, and economically significant consequences for firms and investors.

A fundamental contribution to this debate is provided by Berg, Kölbel and Rigobon (2022), who document substantial disagreement across six major ESG rating agencies. Using data from KLD, Sustainalytics, Moody's ESG (Vigeo-Eiris), S&P Global (RobecoSAM), Refinitiv, and MSCI, they report correlations between 0.38 and 0.71, considerably lower than those observed among credit rating agencies. Importantly, they decompose divergence into the three components of scope (38%), measurement (56%), and weight (6%), finding that measurement differences, being how agencies evaluate the same attribute, are the primary driver of disagreement. The authors also identify a "rater effect," whereby an agency's overall perception of a firm systematically influences category-level scores, suggesting that ESG ratings embody structurally different interpretations of sustainability.

Similar concerns are raised by Chatterji et al. (2016), who examine convergent validity across six CSR rating systems and find limited overlap even after accounting for explicit definitional differences. The persistence of disagreement implies low validity rather than acceptable variation in methodology: in fact, if ratings diverge substantially, the interpretation of aggregate ESG performance becomes provider-dependent and, for managers and investors, this means that a firm's "ESG quality" is not an objective characteristic but a function of the specific framework adopted.

Billio et al. (2021) deepen this argument by analysing heterogeneity in ESG rating criteria across nine agencies, showing that providers differ not only in weighting schemes but also in the definition of characteristics, attributes, and standards underlying E, S, and G components. As a result, agencies may assign opposite evaluations to the same company. As a practical consequence of this heterogeneity, different definitions generate distinct sustainable investment universes and benchmarks, complicating performance attribution, and, if portfolio composition depends on the selected rating provider, comparing ESG fund performance becomes methodologically problematic.

Beyond cross-sectional divergence, ESG scores also exhibit temporal instability. Berg, Fabisik and Sautner (2021) document widespread retrospective revisions in Refinitiv ESG ratings, showing that historical scores are frequently rewritten. Indeed, comparing different data downloads, they find systematic changes that alter firm rankings and ESG quintile classifications. Such practices obviously affect empirical tests linking ESG performance to stock returns and other financial outcomes, and, if historical ESG data are not stable, the reliability and reproducibility of academic

findings are weakened. Rating divergence is not merely a technical issue; it has economically meaningful implications.

Gibson, Krueger and Schmidt (2021) show that ESG rating disagreement is positively associated with stock returns, suggesting a risk premium for firms with higher disagreement.

Avramov et al. (2022) similarly argue that ESG rating uncertainty affects equilibrium asset pricing, increasing the market premium and altering CAPM alphas and betas. In both cases, disagreement introduces an additional dimension of risk since, rather than reflecting only underlying sustainability performance, aggregate ESG scores embed uncertainty about measurement itself.

Disagreement also affects firms' risk profiles and financing conditions. Christensen, Serafeim and Sikochi (2022) show that greater ESG disclosure can amplify rating disagreement, particularly for outcome-based metrics. Rather than resolving informational asymmetries, increased transparency may indeed expose divergent interpretations across raters. On this matter, recent evidence indicates that rating disparities can increase corporate risk and financing constraints, particularly in environments with less institutional standardisation, as also noticed by Avramov et al. (2022), suggesting that rating divergence can generate tangible financial consequences beyond reputational effects.

The methodological ambiguity of ESG data further complicates interpretation. Kotsantonis and Serafeim (2019) highlight four structural problems in ESG datasets: inconsistent corporate reporting practices, unclear benchmarking methodologies, heterogeneous imputation techniques to address missing data, and increasing disagreement as disclosure expands. The authors emphasise that, even though benchmarking choices, namely how peer groups are defined, can substantially affect firm rankings, these procedures are often not fully transparent. Inconsistent gap-filling methods further amplify cross-provider divergence.

At a more structural level, Dimson, Karakaş and Li (2015) demonstrate that ESG engagement can generate financial and governance improvements following successful activism. However, if aggregate ESG scores differ significantly across providers, identifying firms that warrant engagement becomes less straightforward. Divergent ratings may in fact distort signals about where sustainability improvements are most needed, reducing the efficiency of active ownership strategies.

Finally, the misalignment between ESG scores and real environmental performance raises additional concerns: OECD (2022) shows that higher environmental pillar scores do not necessarily correspond to lower carbon emissions or emission intensity and, if aggregate E-scores are weakly correlated with climate-relevant metrics, then their use as proxies for transition alignment becomes problematic.

Taken together, this literature indicates that aggregate ESG scores are not neutral measurement tools but constructed artefacts shaped by scope choices, measurement rules, weighting schemes, data gaps, and methodological assumptions. Rating divergence, historical instability, and opacity imply that aggregate scores should be interpreted with caution. For researchers, this raises concerns about construct validity and robustness and for investors, it underscores the importance of understanding the underlying methodology rather than relying on composite metrics. More generally, the limitations of aggregate ESG ratings motivate a shift toward more granular, dimension-specific, and intensity-based indicators that better reflect measurable environmental and operational performance.

1.3.2 Materiality, disclosure and investor relevance of environmental information

The growing integration of sustainability into financial decision-making has shifted the focus from broad corporate performance metrics to the specific investment performance implications of ESG data. The central question is no longer how firms report sustainability information, but how such data drives portfolio outcomes by affecting risk assessment, expected cash flows, and ultimate firm value. This shift has led to a more refined understanding of environmental disclosure, specifically through the filter of financial materiality for investors.

An essential contribution in this debate is provided by Khan, Serafeim and Yoon (2016), who distinguish between material and immaterial sustainability issues based on industry-specific guidance. Their evidence shows that firms performing well on material sustainability issues significantly outperform those that do not, while performance on immaterial issues has no measurable financial impact. This finding is crucial, as it suggests that not all ESG information is equally relevant to investors, and that the economic consequences of sustainability performance depend on its

alignment with core business risks and opportunities, making materiality a key filter linking environmental performance to financial outcomes.

The informational value of environmental disclosure is further supported by Griffin, Lont and Sun (2017), who analyse market reactions to greenhouse gas emission disclosures and show that investors respond to quantitative GHG information, particularly when disclosure reveals unexpected exposure, suggesting that carbon emissions data reduce information asymmetry and allow investors to reassess risk.

Consistently, Bolton and Kacperczyk (2021) document a carbon risk premium in equity markets, indicating that investors demand compensation for exposure to carbon-intensive activities. Together, these studies confirm that environmental information, when measurable and decision-relevant, becomes part of asset pricing mechanisms.

Theoretical foundations for this mechanism lie in disclosure theory. Healy and Palepu (2001) argue that corporate disclosure reduces information asymmetry between managers and investors, thereby lowering the cost of capital. Extending this framework to nonfinancial disclosure, Dhaliwal et al. (2011) find that firms initiating voluntary CSR disclosure experience reductions in the cost of equity capital. These results suggest that sustainability reporting may generate financial benefits not merely through improved operations, but through improved transparency. However, voluntary disclosure does not guarantee comparability or completeness, motivating regulatory intervention.

Grewal, Riedl and Serafeim (2019) examine market reactions to the EU's mandatory nonfinancial disclosure directive and find that firms with previously low ESG transparency experience stronger market responses. Similarly, Christensen, Hail and Leuz (2021) show that mandatory CSR reporting increases disclosure quality and comparability, although effects vary across institutional contexts. These findings imply that regulation can enhance the credibility and usefulness of sustainability information, especially when voluntary practices are heterogeneous.

Recent work further explores whether sustainability reporting contains financially material content. Haley, Shaffer and Sloan (2025) provide evidence that sustainability reports indeed contain value-relevant information, particularly when disclosures relate to economically significant exposures.

In parallel, Christofi (2025) finds that enhanced sustainability disclosure improves the value relevance of accounting information, suggesting complementarity between financial and nonfinancial reporting.

Finally, Monteiro (2024), using cross-country evidence, reports that sustainability reporting is associated with improved financial performance, though effects differ by institutional environment.

The materiality debate also intersects with industry characteristics: Abu-Allan (2025), analysing Jordanian firms, finds that the financial impact of sustainability reporting is stronger in high-pollution industries, reinforcing the argument that environmental disclosure is particularly relevant where environmental externalities and regulatory risks are significant. In capital-intensive and emission-heavy sectors, consequently, environmental information is not peripheral but central to risk evaluation.

Beyond firm-level disclosure, the investment community has increasingly incorporated ESG information into portfolio strategies. Kotsantonis, Pinney and Serafeim (2016) document the evolution of ESG integration practices in investment management, highlighting both progress and persistent methodological challenges. Similarly, Boffo and Patalano (2020) note that while ESG investing has grown substantially, differences in data sources, metrics and methodologies limit comparability and raise concerns about reliability.

These concerns are also addressed in research on ESG rating divergence. Although rating disagreement was discussed more extensively in the previous section, it also has implications for materiality. Agosto et al. (2025) provide a comprehensive survey of ESG rating divergence and aggregation methods, showing that differences in scope, weighting and data treatment can substantially alter assessments of firm sustainability. Antolín-López et al. (2023) similarly highlights methodological inconsistencies in ESG measurement frameworks and calls for improved transparency and harmonisation. Such divergence matters because investors increasingly rely on ESG ratings for capital allocation and, if ratings aggregate immaterial and material issues indiscriminately, they may dilute the informational content that investors actually require. The problem is not merely disagreement per se, but the risk that aggregation obscures financially relevant environmental exposures.

At the macro-financial level, climate risk has been framed as a potential source of systemic instability. Bolton et al. (2020) introduce the concept of the “green swan,” emphasising that climate-related shocks may produce nonlinear financial

consequences. In this context, accurate and material environmental disclosure becomes essential not only for individual investors but for financial stability more broadly.

Overall, literature converges on several key insights: first, environmental disclosure influences investor behaviour when it conveys material information about firm-specific risks and opportunities; second, regulatory intervention can enhance comparability and credibility, though its effectiveness depends on enforcement and institutional context; and third, aggregation challenges and rating divergence may weaken the link between reported sustainability performance and actual financial relevance.

For the purposes of this dissertation, these findings have important methodological implications. Analysing environmental performance, indeed, requires distinguishing between generic ESG indicators and industry-specific, financially material metrics. Particularly in environmentally intensive sectors, environmental disclosure should be evaluated in light of its relevance to core economic drivers, regulatory exposure and transition risk. In synthesis, materiality operates as the conceptual bridge between environmental information and financial performance: without a materiality filter, sustainability disclosure risks remaining symbolic. When properly aligned with firm-specific risks and industry dynamics, however, environmental reporting can meaningfully inform investor decisions and shape capital allocation.

1.3.3 Environmental performance indicators and intensity-based measures

The empirical analysis of the environmental–financial performance relationship depends critically on how environmental performance is measured: indicators influence theoretical interpretation, econometric specification, and ultimately the conclusions drawn about whether environmental engagement enhances or constrains firm value.

A central distinction in this debate concerns the use of absolute indicators (e.g., total greenhouse gas emissions) versus intensity-based measures (e.g., emissions per unit of output, revenue, or assets). Absolute measures capture the scale of environmental impact. They are essential from a policy and planetary perspective, since climate change mitigation ultimately depends on reducing total emissions;

however, at the firm level they are strongly correlated with size. Larger firms almost mechanically generate higher total emissions, which makes cross-sectional comparison problematic and risks conflating environmental performance with scale effects.

For this reason, empirical research increasingly relies on intensity-based indicators, which normalise environmental impact by economic or physical output. In particular, carbon intensity (e.g., tonnes of CO_2 per unit of sales) and sector-specific metrics (e.g., emissions per tonne of steel) are particularly relevant in environmentally intensive industries, as they allow comparison across firms with different production volumes and facilitate the identification of relative efficiency differences.

The conceptual foundation of intensity metrics lies in the notion of eco-efficiency, which links environmental impact to economic value creation. Eco-efficiency is typically defined as the ratio between economic output and environmental resources used (Callens and Tyteca, 1999; Huppes and Ishikawa, 2005) and, by construction, it is a relational concept, as environmental performance is assessed relative to economic activity rather than in absolute terms.

Figge and Hahn (2013) develop this logic further by decomposing eco-efficiency into distinct value drivers, showing that eco-efficiency depends not only on environmental resource use but also on margins and capital turnover, thereby embedding environmental performance within the firm's broader economic structure. Importantly, they demonstrate that improvements in eco-efficiency do not necessarily imply improvements in absolute environmental sustainability, indeed, a firm may become more carbon-efficient while expanding total production and thus increasing aggregate emissions.

This distinction between relative efficiency and absolute impact is crucial when interpreting empirical findings. From a disclosure perspective, the relevance of quantitative performance indicators is reinforced by Clarkson, Overell and Chapple (2011) which, using emissions data from the National Pollutant Inventory, show that firms with objectively measured environmental performance tend to provide more verifiable and performance-based disclosures. Their findings suggest that environmental performance, when operationalised through concrete metrics rather than symbolic statements, is associated with more substantive reporting practices.

Beyond disclosure quality, the financial relevance of carbon-related metrics has received increasing attention in asset pricing research. Bolton and Kacperczyk (2021)

document a carbon premium in U.S. equity markets, showing that firms with higher carbon emissions earn higher expected returns, consistent with investors demanding compensation for carbon risk. Crucially, their analysis relies on emissions scaled to economic activity, highlighting the importance of intensity-based measures in identifying risk exposures.

Similarly, Wang, Lee and Lee (2025) exploit the introduction of mandatory disclosure under Korea's Target Management System and show that heavy GHG emitters experience a decline in firm value following disclosure requirements. The market reaction suggests that investors actively use emissions data to reassess risk and expected cash flows. The use of structured emissions metrics also strengthens causal identification and reduces self-selection bias associated with voluntary disclosure.

Physical climate risk provides an additional channel through which environmental performance indicators acquire financial relevance. Pankratz, Bauer and Derwall (2023) demonstrate that exposure to extreme heat negatively affects revenues and operating income, and that analysts do not fully anticipate these effects. While their study focuses on physical exposure rather than emissions intensity, it underscores that climate-related variables—when properly quantified—carry material financial implications.

However, not all metrics equally capture underlying environmental reality and recent research raises concerns regarding ESG ratings and climate scores. Drempetic, Klein and Zwergel (2020) find that ESG scores are positively correlated with firm size, suggesting potential resource and visibility biases. Larger firms may achieve higher ratings partly because they possess greater capacity to produce and disclose ESG data, rather than because they are environmentally superior.

Sector-specific evidence reinforces this concern: in particular, Cregan, Kelly and Clinch (2024), analysing the steel industry, find limited evidence that environmental or emissions scores within major ESG ratings reflect actual levels or changes in greenhouse gas emissions. In a hard-to-abate sector, ratings often fail to track real decarbonisation performance, highlighting the importance of relying on transparent, intensity-based operational metrics rather than aggregated ESG scores when studying environmentally intensive industries.

The OECD (2022) similarly emphasises methodological ambiguity and inconsistency in climate-related ESG ratings, warning that divergence across providers may obscure transition risks and weaken market discipline.

Rating disparities can also amplify financing constraints and corporate risk, as suggested by Bao et al. (2024), who document that ESG rating disagreement is associated with higher firm risk through financing channels. At a broader systemic level, climate-related financial instability has been conceptualised as a “green swan” risk (Bolton et al., 2020) and climate shocks, whether physical or transition-related, may generate nonlinear financial disruptions. In this context, accurate measurement of firm-level environmental exposure becomes not merely a corporate governance issue but a macro-financial necessity.

Environmental responsibility has also been linked to firm risk dynamics. Cai, Cui and Jo (2016) show that stronger corporate environmental responsibility is associated with lower firm risk in U.S. industries, findings supporting the risk-reduction hypothesis and indicating that environmental performance metrics can capture meaningful risk-management effects.

Overall, intensity-based environmental indicators offer several advantages: they enhance comparability, mitigate scale bias, and align more closely with production efficiency and cost structures. At the same time, they require careful interpretation since improvements in intensity do not automatically translate into reductions in total environmental impact and rating-based proxies may diverge from operational emissions data. For environmentally intensive sectors such as steel, where decarbonisation requires structural technological change, the choice of indicator is particularly consequential: intensity-based measures—especially carbon intensity and energy intensity—are better suited to capture underlying process efficiency and transition dynamics than aggregate ESG scores.

Nonetheless, empirical analyses must remain attentive to data quality, disclosure regimes, and methodological transparency. In sum, environmental performance measurement is not a secondary technical issue but a core methodological determinant of research outcomes. Intensity-based indicators, when grounded in verifiable emissions data, provide a more precise lens through which to analyse the environmental–financial performance nexus; however, they must be complemented by awareness of absolute impact and systemic climate risk to avoid conflating relative efficiency with sustainability.

1.4 Causality, endogeneity and methodological challenges

The fourth section discusses the main methodological challenges that complicate the analysis of the relationship between environmental and financial performance. In particular, it focuses on issues related to causality and endogeneity.

1.4.1 Direction of causality between environmental and financial performance

One of the most debated issues in the literature on environmental and financial performance concerns the direction of causality. While many studies document a statistical association between corporate social/environmental performance and financial outcomes, establishing whether environmental engagement drives financial results, or whether financially successful firms can simply afford stronger sustainability practices, remains methodologically challenging.

The early contribution by Preston and O'Bannon (1997) represents a foundational attempt to disentangle these mechanisms. They identify several possible causal configurations: (i) social performance leads to financial performance; (ii) financial performance enables social investment; (iii) a virtuous cycle exists; or (iv) both are jointly determined by other factors. Their analysis therefore suggests that the relationship is unlikely to be unidirectional and may instead reflect complex feedback dynamics. This insight has shaped subsequent research, which increasingly recognizes endogeneity as a central empirical concern.

A first line of argument supports the "good management" or value-creation hypothesis, according to which environmental and CSR engagement enhances firm performance; specifically, mechanisms proposed in the literature include improved stakeholder relationships, reputational gains, operational efficiencies and risk mitigation. Eccles, Ioannou and Serafeim (2014), comparing high- and low-sustainability firms over the long term, show that firms adopting sustainability-oriented practices outperform their counterparts in terms of both stock market and accounting performance, suggesting that sustainability is embedded in organizational processes and strategic orientation, rather than being merely symbolic.

Similarly, Flammer (2015), using a regression discontinuity design around close-call shareholder votes on CSR proposals, provides quasi-experimental evidence

that CSR adoption causally improves operating performance and firm value. The identification strategy strengthens the argument that sustainability initiatives can generate tangible economic benefits rather than simply reflecting prior financial strength.

Risk-based explanations reinforce this direction of causality. Albuquerque, Koskinen and Zhang (2019) develop a theoretical and empirical framework showing that CSR reduces firm risk exposure by fostering customer loyalty and stabilizing cash flows, with lower systematic risk translating into lower expected returns and higher valuations. On a similar note, Boubaker et al. (2020) demonstrate that higher CSR engagement is associated with lower financial distress risk, measured through accounting-based indicators such as the Z-score. Their findings suggest that socially responsible firms benefit from improved creditworthiness and access to financing, reinforcing the idea that sustainability can mitigate downside risk.

Meta-analytic evidence further supports a generally positive relationship. Friede, Busch and Bassen (2015), synthesizing more than 2,000 empirical studies, conclude that the majority report a non-negative, and often positive, association between ESG and financial performance, although they also stress substantial heterogeneity across contexts, measures and methodologies, indicating that the relationship is conditional rather than universal.

An alternative explanation emphasizes reverse causality, often referred to as the “slack resources hypothesis”, according to which financially successful firms possess the discretionary resources necessary to invest in environmental initiatives, advanced reporting systems or stakeholder engagement. In this perspective, superior financial performance precedes and enables sustainability improvements, rather than resulting from them. Peloza (2009) highlights the difficulty of isolating financial returns attributable specifically to CSR investments, given overlapping strategic objectives and measurement challenges. In conclusion, without careful identification strategies, positive associations may reflect underlying profitability rather than causal environmental effects.

Surroca, Tribó and Waddock (2010) offer an intermediate perspective, arguing that intangible resources, such as innovation capability, reputation and organizational culture, mediate the CSR–financial performance relationship. In their framework, CSR enhances intangible assets, which in turn drive financial outcomes; a mechanism suggesting a dynamic and indirect causal chain rather than a simple linear relationship.

The possibility of non-linear effects further complicates the causal debate. Nollet, Filis and Mitrokostas (2016) show that the relationship between CSR and financial performance may follow a U-shaped pattern, where moderate CSR engagement is associated with lower financial performance, while high levels generate positive effects, and this implies that partial or symbolic engagement may be costly, whereas integrated sustainability strategies yield economic returns. Such findings challenge simplistic interpretations of causality and suggest threshold effects.

Another strand of literature focuses on information and signalling mechanisms. Lys, Naughton and Wang (2015) argue that sustainability reporting may function as a signal of superior future performance. Their evidence indicates that firms increasing CSR disclosure subsequently experience improvements in profitability, consistent with a signalling channel rather than pure slack-resource dynamics; however, signalling interpretations also raise endogeneity concerns, as managers anticipating improved performance may strategically expand CSR reporting.

Regulatory interventions provide additional insights into causality. Christensen, Hail and Leuz (2021) review evidence on mandatory CSR and sustainability reporting and highlight mixed economic consequences; specifically, while disclosure requirements can improve transparency and comparability, they may also impose compliance costs. Regulatory shocks might offer quasi-experimental settings that help address endogeneity by exogenously altering disclosure incentives.

From a risk-pricing perspective, capital markets appear to incorporate environmental information in valuation decisions. Pankratz, Bauer and Derwall (2023) show that firms exposed to climate transition risk experience negative stock price reactions following climate-related news and, similarly, investor sensitivity to carbon exposure documented by related studies suggests that environmental performance affects financial outcomes through market expectations and risk assessments. These findings are consistent with a causal path from environmental risk to financial performance, mediated by investor perceptions.

Taken together, the evidence does not support a single, universal direction of causality. Instead, the relationship between environmental performance and financial outcomes appears bidirectional and context-dependent: environmental initiatives can enhance performance through efficiency gains, reputational capital and risk reduction and, at the same time, financially stronger firms may be better positioned to undertake

sustainability investments. Moreover, intangible assets, regulatory environments and market conditions may mediate or moderate the relationship.

From a methodological standpoint, these dynamics generate significant endogeneity challenges, with omitted variable bias, reverse causality and simultaneity all having the potential to distort empirical estimates. As emphasized since Preston and O'Bannon (1997), failure to address these issues risks conflating correlation with causation. Consequently, the literature has increasingly relied on quasi-experimental designs (Flammer, 2015), instrumental variable approaches (Albuquerque et al., 2019), dynamic panel models and matched-sample techniques (Boubaker et al., 2020) to strengthen causal inference.

In summary, the direction of causality between environmental and financial performance remains a central empirical and theoretical challenge. While substantial evidence supports a value-creation and risk-mitigation role for sustainability engagement, reverse causality and dynamic feedback mechanisms cannot be excluded. For research focused on environmentally intensive sectors, these issues are particularly relevant, as environmental investments often require substantial capital expenditures and long-term strategic commitment. Addressing causality properly is therefore essential to interpret empirical findings on the environmental–financial performance nexus.

1.4.2 Endogeneity and econometric approaches in the literature

A central methodological challenge in the empirical analysis of the environmental-financial performance relationship concerns endogeneity. The observed association between environmental (or broader ESG/CSR) performance and firm-level financial outcomes may not reflect a causal effect, but rather the joint determination of both variables by omitted factors, reverse causality, or unobserved heterogeneity. For this reason, the literature has progressively shifted from documenting correlations to developing more rigorous identification strategies.

An early and influential critique is offered by McWilliams and Siegel (2000), who argue that many empirical models are misspecified because they omit key determinants of firm performance, R&D intensity in particular. Firms pursuing differentiation strategies may simultaneously invest in innovation and CSR, and failing to control for R&D therefore produces upwardly biased estimates of CSR's financial

impact. Once R&D is included, the previously documented positive relationship tends to disappear, suggesting a neutral effect. This contribution highlights that part of the inconsistency in prior findings may derive from econometric misspecification rather than actual economic differences.

CSR is also strategically endogenous. García-Castro, Ariño and Canela (2010), in particular, emphasize that social performance results from managerial decisions shaped by financial conditions, governance structures and stakeholder pressures. Using panel data and explicitly modelling simultaneity, they show that results obtained under naive specifications can change substantially once endogeneity is addressed and, in some cases, relationships that appear positive under ordinary least squares weaken or reverse when strategic endogeneity is incorporated. CSR and financial performance are thus jointly determined and must be treated within a simultaneous framework.

Reverse causality further complicates inference. Since financially successful firms may possess slack resources enabling greater investment in environmental and social initiatives, instrumental variable (IV) approaches attempt to isolate exogenous variation in CSR. Ferrell, Liang and Renneboog (2016) identify the effect of CSR using governance-related variables and document a positive association between CSR and firm value once endogeneity is addressed.

Similarly, Albuquerque et al. (2019) combines theory and empirical evidence to show that CSR reduces systematic risk and increases firm value, using identification strategies designed to mitigate simultaneity bias. However, even though IV methods represent a methodological improvement, their validity ultimately hinges on the credibility of the exclusion restriction, meaning that they are reliable only if the chosen instruments have no direct impact on the dependent variable and act solely through the independent one.

Event-based and quasi-experimental designs offer alternative strategies. Deng, Kang and Low (2013) examine mergers and find that high-CSR acquirers realize higher announcement returns and improved post-merger performance, supporting the stakeholder value maximization view. Flammer (2021) analyzes corporate green bond issuances and documents positive market reactions and subsequent improvements in environmental performance, interpreting issuance as a credible signal. By exploiting discrete corporate events, these studies reduce concerns regarding simultaneity relative to cross-sectional analyses.

Regulatory shocks provide additional quasi-exogenous variation. Grewal, Riedl and Serafeim (2019) study market reactions to mandatory nonfinancial disclosure in the EU, while Christensen, Hail and Leuz (2021) analyze the broader economic consequences of mandatory CSR and sustainability reporting, concluding that, although regulatory settings mitigate reverse causality, disentangling information effects from real behavioural adjustments remains complex.

Climate finance research further strengthens identification by exploiting exogenous environmental variation. Hong, Karolyi and Scheinkman (2020) and Giglio, Kelly and Stroebel (2021) frame climate risk within asset pricing and macro-finance contexts, highlighting how environmental risks are incorporated into financial markets. At the firm level, Pankratz, Bauer and Derwall (2023) exploit year-to-year variation in extreme temperature exposure to estimate the causal impact of physical climate risk on revenues and operating income, documenting negative effects not fully anticipated by analysts. Such designs substantially improve causal inference relative to purely cross-sectional approaches.

Finally, dynamic panel methods address feedback effects and unobserved heterogeneity. Cai, Cui and Jo (2016), specifically, employ system GMM techniques and find that corporate environmental responsibility reduces firm risk, particularly in manufacturing sectors.

Overall, the literature has evolved from simple cross-sectional regressions to increasingly sophisticated econometric designs, including fixed effects, IV strategies, dynamic panel estimators, event studies and quasi-natural experiments. Nonetheless, identification challenges persist. Instruments rely on strong assumptions, regulatory shocks may operate through multiple channels, and measurement issues, such as ESG rating divergence (Berg, Kölbel and Rigobon, 2022), further complicate inference.

The debate over the environmental-financial performance nexus is therefore both econometric and theoretical, requiring careful specification, transparent assumptions and robust research designs.

1.5 Environmental performance and financial outcomes in hard-to-abate industries

This section narrows the focus to environmentally intensive sectors, where environmental performance is particularly relevant, highlighting why industry-specific

characteristics matter when analysing the ESG–financial performance relationship, focusing in particular on hard-to-abate industries. Due to high energy intensity, process-related emissions, technological rigidity, and increasing regulatory pressure, these sectors represent a critical setting for understanding how environmental performance translates into economic and financial effects.

1.5.1 Hard-to-abate industries: definition, characteristics, and relevance

Hard-to-abate industries occupy a pivotal role in the climate transition because they combine high structural emissions intensity with technological and economic constraints that make rapid decarbonisation particularly complex. These sectors–notably steel, cement, chemicals (including ammonia) and other energy-intensive basic materials–account for a substantial share of global greenhouse gas (GHG) emissions and are deeply embedded in modern value chains. Their products are foundational inputs for infrastructure, construction, transport, agriculture and manufacturing, however, the processes that make them indispensable also make their emissions difficult to eliminate.

Defining hard-to-abate industries

The label “hard-to-abate” typically refers to sectors in which emissions arise not only from fossil energy use but also from intrinsic chemical reactions and high-temperature industrial processes. In cement production, for instance, a large share of emissions derives from calcination; in primary steelmaking, blast furnace routes rely on carbon-intensive reduction chemistry.

These process-related emissions cannot be addressed through incremental energy efficiency alone. Material Economics (2019) explicitly classifies steel, cement, plastics and ammonia among the core “hard-to-abate” sectors in the European context, noting that heavy industry accounts for more than 500 Mt CO_2 annually in the EU, or roughly 14% of total emissions. This characterisation highlights two interrelated features: structural emissions intensity and limited short-term substitution possibilities.

The International Energy Agency (IEA), in its Net Zero Roadmap (2023 update), similarly emphasises that energy-intensive industries represent one of the most challenging components of net-zero pathways, underlining that industrial transformation requires not marginal improvements but deep structural change in

technologies, fuels and production systems. Heavy industry cannot simply electrify existing processes; it often requires fundamentally new production routes, such as hydrogen-based direct reduced iron or carbon capture integration.

A systematic review of deep decarbonisation options confirms that energy-intensive industries account for roughly one-third of global GHG emissions and must deploy near-zero technologies at scale within a few decades to align with the Paris Agreement (Bataille et al., 2018) and, given capital stock lifetimes that frequently exceed 20–30 years, investment decisions taken today risk locking in high emissions trajectories well beyond mid-century.

The “hard-to-abate” designation thus reflects not only technological difficulty, but also temporal rigidity.

Structural characteristics: emissions intensity and capital intensity

Hard-to-abate industries are characterised by both high absolute emissions and high emissions intensity per unit of output.

According to the IEA (2023), industrial sectors remain among the largest sources of global energy-related CO_2 emissions and require transformative technology shifts to meet 1.5°C-consistent pathways; in fact, steel, cement and ammonia production require large volumes of energy–often in the form of fossil fuels–and involve carbon-based raw materials. At the same time, these materials are essential inputs for clean energy technologies: Energy Technology Perspectives 2024 highlights that steel, aluminium and ammonia are critical components of renewable infrastructure, hydrogen systems and electrification technologies, and, therefore, decarbonising heavy industry is not only an environmental objective but also a precondition for scaling the broader energy transition. This dual role creates a structural tension given that output may need to expand even as emissions must fall rapidly.

Capital intensity further differentiates these sectors. Blast furnaces, cement kilns and chemical plants require large upfront investments and are designed for long operational lifetimes. Bataille et al. (2018) stress that slow capital turnover significantly constrains the speed of technological transition as, once installed, industrial assets create path dependency and high sunk costs, making premature retirement economically disruptive.

The scale of reinvestment required is also substantial. The McKinsey Global Institute (2022) estimates that the net-zero transition entails a major increase in annual

capital spending across energy and industrial systems, with heavy industry representing a significant share of the adjustment.

Decarbonisation in these sectors therefore implies not incremental optimisation, but large-scale capital reallocation and infrastructure building.

Limited short-term abatement options

In contrast to power generation–where renewables are mature and cost-competitive–industrial decarbonisation relies heavily on emerging or currently expensive technologies.

Material Economics (2019) identifies hydrogen-based processes, carbon capture and storage (CCS), electrification of high-temperature heat, and circular economy strategies as key levers, but emphasises that their deployment requires systemic coordination and supportive policy frameworks.

The IEA (2023) similarly notes that many industrial mitigation technologies remain at early deployment stages and require accelerated innovation, infrastructure development and policy support and Energy Technology Perspectives 2024 reinforces this point by highlighting supply chain constraints, trade dependencies and manufacturing capacity challenges associated with scaling clean industrial technologies.

The OECD (2023), moreover, stresses that climate mitigation in energy-intensive industries necessitates coordinated policy mixes combining carbon pricing, industrial policy, innovation support and infrastructure planning.

These institutional and regulatory requirements add another layer of complexity, as decarbonisation is not solely a technological challenge but also a governance one.

Relevance for transition risk and empirical research

Hard-to-abate industries are particularly exposed to climate transition risks, as carbon pricing, emissions trading systems and border adjustment mechanisms directly affect their cost structures.

The IEA (2023) underlines that achieving net zero requires rapid emissions reductions in these sectors within the next two decades, increasing pressure on firms operating in carbon-intensive production routes.

At the same time, industrial transformation can generate strategic opportunities. Material Economics (2019) argues that early movers in low-carbon steel, cement or

chemicals may benefit from emerging markets for green materials and from alignment with industrial competitiveness strategies and, similarly, the OECD (2023) frames heavy industry decarbonisation as integral to long-term economic resilience.

From an empirical perspective, these structural features are highly relevant. In fact, as pointed out by McKinsey Global Institute (2022), considering that firms in hard-to-abate sectors typically face higher marginal abatement costs and longer payback periods for environmental investments than firms in less emissions-intensive industries, improvements in environmental performance may require substantial upfront capital expenditure, with financial benefits materialising only gradually, if at all.

Overall, hard-to-abate industries combine technological inertia, capital intensity, systemic interdependencies and regulatory exposure. These characteristics justify their analytical separation within the broader ESG-financial performance literature. In such sectors, the environmental–financial nexus is likely to be mediated by innovation dynamics, policy design, asset lifetimes and market structure. Understanding these structural constraints is therefore essential when interpreting empirical findings and when designing sector-specific decarbonisation strategies aligned with Paris-consistent pathways (Bataille et al., 2018; IEA, 2023).

1.5.2 The steel industry as an illustrative hard-to-abate sector

Among hard-to-abate industries, steel production represents one of the clearest and most analytically useful cases. Its combination of high energy intensity, process-related emissions, long-lived capital stock and exposure to tightening climate regulation includes the structural features that make deep decarbonisation particularly complex.

At the same time, steel remains indispensable to modern economies and to the low-carbon transition itself. This dual role–both carbon-intensive and transition-enabling–makes the sector especially suitable for examining how environmental performance interacts with economic and financial outcomes.

Steel is deeply embedded in contemporary economic systems. As highlighted in the *Iron and Steel Technology Roadmap* (IEA, 2020), steel is fundamental to construction, transport, infrastructure and energy systems, including renewable energy installations and electrification technologies. Global demand has more than tripled since 1970 and is expected to continue growing in line with infrastructure expansion and rising material needs, particularly in emerging economies (IEA, 2020). This

structural demand trajectory limits the feasibility of simple contraction-based decarbonisation strategies and reinforces the need for technological transformation.

The emissions profile of the sector illustrates the scale of the challenge: according to the IEA (2020), the iron and steel industry directly accounts for approximately 2.6 gigatonnes of CO_2 per year, around 7% of global energy system emissions. Therefore, adding that when indirect emissions from electricity use and off-gases are included the share increases further, steel represents a central element in climate terms. Industry-level data confirm the persistence of high carbon intensity, with the *World Steel Association Sustainability Indicators Report 2024* reporting a global average emissions intensity of 1.92 tonnes of CO_2 per tonne of crude steel cast in 2023.

However, significant heterogeneity exists across production routes: for example, the blast furnace–basic oxygen furnace (BF–BOF) route shows an intensity of 2.32 tonnes CO_2 per tonne of crude steel, while scrap-based electric arc furnace (EAF) production averages 0.70 tonnes and direct reduced iron–EAF (DRI–EAF) routes fall in between at 1.43 tonnes. These differences are directly linked to process configuration and, above all, to the role of coal in primary steelmaking.

The technological foundations of the sector explain why it is classified as hard-to-abate. In the dominant BF–BOF route, coal serves both as a fuel and as a chemical reducing agent in ironmaking; emissions are therefore embedded in the core chemical reactions of the process. As noted by the IEA (2020), coal currently provides around three-quarters of the sector's energy demand, and, therefore, decarbonisation cannot rely solely on incremental efficiency improvements but requires structural process changes.

As alternative pathways exist but involve substantial technical and economic uncertainty, hydrogen-based direct reduction emerged as one of the most promising breakthrough options. Vogl, Åhman and Nilsson (2018) show that hydrogen direct reduction combined with electric arc furnaces could theoretically enable near-zero emissions if powered by renewable electricity. However, the process requires approximately 3.48 MWh of electricity per tonne of liquid steel, making competitiveness highly sensitive to electricity prices and carbon pricing levels. This underlines the broader point that low-carbon steel is technically feasible, but system-level conditions are decisive.

Capital intensity further complicates transition dynamics. Steel plants are long-lived assets with high sunk costs and since much of the global blast furnace fleet is relatively young, particularly in emerging economies, as the IEA (2020) emphasises, premature replacement implies stranded asset risks and significant financial write-downs. Consequently, firms face a tension between environmental alignment and capital preservation, generating a “carbon lock-in” effect that is a defining feature of hard-to-abate sectors.

Recycling and scrap use provide partial mitigation but do not eliminate structural constraints. In fact, while scrap-based EAF production is considerably less emissions-intensive and requires far less energy per tonne of steel (IEA, 2020), scrap availability is limited by historical production volumes and in-use stock dynamics and, even with high recycling rates, primary production from iron ore remains necessary to meet projected demand. Hence, process emissions cannot be avoided simply through circular economy expansion.

In parallel, regulatory and market pressures are intensifying, as decarbonisation pathways consistent with climate targets require emissions reductions of more than 50% by mid-century and substantial declines in emissions intensity (IEA, 2020), a transition that implies large-scale capital expenditure in breakthrough technologies and infrastructure.

From a financial perspective, the scale and timing of these investments are critical: as Cregan, Kelly and Clinch (2024) shows, in the steel industry ESG climate scores do not systematically reflect firms’ actual emissions performance or investment in low-carbon technologies, a disconnection that suggests potential information inefficiencies in capital allocation and raises concerns about whether financial markets adequately price transition risks in heavy industry.

Taken together, these characteristics–technological rigidity, embedded process emissions, long asset lifetimes, limited scrap substitution and high investment requirements–illustrate why steel is widely regarded as a paradigmatic hard-to-abate sector. Its decarbonisation demands not only incremental efficiency gains but a fundamental reconfiguration of production processes and energy inputs. Precisely because of this structural complexity, the steel industry provides a particularly appropriate empirical setting for analysing how environmental performance, transition risk and financial outcomes interact in carbon-intensive sectors.

1.6 Research gaps and positioning of the present study

The literature reviewed in this chapter shows that the relationship between environmental performance and financial outcomes has been extensively examined from both theoretical and empirical perspectives. Even though, over time, the debate has moved beyond the simplistic idea of a strict trade-off between environmental responsibility and profitability, important ambiguities remain.

From a theoretical point of view, several frameworks suggest that environmental performance can be compatible with long-term financial success: Stakeholder theory (Freeman, 1984; Donaldson and Preston, 1995) emphasizes the relational nature of value creation, while Jensen's (2001) notion of enlightened value maximization integrates stakeholder management into long-term shareholder value. The Natural-Resource-Based View (Hart, 1995) and the Porter Hypothesis (Porter and van der Linde, 1995) further argue that environmental capabilities and regulation-induced innovation may enhance competitiveness. These perspectives make it plausible that environmental performance is not just a constraint, but potentially a strategic asset.

Empirical syntheses appear to support this possibility: meta-analyses by Orlitzky et al. (2003), Friede et al. (2015) and Busch and Friede (2018) generally report positive or at least non-negative associations between ESG and financial performance. However, these findings should not be overstated. Effect sizes are, indeed, moderate, and substantial heterogeneity persists across industries, institutional contexts and methodological designs.

Moreover, evidence of non-linear dynamics (Barnett and Salomon, 2012; Trumpp and Guenther, 2015) suggests that environmental engagement does not translate into uniform financial consequences.

Measurement issues further complicate interpretation, as the growing reliance on aggregate ESG scores has introduced significant ambiguity. As documented by Berg et al. (2022), ESG ratings diverge considerably across providers, reflecting differences in scope and methodology, therefore, if environmental performance is measured differently depending on the rating agency, empirical results inevitably depend on the chosen metric, and this raises concerns about comparability and validity.

At the same time, causality and endogeneity remain difficult to address fully: it is often unclear whether financially strong firms invest more in environmental initiatives,

whether environmental engagement improves financial outcomes, or whether both reflect deeper organizational capabilities, and even sophisticated econometric approaches cannot entirely eliminate these concerns.

Against this background, several gaps become particularly relevant and justify further research. First, relatively few studies rely on objective, intensity-based environmental indicators. Much of the literature, instead, continues to depend on composite ESG scores or disclosure-based measures. Given documented rating divergence (Berg et al., 2022), focusing on operational indicators such as carbon intensity or energy intensity is likely to provide greater analytical clarity.

Second, sector-specific evidence remains limited, particularly in hard-to-abate industries, where environmental performance is closely tied to production technology, capital intensity and regulatory exposure. Aggregated multi-industry analyses may therefore obscure dynamics that are especially strong and visible in environmentally intensive contexts.

Third, although eco-efficiency frameworks conceptually integrate environmental and economic dimensions (Hart, 1995; Figge and Hahn, 2013), empirical research rarely examines how intensity-based environmental performance interacts with profitability and risk within specific sectors.

In the light of these considerations, the present study concentrates on intensity-based environmental indicators, such as greenhouse gas intensity and energy intensity, within a hard-to-abate industrial setting. By doing so, it aims to reduce measurement ambiguity and to examine environmental performance where it is structurally embedded in production processes and regulatory exposure.

CHAPTER 2 - EMPIRICAL FOCUS: THE CHOICE OF THE STEEL SECTOR AND FERALPI GROUP

The goal of this chapter is to explain the empirical focus of the thesis, namely the rationale for selecting the steel industry as the sectoral context and Feralpi Group as the focal firm among European peers.

Building on the theoretical and methodological discussion developed in Chapter 1, this chapter shifts from a general analysis of the environmental–financial performance relationship to a sector-specific and firm-level contextualisation. First, it explains why the steel industry represents a particularly relevant empirical setting for analysing this relationship. Second, it motivates the choice of Feralpi Group as a case study, highlighting its production model, environmental strategy, and positioning within the European steel industry.

2.1 The steel industry as a hard-to-abate sector

Building on the conceptual discussion of hard-to-abate industries developed in Chapter 1, this section adopts a sector-specific perspective and introduces the steel industry as a paradigmatic example of an environmentally intensive sector. Due to its high energy consumption, process-related emissions, and exposure to climate regulation, the steel industry provides a particularly informative context for examining how environmental performance interacts with firms' economic and financial outcomes.

2.1.1 Economic relevance and structural characteristics of the steel industry

The steel industry plays a key role in the global industrial system and remains one of the most strategically important sectors for both developed and emerging economies, considering that steel is a fundamental input for a wide range of downstream industries, including construction, automotive manufacturing, machinery, shipbuilding, energy infrastructure and transportation systems. Because of its versatility, durability and recyclability, this material has historically been considered fundamental for economic development and industrialisation (OECD, 2025; World Steel Association, 2025) and, in modern economies, it is embedded in all major infrastructure systems—from

buildings and bridges to railways, pipelines and renewable energy installations—making the sector essential for both economic growth and technological development.

The huge size of the industry and its relevance for the global economy is also testified by the fact that, at the global level, steel production remains extremely large in scale compared with other industrial materials, with world crude steel production reaching approximately 1.88–1.90 billion tonnes in recent years (World Steel Association, 2025). In addition, despite cyclical fluctuations in demand, global steel output has remained relatively stable since 2020, indicating the structural importance of steel consumption in modern economies and its pervasive role in everyday economic activity and industrial production, which is also testified by steel per-capita consumption reaching approximately 214.7 kilograms per person in 2024, highlighting (World Steel Association, 2025).

Beyond its direct economic significance, the steel sector is also characterised by a complex and highly globalised industrial structure, with approximately one hundred countries producing crude steel, although production is heavily concentrated in a relatively small number of economies (OECD, 2025). Over the past two decades, the geographical distribution of steel production has undergone profound structural changes, mainly driven by the rapid industrial expansion of emerging economies. The rise of China, in particular, has reshaped global steel markets due to the dramatic increase of production with respect to the twentieth century, which reached almost half of today's global output, making the country the dominant player in the international steel industry (OECD, 2025) and causing fluctuations in its domestic demand and production to have significant repercussions for global steel prices, trade flows and investment decisions.

Generally speaking, the steel industry exhibits several structural characteristics that distinguish it from many other manufacturing sectors. First of all, building a new steel plant requires extremely large upfront investments in equipment, infrastructure and energy systems, often exceeding one billion US dollars even for relatively small facilities (OECD, 2025), and large integrated plants which can reach annual capacities of several million tonnes per year. This high capital intensity creates substantial entry barriers and leads to long investment cycles, meaning that production decisions are typically made with a long-term strategic perspective.

Second, the steel industry is strongly characterised by economies of scale and long asset lifetimes, with steelmaking equipment, such as blast furnaces, basic oxygen

furnaces or electric arc furnaces, often remaining in operation for several decades. This technological durability means that investment decisions have long-lasting implications for both production capacity and environmental performance, and the fact that, once installed, production technologies are costly and complex to replace, contributes to the persistence of structural overcapacity and the slow adjustment of the industry to changing market conditions.

Third, as steel products are widely traded internationally, price fluctuations or policy changes in major producing economies can rapidly influence global markets, causing the industry to be closely intertwined with global trade dynamics. In recent years, for example, the sector has experienced increasing tensions related to trade imbalances, subsidies and excess capacity, particularly as large exporting countries have expanded production beyond domestic demand levels (OECD, 2024; OECD, 2025) that have contributed to volatile market conditions and have led to the frequent use of trade defence measures such as anti-dumping investigations and tariffs.

Another key structural feature of the sector concerns the persistent issue of global excess capacity, as global crude steelmaking capacity reached approximately 2.43 billion tonnes in 2023, significantly exceeding actual production levels (OECD, 2024). This gap between installed capacity and effective output has been a relevant and persistent problem in the industry and represents one of the major structural challenges affecting the sector. The major risks of excess capacity are, first of all, that it might lead to downward pressure on steel prices, reduced profitability and increasing trade disputes among producing regions; and, secondly, the fact that producers often continue operating even during periods of weak demand further aggravates the existing market imbalances.

From a technological perspective, the industry is also characterised by the coexistence of two main different production technologies: the blast furnace–basic oxygen furnace (BF-BOF) route, which relies primarily on iron ore and coal, and the electric arc furnace (EAF) route, which uses recycled steel scrap as its main input. Globally, the BF-BOF route remains the most used, representing roughly 70% of crude steel output, while the remaining share is produced through EAF-based processes (World Steel Association, 2025). Notably, these technological differences have important implications not only for cost structures but also for environmental performance, since the BF-BOF route is significantly more carbon-intensive with respect to scrap-based electric arc furnace production.

Finally, the steel industry plays a crucial role in the broader process of industrial transformation and the transition toward low-carbon economies, as steel products are essential for renewable energy infrastructure, including wind turbines, solar installations and electricity networks, as well as for the production of electric vehicles and energy storage systems (OECD, 2025). At the same time, however, steelmaking itself is among the most energy-intensive industrial activities, creating a complex situation in which the sector must simultaneously support the energy transition while reducing its own environmental footprint.

All these characteristics highlight the dual nature of the steel industry which, on the one hand, is a foundational sector for modern industrial economies while, on the other hand, faces persistent structural challenges related to capital intensity, excess capacity, global competition and technological transformation. These features also make the steel industry a particularly relevant empirical setting for analysing the relationship between environmental performance and economic outcomes, especially in the context of ongoing decarbonisation pressures and evolving regulatory frameworks.

2.1.2 Environmental intensity, emissions and energy consumption

As previously underlined, one of the defining characteristics of the steel industry is its high environmental intensity, particularly in terms of energy consumption and greenhouse gas emissions. Steel production, indeed, requires large quantities of energy and raw materials, and the dominant production technologies rely heavily on fossil fuels, making the sector widely recognised as one of the most carbon-intensive industrial activities and plays a significant role in global climate change discussions.

At the global level, the iron and steel industry represents a substantial share of industrial energy demand and emissions. According to the International Energy Agency, the sector accounts for approximately 8% of global final energy demand and about 7% of energy-related CO_2 emissions, making it the largest emitting sector among heavy industries (IEA, 2023). The fact that in absolute terms, this corresponds to roughly 2.6 gigatonnes of CO_2 emissions annually, an amount higher than the emissions generated by many national economies, highlights even more the magnitude of the environmental challenge linked to steel production.

The environmental footprint of the steel sector derives primarily from the technological structure of production processes. In fact, as mentioned in the previous section, the dominant production route globally remains the blast furnace–basic oxygen furnace (BF–BOF) pathway, which relies on iron ore as the main raw material and coal as the primary energy source. Coal plays a dual role in this process by both providing the thermal energy to operate blast furnaces and also being converted into coke, which acts as a chemical reducing agent in the transformation of iron ore into molten iron (IEA, 2023). Because of this reliance on carbon-based fuels, traditional primary steelmaking generates significant emissions. The carbon intensity of steel production, therefore, varies significantly depending on the production route used, with blast furnace–based production generally having the highest emissions intensity because it requires the reduction of iron ore using carbon-intensive inputs. In contrast, electric arc furnace (EAF) production, particularly when using recycled steel scrap, can significantly reduce both energy consumption and carbon emissions.

Globally, however, average carbon emissions from steel production remain substantial as the industry emitted approximately 1.92 tonnes of CO_2 per tonne of crude steel in 2023, reflecting the predominance of fossil-fuel-based technologies in global steelmaking (World Steel Association, 2025).

Energy consumption is another key dimension of the sector's environmental intensity, due to steelmaking processes requiring extremely high temperatures and energy inputs throughout several stages of production, including iron reduction, steel refining and rolling processes. The global average energy intensity of steel production was approximately 21.27 gigajoules per tonne of crude steel in recent years, highlighting the substantial energy requirements associated with transforming raw materials into finished steel products (World Steel Association, 2025). Such energy intensity contributes directly to the sector's carbon footprint, particularly in regions where electricity generation still depends heavily on fossil fuels.

The environmental impact of steel production is further amplified by the scale of global demand for steel products. Steel is, indeed, indispensable for modern infrastructure, transport systems, buildings and energy technologies, which means that demand is closely linked to economic growth and urbanisation and, as a consequence, that it is expected to increase significantly over the coming decades due to the continuous expansion of global population and economic activity. With projections suggesting that global steel demand could grow by more than one-third by 2050,

reflecting ongoing industrialisation and infrastructure development in emerging economies, important challenges for achieving climate targets rise accordingly (IEA, 2023), and, in response to these environmental pressures, increasing attention has been devoted to the decarbonisation of the steel industry.

Regarding decarbonisation, the sector faces a dual challenge: it must continue to meet rising global demand while simultaneously reducing its carbon footprint in line with international climate goals. Achieving this transformation also requires substantial technological change, as incremental efficiency improvements alone are insufficient to deliver the deep emission reductions required. Studies on industrial decarbonisation pathways in fact highlight that heavy industries—including steel, cement and chemicals—are responsible for roughly one third of global greenhouse gas emissions, emphasising the absolute need for transformative technological and policy solutions (Bataille et al., 2018).

Several technological pathways have been proposed to reduce emissions from steelmaking, including improvements in energy efficiency, the increased use of recycled scrap through electric arc furnaces, the deployment of hydrogen-based direct reduction technologies, and the adoption of carbon capture, utilisation and storage (CCUS) systems. However, each of these approaches presents technological, economic and infrastructural challenges: for instance, hydrogen-based steelmaking requires large quantities of low-carbon electricity, while carbon capture technologies involve substantial capital costs and infrastructure development.

Another important dimension of the environmental transition concerns the availability of steel scrap, as recycling scrap steel through electric arc furnaces represents one of the most effective strategies for reducing emissions in the sector because it requires significantly less energy than primary steel production from iron ore. At the same time, the global distribution of scrap resources is uneven, with regions with long industrial histories, such as Europe and North America, possessing large stocks of recyclable steel, while many developing economies face limited domestic scrap availability (Watari et al., 2023), a disparity that can create structural inequalities in the decarbonisation pathways available to different countries. In the long term, achieving deep decarbonisation of the steel sector will therefore require a combination of technological innovation, policy support and international co-operation.

Material efficiency strategies, increased recycling and the development of near-zero emission production technologies will all play an important role in reducing the

environmental impact of steel production. However, given the long lifespan of steelmaking infrastructure and the scale of global production, the transition toward low-carbon steelmaking is likely to be gradual and capital-intensive.

Overall, the environmental intensity of steel production, combined with the sector's central role in the global economy, makes the steel industry a critical focus of climate policy and industrial transformation; characteristics that also reinforce the relevance of analysing environmental performance within the sector, particularly when examining how environmental indicators relate to firms' economic and financial outcomes.

2.1.3 Regulatory pressure and decarbonisation targets in Europe

In addition to its environmental intensity, the steel industry is increasingly influenced by a rapidly evolving regulatory environment aimed at reducing greenhouse gas emissions and accelerating industrial decarbonisation.

In the European Union, climate policy has now become one of the main drivers influencing the strategic decisions of energy-intensive industries, including steel production, and the combination of emission reduction targets, carbon pricing mechanisms and new trade-related climate instruments has significantly increased the regulatory pressure faced by European steel producers.

European climate policy is embedded within a broader strategic framework that aims to transform the European economy into a climate-neutral system, with a central objective of achieving net-zero greenhouse gas emissions by 2050, with an intermediate target of reducing emissions by at least 55% by 2030 compared to 1990 levels (European Commission, 2021). These two targets represent a substantial increase in climate ambition and require deep emission reductions across all sectors of the economy, including heavy industries such as steel production.

In particular, a cornerstone of the European climate policy framework is the European Union Emissions Trading System (EU ETS), which establishes a market-based mechanism for pricing carbon emissions, covering thousands of industrial installations across Europe and requiring regulated firms to hold emission allowances corresponding to their greenhouse gas emissions (Directive (EU) 2023/959). By placing a price on carbon emissions, the system aims to create economic incentives for firms to reduce emissions and invest in low-carbon technologies.

In general, for energy-intensive sectors such as steel production, the EU ETS has become a central factor influencing production costs, investment strategies and long-term technological choices, and has been progressively strengthened over time to align with the Union's climate objectives. The 2023 reform significantly tightened the system by reducing the number of available allowances and adjusting the allocation rules to support the transition toward low-carbon industrial processes (Directive (EU) 2023/959). The rationale behind this is that, as the carbon price increases, firms are expected to face stronger economic incentives to adopt cleaner production technologies or reduce emissions through efficiency improvements and innovation.

However, the tightening of environmental regulations also raises concerns regarding industrial competitiveness, since, when climate policies differ substantially across countries, firms operating in jurisdictions with more stringent regulations may face higher production costs compared to competitors located in regions with weaker environmental standards. This situation can potentially lead to carbon leakage, whereby production shifts from regions with strict climate policies to jurisdictions with less stringent regulations, thereby undermining the effectiveness of emission reduction efforts (Dechezleprêtre and Sato, 2017).

To address this risk, the European Union has introduced additional policy instruments designed to preserve the competitiveness of domestic industries while maintaining ambitious climate goals, with one the most important developments being the Carbon Border Adjustment Mechanism (CBAM), established by Regulation (EU) 2023/956, which aims to ensure that imported goods are subject to a carbon price equivalent to that paid by European producers under the EU ETS. By applying a carbon cost to imports of carbon-intensive products such as iron and steel, this mechanism seeks to prevent carbon leakage and maintain a level playing field between domestic and foreign producers. The CBAM will be implemented gradually: the transitional phase began in 2023, during which importers are required to report the emissions embedded in imported goods, while the full system will become operational from 2026 onwards (European Commission, 2023). During the definitive phase, in particular, importers will need to purchase CBAM certificates corresponding to the carbon emissions embedded in imported products, thereby aligning the carbon cost of imports with that of goods produced within the European Union.

This regulatory framework reflects a broader shift in industrial climate policy toward integrating environmental objectives with trade and industrial policy

considerations: as the European Union increases its climate ambition, policy instruments such as the EU ETS and CBAM aim not only to reduce emissions within Europe but also to encourage cleaner production practices globally. The CBAM, in particular, is expected to incentivise foreign producers to adopt lower-emission technologies in order to maintain access to European markets (Regulation (EU) 2023/956).

At the same time, these policies introduce new challenges for firms operating in the steel sector, as carbon pricing mechanisms increase the cost of carbon-intensive production processes, which may require substantial investments in new technologies such as hydrogen-based steelmaking, carbon capture and storage, or increased scrap recycling. Moreover, firms must adapt to an evolving regulatory landscape characterised by increasing climate ambition and growing policy complexity.

In the most recent phase, however, the European carbon pricing framework has entered a period of heightened political and economic tension, reflecting a growing debate over the balance between climate ambition and industrial competitiveness. In early 2026, several EU Member States and major industrial stakeholders openly questioned the current trajectory of the EU ETS, particularly in light of persistent energy price volatility and weakening industrial output across Europe. Notably, countries such as Italy and other energy-dependent economies have called for temporary adjustments or even partial suspension mechanisms to mitigate the impact of carbon costs on industry, while major business associations have urged reforms to prevent risks of deindustrialisation and investment relocation outside the EU (Reuters, 2026).

These concerns have been further amplified by recent market developments. Carbon prices, which had previously reached peaks close to €90–100 per tonne, have shown significant volatility and declined to around €60–75 per tonne in early 2026, partly reflecting expectations of potential policy intervention and weaker industrial demand (Reuters, 2026). Moreover, in March 2026, discussions at the EU level explicitly considered possible interventions in the carbon market—such as increasing the supply of allowances through the Market Stability Reserve or slowing the phase-out of free allocations—in order to contain cost pressures on firms (Reuters, 2026). At the same time, geopolitical developments and the associated energy shock have intensified these pressures, leading EU policymakers to evaluate short-term relief measures, including subsidies, tax reductions and greater flexibility in state aid rules, particularly for energy-intensive industries (Reuters, 2026).

These discussions have also highlighted the critical interaction between the EU ETS and the CBAM, especially given that the gradual phase-out of free allowances between 2026 and 2035 will coincide with the progressive implementation of the CBAM, effectively increasing the direct carbon cost exposure of European producers (ECB, 2026).

Overall, the recent debate suggests that the EU ETS is no longer viewed solely as a technical climate policy instrument but increasingly as a central element of European industrial policy, subject to negotiation and adjustment in response to macroeconomic shocks and competitiveness concerns. For energy-intensive sectors such as steel, this evolving policy landscape introduces an additional layer of uncertainty, reinforcing the importance of analysing how carbon pricing dynamics and regulatory adjustments influence firms' cost structures, strategic decisions and financial performance.

In general, the European steel industry operates within one of the most advanced and stringent climate policy frameworks worldwide, with the interaction between carbon pricing, trade measures and industrial decarbonisation strategies making the sector a particularly relevant context for analysing the relationship between environmental performance and economic outcomes. These regulatory dynamics also reinforce the importance of examining how environmental indicators and decarbonisation strategies may influence the financial performance of firms operating in environmentally intensive sectors.

2.2 Decarbonisation pathways and environmental strategies in the steel industry

The second section discusses the main technological and strategic options available to steel producers in order to reduce their environmental impact, underlining the heterogeneity of decarbonisation pathways across firms and the different implications that these strategies might have for environmental and financial performance.

2.2.1 Conventional and low-carbon steelmaking technologies

The decarbonisation of the steel industry represents one of the central challenges of the global energy and climate transition, due to the fact that steel production relies on carbon-intensive processes, particularly the blast furnace–basic oxygen furnace (BF–

BOF) route, which uses coal both as an energy source and as a chemical reducing agent in ironmaking, resulting in the sector remaining one of the largest industrial sources of greenhouse gas emissions worldwide. Achieving deep emission reductions therefore requires not only incremental efficiency improvements but also the development and deployment of fundamentally new production technologies and industrial processes.

In the context of global climate mitigation strategies, heavy industry plays a crucial role in achieving long-term decarbonisation targets, with industrial sectors such as steel, cement and chemicals collectively accounting for a significant share of global emissions, and their transformation being considered essential to maintaining a viable pathway toward climate neutrality (IEA, 2023). At the same time, these sectors are often classified as *hard-to-abate* because their production processes involve chemical reactions that are difficult to electrify or substitute with low-carbon alternatives.

Within the steel sector, several technological pathways have been proposed to reduce emissions while maintaining industrial competitiveness and meeting global demand for steel products, which can broadly be grouped into three main categories: improvements in existing production processes, the development of breakthrough low-carbon technologies, and the increased use of circular economy approaches based on material efficiency and recycling.

The first category includes incremental technological improvements to existing steelmaking routes, aiming to reduce emissions through higher energy efficiency, process optimisation, and partial substitution of fossil fuels. Although such measures can contribute to emission reductions in the short term, their overall mitigation potential is limited because the fundamental production processes remain dependent on carbon-based inputs and, as a result, these alone are insufficient to achieve the deep emission reductions required by long-term climate targets.

A second and increasingly important pathway involves the development of breakthrough technologies capable of fundamentally transforming steel production processes. Among these, hydrogen-based steelmaking has emerged as one of the most promising technological options for achieving near-zero emissions steel production since, in hydrogen direct reduction processes, hydrogen replaces carbon as the reducing agent in ironmaking, producing water vapour instead of carbon dioxide as a by-product. If the hydrogen is produced using renewable electricity through electrolysis, the resulting steel production process can achieve extremely low emission

levels (Vogl, Åhman and Nilsson, 2018). Research suggests that hydrogen-based direct reduction could play a key role in future low-carbon steel production systems, with the process typically involving the reduction of iron ore using hydrogen to produce direct reduced iron (DRI), which is then processed in an electric arc furnace (EAF) to produce steel. According to process modelling studies, hydrogen-based steelmaking requires significant electricity input, primarily for hydrogen production through electrolysis, but it has the potential to achieve almost zero emissions when powered by renewable electricity (Vogl, Åhman and Nilsson, 2018). However, the economic viability of such technologies depends on several factors, including the availability of low-cost renewable electricity and the evolution of carbon pricing policies.

Another set of technological solutions focuses on the deployment of carbon capture, utilisation and storage (CCUS) technologies within existing steel production routes, as approaches aiming to capture carbon dioxide emissions from blast furnace processes and either store them underground or reuse them in other industrial applications. CCUS technologies could allow existing production facilities to continue operating while significantly reducing their emissions, but it must be taken into account that these solutions involve high investment costs and require the development of appropriate transport and storage infrastructure for captured carbon.

In addition to technological innovation in production processes, the decarbonisation of the steel sector is also closely linked to the broader transition toward a more circular industrial system. Steel is inherently recyclable, and increasing the share of recycled steel in production can substantially reduce emissions because electric arc furnace processes based on scrap require significantly less energy and generate lower emissions compared to primary steel production. The expansion of scrap-based steelmaking is therefore considered an important component of long-term decarbonisation strategies (Material Economics, 2019).

Circular economy strategies can also include improvements in material efficiency, product design, and end-of-life recycling systems, these approaches aiming to reduce the overall demand for primary steel production by making more efficient use of existing materials and increasing recycling rates across industrial value chains. Regarding this, studies suggest that improved materials efficiency and recycling could significantly reduce emissions from heavy industries while maintaining the availability of essential materials for economic development (Material Economics, 2019).

At the policy and innovation level, large-scale industrial transformation will require coordinated investments in research, development and innovation. The Clean Steel Partnership, an initiative established under the European Union's Horizon Europe framework, represents one example of a coordinated effort to accelerate technological development in the steel sector and aims at supporting the deployment of breakthrough technologies capable of reducing carbon dioxide emissions from European steel production by up to 80–95% by 2050 while maintaining the global competitiveness of the European steel industry (Clean Steel Partnership, 2021).

Similarly, international initiatives have highlighted the importance of coordinated action across the steel value chain to accelerate the transition toward low-emission steel production. Industry platforms such as the Net-Zero Steel Initiative emphasise the need for collaboration between steel producers, energy suppliers, policymakers and financial institutions in order to mobilise the investments required for the deployment of new technologies (Mission Possible Partnership, 2021).

Overall, the transition toward low-carbon steel production is expected to involve a combination of technological innovation, industrial restructuring and systemic changes in material use. No single technological solution is likely to dominate the transition; rather, multiple pathways are expected to coexist depending on regional resource availability, technological readiness and policy frameworks.

The steel sector therefore represents a particularly relevant context for analysing the interaction between environmental performance and economic outcomes, as firms must simultaneously adapt to technological transformation, regulatory pressure and evolving market conditions.

2.2.2 Circular economy, scrap usage and resource efficiency

Beyond technological innovation in primary steel production, the transition toward a low-carbon steel sector is also closely linked to the increasing importance of circular economy strategies and the use of steel scrap. Circularity, indeed, represents a fundamental component of long-term decarbonisation pathways because it reduces the need for primary steel production and improves the overall efficiency of material use across industrial value chains.

Steel occupies a unique position within circular economy frameworks due to its physical properties and long life cycle: unlike many other materials, it can be recycled

repeatedly without significant degradation of its intrinsic mechanical properties, making it particularly suitable for circular material flows.

In circular production systems, materials are maintained in productive use through strategies such as reuse, remanufacturing, recycling and material efficiency improvements, replacing traditional linear models based on extraction, production, use and disposal. As illustrated in the circular economy framework developed for the steel sector, the transition from linear to circular systems is typically conceptualised through the four key strategies of *reduce, reuse, remanufacture and recycle*, which together aim to minimise resource consumption and environmental impacts across the product life cycle (World Steel Association, 2016).

Among these strategies, recycling through the use of steel scrap plays a particularly important role in reducing emissions from steel production. Scrap-based steelmaking typically takes place in electric arc furnaces (EAF), which rely primarily on electricity rather than carbon-based reducing agents. As a result, secondary steel production generally requires significantly less energy and produces substantially lower emissions compared with primary steelmaking routes based on iron ore reduction. The increasing share of scrap-based production has therefore been identified as a key driver of emission reductions in the steel sector (Panasiuk *et al.*, 2022).

The growing importance of scrap in steel production is also linked to the long-term dynamics of steel use within modern economies. Steel products are widely used in infrastructure, buildings, transport equipment and industrial machinery, which leads to the accumulation of large in-use stocks of steel within societies that represent both a physical reservoir of materials and a potential future source of scrap for recycling once products reach the end of their life cycle. The availability of scrap is therefore closely related to the historical development of steel consumption and the lifetime of steel-containing products (Pauliuk and Müller, 2014).

From a systemic perspective, understanding the flows of steel through the economy is essential for identifying opportunities to improve material efficiency and reduce emissions. Studies mapping global steel flows have shown that large quantities of steel are embedded in products and infrastructure and eventually return to the production cycle as scrap: such material flows create opportunities for circular strategies aimed at delivering the same level of services with lower material throughput and lower environmental impact (Cullen, Allwood and Bambach, 2012).

However, while increasing the use of scrap represents a major opportunity for decarbonisation, it also presents a number of technical and economic challenges. One of the most important limitations concerns the quality of recycled steel, which may deteriorate due to the accumulation of so-called "*tramp elements"* such as copper, tin, nickel and molybdenum, which are unintentionally introduced during the recycling process because modern products often contain complex combinations of materials that are difficult to separate completely during dismantling and recycling. Over repeated recycling cycles, these impurities can accumulate in scrap and potentially affect the quality and mechanical properties of the resulting steel products (Panasiuk *et al.*, 2022). The presence of such impurities can impose technical constraints on the use of recycled steel in certain high-quality applications, particularly in sectors requiring strict material specifications.

For this reason, scrap-based steel production often involves the dilution of recycled material with primary iron inputs or high-quality scrap streams in order to maintain the required chemical composition of the final product. This issue highlights the importance of effective scrap sorting, improved recycling technologies and enhanced collaboration between recycling industries and steel producers in order to maintain material quality within circular production systems (Panasiuk *et al.*, 2022).

In addition to recycling, broader circular economy strategies can also contribute to reducing emissions by improving material efficiency and product design. Circular approaches aim not only to recycle materials but also to reduce the total demand for primary steel by increasing product durability, facilitating repair and remanufacturing, and promoting more efficient use of materials across supply chains.

Case studies in the metalworking sector have demonstrated that the implementation of circular production strategies—such as optimising product design, reducing material waste and improving recovery of manufacturing residues—can significantly improve material efficiency and reduce the environmental footprint of steel products (Hagedorn *et al.*, 2022).

Recent policy analyses also emphasise that circular economy strategies may play a substantial role in achieving long-term decarbonisation targets in the steel sector as, by reducing demand for primary steel production and encouraging the expansion of secondary steelmaking routes, circular economy approaches can contribute to lowering both energy consumption and greenhouse gas emissions.

According to recent assessments, improvements in material efficiency and recycling rates could significantly reduce global steel demand and contribute to emission reductions in the coming decades (OECD, 2024). Nevertheless, the implementation of circular economy strategies in the steel sector remains uneven across regions and industries. As several barriers continue to limit the expansion of circular practices, including insufficient scrap collection infrastructure, limited information on material composition in complex products and the lack of integrated policy frameworks linking circular economy strategies with climate mitigation objectives, addressing these challenges will therefore require coordinated policy interventions, technological innovation and stronger integration between industrial value chains.

Overall, circular economy approaches represent an essential complement to technological innovation in steel production. While breakthrough technologies such as hydrogen-based steelmaking are expected to play a major role in reducing emissions from primary production processes, circular strategies centred on scrap utilisation and material efficiency can significantly reduce the overall demand for primary steel and thus contribute to the decarbonisation of the sector.

2.2.3 Strategic implications of environmental investments

The transition of the steel industry toward climate neutrality does not depend exclusively on technological innovation and industrial strategies, with public policy frameworks and regulatory environments also playing a fundamental role in shaping the incentives for firms to invest in low-carbon technologies and to transform existing production systems. In the case of environmentally intensive sectors such as steel, the interaction between regulation, innovation and competitiveness has therefore become a central issue in both academic research and policy debates.

Traditional economic perspectives have often framed environmental regulation as a cost burden imposed on firms, potentially reducing their competitiveness. According to this conventional view, stricter environmental standards increase production costs by forcing firms to invest in pollution abatement technologies or to adopt less efficient production processes and, as a consequence, environmental regulation could place firms operating in regulated jurisdictions at a disadvantage

compared with competitors located in countries with weaker environmental standards (Ambec and Lanoie, 2008).

However, an alternative perspective has emerged in the literature, arguing that well-designed environmental regulations can actually stimulate technological innovation and improve resource efficiency. This argument, commonly referred to as the *Porter Hypothesis*, suggests that stringent but flexible environmental policies may encourage firms to develop new technologies, improve production processes and reduce waste, thereby partially or even fully offsetting the costs associated with regulatory compliance (Porter and van der Linde, 1995).

In this dynamic perspective, environmental regulation can act as a catalyst for innovation by revealing previously overlooked inefficiencies in production systems. Pollution is often associated with the inefficient use of resources such as energy and raw materials, meaning that efforts to reduce emissions can simultaneously improve productivity and operational efficiency. As Porter and van der Linde (1995) argue, environmental regulations can therefore trigger innovation that improves both environmental performance and economic outcomes, challenging the traditional assumption that environmental protection necessarily entails a trade-off with competitiveness.

In the steel sector, the importance of regulatory frameworks is particularly evident because of the high capital intensity and long investment cycles associated with steel production facilities. Steel plants are typically designed to operate for several decades, which means that investment decisions made today will determine the emissions trajectory of the sector for many years. For this reason, stable and predictable policy frameworks are considered essential for supporting the large-scale deployment of low-carbon technologies.

At the European level, policy initiatives aimed at supporting the decarbonisation of heavy industry have increasingly emphasised the role of coordinated research, innovation and investment programmes. One of the most prominent initiatives in this field is the Clean Steel Partnership, which aims to accelerate the development and deployment of breakthrough technologies capable of drastically reducing emissions from steel production. The partnership is aligned with broader European climate policies, including the European Green Deal and the objective of achieving climate neutrality by 2050. According to the Strategic Research and Innovation Agenda of the Clean Steel Partnership, the long-term objective is to develop technologies capable of

reducing CO_2 emissions from European steel production by 80–95% by 2050, compared with 1990 levels. Intermediate milestones include the development of technologies capable of achieving approximately 50% emission reductions by 2030, while maintaining the competitiveness of the European steel industry and ensuring the continued availability of steel as a strategic material for industrial value chains. Achieving these objectives requires large-scale investment in research, development and innovation, as well as strong collaboration between industry, research institutions and public authorities. The Clean Steel Partnership therefore promotes a coordinated approach to technological development through a series of research projects, pilot plants and industrial demonstration initiatives aimed at advancing technologies from early research stages to commercial deployment. The partnership also emphasises the importance of collaboration across the entire steel value chain, including suppliers, technology providers, research organisations and industrial users of steel products.

More broadly, international cooperation has also been identified as a key factor for accelerating the decarbonisation of energy-intensive industries. Global initiatives such as the Breakthrough Agenda seek to promote collaboration among governments, companies and financial institutions in order to accelerate the development and diffusion of low-emission technologies in sectors including steel, hydrogen and electricity generation. Through coordinated action, countries can harmonise standards, mobilise investment and facilitate knowledge sharing, thereby reducing the costs and risks associated with the transition to low-carbon industrial systems (IEA, 2025).

At the same time, policy frameworks increasingly aim to support the creation of lead markets for low-carbon steel products and to stimulate investment in industrial innovation. Recent European initiatives emphasise measures such as reducing energy costs, supporting research projects and increasing circularity within the steel production chain. These policies aim not only to reduce emissions but also to strengthen the competitiveness of the European steel industry in the global transition toward low-carbon production systems (European Commission, 2025).

Beyond policy incentives, the integration of sustainability considerations into corporate strategies is also becoming increasingly relevant for industrial competitiveness. Empirical research suggests that companies adopting sustainability-oriented strategies often develop organisational structures, governance mechanisms and stakeholder engagement processes that differ from those of traditional firms. These organisational changes may contribute to improved long-term performance and

enhanced resilience in rapidly evolving regulatory and market environments (Eccles, Ioannou and Serafeim, 2014).

Overall, the decarbonisation of the steel sector requires a complex interaction between technological innovation, corporate strategies and public policy frameworks. While technological breakthroughs such as hydrogen-based steelmaking or carbon capture technologies represent critical components of the transition, their successful deployment depends heavily on supportive regulatory environments and coordinated industrial policies. In this context, policy initiatives and international collaboration play a crucial role in reducing investment risks, fostering innovation and enabling the large-scale transformation of one of the most carbon-intensive industrial sectors.

2.3 Environmental performance measurement in the steel industry

The third section focuses on how environmental performance is measured and reported in the steel sector, providing a bridge between the sectoral analysis developed in this chapter and the methodological choices discussed in the following chapters regarding the empirical analysis.

The growing relevance of environmental, social and governance (ESG) considerations in financial markets has led to an increasing reliance on ESG ratings as indicators of firms' sustainability performance. These ratings are widely used by investors, asset managers and researchers to evaluate corporate environmental behaviour and to integrate sustainability criteria into investment decisions, as they condense large volumes of sustainability-related information into standardized scores that facilitate cross-firm comparisons.

Despite their widespread use, ESG ratings present important conceptual and methodological limitations that complicate their interpretation. Environmental performance is inherently multidimensional—encompassing emissions, energy use, resource efficiency and environmental innovation—and cannot be fully captured by a single aggregated indicator. As a result, ESG ratings rely on simplifying assumptions and methodological choices that may significantly affect the resulting evaluations.

A key issue concerns the lack of standardised frameworks for ESG measurement and disclosure. Firms report environmental data using heterogeneous metrics and formats, which limits comparability across companies and industries.

Consequently, ESG rating agencies rely on diverse data sources and proprietary methodologies, leading to inconsistencies across providers.

A substantial body of research documents significant divergence among ESG ratings: Berg, Kölbel and Rigobon (2022) show that correlations between major providers are relatively low, indicating disagreement on how sustainability performance should be measured. This divergence largely reflects methodological differences, including variations in the scope of attributes considered, the indicators used to proxy sustainability dimensions and the weighting schemes applied in score aggregation.

Such inconsistencies have important implications: for investors, they introduce uncertainty in assessing firms' sustainability performance; for firms, they may weaken incentives to improve environmental outcomes; and for researchers, they create measurement challenges that can affect empirical results. Additional concerns relate to the reliability and stability of ESG ratings over time. ESG scores may be revised retrospectively following methodological changes, potentially altering firms' rankings and affecting empirical analyses (Berg, Fabisik and Sautner, 2021). Moreover, ESG assessments involve subjective judgments, and increased disclosure does not necessarily reduce disagreement among rating agencies (Christensen, Serafeim and Sikochi, 2022).

In general, these limitations are particularly relevant in environmentally intensive sectors such as the steel industry, where environmental performance depends on sector-specific factors such as emissions intensity and decarbonisation technologies. Recent evidence suggests that ESG environmental scores may not accurately reflect underlying environmental performance in this context: Cregan, Kelly and Clinch (2024) find a weak correspondence between ESG scores and firms' emissions or low-carbon investments.

Overall, while ESG ratings provide a useful synthesis of complex information, their interpretation requires caution, especially in empirical analyses of the environmental–financial performance relationship, where measurement choices can significantly influence results.

2.3.2 Quantitative and intensity-based environmental indicators

The measurement of corporate environmental performance represents a central challenge in sustainability research as well as in empirical analyses that attempt to link environmental outcomes with firms' economic and financial performance.

Although ESG ratings provide aggregated indicators intended to capture firms' sustainability behaviour, many studies emphasize the importance of relying on more specific environmental metrics in order to obtain a more accurate representation of firms' environmental impacts, particularly when the objective is to analyse the relationship between environmental performance and financial outcomes. These indicators typically rely on measurable environmental outcomes—such as emissions, resource consumption or environmental efficiency—rather than on composite sustainability scores.

Environmental accounting literature highlights that environmental performance can be assessed through different types of indicators depending on the objectives of the analysis. Environmental indicators may measure absolute environmental impacts, such as total emissions or resource consumption, relative efficiency measures—such as emissions intensity or eco-efficiency ratios—or broader sustainability indicators that combine environmental and economic information. The choice among these different measures is not merely technical but reflects alternative conceptual approaches to measuring corporate sustainability performance (Schaltegger and Burritt, 2000).

Within environmental management and accounting research, the concept of eco-efficiency has become particularly relevant for evaluating corporate environmental performance. Eco-efficiency indicators relate environmental impacts to economic outputs or production levels, thereby capturing the efficiency with which firms use natural resources and generate emissions. This approach reflects the broader idea that companies can contribute to sustainable development by creating economic value while simultaneously reducing the environmental intensity of their activities (Figge and Hahn, 2013).

From a methodological perspective, eco-efficiency indicators offer several advantages compared with aggregate ESG scores. Because they rely on measurable environmental outcomes—such as greenhouse gas emissions or energy consumption—they avoid some of the complexities associated with rating methodologies that combine multiple sustainability dimensions into a single index. In addition, eco-efficiency indicators allow for clearer comparisons across firms operating within the same industry, especially in sectors where environmental impacts are

closely linked to production processes. At the same time, these indicators provide information that is more directly related to firms' operational performance and technological choices.

Nevertheless, environmental indicators also present certain methodological limitations. Absolute environmental measures—such as total emissions—may largely reflect the scale of a firm's operations rather than the environmental efficiency of its production processes. Larger firms may therefore generate higher levels of emissions simply because they operate at greater production volumes, even when their production technologies are relatively efficient. For this reason, many studies prefer intensity-based indicators that relate environmental impacts to measures of output, such as emissions per unit of production or per unit of revenue.

The relevance of intensity-based indicators becomes particularly evident in environmentally intensive sectors such as steel production, where environmental impacts are closely linked to physical production processes and energy use. In such contexts, measures such as carbon intensity or energy intensity provide more meaningful information about firms' environmental efficiency than aggregate ESG scores or qualitative sustainability assessments.

The steel industry offers a clear illustration of this issue, since steel production is associated with high energy consumption and substantial greenhouse gas emissions. According to data reported by the World Steel Association, the global average carbon intensity of steel production was approximately 1.92 tonnes of CO_2 per tonne of crude steel produced in 2023, which highlights the importance of using intensity-based indicators when analysing environmental performance in this sector.

Recent regulatory developments have further reinforced the importance of standardized environmental reporting. The European Union's Corporate Sustainability Reporting Directive (CSRD), for instance, requires large companies and listed firms to disclose detailed information regarding environmental impacts, risks and opportunities, with the aim of improving the availability, comparability and reliability of sustainability data used by investors and other stakeholders. The CSRD is complemented by the European Sustainability Reporting Standards (ESRS), which specify the sustainability information that companies must disclose regarding environmental, social and governance issues. These standards require firms to report quantitative environmental indicators, policies, targets and performance metrics related to sustainability topics

such as climate change, pollution and resource use, thereby improving the consistency of sustainability disclosures across firms and industries.

Despite these regulatory developments, several studies emphasize that ESG scores may still fail to accurately reflect firms' underlying environmental performance. Research on ESG ratings suggests that these scores can be influenced by factors such as firm size, data availability and disclosure practices rather than by actual environmental impacts. Drempetic, Klein and Zwergel (2020), for example, find that larger firms often receive higher ESG scores because they possess greater resources to produce sustainability disclosures and interact with rating agencies.

These findings raise important methodological questions for empirical research examining the relationship between environmental performance and financial performance. If ESG scores are influenced by disclosure practices and firm characteristics unrelated to environmental impacts, they may not represent reliable proxies for environmental performance, and empirical analyses relying exclusively on ESG ratings may therefore produce misleading conclusions regarding the relationship between sustainability and firm value. For this reason, several studies advocate the use of environmental indicators based on measurable outcomes. Indicators such as emissions intensity, energy intensity or eco-efficiency ratios provide a more direct representation of firms' environmental performance and reduce the influence of methodological biases embedded in ESG rating systems.

In summary, while ESG ratings offer a convenient way to aggregate sustainability information, they also present important methodological limitations. Environmental indicators based on measurable outcomes—particularly intensity-based metrics—can provide more precise information about firms' environmental performance, especially in environmentally intensive sectors such as steel production. These considerations are particularly relevant for empirical research analysing the relationship between environmental and financial performance, where the choice of environmental indicators can significantly influence the results of the analysis.

2.4 Feralpi Group as a case study

This section motivates the selection of Feralpi Group as the focal firm of the empirical analysis.

2.4.1 Overview of Feralpi Group and its business model

Feralpi Group represents one of the most significant European steel producers operating within the electric arc furnace (EAF) production model, which relies primarily on recycled steel scrap as a key input.

Founded in Italy in 1968 and progressively expanded across European markets, the company has developed a diversified industrial structure combining steel production, downstream processing activities, and commercial distribution networks, positioning itself as an important player within the European steel industry, particularly in the production of long steel products used in construction and infrastructure sectors.

The organisational structure of Feralpi Group reflects a vertically integrated model that includes steelmaking operations, downstream processing and distribution activities across several European countries. The group operates through a network of subsidiaries specialised in different phases of the steel value chain, including steel production, rolling mills, cold processing, distribution and recycling activities, a structure that allows the company to manage production processes and supply chains across multiple geographical markets while maintaining a strong industrial base in Italy and Germany.

Within this organisational framework, the group's main industrial entities include companies specialised in primary steel production as well as firms involved in downstream processing activities such as cold drawing, reinforcement products and structural steel components, with several subsidiaries operating across Europe, including steelmaking plants, distribution companies and service centres. These entities form an integrated production and distribution system that enables the group to serve construction and infrastructure markets across multiple European countries.

The economic relevance of Feralpi Group within the European steel sector is also reflected in its production and financial performance over recent years. Consolidated financial data indicate that the group has experienced substantial growth in turnover and production volumes, reflecting both favourable market conditions and strategic investments in production capacity and technological innovation: for example, consolidated revenues increased significantly between 2019 and 2021, reaching approximately €1.93 billion in 2021, compared with approximately €1.30 billion in 2019. This expansion can reflect both cyclical dynamics in steel markets and the strategic positioning of the group within segments of the steel industry characterised by

relatively stable demand, particularly in construction-related products such as reinforcing bars and wire rod. The company's production activities are therefore closely connected to European construction markets and infrastructure investments, which represent key drivers of demand for long steel products.

Another distinctive element of the group's strategy concerns its commitment to technological innovation and industrial modernisation. The company has, in fact, progressively invested in advanced manufacturing technologies, digitalisation processes and research and development activities aimed at improving production efficiency and product quality, initiatives that are often framed within broader industrial transformation processes linked to Industry 4.0 and the digitalisation of manufacturing systems.

In parallel, sustainability considerations have increasingly become a central element of the group's strategic positioning, with Feralpi progressively integrating environmental and social objectives into its corporate strategy, particularly in relation to climate transition and circular economy practices, reflecting broader transformations within the steel industry, where decarbonisation and resource efficiency have become key priorities for both regulators and industrial actors. The group's sustainability strategy focuses primarily on three interconnected dimensions: environmental efficiency, circular economy practices and technological innovation.

Within the environmental dimension, the company has implemented several initiatives aimed at reducing greenhouse gas emissions, improving energy efficiency and optimising resource use in production processes, which are particularly relevant given the energy-intensive nature of steel production and the increasing regulatory pressure to decarbonise industrial sectors. Circular economy principles also play a central role in the group's production model, since steel production based on electric arc furnace technology relies heavily on recycled steel scrap, which represents a key input in the manufacturing process.

This production model contributes to the circularity of material flows within the steel industry, allowing scrap steel to be continuously recycled and reintegrated into new production cycles and resulting in the EAF production route being generally associated with lower carbon emissions compared with traditional blast furnace processes based on primary iron ore inputs. Feralpi's strategic orientation toward circular production systems is therefore closely aligned with broader sustainability objectives within the steel industry, as the group emphasises the importance of

resource efficiency, recycling and waste reduction in order to minimise environmental impacts while maintaining industrial competitiveness.

In this context, the company has also invested in projects aimed at improving material recovery processes and enhancing the efficiency of scrap-based production systems. More recently, the group has also adopted an integrated reporting approach combining financial and sustainability information within a single reporting framework, reflecting the increasing importance of ESG considerations in corporate governance and corporate communication. Integrated reporting, indeed, aims to provide stakeholders with a comprehensive overview of the company's economic performance, sustainability strategy and long-term value creation model. Within these reports, the group emphasises the need to reconcile industrial competitiveness with environmental and social objectives, particularly in the context of global economic transformations such as climate change, energy market volatility and supply chain disruptions. According to the group's leadership, these challenges require companies to develop business models capable not only of adapting to economic discontinuities but also of contributing to broader sustainability goals.

Overall, Feralpi Group can therefore be considered an illustrative case within the European steel industry for analysing the relationship between environmental performance and financial outcomes. The company combines a scrap-based production model, a strong focus on circular economy practices and increasing commitments toward decarbonisation and sustainability reporting, characteristics that make the group a particularly relevant empirical case for examining how environmental performance indicators relate to economic performance in environmentally intensive industrial sectors.

2.4.2 Electric arc furnace production and environmental strategy

Environmental sustainability has become a central strategic dimension for firms operating in the steel industry, particularly in the European context where regulatory pressure, technological transformation and market expectations are accelerating the transition toward low-carbon production models. Within this evolving landscape, steel producers are increasingly required to combine industrial competitiveness with environmental performance, adopting strategies aimed at reducing emissions, improving resource efficiency and strengthening circular production systems. In this

context, Feralpi Group represents a relevant example of this transition within the European steel industry, as environmental sustainability has progressively become integrated into the company's long-term industrial strategy.

As previously mentioned, the steel sector plays a crucial role in the global economy but also represents one of the most environmentally intensive industrial activities: steel production is indeed responsible for a significant share of global industrial emissions but remains a fundamental material for modern infrastructure, construction, transport and energy systems, making its decarbonisation a key priority for achieving global climate objectives.

Within this context, international policy initiatives increasingly emphasise the need for coordinated action to accelerate the deployment of low-emission technologies in energy-intensive sectors such as steel and such a global transition toward cleaner industrial systems therefore requires collaboration between governments, companies and financial actors in order to support technological innovation, infrastructure development and the scaling of new production processes (IEA, 2025). These dynamics are particularly relevant for the European steel industry, where regulatory frameworks such as carbon pricing mechanisms and sustainability reporting standards are pushing firms to integrate environmental considerations into their business models.

In this broader industrial transformation, circular economy principles have emerged as one of the most important pathways for reducing emissions in the steel sector since, as steel is inherently compatible with circular production models because it can be recycled repeatedly without losing its physical properties, scrap-based production routes can significantly reduce the environmental footprint of steelmaking compared with primary production processes based on iron ore and coal. According to international decarbonisation scenarios, the increased availability and utilisation of steel scrap could play a major role in reducing global emissions, potentially contributing to a substantial share of emission reductions in the sector by mid-century (OECD, 2024).

From this perspective, the environmental strategy adopted by Feralpi Group is closely aligned with these broader structural transformations of the steel industry, as the company's production model relies predominantly on the electric arc furnace (EAF) route, which uses recycled steel scrap as the primary input for steelmaking and, compared with traditional blast furnaces–basic oxygen furnace processes, generally

generates lower carbon emissions and requires fewer primary raw materials, making it more compatible with circular economy principles.

Feralpi's industrial strategy therefore emphasises the importance of circular production systems and resource efficiency, highlighting the central role of scrap recycling within its production model and underlining how the use of secondary raw materials contributes to reducing the environmental impact of steel production while simultaneously supporting the circularity of material flows within the broader economy. In this sense, steel scrap represents not only an input for industrial production but also a key component of sustainable material cycles.

The global importance of recycling in the steel industry is reflected in the increasing share of secondary production processes in overall steelmaking. Steel is one of the most recycled materials in the world, and scrap already represents a substantial share of the metallic input used in steel production globally; in this context industry projections suggest that the role of recycled steel will continue to expand as existing steel stocks reach the end of their lifecycle and re-enter production systems through recycling processes (World Steel Association, 2025).

Beyond recycling activities, the environmental strategy of Feralpi also includes initiatives aimed at improving energy efficiency and reducing greenhouse gas emissions across production processes. Considering that steel production is highly energy intensive, and improvements in energy management can therefore generate significant environmental benefits, in recent years the company has implemented several technological investments designed to optimize production efficiency, reduce energy consumption and modernise industrial facilities.

At the strategic level, Feralpi has increasingly integrated sustainability considerations into its corporate governance and reporting practices, progressively adopting integrated reporting frameworks that combine financial information with environmental, social and governance indicators, reflecting the growing importance of ESG considerations for corporate stakeholders, with the aim to provide a comprehensive overview of the company's economic performance and sustainability strategy, highlighting how environmental initiatives are linked to long-term value creation. This approach reflects a broader shift in corporate reporting practices within environmentally intensive industries as, increasingly, companies are expected not only to disclose financial performance but also to demonstrate how environmental and social factors are incorporated into their strategic decision-making processes.

Sustainability reporting therefore plays an important role in improving transparency, strengthening stakeholder engagement and supporting the credibility of corporate environmental commitments.

Within the European steel industry, environmental strategies are also strongly influenced by the need to anticipate future regulatory developments and technological transitions. Indeed, as climate policies, decarbonisation targets and industrial innovation programmes are progressively reshaping the competitive landscape of the sector, companies must adapt their business models in order to remain competitive while simultaneously complying with increasingly stringent environmental standards. For Feralpi Group, this transition involves balancing the three key strategic objectives of maintaining industrial competitiveness, improving environmental performance and supporting technological innovation, and, therefore, the company's strategy combines investments in energy efficiency, the expansion of circular production systems and the progressive integration of sustainability principles into corporate governance and reporting practices.

Overall, the environmental positioning of Feralpi reflects the broader transformation currently affecting the global steel industry, a context where, as the sector moves toward lower-carbon production models, companies that adopt circular economy principles, invest in cleaner technologies and strengthen sustainability governance are likely to play an increasingly important role in shaping the future of industrial decarbonisation.

2.4.3 Feralpi versus European peers: motivation for a comparative analysis

The previous sections have discussed the structural characteristics of the steel industry and the environmental strategy adopted by Feralpi Group within the broader context of industrial decarbonisation: building on this background, the present study chooses Feralpi Group as the focal firm for the empirical analysis of the relationship between environmental performance and financial outcomes in the European steel industry.

The choice of a focal firm within a comparative sample of European steel producers allows the analysis to combine sector-level dynamics with firm-level environmental and financial indicators. More specifically, the empirical analysis developed in the following chapters examines the relationship between environmental

performance and accounting-financial performance using a panel dataset that includes Feralpi Group and a set of comparable European steel producers.

The analysis focuses on intensity-based environmental indicators—such as emissions intensity and related eco-efficiency measures—rather than aggregated ESG ratings, a methodological choice that reflects the increasing recognition in the literature that intensity-based environmental indicators provide a more direct representation of firms' environmental efficiency, particularly in environmentally intensive sectors such as steel production.

The steel industry represents a particularly suitable empirical context for this type of analysis for several reasons, the first being that steel production is one of the most energy-intensive industrial activities and accounts for a significant share of global industrial emissions. Recent estimates indeed suggest that steel production is responsible for approximately 7–8% of global carbon emissions, making the sector a critical component of global decarbonisation strategies (Cregan, Kelly and Clinch, 2024).

Second, the industry is undergoing a profound technological and regulatory transformation driven by climate policies, technological innovation and market pressures toward low-carbon production systems: within this broader context, the European steel industry faces a complex combination of economic and environmental challenges as, on the one hand, global steel markets are characterised by increasing competition, excess production capacity and volatile demand dynamics while, on the other hand, European producers are subject to increasingly stringent climate policies aimed at reducing greenhouse gas emissions and promoting industrial decarbonisation. These factors are reshaping the competitive landscape of the sector and influencing firms' strategic decisions regarding investments, technological innovation and environmental performance (OECD, 2025).

The European Union has also introduced new regulatory instruments designed to address the environmental impact of carbon-intensive industries, including the Carbon Border Adjustment Mechanism (CBAM), which aims to prevent carbon leakage by ensuring that imported products are subject to carbon pricing mechanisms equivalent to those applied within the European Union and which therefore represents an important policy tool aimed at maintaining the competitiveness of European industries while simultaneously strengthening climate policies and promoting global emission reductions (Regulation (EU) 2023/956).

Within this evolving regulatory and technological landscape, firms operating in the steel sector must increasingly balance environmental performance with economic competitiveness, as investments in cleaner technologies, improvements in energy efficiency and the adoption of circular production systems are becoming key determinants of firms' long-term strategic positioning and, at the same time, environmental initiatives may involve significant capital expenditures and operational adjustments, potentially influencing financial performance.

From a research perspective, this interaction between environmental performance and financial outcomes represents a central question in the broader literature on corporate sustainability and firm competitiveness, with recent studies emphasising that the relationship between environmental and financial performance may depend strongly on measurement choices, sectoral characteristics and methodological approaches. In carbon-intensive industries such as steel production, environmental performance indicators based on emissions intensity and resource efficiency may therefore provide more meaningful information than aggregate ESG scores or qualitative sustainability ratings.

At the same time, empirical research has highlighted several limitations associated with commonly used ESG indicators and sustainability ratings, as some studies suggest that ESG ratings may not accurately reflect firms' underlying environmental performance, particularly in sectors characterised by complex technological processes and heterogeneous production structures. For example, empirical analyses of the steel sector indicate that environmental and emissions scores provided by ESG rating agencies may not always correspond closely to firms' actual greenhouse gas emissions or emissions intensity (Cregan, Kelly and Clinch, 2024).

These considerations reinforce the importance of using more specific environmental indicators when analysing environmental performance in industrial sectors, and for this reason the empirical analysis developed in the present study focuses on intensity-based environmental indicators derived from corporate sustainability disclosures and industry data, as such indicators may potentially allow for more precise comparisons between firms operating within the same sector and help capture differences in environmental efficiency across production systems.

Within this analytical framework, Feralpi Group represents a particularly relevant case study because, first of all, it operates primarily through electric arc furnace technology based on recycled steel scrap, which generally results in lower emissions

intensity compared with traditional blast furnace production routes; second, it has progressively integrated sustainability considerations into its corporate strategy and reporting practices, providing relatively detailed environmental disclosures that enable the construction of firm-level environmental indicators; and finally, it operates within the European regulatory environment, where climate policies and decarbonisation initiatives play an increasingly important role in shaping industrial strategies.

By combining firm-level environmental indicators with financial performance data, the empirical analysis developed in the following chapters aims to contribute to the literature on the relationship between environmental performance and firm competitiveness seeking, in particular, to evaluate whether improvements in environmental efficiency—captured through intensity-based indicators—are associated with changes in firms' financial performance within the context of the European steel industry.

In summary, the selection of Feralpi Group as the focal firm of the empirical analysis reflects both methodological and substantive considerations: methodologically, the firm provides a relevant case for analysing the interaction between environmental efficiency and financial outcomes using intensity-based environmental indicators while, substantively, the company operates within a sector undergoing rapid technological and regulatory transformation, making it a suitable context for examining how environmental performance may influence firms' economic competitiveness.

CHAPTER 3 - DATA, METHODOLOGY, EMPIRICAL ANALYSIS AND MAIN FINDINGS

3.1. Data, methodology and preliminary analysis

3.1.1. Data selection: reasons behind the choice of companies in the sample

The selection of the companies included in the sample is a key step in the empirical analysis, because the relationship between environmental and financial performance in the steel industry depends not only on firm size or country, but also on how steel is actually produced.

As discussed in Chapters 1 and 2, the steel sector is particularly suitable for this type of analysis because it is both economically important and highly environmentally intensive. At the same time, however, it is far from homogeneous, firms indeed differ significantly in their production models, and this has direct implications for environmental performance.

The two main steelmaking methods, which are blast furnace/basic oxygen furnace (BF–BOF) and electric arc furnace (EAF), are associated with very different environmental outcomes since BF–BOF production is based on iron ore and coal and is therefore highly carbon-intensive, while EAF production relies mainly on recycled scrap and is generally less emission-intensive and more aligned with circular economy principles (IEA, 2023; World Steel Association, 2025). In addition, several firms operate with hybrid models, combining different technologies or transitioning from one system to another.

It must be noted that the choice of a preferred production method does also depend on the type of activity performed by the firm itself and, in particular, on whether the company simply transforms already existing steel by remelting scraps or it covers the entire production cycle from mineral extraction to crude steel. For this reason, the sample has been constructed not simply to include large European steel companies, but to capture variation in production technologies, which is one of the main drivers of differences in environmental performance. This choice is consistent with the literature discussed in the first chapter, which highlights that results in ESG–financial performance studies strongly depend on how performance is measured and on the context in which firms operate (Ullmann, 1985; Griffin and Mahon, 1997): therefore, by

including firms with different production models, the analysis can better capture how environmental efficiency relates to financial outcomes.

The sample includes ten companies that differ in size, geographical location and business model, but that are all exposed, to different degrees, to the environmental and regulatory challenges typical of energy-intensive industries.

It must also be noted that the sample selection was bounded by the availability of annual integrated reports including environmentally related data for a sufficient time span in order to perform a statistically significant analysis.

Feralpi Group represents the focal firm of the analysis and a clear example of an EAF-based producer. Its production model is largely based on recycled steel scrap and electric arc furnace technology, which makes it strongly aligned with circular economy principles, providing a benchmark for analysing a lower-emission production model within a traditionally hard-to-abate sector. As opposed, ArcelorMittal is included as a large and diversified global steel producer operating across multiple technologies. The company combines blast furnace, basic oxygen furnace, electric arc furnace and direct reduction processes, and can therefore be classified as hybrid. This makes it particularly useful for the analysis, as it reflects a complex industrial structure where different production routes coexist and where decarbonisation strategies are already being implemented to some extent.

Voestalpine is also classified as hybrid, as it still relies significantly on blast furnace-based production but is actively investing in a transition towards electric arc furnace technologies. This makes the company an interesting case of ongoing technological transformation, where current environmental performance reflects both traditional systems and future-oriented investments.

A similar situation can be observed for SSAB, which combines traditional blast furnace operations with electric arc furnace production and is actively pursuing a transition towards fossil-free steelmaking. Therefore, also this company represents a relevant example of a firm in transition, where environmental strategy, innovation and production technology are closely interconnected.

Outokumpu, on the other hand, can be broadly classified as EAF-based, as its stainless steel production relies heavily on recycled materials and circular processes. The company explicitly emphasises the use of recycled inputs as a core element of its business model, which results in significantly lower emissions compared to industry

averages. This makes it particularly relevant for capturing the environmental advantages associated with circular production models.

Salzgitter AG is currently best classified as a BF–BOF producer, as its production is still largely based on integrated steelmaking processes. However, the company is starting to invest in new technologies to reduce emissions, which makes it representative of traditional producers under transition pressure.

A similar classification applies to Thyssenkrupp, whose Steel Europe division is still primarily based on integrated blast furnace production, even though the group is actively developing decarbonisation solutions. Aperam represents a hybrid model, combining a strong focus on recycling and circularity with vertically integrated production processes. The company emphasises the use of recycled inputs and resource efficiency as core elements of its strategy, making it an important case for analysing the role of circularity in environmental performance.

Tata Steel Nederland is included as a representative of a BF–BOF producer, with production based on integrated steelmaking processes. At the same time, the company is under strong pressure to reduce emissions and is planning a transition towards cleaner technologies, making it particularly relevant for analysing the trade-off between environmental performance and financial outcomes in the short and medium term.

Finally, Boliden is included as a company operating in the broader metals and mining sector. Although it is not a steel producer in a strict sense, its activities involve energy-intensive metallurgical processes and are subject to similar environmental constraints and regulatory pressures. In addition, its operations include a strong focus on recycling and circular material flows. For the purposes of this analysis, it can therefore be considered functionally comparable to steel producers and can be broadly associated with a recycling-based (EAF-like) production logic. Its inclusion allows expanding the analysis to a wider set of energy-intensive industrial firms, increasing the variability of environmental performance within the sample without compromising its overall coherence.

Overall, the illustrated sample, as summarised in the table below, includes firms operating under three main production configurations: EAF-based models (e.g., Feralpi, Outokumpu), BF–BOF models (e.g., Salzgitter, Thyssenkrupp, Tata Steel Nederland), and hybrid models (e.g., ArcelorMittal, voestalpine, SSAB, Aperam). This heterogeneity, however, does not represent a limitation, but rather a strength of this

empirical analysis: including firms with different production technologies could in fact allow the analysis to capture meaningful differences in environmental intensity and to better investigate how these differences relate to financial performance. In this sense, the sample is consistent with the theoretical and empirical framework developed in the previous chapters and provides a solid basis for analysing the environmental–financial performance relationship in a hard-to-abate sector where production technology plays a central role.

Table 1 - Selected firms

Company	Country	Production model	% EAF-based production	Key characteristics
Feralpi Group	Italy	EAF		Fully scrap-based production model based on electric arc furnaces.
Outokumpu	Finland	EAF		Stainless steel production predominantly based on recycled scrap.
Boliden	Sweden	EAF-like (recycling-based)		Recycling-oriented metallurgical operations; not a pure steel producer but based on processes structurally similar to EAF logic.
ArcelorMittal	Luxembourg	Hybrid	≈ 25%	Highly diversified production system combining BF–BOF, EAF and DRI technologies.
voestalpine	Austria	Hybrid	≈ 15%	Predominantly BF–BOF-based production, with gradual investments in low-carbon technologies such as hydrogen-based steelmaking.
SSAB	Sweden	Hybrid	≈ 35%	Production model in transition from BF–BOF to EAF and DRI, supported by a clear decarbonization strategy.
Aperam	Luxembourg	Hybrid	≈ 65%	Increasingly circular production model with extensive use of scrap, although still partially reliant on primary inputs.
Salzgitter AG	Germany	BF–BOF		Traditional ore-based production system, with ongoing transition projects towards DRI and EAF technologies.
Thyssenkrupp AG	Germany	BF–BOF		Historically integrated and carbon-intensive production model, with early-stage technological transition.
Tata Steel	Netherlands	BF–BOF		Large-scale integrated steel production, still largely dependent on conventional processes despite increasing decarbonization efforts.

Source: originally produced
Note: Boliden is not a steel producer in a strict sense, but is included in the sample due to its comparable exposure to energy-intensive processes, circular material flows and environmental regulation.

Table 1 "*Selected firms*", which summarizes the firms chosen for the sample, also introduces a classification of firms based on their production model, distinguishing between Electric Arc Furnace (EAF), Blast Furnace–Basic Oxygen Furnace (BF–BOF), and hybrid firms.

EAF firms are characterised by a production process primarily based on scrap recycling, which is typically associated with lower emissions intensity and higher resource efficiency.

In contrast, BF–BOF firms rely on primary steelmaking based on iron ore and coal, resulting in significantly higher emissions intensity due to both energy use and process-related emissions. Hybrid firms represent an intermediate category, combining elements of both production routes and therefore exhibiting mixed technological configurations.

To better capture this heterogeneity, Table 1 includes an approximate indicator of the share of production based on EAF technology (%EAF). This variable does not represent an exact or fully comparable measure across firms, but rather a rough proxy derived from available information in annual reports and industry disclosures. Its purpose is primarily interpretative: it allows to refine the analysis by positioning hybrid firms along a continuum between EAF and BF–BOF models, rather than treating them as a homogeneous group. It is important to stress that both the classification of firms and the %EAF values should be interpreted carefully, as they are inherently approximate and based on publicly available data, which may differ in terms of reporting standards and level of detail. As a result, these categories should not be considered as rigid or absolute, but rather as analytical tools that help contextualise the empirical results and improve the interpretation of differences across firms.

3.1.2. Data selection: reasons behind the choice of financial and environmental performance indicators to analyse

The selection of financial and environmental performance indicators is a crucial step in the empirical analysis, because the way these variables are measured directly affects both the interpretation of the results and the consistency of the study with the literature discussed in the first two chapters.

As widely recognised in the literature, the relationship between environmental and financial performance depends heavily on how these concepts are measured, and different indicators can lead to different results (Ullmann, 1985; Griffin and Mahon, 1997). For this reason, the choice of variables must be grounded in existing theory, empirically robust, and consistent with the specific characteristics of the steel industry. Regarding financial performance, this study focuses on four key indicators—ROA, ROE, leverage, and the CAPEX/Assets ratio—which together capture different but complementary dimensions of firm performance.

First, this selection is consistent with empirical evidence showing that accounting-based indicators tend to exhibit stronger and more stable relationships with ESG performance compared to market-based measures (Orlitzky, Schmidt and Rynes, 2003; Friede, Busch and Bassen, 2015).

Second, these indicators reflect the main theoretical mechanisms discussed in Chapter 1, particularly those related to the Natural-Resource-Based View (NRBV) and the Porter Hypothesis.

ROA is selected as the main indicator of financial performance because it measures how efficiently a firm uses its assets to generate profits. This is particularly relevant in the context of environmental performance, since many environmental improvements, such as reducing energy use, emissions, or material waste, are directly linked to better use of resources. According to the NRBV, firms that are more efficient in using resources develop capabilities that can lead to competitive advantage (Hart, 1995; Russo and Fouts, 1997); therefore, if environmental performance improves resource efficiency, this could be reflected in a higher ROA.

ROE is included to capture profitability from the shareholders' perspective, measuring the return generated on equity capital. Compared to EBIT, which was initially considered, ROE is less sensitive to firm scale and therefore allows for more meaningful comparisons across firms of different sizes. This is particularly important in the steel industry, where companies in the sample vary significantly in terms of scale and production capacity. While EBIT can provide useful information on operating performance, it is strongly influenced by firm size, which may bias cross-sectional comparisons. For this reason, ROE is preferred, as it normalises profitability relative to equity and better reflects value creation for investors. In addition, ROE captures the combined effects of operational efficiency, financial structure, and investment decisions, making it a more comprehensive indicator of overall financial performance.

Leverage is included to capture firms' financial structure and risk profile, which is important because environmental performance can also affect financial outcomes indirectly, through its impact on risk. The literature suggests that firms with better ESG performance are perceived as less risky and may therefore benefit from better financing conditions (Zheng et al., 2025), an aspect that is particularly relevant in the European steel industry, where firms are exposed to increasing regulatory pressure, such as the EU Emissions Trading System and the Carbon Border Adjustment Mechanism, which affect both costs and risk levels (European Commission, 2021;

Regulation (EU) 2023/956). Including leverage therefore allows the analysis to capture this risk-related channel.

Finally, the CAPEX/Assets ratio is used to measure investment intensity relative to firm size. This indicator is important because environmental performance is not only the result of current efficiency, but also of past and ongoing investment decisions. As discussed in Chapters 1 and 2, improving environmental performance in the steel industry requires substantial investments in new technologies and production processes (Hart and Dowell, 2011; IEA, 2023); the CAPEX/Assets ratio therefore helps to capture the "strategic" dimension of environmental performance, linking it to firms' long-term investment behaviour.

Moving to environmental performance, the selection of indicators is based on a key methodological point highlighted in the literature: the importance of using intensity-based measures rather than absolute indicators. Absolute measures, such as total emissions or total energy consumption, are, indeed, strongly influenced by firm size, meaning that larger firms will almost always appear "worse", even if they are more efficient, which can lead to misleading conclusions and makes comparisons across firms difficult (Griffin and Mahon, 1997). In contrast, intensity-based indicators measure environmental impact relative to output, allowing for a more meaningful comparison of firms' efficiency.

This approach is directly linked to the concept of eco-efficiency, which focuses on how much environmental impact is generated per unit of economic activity and, from a theoretical perspective, is consistent with the NRBV, which argues that firms can gain competitive advantage by improving how efficiently they use resources (Hart, 1995; Christmann, 2000). If firms become more efficient, they will produce less pollution or use fewer resources per unit of output, and this is exactly what intensity-based indicators capture.

Similarly, the Porter Hypothesis suggests that environmental constraints push firms to identify inefficiencies and adopt better technologies, leading to improvements that are also reflected in lower environmental intensity (Porter and van der Linde, 1995).

Furthermore, the use of intensity-based indicators is particularly important in the steel industry, where firms differ significantly in size, production technologies, and business models (OECD, 2025; World Steel Association, 2025) and therefore, without

normalisation, it would be difficult to distinguish between structural differences and true performance differences.

Based on these considerations, this thesis adopts four environmental indicators, being emissions intensity, energy intensity, recycling rate, and water intensity, which in theory allow to capture different but most of the different dimensions of environmental performance.

Emission intensity is the most important indicator, as the steel industry is one of the most carbon-intensive sectors globally (IEA, 2023; World Steel Association, 2025). This indicator measures how much CO_2 is generated per unit of output and therefore captures firms' ability to reduce their carbon impact relative to production. It reflects both technological choices and operational efficiency, and is directly linked to the decarbonisation challenge discussed in Chapter 2. From a theoretical point of view, lower emissions intensity can suggest better capabilities in managing production processes and adopting cleaner technologies, in line with the NRBV (Hart, 1995), and may also result from regulatory pressure and innovation, as suggested by the Porter Hypothesis (Porter and van der Linde, 1995).

Energy intensity, instead, captures how efficiently firms use energy in their production processes. This is particularly relevant in the steel industry, where energy costs represent a large share of total costs: if a firm reduces its energy consumption per unit of output, it not only improves its environmental performance but also reduces costs, potentially improving profitability (IEA, 2023). This indicator therefore provides a direct link between environmental efficiency and financial performance, and reflects firms' capabilities in process optimisation (Christmann, 2000).

The recycling rate captures the circularity dimension of environmental performance, measuring the extent to which firms use recycled materials, such as scrap steel. This is especially important in the steel sector, where production based on recycled inputs (e.g., electric arc furnaces) is significantly less carbon- and energy-intensive than traditional production methods (World Steel Association, 2025). The recycling rate therefore reflects not only operational efficiency but also strategic choices related to production models. In this sense, it complements emissions and energy intensity by capturing structural differences across firms. It is also consistent with the NRBV, which emphasises resource productivity and waste reduction as sources of competitive advantage (Hart, 1995; Hart and Dowell, 2011).

Finally, water intensity measures how efficiently firms use water in their production processes. Although less central than emissions or energy, water use is still an important environmental dimension in heavy industries such as steel, where large amounts of water are required for cooling and processing. Improving water efficiency can reduce environmental impact and regulatory risks, and reflects firms' capabilities in managing resources effectively (IEA, 2023). Including this indicator therefore allows for a more comprehensive assessment of environmental performance.

It is important to recognise that not all environmental indicators used in this study are equally "*standard*" in the ESG–financial performance literature. Emissions intensity and energy intensity are widely used and well-established proxies of environmental performance, as they directly capture firms' efficiency in managing emissions and energy use. In contrast, the recycling rate is less commonly used in empirical studies, but it becomes particularly relevant in the context of the steel industry.

As discussed in Chapter 2, the sector is characterised by different production technologies, and the use of recycled materials (such as scrap steel) plays a key role in reducing both emissions and energy consumption. For this reason, the inclusion of the recycling rate reflects a deliberate choice to adopt a more sector-specific approach to environmental performance measurement. Rather than relying only on standard indicators, this choice recognises that the relevance of ESG variables may depend on industry characteristics: in the steel sector, in this case, circularity and production models are central to understanding environmental performance, and the recycling rate provides useful additional information that cannot be captured by emissions and energy intensity alone; therefore, its inclusion is consistent with a contextualised approach to ESG measurement, which aims to better capture meaningful differences across firms within the same industry.

The selected indicators are reported in Table 2 "*Selected indicators*" below.

Table 2 - Selected indicators

Selected financial performance indicators	Selected environmental performance indicators
ROA	Emission intensity (t/t)
ROE	Energy intensity (GJ/t)
Leverage	Recycling rate (%)
CAPEX/Assets	Water intensity (m3/t)

Source: originally produced

3.1.3. Methodology: structure of the empirical analysis

The empirical analysis will be composed of three sequential stages: a preliminary descriptive analysis, a correlation analysis and, finally, a regression analysis, collectively allowing for a progressively more rigorous investigation of the relationship between environmental and financial performance in the steel industry.

The rationale behind this three-step structure lies in the need to move from an initial exploratory understanding of the data to a more structured and inferential assessment of relationships between variables, in order to ensure both robustness and transparency of results as much as possible. This approach is consistent with the empirical literature discussed in the first two chapters, which emphasises that the ESG–financial performance relationship is complex, potentially non-linear, and sensitive to methodological choices.

The first stage consists of a preliminary descriptive analysis, aimed at providing an initial overview of the dataset, which includes the computation of average values of the selected indicators both by year and by firm, with an additional disclosure of the overall percentage changes over the period, as presented in Tables 1, 2 and 3 of the following section. This step has two main further objectives: first, it allows to identify general trends over time, such as improvements in environmental efficiency or variations in financial performance, linked for example to macroeconomic conditions such as the 2020 downturn and the post-pandemic recovery; and second, it enables a comparison across firms, highlighting structural differences related to production models (BF–BOF, EAF, HYBRID).

In particular, this step is essential for contextualising the data and for identifying potential patterns, such as lower emission intensity in EAF-based firms, that can later

be tested rigorously. The second stage involves correlation analysis, which represents the first attempt to formally assess potential relationships between variables.

This analysis is conducted along two dimensions: on the one hand, correlations among financial indicators (ROA, ROE, leverage and CAPEX/Assets) are examined to make sure the financial data is consistent and to avoid overlapping variables. On the other hand, correlations between environmental and financial indicators are analysed to provide an initial indication of whether environmental performance is associated with financial outcomes.

From a methodological perspective, correlation analysis is useful as an exploratory tool since it allows identifying linear associations without imposing strong assumptions about causality. However, as acknowledged in the literature (Ullmann, 1985; Griffin and Mahon, 1997), correlation does not imply causality and may be affected by omitted variables, reverse causality, or confounding factors. For this reason, the results of this stage are interpreted with caution and mainly used to guide the subsequent regression analysis.

The third and final stage consists of the regression analysis, which provides a more rigorous and inferential framework for examining the relationship between environmental and financial performance. In this study, regression models are estimated using two selected financial indicators, ROA e CAPEX/Assets**,** as dependent variables, and the environmental indicator of emission intensity as the independent variable.

The rationale for employing regression analysis is based on its ability to isolate the marginal effect of environmental performance on financial outcomes, holding all the other variables constant, which is particularly important in the context of the steel industry where firms differ significantly in size, production technology, and strategic orientation. By moving beyond simple correlations, regression analysis may allow for a more precise assessment of whether environmentally efficient firms tend to exhibit better financial performance, in line with the theoretical mechanisms discussed in the first chapter, including the Natural-Resource-Based View and the Porter Hypothesis.

At the same time, it is important to acknowledge the limitations of this methodology: in the first place, with the relatively small sample size and the high heterogeneity across firms, the regression results should be interpreted as indicative rather than definitive. Moreover, issues such as endogeneity, reverse causality (for example more profitable firms being able to invest more in environmental

improvements), and measurement errors in ESG-related data may affect the robustness of the findings. While these limitations cannot be fully addressed within the scope of this analysis, the structured approach adopted, of moving from descriptive statistics to correlation and then to regression, has the goal to help mitigate some of these concerns by providing multiple layers of evidence.

Overall, the chosen methodology is consistent with the objectives of this study and with the empirical strategies commonly used in the ESG–financial performance literature and, by combining exploratory and inferential techniques, it allows for a relatively comprehensive analysis of the data, maintaining simplicity but also analytical rigor in order to provide a basis as solid as possible for the interpretation of results presented in the following sections.

3.1.4. Preliminary analysis

As introduced in the previous section, a preliminary step of the empirical analysis includes the evaluation of the average value for each indicator selected before, both by year and by firm, as summarised in the following tables, in order to gain an initial understanding of the relationship between financial and environmental performance by identifying general trends and highlighting structural differences within the sample before moving to more formal statistical techniques like correlation and regression analyses.

Table 3 - Average indicators by year

Year	Average recycling rate (%)	Average emission intensity (t/t)	Average water intensity (m3/t)	Average energy intensity (GJ/t)	ROA	ROE	Leverage	CAPEX/Assets
2017	48,500	1,473	3,241	13.319,210	0,050	0,110	0,200	0,050
2018	48,900	1,454	3,176	13.377,110	0,050	0,110	0,190	0,050
2019	49,500	1,458	3,222	13.531,130	0,030	0,060	0,190	0,050
2020	50,200	1,446	3,297	13.996,960	-0,010	-0,090	0,200	0,050
2021	51,100	1,403	3,200	13.459,180	0,090	0,170	0,160	0,050
2022	51,900	1,385	3,143	13.373,900	0,120	0,220	0,140	0,050
2023	52,720	1,330	3,155	13.225,820	0,050	0,090	0,130	0,060
2024	53,450	1,253	3,010	12.786,860	0,040	0,070	0,120	0,060
Total average	**50,784**	**1,400**	**3,180**	**13.383,771**	**0,053**	**0,093**	**0,166**	**0,053**
Total % change	**10,206**	**-14,894**	**-7,105**	**-3,997**	**-20,000**	**-36,364**	**-40,000**	**20,000**

Source: originally produced

Starting from Table 3 “*Average indicators by year*”, which reports the average values of all indicators by year, a number of relevant patterns emerge. First of all, environmental performance appears to improve over time across the sample. In particular, the average recycling rate increases steadily from 48.5% in 2017 to 53.45% in 2024, suggesting a gradual shift towards more circular production models.

At the same time, both emission intensity and water intensity show a declining trend, with total reductions of approximately -14.9% and -7.1%, respectively, suggesting an overall improvement in environmental efficiency.

A similar, although less pronounced and more volatile, pattern can be observed for energy intensity, which decreases by about 4% over the period, showing a rising trend until 2021 and a declining one from 2022 onwards.

These trends appear to suggest that environmental improvements are driven by a combination of factors, including efficiency gains, changes in input mix (such as a higher use of recycled materials) and gradual technological adjustments.

Moreover, the gradual reduction in environmental intensity seems to be consistent with the Natural-Resource-Based View (NRBV), according to which firms can develop competitive advantages by improving resource efficiency and reducing environmental impacts.

At the same time, the observed improvements could also reflect the mechanisms described by the Porter Hypothesis, stating that increasing regulatory pressure and environmental constraints stimulate firms to innovate and adopt more efficient production processes.

From a financial perspective, the evolution is instead more volatile and less clear. The two profitability indicators previously selected, ROA and ROE, show a clear downturn in 2020, where both become negative on average, reflecting the impact of the COVID-19 shock on industrial activity. This is followed by a strong improvement in 2021 and 2022, and then a partial stabilisation in the following years. Despite this recovery, the overall change over the entire period is negative (-20% for ROA and -36.36% for ROE), suggesting that, on average, firms experienced a deterioration in profitability compared to 2017.

At the same time, leverage decreases significantly (-40%), which may indicate that firms are probably paying down their debts, or becoming more financially responsible and tightening their budget, while the CAPEX/Assets ratio slightly increases (+20%), suggesting that firms have continued to invest in fixed assets. This

investment dynamic is particularly relevant when interpreted through the NRBV lens, as it may signal the accumulation of capabilities related to cleaner technologies and more efficient resource uses, with firms investing to adapt their production processes and improve efficiency, even if these investments - involving high upfront costs - do not immediately translate into higher profitability. In line with the Porter Hypothesis, these investments may reflect the need to comply with environmental constraints imposed by regulators and upgrade technologies, with benefits that, as previously said, are likely to materialise only in the medium to long term.

One key stylised fact can be retrieved by Table 3, being that environmental performance tends to improve steadily over time, while financial performance is more cyclical and influenced by macroeconomic shocks; a difference which already suggests that the relationship between environmental and financial performance is unlikely to be linear and straightforward and may involve time lags, as also suggested by the previously analysed literature.

Table 4 - Average indicators by firm

Firm	Average recycling rate (%)	Average emission intensity (t/t)	Average water intensity (m3/t)	Average energy intensity (GJ/t)	Production technology	ROA	ROE	Leverage	CAPEX/Assets
Feralpi	97,638	0,322	1,519	2.207,700	EAF	0,060	0,110	0,260	0,040
Outokumpu	89,700	1,479	4,786	9.089,800	EAF	0,030	0,070	0,180	0,040
Boliden	35,500	1,973	3,552	16.831,290	EAF-like (recycling based)	0,090	0,160	0,110	0,070
ArcelorMittal	32,875	2,019	2,846	7.659,540	HYBRID	0,060	0,100	0,080	0,040
Voestalpine	29,500	1,658	1,974	30.864,850	HYBRID	0,060	0,120	0,250	0,080
SSAB	24,000	1,619	2,661	13.875,360	HYBRID	0,080	0,150	0,120	0,050
Aperam	86,250	0,329	4,950	10.645,720	HYBRID	0,070	0,120	0,120	0,040
Salzgitter	36,875	1,896	2,822	15.831,340	BF-BOF	0,040	0,070	0,140	0,060
Thyssenkrupp	32,000	1,934	2,606	16.915,440	BF-BOF	-0,010	-0,070	0,210	0,050
Tata Steel	43,500	0,772	4,090	9.916,670	BF-BOF	0,050	0,110	0,200	0,050
Total average	**50,784**	**1,400**	**3,180**	**13.383,771**	**-**	**0,053**	**0,094**	**0,167**	**0,052**

Source: originally produced

Moving to Table 4 "*Average indicators by firm*", which reports the average values of indicators by firm, the analysis shifts from a temporal to a cross-sectional perspective, allowing to highlight potential heterogeneity within the sample.

The most evident pattern concerns environmental indicators, which vary significantly across firms and appear to be strongly linked to production technologies. EAF-based firms, such as Feralpi and Outokumpu, exhibit substantially higher

recycling rates (above 85% and close to 100% for Feralpi) and significantly lower emission intensity compared to the rest of the sample, reflecting the structural advantage of scrap-based production, which is inherently less carbon and energy intensive.

BF–BOF producers, such as Salzgitter, Thyssenkrupp and Tata Steel, show higher emission intensity (around 1.9–2.0 t/t in some cases) and lower recycling rates in comparison, which is consistent with their reliance on primary raw materials and integrated production processes.

Hybrid firms instead occupy an intermediate position, with values that vary considerably in terms of environmental indicators: for example, while Aperam has a high recycling rate (86.25%) and low emissions (0.33 t/t), others like ArcelorMittal have much higher emission intensities (2.02 t/t) and lower recycling rates (32.88%), a variability that may reflect a combination of traditional and more circular production models, although with some dispersion depending on their specific production mix.

This cross-sectional evidence seems to provide a concrete illustration of the NRBV argument, with firms adopting production models that are more resource-efficient (such as EAF-based production) tending to exhibit structurally better environmental performance.

Energy intensity shows even higher variability across firms (for example, from about 2,200 GJ/t for Feralpi to over 30,000 GJ/t for Voestalpine), suggesting that this indicator is influenced not only by production technology but also by firm-specific factors, such as product mix, level of vertical integration and operational structure and therefore that it should be interpreted with more caution compared to emission intensity.

From a Porter Hypothesis perspective, this heterogeneity may reflect different stages of technological adaptation, with some firms already benefiting from efficiency gains associated with innovation, while others are still constrained by historical systems.

From a financial perspective, heterogeneity is also present but less clearly associated with production models. While some firms such as Boliden and SSAB show relatively higher profitability (ROA and ROE), others, such as Thyssenkrupp, exhibit negative average profitability over the period.

It is also interesting to look at financial performance relative to the three different production models. Hybrid firms, notably, seem to show the strongest financial results:

SSAB and Aperam lead the group in profitability (ROE between 0.12 and 0.15), ArcelorMittal stands out for having the lowest leverage (0.08) in the entire sample, while Voestalpine shows the highest investment propensity (CAPEX/Assets).

EAF-based firms appear to be characterized by stable returns in terms of ROA/ROE but slightly lower than the average of hybrid producers, while BF-BOF adopting firms show mixed evidence, even though Thyssenkrupp is the only firm with negative profitability indicators (ROA -0.01). Leverage is generally higher here, indicating a greater reliance on debt.

In general, these dispersed results are probably suggesting that financial performance is influenced by a broader set of factors beyond environmental efficiency and production technology, including market positioning, cost structure and strategic choices.

The interpretation of hybrid firms' environmental performance can be refined by also considering the %EAF indicator reported in Table 1, which provides a proxy of the extent to which production relies on scrap-based technologies. Hybrid firms are, indeed, not homogeneous, and their environmental indicators reflect this internal heterogeneity, with firms with a higher share of EAF production generally displaying lower emission intensity and higher recycling rates, aligning more closely with the performance of pure EAF firms. In contrast, hybrid firms with a lower %EAF tend to retain characteristics more similar to BF–BOF producers, including higher emission intensity and lower levels of circularity. This distinction helps explain why, in Table 4, hybrid firms do not cluster around a single pattern but instead exhibit significant dispersion in environmental indicators.

In general, Table 4 confirms that the sample is highly heterogeneous, particularly in terms of environmental performance, and that probably this heterogeneity is largely driven by structural differences in production technologies, as anticipated in Section 3.1.1. These data also seem to suggest that a high recycling rate translates directly into a lower environmental impact, specifically regarding emissions and energy intensity; that the hybrid model appears to be the most financially balanced, managing to maintain good profitability and low debt despite having higher resource intensity than EAF firms; and that companies using traditional blast furnaces (BF) might be facing the greatest challenges, with profitability under pressure and the need to manage a costly technological transition to reduce emissions. Obviously, these

interpretations are not statistically robust, therefore further justifications will be looked for in the following sections.

Table 5 - 2017-2024 indicators' % change by firm

Firm	Recycling rate	Emission intensity	Water intensity	Energy intensity	ROA	ROE	Leverage	CAPEX/Assets
Feralpi	1,546	-9,622	-30,051	-12,000	141,935	90,476	-27,536	9,756
Outokumpu	11,765	-34,975	-10,345	-14,589	-50,000	-61,538	-40,566	42,857
Boliden	21,875	-5,556	-1,411	0,718	2,410	-10,274	-40,909	26,230
ArcelorMittal	16,129	-17,400	14,144	7,284	-27,273	-46,789	-78,846	14,286
Voestalpine	10,714	-10,096	-4,920	-2,200	-44,737	-51,007	-23,297	17,105
SSAB	22,727	-19,884	-16,903	-15,056	-35,135	-46,939	-50,993	43,182
Aperam	3,529	-17,795	-5,609	0,130	-18,750	-30,328	-44,521	43,333
Salzgitter	11,429	-16,667	-16,667	-6,313	-32,143	-42,373	-37,888	40,000
Thyssenkrupp	13,333	-6,957	-1,613	1,304	-92,593	-91,209	-15,349	-5,660
Tata Steel	17,500	-2,222	-4,000	-6,667	-39,024	-48,544	-40,161	30,435
Average % change	**13,055**	**-14,117**	**-7,737**	**-4,739**	**-19,531**	**-33,852**	**-40,007**	**26,152**

Source: originally produced

Finally, Table 5 "*2017-2024 indicators' % change by firm*" reports the percentage variation of each indicator over the period 2017–2024 for each firm, allowing to analyse the dynamic evolution of performance and to complement the more static picture provided by Table 4.

First, most firms show a reduction in emission intensity over time, confirming the general trend observed at the aggregate level. However, the magnitude of this improvement varies significantly: for example, Outokumpu exhibits a particularly strong reduction (-34.98%), while Thyssenkrupp shows a much more limited decrease (-6.96%). This suggests that firms differ not only in their environmental performance levels, but also in their capacity to improve over time, which may depend on their initial technological configuration and investment strategies.

Second, recycling rates tend to increase for almost all firms, although again with different magnitudes, reinforcing the idea of a gradual shift towards more circular production models across the industry, although with different intensities. This dynamic is consistent with both the NRBV, through the progressive improvement of resource efficiency, and the Porter Hypothesis, as firms respond to regulatory and market pressures by incrementally adapting their production processes.

From a financial perspective, the picture is more mixed. Most firms experience a decline in profitability indicators (ROA and ROE), in line with the aggregate trend

observed in Table 1, although the extent of this decline varies considerably. Notably, Feralpi represents an exception, showing a strong improvement in both ROA and ROE, which may reflect the combined effect of a more efficient production model and firm-specific strategic choices.

At the same time, leverage decreases for most firms, suggesting a general trend towards lower financial risk, while the CAPEX/Assets ratio increases in almost all cases, confirming that firms are actively investing. In line with the Porter Hypothesis, these investments may represent a necessary step to comply with environmental regulation and to improve efficiency, even if their financial benefits materialise only in the longer term.

Taken together, Tables 4 and 5 highlight an important point for the subsequent analysis: while environmental performance improvements are relatively consistent across firms, financial performance shows a much higher degree of variability, and the relationship between the two dimensions is not immediately evident.

It should also be noted that these descriptive patterns do not control for firm-specific characteristics or external factors, and therefore should be interpreted with caution. For this reason, the preliminary analysis alone is not sufficient to draw conclusions about the environmental–financial performance relationship and, a more formal statistical assessment is therefore required and it will be developed in the following section through correlation analysis and, subsequently, regression analysis.

3.2. Correlation analysis

3.2.1. Description and motivation

Following the preliminary descriptive analysis, the second step of the empirical investigation consists in performing a correlation analysis. The objective of this stage is to provide an initial, formal assessment of the relationships between the selected variables, focusing both on the internal consistency of financial indicators and on the potential associations between environmental and financial performance.

More specifically, the correlation analysis is conducted along two main dimensions. First, it examines the relationships among financial variables (ROA, ROE, leverage and CAPEX/Assets), in order to verify whether they capture distinct aspects of firm performance or, alternatively, whether they are highly overlapping. This step is

important from a methodological perspective, as strong correlations among independent variables may signal potential multicollinearity issues in the subsequent regression analysis.

Second, and more importantly, the analysis explores the correlations between environmental indicators (recycling rate, emission intensity, water intensity and energy intensity) and financial performance measures, allowing for a first evaluation of whether firms with better environmental performance, measured in terms of efficiency and circularity, also tend to exhibit superior financial outcomes.

From a theoretical point of view, this step is directly connected to the frameworks discussed in the first chapter. In fact, according to the Natural-Resource-Based View (NRBV), firms that develop capabilities in resource efficiency and environmental management may achieve competitive advantages, which could translate into better financial performance. Similarly, the Porter Hypothesis suggests that environmental constraints may stimulate innovation and efficiency improvements, potentially leading to positive economic outcomes.

At the same time, the empirical literature emphasises that the relationship between environmental and financial performance is often weak, heterogeneous and sensitive to measurement choices (Ullmann, 1985; Griffin and Mahon, 1997) and, for this reason, correlation analysis should be interpreted as an exploratory tool rather than as evidence of causality. In particular, correlations do not allow to control for confounding factors, and neither address issues such as reverse causality or omitted variables, which are especially relevant in this context. Therefore, the results presented in the following section will be interpreted with caution as they provide useful indications on the direction and strength of linear associations between variables, but they do not imply the existence of causal relationships. Their main role is, indeed, to guide the subsequent regression analysis and to highlight potential patterns worth investigating in more detail.

3.2.2. Correlation analysis results and interpretation

Table 6 - Correlation analysis and significance level

Pearson correlation coefficient (r)	Average recycling rate	Average emission intensity	Average water intensity	Average energy intensity	ROA	ROE	Leverage	CAPEX/Assets
Average recycling rate	1,000	-0,749**	0,330	-0,609*	-0,019	0,052	0,280	-0,591*
Average emission intensity	-0,749**	1,000	-0,210	0,494	-0,190	-0,246	-0,361	0,457
Average water intensity	0,330	-0,210	1,000	-0,220	0,029	0,091	-0,423	-0,321
Average energy intensity	-0,609	0,494	-0,220	1,000	-0,024	-0,037	0,171	0,886***
ROA	-0,019	-0,190	0,029	-0,024	1,000	0,967***	-0,399	0,208
ROE	0,052	-0,246	0,091	-0,037	0,967***	1,000	-0,297	0,200
Leverage	0,280	-0,361	-0,423	0,171	-0,399	-0,297	1,000	0,174
CAPEX/Assets	-0,591*	0,457	-0,321	0,886***	0,208	0,200	0,174	1,000

Source: originally produced

The results of the correlation analysis are reported in the Table 6 - "*Correlation analysis and significance level*" above: overall, the matrix reveals a number of interesting patterns, although most of the relationships appear to be relatively weak, especially between environmental and financial variables.

Starting from financial indicators (blue area of Table 6), a very strong positive correlation emerges between ROA and ROE (0.97), which is expected, as both variables capture firm profitability from closely related perspectives. This confirms the internal consistency of the dataset, while at the same time suggesting that the two variables convey largely overlapping information.

In contrast, leverage shows a moderate negative correlation with profitability (−0.40 with ROA and −0.30 with ROE). Even though this may suggest that more leveraged firms tend to exhibit lower returns, which is consistent with higher financial risk, this relationship should be interpreted with caution; indeed, since the analysis is based on accounting data, the relationship between leverage and profitability is not necessarily straightforward: according to the financial leverage effect, higher indebtedness may increase ROE when the return on assets exceeds the cost of debt; therefore, the observed negative correlation may reflect specific conditions within the sample, such as periods of lower profitability or higher financial costs, rather than a general causal relationship between leverage and firm performance.

The CAPEX/Assets ratio shows only weak positive correlations with profitability, suggesting that investment intensity is not immediately associated with higher returns in the short term.

Turning to environmental indicators (green area of Table 6), some strong relationships emerge among them. In particular, the recycling rate is strongly negatively correlated with emission intensity (−0.75) and moderately negatively correlated with energy intensity (−0.61). This result is fully consistent with the technological characteristics of the steel industry: firms that rely more on recycled inputs (typically EAF-based producers) tend to generate lower emissions and use less energy per unit of output. In this sense, the correlation matrix provides further empirical support to the structural differences related to production models highlighted in the previous section.

At the same time, emission intensity is positively correlated with energy intensity (0.49), suggesting that more energy-intensive production processes are also more carbon-intensive, which is coherent with the nature of integrated BF–BOF production. Water intensity, instead, shows weaker and less systematic relationships with the other environmental indicators, indicating that water use may be driven by more firm-specific or process-specific factors.

When focusing on the relationship between environmental and financial performance (orange area of Table 6), the results appear more ambiguous. Most correlations between environmental indicators and profitability measures (ROA and ROE) are weak and close to zero. For instance, the recycling rate shows almost no correlation with ROA (−0.02) and a very small positive correlation with ROE (0.05), while emission intensity is weakly negatively correlated with both profitability indicators (−0.19 with ROA and −0.25 with ROE).

These results suggest that, at least at a descriptive level, there is no strong linear relationship between environmental efficiency and financial performance within the sample. While the negative sign of emission intensity is broadly consistent with the idea that more efficient firms may perform better financially (as suggested by the NRBV), the magnitude of the correlation is too small to support any strong conclusion.

A slightly more pronounced relationship emerges between environmental indicators and CAPEX/Assets. In particular, energy intensity is very strongly positively correlated with CAPEX/Assets (0.89), and emission intensity also shows a moderate positive correlation (0.46). This may suggest that firms with more energy and emission intensive production processes are also those investing more heavily in fixed assets, possibly reflecting ongoing efforts to upgrade technologies and reduce environmental

impact. This interpretation is consistent with the Porter Hypothesis, which emphasises the role of investment and innovation in response to environmental constraints.

Finally, it can be noted that leverage is negatively correlated with emission intensity (−0.36) and water intensity (−0.42), although these relationships are only moderate, which might indicate that firms with higher environmental impact could be also exposed to different financial structures or risk profiles.

Overall, the correlation analysis provides three main insights. First, environmental indicators are strongly interrelated and reflect underlying production technologies. Second, financial indicators are internally consistent but capture different dimensions of performance. Third, and most importantly, the relationship between environmental and financial performance appears weak and not statistically meaningful at this stage, suggesting that environmental performance alone is not a strong predictor of financial outcomes within the sample.

In addition, it is important to complement the analysis by considering the statistical significance of the estimated correlations, as reported in Table 6 through the use of significance levels. The significance of each correlation coefficient is, in fact, assessed through a t-test, which evaluates whether the observed correlation is statistically different from zero; more specifically, the test is based on the transformation of the Pearson correlation coefficient into a t-statistic, which depends on both the magnitude of the correlation and the sample size. The resulting p-values are then used to determine significance levels, conventionally indicated by asterisks (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$).

From an interpretative perspective, statistical significance indicates the likelihood that the observed relationship is not due to random variation in the data. Therefore, only correlations that are statistically significant can be considered as providing meaningful evidence of an underlying association between variables, while non-significant correlations should be interpreted as irrelevant, as they may simply reflect noise rather than a systematic relationship.

In this case, only a limited number of correlations are statistically significant; in particular, the strong negative relationship between recycling rate and emission intensity, as well as the strong positive relationship between energy intensity and CAPEX/Assets, are statistically significant, reinforcing the interpretation that these relationships reflect structural characteristics of the industry.

On the contrary, most correlations between environmental and financial variables are not statistically significant, further supporting the idea that the relationship between environmental and financial performance is weak and not robust at this stage of the analysis.

For these reasons, correlation analysis alone is not sufficient to draw conclusions about the existence and direction of this relationship. A more structured approach is therefore required and will be developed in the next section, using regression analysis to examine the relationship between environmental and financial performance while controlling for multiple variables simultaneously, providing a more robust framework for the empirical investigation.

3.3. Regression analysis

3.3.1. Description and motivation

Based on the results and considerations from the preliminary and correlation analyses performed in the previous sections of this chapter, the final step of the empirical research consists in performing a regression analysis. The objective, at this stage, is to move from simple descriptive analysis and simple one-to-one correlations to a more structured assessment of the relationship between environmental and financial performance by isolating the marginal effect of environmental variables on financial outcomes, while holding other factors constant.

With regard to financial performance, the regression analysis focuses primarily on two dependent variables: ROA and the CAPEX/Assets ratio. ROA is selected as the main indicator of profitability, as it captures how efficiently firms use their assets to generate earnings. This feature makes it particularly suitable for testing the core mechanism suggested by the NRBV, according to which improvements in environmental performance reflect more efficient use of resources and may therefore translate into better financial outcomes. In addition, ROA is less affected by firm size compared to absolute measures and could allow for meaningful comparisons across companies operating under different production models.

The CAPEX/Assets ratio is included as a second dependent variable in order to capture the investment dimension of the environmental–financial performance relationship. As discussed in Chapter 2, improving environmental performance in the

steel industry requires substantial investments in new technologies and production processes. Therefore, analysing CAPEX intensity allows to explore whether firms with different environmental characteristics also differ in their investment behaviour, which is particularly relevant also in light of the Porter Hypothesis, according which environmental constraints and regulatory pressure may stimulate firms to invest in innovation and efficiency improvements, even if the financial benefits of such investments materialise only in the medium to long term.

Although ROE was initially considered as an additional measure of profitability, it is not used as a primary dependent variable in the main regression models. The correlation analysis has shown a very strong positive relationship between ROA and ROE, suggesting that the two indicators capture largely overlapping information. For this reason, including both variables in the core specification would probably not significantly increase the explanatory power of the model, while potentially introducing redundancy.

Similarly, leverage is not treated as a main dependent variable, but it may be included as a control variable in the regression models. This choice reflects the fact that leverage captures firms' financial structure and risk profile, which may influence financial performance independently of environmental efficiency. Including leverage as a control variable therefore helps to partially account for differences in risk exposure across firms, without shifting the focus of the analysis away from the core relationship of interest.

In terms of environmental performance, the regression analysis is centred on emission intensity as the main independent variable. From a theoretical point of view, emission intensity directly reflects firms' ability to reduce environmental impact per unit of output, which is consistent with the concept of eco-efficiency of the NRBV while, from an industry perspective, the steel sector is characterised by high carbon emissions, and decarbonisation represents the main environmental challenge faced by firms, therefore, emission intensity might constitute the most relevant and informative proxy of environmental performance within this context. In addition to emission intensity, the recycling rate will be used as an alternative environmental variable in the regression analysis. Indeed, even though less commonly employed in the ESG–financial performance literature, this indicator is particularly meaningful in the steel industry, as it captures the degree of circularity and the reliance on scrap-based production processes.

As highlighted in the preliminary analysis, recycling rate is closely linked to production technologies, with EAF-based firms exhibiting significantly higher values compared to BF–BOF producers. Including this variable therefore allows to account for structural differences in business models and to provide a more sector-specific perspective on environmental performance.

The remaining environmental indicators, energy intensity and water intensity, are not included in the baseline regression models, but are instead used in alternative specifications and robustness checks. While energy intensity is theoretically relevant, as it reflects both environmental efficiency and cost-related aspects, the preliminary analysis has shown a high degree of variability across firms and a strong correlation with investment intensity, which may complicate the interpretation of results.

Water intensity, on the other hand, appears to be less related to both environmental and financial variables, and is therefore could be considered less central for the purpose of this analysis.

From a practical perspective, the analysis is implemented through the Gretl software, using panel data techniques on a dataset composed of 10 firms observed over the period 2017–2024, and the models are estimated using fixed effects specifications.

The regression analysis is performed using fixed-effects panel models with clustered standard errors at firm level. The fixed-effects specification is selected in order to control for unobserved time-invariant firm-specific characteristics that may influence both environmental and financial performance, such as production technology, organisational structure, managerial practices and long-term strategic orientation. This approach appears particularly suitable in the context of the steel industry, where firms differ significantly in terms of production models, environmental exposure and technological configuration. Fixed-effects models are preferred over random-effects specifications because the analysis focuses on a relatively small and specific sample of firms characterised by significant structural heterogeneity. Moreover, it is reasonable to assume that firm-specific unobserved characteristics may be correlated with the explanatory variables, making the fixed-effects approach more appropriate.

In addition to firm fixed effects, the models also include year fixed effects through the inclusion of time dummies. The introduction of time effects is particularly important considering the strong exposure of the steel industry to common

macroeconomic, regulatory and energy-related shocks during the observed period. In particular, year dummies help control for external factors simultaneously affecting all firms in the sample, including fluctuations in energy prices, inflationary pressures, post-pandemic recovery dynamics, changes in European environmental regulation and broader steel market conditions. The strong statistical significance of time effects across most models further confirms the relevance of common temporal dynamics within the analysed period.

Furthermore, environmental variables are included in lagged form (t−1) in order to partially address simultaneity concerns and better capture the delayed effect that environmental performance may exert on financial outcomes. Environmental investments and efficiency improvements often require time before producing measurable economic effects and, for this reason, the use of lagged variables appears more consistent with the theoretical and empirical ESG literature discussed in Chapters 1 and 2. This specification also helps reduce potential reverse-causality concerns, since stronger contemporaneous financial performance could itself facilitate environmental investments and sustainability improvements.

Clustered standard errors at firm level are used in all specifications in order to account for potential heteroskedasticity and serial correlation within firms over time.

The empirical strategy is structured in three main steps. First, a set of baseline models is estimated using emission intensity as the main explanatory variable, with ROA and CAPEX/Assets as dependent variables; these models represent the core of the analysis and are designed to test the main research question. Second, alternative models are estimated by replacing emission intensity with the recycling rate, allowing to explore whether a different dimension of environmental performance, more closely related to production technology and circularity, provides additional explanatory power and, finally, a series of robustness checks is conducted by using the remaining environmental indicators, which are energy intensity and water intensity. These models are not central to the analysis but serve to verify whether the main results remain consistent when alternative measures of environmental performance are considered.

In summary, the way in which the regression analysis is designed is made to test whether environmental performance, measured primarily through emission intensity, is associated with financial outcomes, captured by ROA, and with firms' investment behaviour, approximated by the CAPEX/Assets ratio, with recycling rate and additional environmental indicators being employed to verify the robustness of the

results and to explore the role of sector-specific characteristics. This approach could allow to also take into account the limitations of the dataset, such as the small sample size, the heterogeneity across firms and the potential presence of endogeneity issues but, still, for these reasons, the results of the regression analysis have to be interpreted with caution and are primarily intended to provide only indicative evidence on the relationship between environmental and financial performance in the European steel industry.

3.3.2. Results

This section presents the results obtained from the regression analysis, which are summarised in the following figures, focusing on baseline models (*Tables 7 and 8*) and alternative specifications (*Tables 9 and 10*), while the results of robustness checks (*Tables 1, 2, 3 and 4 in the Appendix*), even though briefly exposed, can be found in the Appendix.

Table 7. Model 1a – Baseline
(ROA)

Model equation:
$ROA_{it} = \alpha + \beta_1\ Emission\ intensity_{i,t-1} + \beta_2\ Leverage_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

Variables	Coef.	Std. Err.	t-stat	p-value
Emission intensity	0.061	0.044	1.384	0.1996
Leverage	−0.707***	0.213	−3.316	0.0090
Constant	0.047	0.034	1.395	0.1964
Model information				
Estimation method	Fixed effects			
Firm fixed effects	Included			
Year fixed effects	Included			
Clustered robust SE	Included			
Observations	70			
Number of firms	10			
R^2 (LSDV)	0.866			
Within R^2	0.806			
F-statistic	11.215			
Prob > F	0.0036			
Durbin-Watson	2.125			

Joint test on regressors: F(2, 9) = 11.2149; p-value = 0.00359793
Robust test for group intercepts: Welch F(9, 23.6) = 14.3026; p-value = 1.42694e-07
Wald test on time dummies: $\chi^2(6) = 116.371$; p-value = 9.41673e-23

*Notes: Clustered robust standard errors (SE) are used. Firm and year fixed effects are included. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

Table 8. Model 1b – Alternative
(ROA)

Model equation:
$ROA_{it} = \alpha + \beta_1\ Recycling\ rate_{i,t-1} + \beta_2\ Leverage_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

Variables	Coef.	Std. Err.	t-stat	p-value
Recycling rate	−0.005*	0.002	−2.126	0.0624
Leverage	−0.729***	0.153	−4.752	0.0010
Constant	0.395**	0.136	2.916	0.0171
Model information				
Estimation method	Fixed effects			
Firm fixed effects	Included			
Year fixed effects	Included			
Clustered robust SE	Included			
Observations	70			
Number of firms	10			
R^2 (LSDV)	0.868			
Within R^2	0.809			
F-statistic	130.674			
Prob > F	2.146e-08			
Durbin-Watson	2.167			

Joint test on regressors: F(8, 9) = 130.674; p-value = 2.14603e-08
Robust test for group intercepts: Welch F(9, 23.6) = 12.5151; p-value = 4.95757e-07

*Notes: Clustered robust standard errors (SE) are used. Firm and year fixed effects are included. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

Source: AI-generated table (produced using original data)

Starting from ROA-based models, Table 7 reports the results of the first baseline model, which analyses the relationship between lagged emission intensity and profitability using ROA as the dependent variable. The coefficient associated with emission intensity is positive but not statistically significant, indicating that past

emission intensity does not appear to have a robust effect on profitability within the sample. By contrast, leverage remains negative and statistically significant at the 1% level, confirming that firms characterized by higher indebtedness tend to report lower profitability levels.

The explanatory power of the model is relatively high. In particular, the LSDV R^2 is equal to 0.866, meaning that approximately 87% of the overall variation in ROA is explained by the model. Similarly, the within R^2 reaches 0.806, indicating a strong ability of the specification to explain profitability changes occurring within firms over time. The F-statistic equal to 11.215 and the associated p-value further confirm the overall significance of the model. The Durbin-Watson statistic is equal to 2.125, a value very close to 2, suggesting that residual autocorrelation is not a major concern. Overall, the model appears statistically robust in terms of overall fit, although emission intensity itself does not display a statistically significant relationship with ROA.

Table 8 reports the results of the first alternative specification, which replaces lagged emission intensity with lagged recycling rate while maintaining ROA as the dependent variable. In this case, the coefficient associated with recycling rate is negative and statistically significant at the 10% level. This suggests that firms characterized by higher past recycling rates tend to report slightly lower profitability levels during the sample period, although the statistical significance remains relatively weak compared to conventional 5% or 1% thresholds. The coefficient associated with leverage once again remains negative and highly significant, confirming the robustness of the negative relationship between indebtedness and profitability across specifications.

The explanatory power of this model is also very high. The LSDV R^2 is equal to 0.868, while the within R^2 reaches 0.809, indicating that the model explains around 87% of the overall variation in ROA and more than 80% of the variation occurring within firms over time. The F-statistic equal to 130.674 and the extremely low p-value confirm the strong overall significance of the specification. The Durbin-Watson statistic is equal to 2.167, again suggesting the absence of severe autocorrelation problems. Overall, the model appears statistically solid, combining high explanatory power with strong overall significance, while the recycling rate variable shows a weak but statistically detectable relationship with profitability.

Table 9. Model 2a – Baseline
(CAPEX/Assets)

Model equation:

$$CAPEX/Assets_{it} = \alpha + \beta_1\, Emission\ intensity_{i,t-1} + \beta_2\, Leverage_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Variables	Coef.	Std. Err.	t-stat	p-value
Emission intensity	−0.016	0.010	−1.635	0.1365
Leverage	0.033	0.102	0.324	0.7531
Constant	0.075***	0.019	3.877	0.0037

Model information	
Estimation method	Fixed effects
Firm fixed effects	Included
Year fixed effects	Included
Clustered robust SE	Included
Observations	70
Number of firms	10
R^2 (LSDV)	0.954
Within R^2	0.532
F-statistic	28.841
Prob > F	1.567e-05
Durbin-Watson	1.001

Joint test on regressors: F(8, 9) = 28.8411; p-value = 1.56651e-05
Robust test for group intercepts: Welch F(9, 23.8) = 81.0352; p-value = 1.17466e-15

*Notes: Clustered robust standard errors (SE) are used. Firm and year fixed effects are included. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

Table 10. Model 2b – Alternative
(CAPEX/Assets)

Model equation:

$$CAPEX/Assets_{it} = \alpha + \beta_1\, Recycling\ rate_{i,t-1} + \beta_2\, Leverage_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Variables	Coef.	Std. Err.	t-stat	p-value
Recycling rate	0.001**	0.000	2.328	0.0449
Leverage	0.034	0.099	0.348	0.7360
Constant	0.003	0.024	0.144	0.8885

Model information	
Estimation method	Fixed effects
Firm fixed effects	Included
Year fixed effects	Included
Clustered robust SE	Included
Observations	70
Number of firms	10
R^2 (LSDV)	0.954
Within R^2	0.530
F-statistic	33.084
Prob > F	8.735e-06
Durbin-Watson	1.013

Joint test on regressors: F(8, 9) = 33.084; p-value = 8.73453e-06
Robust test for group intercepts: Welch F(9, 24.0) = 52.366; p-value = 1.35563e-13

*Notes: Clustered robust standard errors (SE) are used. Firm and year fixed effects are included. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

Source: AI-generated table (produced using original data)

Moving to CAPEX/Assets-based models, Table 9 presents the second baseline specification, which analyses the relationship between lagged emission intensity and investment intensity through the CAPEX/Assets ratio. The coefficient associated with emission intensity is negative but not statistically significant within the sample, indicating that firms characterized by higher past emission intensity do not appear to display systematically different levels of investment intensity relative to total assets. Leverage instead displays a positive but clearly non-significant coefficient, indicating the absence of a meaningful relationship between indebtedness and investment intensity in this specification.

The model presents a very high explanatory power. The LSDV R^2 is equal to 0.954, meaning that approximately 95% of the overall variation in CAPEX/Assets is explained by the model, while the within R^2 is equal to 0.532, indicating that the specification explains more than half of the variation occurring within firms over time. The overall regression is statistically significant, as confirmed by the F-statistic equal to 28.841 and by the associated p-value. The Durbin-Watson statistic is equal to 1.001, which is relatively distant from the ideal value of 2 and may suggest the presence of some positive autocorrelation in the residuals. Nevertheless, the use of clustered robust standard errors helps improve the reliability of the estimates.

Table 10 presents the second alternative specification, which analyses the relationship between lagged recycling rate and investment intensity through the CAPEX/Assets ratio. In this case, the coefficient associated with recycling rate is positive and statistically significant at the 5% level. This suggests that firms characterized by higher past recycling rates also tend to report higher investment intensity relative to total assets. More specifically, the coefficient equal to 0.001 indicates a positive association between recycling activities and firms' capital expenditure intensity. Leverage again remains statistically non-significant, confirming that indebtedness does not appear to play a major role in explaining investment intensity within this specification.

This model also presents a very high explanatory capacity. The LSDV R^2 is equal to 0.954, while the within R^2 reaches 0.530, indicating that the model explains a very large share of both overall and within-firm variation in CAPEX intensity. The overall model is statistically significant, as confirmed by the F-statistic equal to 33.084 and the associated p-value. The Durbin-Watson statistic is equal to 1.013, again suggesting the possible presence of positive serial correlation in the residuals, although clustered robust standard errors partially mitigate this issue. Overall, among the CAPEX/Assets specifications, the recycling rate appears to display a clearer and more statistically robust relationship with investment intensity than emission intensity.

The remaining four models, presented in Tables 11 to 14, mainly serve as robustness checks aimed at verifying whether the results remain relatively stable when lagged water intensity and waste intensity are used instead of emission intensity and recycling rate. Overall, these specifications produce weaker and less consistent results compared with the first four models, as none of the environmental variables included in these regressions appears statistically significant.

In particular, water intensity does not display a statistically significant relationship either with profitability or with investment intensity. In the ROA specification reported in Table 1 in the Appendix, the coefficient associated with water intensity is negative but highly non-significant, suggesting that differences in water efficiency do not appear systematically associated with firms' profitability levels within the sample.

Similarly, in the CAPEX/Assets specification presented in Table 2 in the Appendix, water intensity again shows a negative but statistically non-significant coefficient, indicating the absence of a robust relationship with firms' investment

intensity. In both models, leverage remains negative and highly significant in the profitability specification, while it is positive but non-significant in the investment model. Both regressions nevertheless maintain very high explanatory power, with LSDV R^2 values above 0.86 for the ROA model and above 0.95 for the CAPEX/Assets specification.

A similar pattern also emerges in Tables 3 and 4 in the Appendix, which introduce lagged waste intensity as the environmental explanatory variable. In the profitability model, waste intensity displays a positive but non-significant coefficient, while in the CAPEX/Assets specification the coefficient becomes negative but again statistically non-significant. This suggests that waste intensity does not appear to exert a meaningful influence on either profitability or investment intensity within the analysed sample. Leverage once again remains consistently negative and statistically significant only in the ROA specification, while remaining non-significant in the investment-related model.

Overall, the robustness checks confirm that the strongest and most statistically meaningful relationships emerge primarily in the recycling rate specifications, whereas water intensity and waste intensity appear much less strongly associated with firms' financial performance.

3.4. Interpretation of empirical findings

3.4.1. Interpretation of the results of regression analysis

The results of the regression analysis should be interpreted jointly with the preliminary and correlation analyses and within the theoretical and empirical framework developed in Chapters 1 and 2.

Furthermore, the interpretation of regression results should take into account the specific econometric structure adopted in the empirical analysis. In particular, the use of fix ed-effects models with year dummies and lagged environmental variables implies that the estimated relationships should not be interpreted as simple contemporaneous correlations, but rather as associations between past environmental efficiency and subsequent financial outcomes. This approach allows the analysis to partially isolate the delayed economic implications of environmental performance while

controlling for unobserved firm-specific heterogeneity and common temporal shocks affecting the steel industry.

Overall, the findings suggest that the relationship between past environmental performance and financial performance in the European steel industry is complex, heterogeneous and not always aligned with the more optimistic expectations frequently associated with sustainability strategies in the broader ESG literature.

A first important result emerges from the joint interpretation of Models 1a and 1b, which analyse the relationship between environmental performance and profitability through ROA and should be interpreted together as they address the same underlying research question, being “to what extent is sustainability associated with corporate profitability in the steel industry?”.

Model 1a shows a positive but statistically non-significant relationship between emission intensity and ROA, while Model 1b shows a negative relationship between recycling rate and ROA that is only weakly significant at the 10% level. Taken together, these findings suggest that, within the analysed sample and time period, the relationship between environmental sustainability and profitability remains weak and only partially supported by the empirical evidence. More specifically, firms with higher emission intensity do not appear to experience significantly different profitability levels, while firms characterised by stronger recycling performance tend to display slightly lower ROA values, although the statistical evidence remains relatively weak.

These findings partially contrast with the more optimistic interpretations proposed by part of the literature reviewed in Chapter 1, particularly the NRBV perspective developed by Hart (1995), Russo and Fouts (1997), and Christmann (2000), according to which environmental capabilities and resource efficiency may become sources of competitive advantage and superior economic performance. Similarly, the Porter Hypothesis suggests that environmental pressure and sustainability-oriented innovation may eventually improve efficiency and competitiveness (Porter and van der Linde, 1995). However, the empirical evidence obtained in this dissertation suggests that these mechanisms do not emerge strongly or consistently within the analysed firms and time horizon.

At the same time, such results remain coherent with the broader empirical literature discussed in Chapter 1, which repeatedly highlights that the ESG–financial performance relationship is often heterogeneous, context-dependent and characterised by mixed evidence (Ullmann, 1985; Griffin and Mahon, 1997). In hard-

to-abate sectors such as steel, environmental investments are particularly capital intensive and frequently associated with long payback periods and, consequently, firms that are already more advanced in the environmental transition may temporarily experience weaker accounting profitability because transition-related investments and adjustment costs may affect short-term financial performance more strongly than long-term strategic benefits.

More generally, the results may be consistent with the idea that, within the current transition phase of the European steel industry, the economic costs associated with decarbonisation and sustainability investments still appear significant, while the financial benefits remain only partially visible in short-term accounting performance indicators such as ROA. Therefore, the analysis does not provide strong evidence that higher environmental sustainability systematically translates into stronger short-term profitability within the analysed sample.

A second major result emerges from the joint interpretation of Models 2a and 2b, which analyse the relationship between environmental performance and investment intensity through the CAPEX/Assets ratio, addressing a different research question by investigating whether the transition toward more sustainable production appears stronger among firms with weaker environmental performance or among firms that are already relatively more sustainable.

The results obtained provide only partial support for a coherent investment-related pattern, as Model 2a shows a negative but statistically non-significant relationship between emission intensity and CAPEX/Assets, while Model 2b shows a positive and statistically significant relationship between recycling rate and CAPEX/Assets, suggesting that firms characterised by stronger recycling performance tend to invest proportionally more, while no statistically robust evidence emerges for the relationship between emission intensity and investment intensity.

This result is particularly relevant because it suggests that firms already characterised by relatively stronger environmental performance may currently be investing more intensively in the transition process itself. More specifically, the evidence associated with recycling performance seems to indicate that firms already positioned more favourably from an environmental perspective are also those investing more intensely in further transition and sustainability improvements. In other words, the transition process appears stronger among firms that are already relatively advanced in environmental performance.

This interpretation is coherent with several theoretical arguments discussed in Chapter 1. From an NRBV perspective, firms that already possess environmental capabilities, organisational routines and sustainability-oriented resources may be better positioned to continue investing in decarbonisation and process innovation. Similarly, the literature on dynamic capabilities and proactive environmental strategies (Aragón-Correa and Sharma, 2003; Hart and Dowell, 2011) suggests that firms with stronger pre-existing environmental competencies may find it easier to sustain further transition investments over time.

At the same time, the results may also suggest that the environmental transition remains uneven across the industry, although the empirical evidence does not provide a statistically robust relationship between higher emission intensity and stronger investment dynamics. Consequently, the empirical evidence does not support the existence of a strong convergence process in which the least sustainable firms are rapidly increasing investments in order to catch up environmentally. Instead, the findings appear more consistent with a transition process in which firms that are already relatively sustainable continue strengthening their environmental positioning through proportionally higher investments.

The robustness models based on energy intensity and water intensity generally reinforce this interpretation since, while the environmental variables are often not statistically significant, the overall pattern remains relatively coherent with the idea that environmental transition dynamics in the steel sector are gradual, heterogeneous and characterised by substantial differences across firms.

Overall, the regression analysis suggests that the relationship between environmental performance, profitability and investment intensity in the European steel industry remains complex and partially contradictory. The results do not provide strong evidence that better environmental performance systematically improves short-term profitability. However, they partially suggest that firms already more advanced in sustainability, particularly in terms of recycling performance, tend to invest more intensively in the transition process itself. In this sense, the findings portray a sector where the environmental transition is ongoing but still uneven, with sustainability leadership appearing more concentrated among firms that had already developed relatively stronger environmental positioning before the current phase of increasing regulatory and market pressure.

3.4.2. Limitations of the empirical analysis performed and open issues

Despite the structured empirical approach adopted in this chapter, several limitations need to be acknowledged in order to correctly interpret the results and to position them within the broader literature previously discussed. In particular, the findings of this study should be interpreted as firm-level and sector-specific evidence rather than as proof of a universal causal relationship between environmental and financial performance.

A first limitation concerns the potential presence of endogeneity, which represents one of the most critical issues in the ESG–financial performance literature. As highlighted by McWilliams and Siegel (2000), empirical models that omit relevant variables, such as R&D intensity, innovation capability or strategic orientation, may produce biased estimates of the relationship between environmental and financial performance. In the context of this study, the regression models include a limited number of control variables and therefore it cannot be excluded that omitted factors may simultaneously influence both environmental and financial outcomes, an issue which is particularly relevant in relation to the positive coefficient associated with emission intensity in Model 1. Indeed, as discussed in the interpretation of the results, firms characterized by higher emission intensity are often larger and more integrated producers operating through BF–BOF or hybrid production models. These firms may simultaneously display higher profitability, stronger market positioning and higher environmental intensity. Consequently, the positive relationship observed between emission intensity and ROA should not be interpreted as evidence that higher emissions improve profitability, but rather as a possible reflection of structural differences across firms and production models.

Closely related to this issue is the problem of reverse causality. As discussed by Preston and O'Bannon (1997), the relationship between environmental and financial performance may be bidirectional, since financially stronger firms may have greater resources available to invest in environmental technologies, recycling systems and decarbonization strategies, which is coherent with the "slack resources hypothesis" analyzed in Chapter 1. In the context of the present study, it is therefore possible that some of the environmental improvements observed in the sample are partially driven by firms' pre-existing financial strength rather than by environmental performance generating better financial outcomes, a consideration that is particularly relevant for

firms characterized by higher CAPEX intensity, where environmental investments may simply reflect greater financial capacity and easier access to capital. A further limitation concerns simultaneity and strategic endogeneity. As emphasized by García-Castro, Ariño and Canela (2010), environmental performance is not an exogenous variable, but rather the result of strategic decisions that are jointly determined with financial outcomes. Firms simultaneously choose their production technologies, investment strategies, financing structure and environmental policies, making it difficult to isolate the independent marginal effect of environmental variables. Even though the empirical strategy adopted in this study, based on panel data models with clustered robust standard errors, partially controls for unobserved heterogeneity, it does not fully eliminate simultaneity bias. For this reason, the estimated coefficients should be interpreted as associations rather than as strictly causal effects.

Another important limitation concerns the relatively small sample size. The analysis is based on a panel of ten European firms observed over the period 2017–2024. Although the panel structure increases the total number of observations, the empirical evidence still relies on a relatively restricted group of companies, a limitation that is partly mainly due to the limited availability and comparability of environmental data within the European steel industry, especially when using intensity-based indicators collected from annual reports and sustainability reports. The restricted sample size may reduce the statistical power of the regressions and partially explain why some coefficients appear weakly significant or statistically non-significant, particularly in the robustness models based on energy intensity and water intensity. Consequently, the results should be interpreted with caution and should not be automatically generalized to other industries or geographical contexts.

Measurement issues represent another important limitation. Chapter 1 highlighted the substantial challenges associated with ESG and environmental performance indicators. In particular, Berg, Kölbel and Rigobon (2022) show that ESG ratings are characterized by significant divergence across providers, while Christensen, Hail and Leuz (2021) emphasize the lack of standardization in sustainability reporting. Although this study relies on industry-specific and intensity-based indicators rather than aggregate ESG scores, measurement problems are not completely eliminated. Differences in reporting practices, estimation methodologies and disclosure quality may still affect the comparability and reliability of the variables used in the analysis. This issue is particularly relevant in a cross-firm comparison

involving companies operating in different countries and adopting different reporting standards.

A related limitation concerns the distinction between environmental performance and environmental disclosure. As noted by Clarkson, Overell and Chapple (2011), firms may differ not only in their actual environmental efficiency, but also in the way they measure and communicate environmental information. Consequently, some indicators may partially reflect disclosure practices rather than purely operational performance. This limitation is especially relevant in sectors such as steel, where environmental reporting remains heterogeneous and where certain indicators are sometimes estimated rather than directly measured.

The time horizon of the analysis also represents a limitation. As discussed by Ambec et al. (2013) and Hart and Dowell (2011), the financial effects of environmental investments may emerge only over long-time horizons, particularly in environmentally intensive industries characterized by long investment cycles and high capital intensity. In the steel sector, decarbonization projects often require large upfront investments whose economic benefits may materialize only gradually over time and, consequently, the 2017–2024 period considered in this study may not be sufficient to fully capture the long-term financial implications of environmental transition strategies.

Finally, the empirical analysis focuses specifically on the European steel industry, which represents a highly particular context characterized by strong regulatory pressure, high energy intensity and significant exposure to climate transition risks. As discussed in Chapter 2, the sector is strongly influenced by EU climate policies, carbon pricing mechanisms and decarbonization requirements; therefore, the relationships observed in this study are likely to be shaped by the specific structural characteristics of the steel industry and may differ substantially from those observable in less environmentally intensive sectors. For this reason, the results should not be interpreted as universally applicable evidence regarding the ESG–financial performance relationship, but rather as contextual evidence related to a hard-to-abate industry undergoing a complex environmental transition.

CONCLUSIONS

This thesis analysed the relationship between environmental performance and financial performance in the European steel industry through a firm-level empirical analysis conducted on a sample of ten European companies observed between 2017 and 2024, combining a theoretical review of the literature with an empirical analysis based on preliminary descriptive analysis, correlation analysis and panel fixed-effects regression models using lagged environmental variables and year dummies. Particular attention was devoted to intensity-based environmental indicators in order to better capture operational environmental efficiency within a hard-to-abate sector characterised by high emissions, significant technological challenges and increasing regulatory pressure.

Overall, results suggest that the relationship between environmental performance and financial performance in the European steel industry is complex and heterogeneous. The regression analysis does not identify a strong and systematic relationship between stronger environmental performance and higher short-term profitability, supporting the view that the economic implications of sustainability strategies may vary across firms, sectors and time horizons.

At the same time, it provides some evidence that firms characterised by relatively stronger environmental performance may also display proportionally higher sustainability-related investment dynamics, although this relationship is not uniformly observed across all models. Conversely, more environmentally intensive firms within the analysed sample do not appear to invest proportionally more in transition-related activities, potentially reflecting the presence of financial, technological and organisational constraints.

Overall, findings suggest that the environmental transition of the European steel industry remains uneven and influenced by structural characteristics, production models and firms' ability to sustain long-term investments. More generally, this thesis highlights the importance of adopting sector-specific and intensity-based environmental indicators when analysing the economic implications of sustainability strategies in environmentally intensive industries, where the benefits of environmental improvements may emerge gradually rather than through immediate profitability gains.

APPENDIX – REGRESSION MODELS

Table 1. Model 3 - Robustness
(ROA)

Model equation:

$ROA_{it} = \alpha + \beta_1\ Water\ intensity_{i,t-1} + \beta_2\ Leverage_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

Variables	Coef.	Std. Err.	t-stat	p-value
Water intensity	−0.007	0.015	−0.491	0.6353
Leverage	−0.659***	0.147	−4.487	0.0015
Constant	0.146**	0.059	2.486	0.0347

Model information	
Estimation method	Fixed effects
Firm fixed effects	Included
Year fixed effects	Included
Clustered robust SE	Included
Observations	70
Number of firms	10
R^2 (LSDV)	0.863
Within R^2	0.802
F-statistic	496.589
Prob > F	5.515e-11
Durbin-Watson	2.084

Joint test on regressors: F(8, 9) = 496.589; p-value = 5.51508e-11
Robust test for group intercepts: Welch F(9, 23.5) = 13.8029; p-value = 2.05367e-07

*Notes: Clustered robust standard errors (SE) are used. Firm and year fixed effects are included. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

Table 2. Model 4 - Robustness
(CAPEX/Assets)

Model equation:

$CAPEX/Assets_{it} = \alpha + \beta_1\ Water\ intensity_{i,t-1} + \beta_2\ Leverage_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

Variables	Coef.	Std. Err.	t-stat	p-value
Water intensity	−0.004	0.003	−1.706	0.1223
Leverage	0.026	0.100	0.261	0.8000
Constant	0.069***	0.016	4.300	0.0020

Model information	
Estimation method	Fixed effects
Firm fixed effects	Included
Year fixed effects	Included
Clustered robust SE	Included
Observations	70
Number of firms	10
R^2 (LSDV)	0.953
Within R^2	0.522
F-statistic	9.703
Prob > F	0.0013
Durbin-Watson	1.081

Joint test on regressors: F(8, 9) = 9.70277; p-value = 0.00128702
Robust test for group intercepts: Welch F(9, 24.1) = 98.3061; p-value = 9.23918e-17

*Notes: Clustered robust standard errors (SE) are used. Firm and year fixed effects are included. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

Table 3. Model 5 - Robustness
(ROA)

Model equation:

$ROA_{it} = \alpha + \beta_1\ Waste\ intensity_{i,t-1} + \beta_2\ Leverage_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

Variables	Coef.	Std. Err.	t-stat	p-value
Waste intensity	0.047	0.057	0.818	0.4346
Leverage	−0.697***	0.153	−4.565	0.0014
Constant	0.105***	0.024	4.316	0.0019

Model information	
Estimation method	Fixed effects
Firm fixed effects	Included
Year fixed effects	Included
Clustered robust SE	Included
Observations	70
Number of firms	10
R^2 (LSDV)	0.863
Within R^2	0.802
F-statistic	3837.870
Prob > F	5.637e-15
Durbin-Watson	2.082

Joint test on regressors: F(8, 9) = 3837.87; p-value = 5.63743e-15
Robust test for group intercepts: Welch F(9, 23.6) = 12.395; p-value = 5.44164e-07

*Notes: Clustered robust standard errors (SE) are used. Firm and year fixed effects are included. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

Table 4. Model 6 - Robustness
(CAPEX/Assets)

Model equation:

$CAPEX/Assets_{it} = \alpha + \beta_1\ Waste\ intensity_{i,t-1} + \beta_2\ Leverage_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

Variables	Coef.	Std. Err.	t-stat	p-value
Waste intensity	−0.019	0.025	−0.741	0.4777
Leverage	0.035	0.112	0.313	0.7612
Constant	0.063***	0.014	4.544	0.0014

Model information	
Estimation method	Fixed effects
Firm fixed effects	Included
Year fixed effects	Included
Clustered robust SE	Included
Observations	70
Number of firms	10
R^2 (LSDV)	0.952
Within R^2	0.511
F-statistic	11.771
Prob > F	0.0006
Durbin-Watson	0.996

Joint test on regressors: F(8, 9) = 11.7712; p-value = 0.000612465
Robust test for group intercepts: Welch F(9, 24.1) = 133.093; p-value = 2.6935e-18

*Notes: Clustered robust standard errors (SE) are used. Firm and year fixed effects are included. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.*

Source: AI-generated table (produced using original data)

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Dichiarazione del ricorso a strumenti di Intelligenza Artificiale (IA)

La sottoscritta *Claudia Bulgari*, matricola numero *904531*, iscritta presso Ca' Foscari al corso di *Laurea magistrale in International Management*, autrice dell'elaborato finale/tesi di laurea *"Environmental performance and financial performance in the European steel industry: a firm-level analysis"*, relatore/relatrice Ugo Rigoni, consapevole delle sanzioni previste dall'art. 76 del Testo unico, D.P.R. 28/12/2000 n.445, e della decadenza dei benefici prevista dall'art. 75 del medesimo Testo unico in caso di dichiarazioni false o mendaci, sotto la propria personale responsabilità ai sensi degli artt. 46 e 47 del D.P.R. 28/12/2000 n. 445,

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di aver fatto ricorso a tecnologie di intelligenza artificiale generativa per supportare vari aspetti della ricerca e della scrittura del suo elaborato finale/della mia tesi di laurea, in particolare:

- *ChatGPT-5.5, versione rilasciata a maggio 2026, è stato utilizzato per:*
  - *La revisione e ottimizzazione dei testi dei Capitoli 1 e 2 al fine di migliorarne chiarezza e coerenza;*
  - *La generazione delle Tabelle 7, 8, 9 e 10 del Capitolo 3 e delle Tabelle 1, 2, 3 e 4 dell'Appendice per la presentazione dei dati;*
- *La correttezza, la qualità e l'attendibilità delle immagini e dei testi generati di cui sopra è stata verificata, rispettivamente, tramite il confronto delle tabelle generate con gli output del software statistico utilizzato per l'analisi di regressione (Gretl) e tramite il confronto del testo generato con le fonti di letteratura indicate in bibliografia e citate nel suddetto testo.*

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che tutto il materiale generato dall'IA è stato attentamente verificato, rivisto e rielaborato dall'autore/dall'autrice, che si assume la piena responsabilità per la qualità, l'accuratezza e l'integrità scientifica del lavoro.