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Article

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Contemporary Economics

Provided in Cooperation with:

VIZJA University, Warsaw

Suggested Citation: Clément, Alexandre; Robinot, Élisabeth; Trespeuch, Léo (2025) : Beyond resource use: XGBoost reveals unexpected drivers of corporate CO2 emissions, Contemporary Economics, ISSN 2300-8814, VIZJA University, Warsaw, Vol. 19, Iss. 2, pp. 163-185, <https://doi.org/10.5709/ce.1897-9254.560>

This Version is available at:

<https://hdl.handle.net/10419/323489>

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Primary submission: 13.02.2025 | Final acceptance: 08.03.2025

Beyond Resource Use: XGBoost Reveals Unexpected Drivers of Corporate CO2 Emissions

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ABSTRACT

This study aimed to determine the most relevant variables for carbon dioxide (CO₂) intensity using an XGBoost artificial intelligence (AI) model's feature selection. From more than 600 variables used to assess businesses using extra-financial data and environmental, social, and governance (ESG) scores, the AI algorithm was used to identify the most influential variables for CO₂ emissions. The study also explored theories to explain the relationships between the variables and conducted tests based on sectors of activities and geographic locations to display specific disparities. For researchers, the results reveal an interesting relationship between ESG information and CO₂ emissions in business. For managers, they confirm assumptions about CO₂ emissions and provide new insights into business emissions. This study found that energy, water, and renewable energy consumption significantly impact businesses' CO₂ emissions. Additionally, the proportion of women in the workforce was found to interact with a business's CO₂ emissions in most tests, whereas corporate philanthropy showed a weaker relationship.

KEY WORDS:

Corporate Social Responsibility (CSR), CO₂ Emissions, ESG Scores, Women's Influence, XGBoost.

JEL Classification: Q52, Q56, M14, O44.

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1. Introduction

The effects of climate change are becoming more noticeable as temperatures increase, forests continue to burn at an alarming rate, and floods occur more frequently. Unfortunately, experts have warned that these changes will have a negative impact on our lives and will continue to worsen (Masson-Delmotte & IPCC, 2021). Human activities, notably the burning of fossil fuels, have caused an alarming increase in the concentration of CO₂ (carbon dioxide) in the atmosphere (Dong et al., 2019). Excess CO₂ in the air is harmful to the environment because of its heat-trapping ability and long-lasting effects (Bazzaz, 1990). Once CO₂ is released into the atmosphere, it can remain there for hundreds or even thousands of years, implying that current emissions will continue to have a signifi-

cant impact far into the future. Evidence shows that CO₂ emissions are the primary driver of anthropogenic climate change, and unlike other metrics related to climate, CO₂ intensity shows a direct and unambiguous connection between global warming and business as its key contributor, making it a clear and reliable measure (Masson-Delmotte & IPCC, 2021).

The 26th United Nations Climate Change Conference, also known as COP26, took place in Glasgow in 2021; the conference was focused on climate change mitigation. It led to the creation of an international agreement called the Climate Pact, which sets ambitious goals for achieving net-zero emissions and encompasses approximately 90% of global emissions. Regarded as a significant step, the Climate Pact aims to cap the global temperature increase at 1.5°C through CO₂ reduction (Lennan

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& Morgera, 2022). However, its success hinges on the commitment of participating nations, particularly major corporations in developed countries and the world's largest polluters. CO₂ emissions are directly linked to climate change and represent a crucial metric that must be addressed to prevent catastrophic events and protect the planet.

People can contribute positively in addressing climate change in different ways, such as lifestyle changes (Balderjahn et al., 2020; Gallo et al., 2023), consumption reduction (e.g., reducing electricity consumption (Van Den Broek et al., 2019), traveling less frequently (Kantenbacher et al., 2017), reducing waste production (Aschemann-Witzel et al., 2019)), product substitution (e.g., meat substitution (Lemken et al., 2019)), and the adoption of innovative technologies (e.g., electric cars (Thøgersen & Ebsen, 2019)). Although some solutions may have a greater impact than others, people have diverse options for addressing climate change (Thøgersen, 2021). In the near future, businesses that are underperforming with regard to their CO₂ reduction goals will likely begin to lose customers because of their emissions. Thus, studying the multiple factors linked to the CO₂ emissions of a business is crucial.

CO₂ emissions are important in the context of climate change, and businesses require a measurement metric to address climate change. CO₂ has emerged as “the” metric businesses need to focus on to do their part in the decarbonization of the economy. Environmental, social, and governance (ESG) is a general term associated with quantitative metrics aligned with these three factors. In general, ESG scores are developed to evaluate a business's environmental impact. However, these scores have faced criticisms and have some limitations (Clément et al., 2022a, 2022b; Escrig-Olmedo et al., 2019). One limitation is that they try to capture various broad concepts related to corporate social responsibility (CSR), not just one concept such as climate. CSR involves integrating environmental and social concerns into a business model. The difference between ESG and CSR is that the former is an explicit measurement of environmental performance, whereas the latter is a management philosophy. Thus far, limited research has examined quantitative ESG metrics, their integration into

CSR performance, and the relationships between metrics that can influence the reduction and measurement of CO₂.

Against this background, the current study aims to evaluate the ESG metrics that can influence CO₂ emissions by businesses and support their emission reduction goals. The study is conducted using an extreme gradient boosting (XGBoost) artificial intelligence (AI) model that facilitates the assessment of the most important variables for CO₂ emissions in business.

2.2. Theoretical Framework

The theoretical framework includes a literature review that outlines the relationship between CSR and the use of CO₂ intensity to measure a business's environmental performance. This is followed by a review of the XGBoost AI model, the database and index used, and three evaluations that were conducted—CO₂ intensity, CO₂ intensity by sector of activity, and CO₂ intensity segmented by continents—with the aim of determining the most relevant variables for CO₂ intensity using the XGBoost AI model's feature selection.

2.1. Relationship Between CSR and ESG

Because business activity is an important driver of climate change, a vast body of literature has focused on business environmental impacts and sustainability in recent years (Ahmad et al., 2024). Two approaches can be used to assess business environmental impact and sustainability. The first is a qualitative or philosophical perspective that examines business environmental impact through the lens of CSR practices. This approach allows for a nuanced understanding of a company's ethical considerations and voluntary actions toward environmental stewardship. The second perspective employs a more quantitative method, utilizing ESG scores to assess and compare CSR practices across businesses numerically. These ESG metrics provide a standardized framework for evaluating a company's environmental performance, among other factors (Kaźmierczak, 2022). Importantly, these two approaches are not mutually exclusive, but rather complementary (Nugroho et al., 2024), offering a comprehensive view of a business's environmental stance and actions.

CSR is a management approach that incorporates social and environmental concerns into a company's operations and stakeholder relationships, which is distinct from the more quantitative ESG that is based on numbers. Specific to CSR, Igalens & Joras (2006) demonstrated that companies prioritizing CSR enjoy numerous benefits, including the development of a positive brand image (Ramesh et al., 2019), improved employee recruitment and retention (Supanti et al., 2015), and reduced tax and duty costs (Sprinkle & Maines, 2010). CSR is essential to a brand as it has the potential to significantly impact consumer behavior and brand equity (Kitchin, 2003). Studies have also shown that at least half of the consumers surveyed are willing to pay more for products that are sustainable and environmentally friendly (Y.-S. Chen, 2010). This indicates that good CSR practices can improve consumer loyalty and the perceived value of brand equity (Mahmood & Bashir, 2020). Moreover, today's consumers are willing to pay more and look for brands that do more than just pursue profits (Dangelico & Vocalelli, 2017). According to van Doorn et al. (2017), good CSR practices can positively influence consumer behavior, which is especially important for innovative companies with limited marketing budgets.

In addition to improving brand reputation and consumer trust, CSR practices can help companies recruit and retain employees (S. Du et al., 2007; Islam et al., 2021; Mahmood & Bashir, 2020) as well as retain customers (Nugroho et al., 2024). By engaging in socially responsible practices, companies can create a more motivated and engaged workforce that is more invested in the organization's development. These benefits are further reinforced by consumers and governments preferring and supporting companies that perform well on environmental and social issues.

While it is commercially advantageous to practice CSR to improve the performance of business operations (Peratz & Strønen, 2024) or marketing, its positive impact on climate change is less evident. Moreover, businesses associated with high greenhouse gas emissions or resistance to environmental regulations may suffer reputational damage, leading to decreased customer loyalty and even boycotts (Bansal & DesJardine, 2014; Kotsantonis & Serafeim, 2019). This suggests that the promotion of the advantageous elements of CSR practices can be diminished solely by

poor CO2 performance. Businesses need to balance broad environmental and social initiatives while reducing the risk of being accused of greenwashing, by ensuring that they clearly understand the impact of business actions on the planet.

ESG scores are sometimes used to quantitatively express CSR practices, as CSR practices are broad and difficult to measure. The objective of ESG scores is to provide a type of metric that allows the assessment of businesses' environmental sustainability and ultimately allows comparability. However, a growing body of literature employing various methodologies and datasets demonstrates that ESG scores may not be a comprehensive representation of a company's sustainability (Eccles et al., 2020; Eccles & Strohle, 2018; Escrig-Olmedo et al., 2019; Gillan et al., 2021; Kotsantonis & Serafeim, 2019; Olmedo et al., 2010; Widyawati, 2020). These scores need to be more accurate in depicting organizations' beneficial impacts on the planet (Bernier-Monzon et al., 2019). Instead, the design of ESG scores is such that they primarily gauge the associated risks emanating from ESG factors, thereby minimizing the negative repercussions of a company's actions on its investment prospects (Berg et al., 2022; Bernier-Monzon et al., 2019; Cornell & Damodaran, 2020; Maiti, 2021; Taparia, 2021). Therefore, ESG scores are the predominant tool that investors use to assess a company's environmental dimensions (Widyawati, 2020). Additionally, researchers have increasingly utilized ESG scores as a standard yardstick for comparing sustainability performance across corporations (Clément et al., 2022b).

CSR and ESG scores are similar in their encompassing various elements, such as child labor policies, employee-customer relations, and global supply chain practices. They are both broad measures that track different subjects. They are not designed to track specific issues such as the increase in global CO2 emissions or business impacts on climate change. "The role of CSR in combating some of the world's most urgent environmental problems, such as greenhouse gas emissions, loss of biodiversity, etc., is even more vague" (Kudlak, 2019, p. 169). To combat climate change and assess the impact of organizations on the environment, an effective approach would be to focus on a single metric incorporated in companies'

CSR practices and ESG scores, such as CO₂ emissions.

Reporting on CSR and being transparent in ESG assessments are effective ways for businesses to demonstrate to their customers and the public that they are taking action toward mitigating climate change and other social challenges. However, the tangible impact of such reporting on a global scale is still debatable (Walls et al., 2012). Yet, reporting on CO₂ emissions can help companies show their progress toward meeting international climate commitments, such as those outlined in the Paris Agreement. CO₂ and CSR practices are related; in fact, companies that prioritize CSR within their organizations, mainly through self-regulatory measures, tend to have lower emissions than their peers (Kudlak, 2019). The same applies to those maintaining transparency in their ESG assessments (Chouaibi & Affes, 2021).

However, ESG scores have several limitations. ESG rating agencies have their own methodologies, which are relatively opaque, and the CSR practices they measure for a company can vary greatly from one agency to another (Kotsantonis & Serafeim, 2019; Olmedo et al., 2010; Serafeim et al., 2019). Prior research by Berg et al. (2022) identified a modest correlation among ESG scores from different agencies, a notable finding given the near-perfect correlation found between credit ratings such as Moody's and Standard & Poor's. For instance, a 38% correlation was observed between MSCI and Refinitiv, and a 70% correlation between Sustainalytics and Vigeo Eiris, with an industry average of 60% correlation (Berg et al., 2022). Other previous studies have corroborated this discrepancy (Dimson et al., 2020). The issuing agency's objectives and target clientele critically influence the comprehensiveness and range of the ESG scores produced (Eccles et al., 2020). Moreover, the depth of qualitative data can fluctuate based on the geographic location of the companies being evaluated, thereby affecting the representativeness of the scores (Baldini et al., 2018; Daugaard & Ding, 2022). The voluntary nature of ESG disclosures frequently limits transparency levels, (Hazen, 2021) and the degree of transparency of the evaluated business is critical in determining the final ESG score (Chouaibi & Affes, 2021). Another key issue with CSR and ESG is the absence of standardized metrics or guidelines. This results in companies defining and reporting their CSR

activities differently, making it challenging to compare their efforts (Drempevic et al., 2020; Friede et al., 2015; Gillan et al., 2021; Saadaoui & Soobaroyen, 2018).

The limitations of ESG and CSR in addressing climate change are a matter of concern because both measures are linked to many variables that are distinct from climate change and are not measured using similar methods (Berg et al., 2022). ESG providers offer a quantitative representation of business CSR policies (Kudlak, 2019), but still fail to directly address climate change. Environmental concerns encompass several issues, not just those related to CO₂; however, there is a strong consensus worldwide that CO₂ is the main contributor to climate change. CO₂ is one of the hundreds of variables that compose ESG and is not explicitly covered by CSR policies. However, because the problems of climate change are directly linked to CO₂, shifting from ESG to CO₂ to measure the impact of a business on the environment is crucial.

2.2. Carbon Intensity

Regardless of the rapid incorporation and broad adoption of CSR and ESG, global emissions have not decreased or stopped; in fact, they have increased (Masson-Delmotte & IPCC, 2021). On the one hand, there is agreement that CO₂ is the most important metric to express climate change, and reducing overall emissions is the key to limiting the impact of climate change (Masson-Delmotte & The Intergovernmental Panel on Climate Change [IPCC], 2021). Additionally, it is difficult for a company to know how to achieve CO₂ emission reductions based on past environmental innovations (Albitar et al., 2023). As CO₂ emissions are a link between human activities and climate change, more research on business sustainability could benefit from focusing on CO₂ directly. To address climate change and avoid greenwashing, improving on the ESG metric is not enough. There is strong consensus that CO₂ is the main metric that must be assessed by every stakeholder to fight climate change (Masson-Delmotte & IPCC, 2021).

Similar to the literature on CSR and ESG, CO₂ emissions considerations from a business perspective can lead to many managerial advantages. According to Rahman et al.(2021), environmental innovation, emissions reduction, and the effective

use of natural resources are the three best areas to focus on for enhancing brand value. Some critics argue that CSR initiatives or ESG performance are often implemented as a public relations strategy rather than as a genuine commitment to social or environmental issues (Turker, 2009; Weber, 2008). Research indicates that lowering carbon emissions benefits the environment and can lead to significant business advantages, including cost savings, enhanced brand reputation, and compliance with regulatory standards (Kolk et al., 2008). Moreover, businesses that actively manage their CO2 emissions and are transparent about them perform better in terms of CO2 intensity relative to their peers (Haque & Ntim, 2022). Finally, lower carbon emissions through innovation generally result in better financial performance for a firm and better return on equity (Albitar et al., 2023; Gallego Alvarez, 2012).

Focusing on CO2 emission instead of CSR or ESG could lessen the global assessment of business impacts. Nonetheless, it presents a more straightforward and transparent approach to addressing the urgent issue of mitigating climate change. Moreover, customers are becoming averse to greenwashing, and CSR and ESG are increasingly facing this critique. For comparability, a standardized version of carbon emissions from businesses is expressed as carbon intensity. Carbon intensity is the amount of CO2 emitted per unit of economic activity or energy and is used to help identify the sectors and activities that are most carbon-intensive (Q. Wang et al., 2017).

Carbon emissions vary greatly among different industries, which is why carbon intensity provides a more comprehensive view of a company's environmental impact. The CO2 intensity metric considers not only the total amount of emissions but also the efficiency with which energy is used. For instance, two companies may have the same total emissions. However, if one produces more output, its carbon intensity will be lower. Therefore, carbon intensity provides a more nuanced and accurate picture of a company's environmental and economic performance. It also allows meaningful comparisons and benchmarking across different businesses, sectors, and countries (Canadell et

al., 2007). Lower carbon intensity can serve as a competitive advantage for businesses, as it demonstrates their commitment to sustainability.

As companies grow and evolve, their total emissions may also change. Tracking carbon intensity can help determine whether a company is becoming efficient, and whether its growth is sustainable from a climate perspective (Burgess et al., 2020). CO2 intensity is valuable for developing mitigation strategies and can be incorporated into broader CSR plans (P. Chen, 2023). Le Quéré et al. (2015) highlighted the complexities involved in accurately measuring carbon intensity, including the need for standardized methodologies and the challenges of comparability across different industries. Despite these challenges, carbon intensity has become the primary metric used to evaluate businesses in the finance sector (Berg et al., 2022).

Traditionally, the energy (generation or energy-intensive business) and transportation sectors have high carbon intensities (Ritchie et al., 2023). The energy production sector is one of the largest carbon emitters, because it relies heavily on fossil fuels (Burgess et al., 2020; Masson-Delmotte & IPCC, 2021). When these fuels are burned to generate electricity or heat, they release significant CO2 into the atmosphere. The transportation sector is another major contributor, mainly because of its use of non-renewable resources. Industrial processes also have a high carbon footprint, particularly in the steel, cement, and chemical production industries, where fossil fuels are used for energy and manufacturing (Murshed et al., 2021).

Yet, detecting high CO2 intensity levels may offer opportunities for companies to improve their efficiency, explore cleaner energy sources, and innovate in processes and technologies. Unlike other metrics, CO2 intensity offers a direct and unambiguous connection with key contributors to global warming, making it a clear and reliable measure for businesses and consumers (N. Stern, 2007, 2014).

Assuming that CO2 emissions are the most important metric related to climate change, the objective of this study is to evaluate the drivers of business linked to its CO2 emissions. ESG scores

are composed of more than 600 variables, known as extra financial variables. “Extra-financial variables” is a broad term that describes all the information regarding a business that is not financial in nature. The ESG score is derived from an aggregation of these non-financial variables, which evaluate many CSR aspects. CSR practices such as business values and management styles are sometimes difficult to quantify mathematically. Therefore, assessing extra-financial variables with CO₂ emissions could point to interesting avenues for enhancing CSR management in business, with the ultimate objective of CO₂ reduction. The primary metric chosen is CO₂ intensity because of its direct link to climate change and comparability across industries. Unlike ESG scores, CO₂ intensity provides a clear, quantifiable measure of a company's environmental impact relative to its economic output. This metric allows for meaningful cross-sector analysis, useful for diverse stakeholders to measure their impacts on the environment, improve their performance, and reduce their negative impacts. In essence, CO₂ intensity acts as a universal measure for a universal problem.

2.3. Hypothesis Development

Evidence shows that how corporations use resources is a major and immediate factor driving CO₂ emissions (Murshed et al., 2021). Companies that rely heavily on fossil fuels for energy inevitably produce greater greenhouse gas emissions, owing to the carbon-heavy nature of these sources. Similarly, high water usage often aligns with broader resource management inefficiencies that can increase a company's carbon footprint, particularly regarding the energy required for water treatment, transportation, and heating.

Meanwhile, businesses that proactively optimize or curtail resource use through conservation strategies, sustainable innovations, and renewable energy integration can significantly reduce their emission intensities. Collectively, these findings indicate that visible signs of resource inefficiency—high energy consumption, limited use of renewable energy, and excessive water usage—are usually associated with elevated CO₂ intensity levels, highlighting resource management as a crucial

area for tackling climate change (Murshed et al., 2021).

H1. Greater resource usage is associated with higher CO₂ intensity.

Research has consistently highlighted that philanthropic actions, often viewed as “good business citizenship,” reflect a company's commitment to social welfare (Kudlak, 2019; Wang et al., 2008). By voluntarily channeling resources into charitable causes, organizations demonstrate their intention to exceed basic legal and commercial commitments. This proactive approach often encompasses environmental efforts; if a company's leaders are ready to invest in projects that benefit communities, they are also more likely to implement strategies that reduce their ecological impact.

Engaging in philanthropic endeavors can help build stronger stakeholder networks, creating both social capital and reputational advantages that further promote environmentally responsible behavior. Consequently, initiatives such as donating a portion of revenue may indicate a broader, value-driven corporate culture that emphasizes the well-being of both social and ecological systems.

H2. Companies that actively engage in philanthropy or charitable giving are more likely to exhibit lower CO₂ intensity, suggesting a positive spillover from social responsibility to environmental stewardship.

Previous studies have shown that having women in top management positions positively affects a company's environmental performance. Research indicates that increased female representation in executive positions enhances stakeholder-oriented decision making (Bernardi & Threadgill, 2010), raises awareness of sustainability issues (Setó-Pamies, 2015), and cultivates a social responsibility culture (del Carmen Valls Martínez et al., 2022; Mehmood, 2022). These claims stem from broader evidence that suggesting that female leaders often demonstrate higher ethical standards and adopt more comprehensive governance approaches. In theory, these attributes should lead to tangible environmental results such as effective CO₂ reduction strategies.

H3. Executive gender diversity does not, by itself, exert a significant direct effect on corporate CO₂ intensity.

Prior research consistently points to women's heightened sensitivity to a broad spectrum of stakeholder interests and their greater propensity to integrate long-term social and environmental objectives into organizational strategies (Brammer et al., 2007). This pattern appears to reflect a stronger inclination toward balancing diverse stakeholder demands rather than pursuing narrow, profit-driven goals. Such stakeholder-oriented approaches may, in turn, promote more comprehensive climate initiatives, given that effective CO₂-reduction strategies often entail cross-departmental collaboration, transparent communication with external parties, and a readiness to invest in potentially costly but beneficial long-term environmental measures (Glass et al., 2015). Building on this perspective, scholars have argued that women in the workforce are less likely to favor short-term earnings maximization at the expense of sustainable growth, often advocating policies that consider both ecological constraints and community well-being (Tronto, 2022).

H4. Higher gender diversity in the workforce is associated with lower CO₂ intensity.

3. Methodology

3.1. Refinitiv dataset

This study explores the connection between extra-financial information comprising ESG scores in the Refinitiv database. It proposes a hierarchy based on the importance of each variable to CO₂ intensity. The Refinitiv database provides information about businesses, including aspects such as workforce diversity, management practices, supply chain, societal impact, and resource management. The Refinitiv dataset provides a comprehensive overview of ESG factors, each of which can influence a company's CO₂ intensity in different ways.

The "environmental" dimension evaluates the effect of businesses on natural ecosystems and resources. The key metrics encompass greenhouse gas emissions, energy consumption and efficiency, waste management strategies, water usage, and biodiversity. The "social" dimension focuses on an organization's engagement with its employees, suppliers, customers, and local communities. Important

indicators include workforce diversity and inclusion, labor practices, and community involvement initiatives. Governance emphasizes effective leadership, board composition and independence, shareholder rights, and corporate transparency. Metrics indicating well-organized boards, ethical executive pay, strong risk management, and anti-corruption measures are essential for promoting climate-related initiatives. Strong governance bodies can implement environmental policies that align with business objectives. Simultaneously, motivated employees and strong community relationships can support the necessary operational changes to reduce emissions. Thus, each pillar has the power to influence both the direct and indirect factors affecting carbon intensity.

Refinitiv's dataset, which includes hundreds of variables across these pillars, supports rigorous cross-company comparisons. By applying a systematic selection or regularization approach to identify the most relevant ESG metrics, researchers can more accurately pinpoint the factors that significantly affect CO₂ intensity. In a broader context, understanding these key variables helps investors and stakeholders determine which companies are positioning themselves to meet evolving climate challenges, manage regulatory risks, and potentially create long-term shareholder value through more sustainable operations.

The universe used for the analysis was the MSCI ACWI. This index includes a broad coverage of listed equity companies in both industrial nations and emerging markets. It is composed of 2802 companies from all industrial sectors, including retail, energy, and transport, among others. Therefore, this index allows a broad range of coverage, making it ideal for comparing data from various types of companies.

The data were obtained through Refinitiv's Eikon database. Refinitiv calculates ESG scores through an exhaustive evaluation of a company's sustainability efforts and performance. The selection of ESG metrics used a regularization methodology to evaluate the available metrics and identify those to be utilized in the evaluation. Figure 1 illustrates this regularization. All the available metrics in the database were considered. The database consists of 630 variables, mostly Boolean and numerical variables.

3.1.1. Metric Selection

From April 20th to May 5th, 2024, the Refinitiv database was used to extract ESG data for MSCI ACWII. All the ESG data points available at the time were considered for this research. The Refinitiv database is a reliable source of information and has been used previously by scholars such as Filippou and Taylor (2021) for their analyses of European firms. During our analysis, we identified 630 variables, of which 4 were categorical, 268 were Boolean, and 358 were numeric. In the first step, variables with low coverage in the dataset were removed. Specifically, 277 variables with more than 50% missing values (NA) were excluded, reducing the NA in the dataset from 703 772 to 19 506 samples.

There were 269 variables linked to the environmental pillar, 33 of which had no coverage of any listed companies in the MSCI ACWI universe. Of the remaining variables, 72 were Boolean, 161 were numeric, and 3 were categorical. For the social pillar, 279 variables were available that express the different social characteristics of the companies. Of these, 26 variables offered no coverage of any company present in the MSCI dataset. Of the remaining variables, 151 were numeric, 1 was categorical, and 101 were Boolean. Finally, the governance pillar consisted of 165 variables, of which 24 did not have any coverage for any company present in the MSCI ACWI universe. Of the remaining variables, 46 were numeric and 95 were Boolean. Figure 1 presents the procedure employed to obtain the final dataset.

Some variables are unique to a specific industry, while others are closely related to one another. For instance, banks possess data on their assets under management related to ESG, which are not available for other industries. Moreover, there are numerous variables that measure the same metric using different methodologies, such as CO2 emissions tracked under 20 metrics, including CO2 tons to millions of USD and CO2 tons by CARG or EVIC, among others. To address this issue, financial analysts from the socially responsible investment team at an institutional bank collaborated with the authors in two separate meetings, each lasting 1 h, to review all the variables and select those that could be removed while retaining a representative dataset of all industries. Only variables related to X to revenue in

a million were retained. All others linked to CARG and EVIC or other financial ratios were removed. The coverage of ESG issues linked to revenue was larger and easier to understand for further analysis. Similarly, all variables specific to an industry, such as “flaring gas,” were also removed. In this step, 75 variables were eliminated.

The final dataset was classified based on conceptual congruence. Instead of a formal algorithmic method, a heuristic approach is used to propose a more segmented classification than the three pillars of ESG that are normally proposed. This approach is useful for qualitative problems such as this classification (Douglass & Moustakas, 1985), providing a more comprehensive classification. The first three categories are the same as the ESG score, but an additional category was created, internal social responsibility, which encompasses employee metrics. Table 1 presents the results of the study.

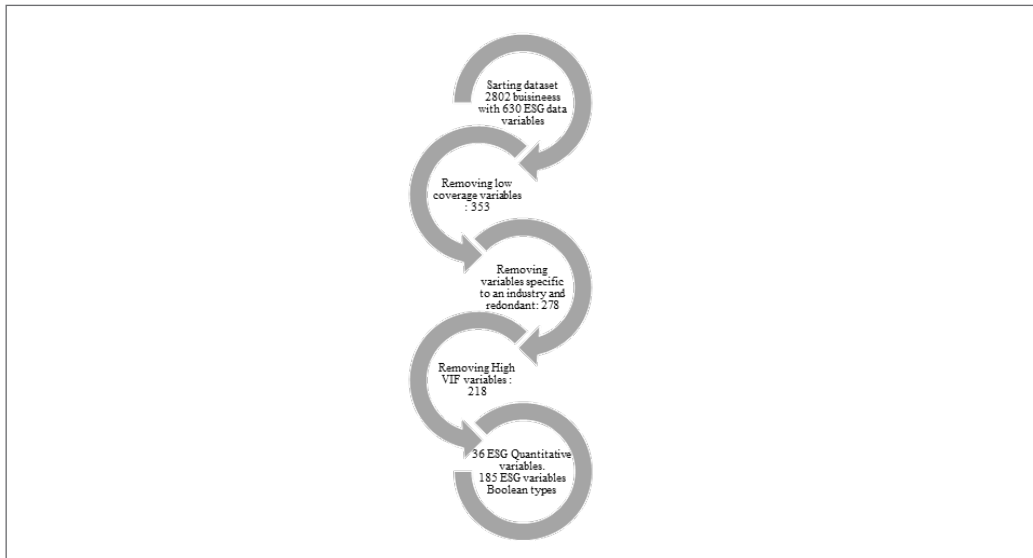
The variance inflation factor (VIF) is useful for identifying multicollinearity among variables (Craney & Surles, 2007). The ultimate objective is to obtain a dataset in which none of the features are correlated with each other. Achieving this requires testing various parameters to determine the optimal combination. In this particular case, the aim was to retain as many variables as possible while ensuring that the VIF of each variable remained below 5. Consequently, 60 variables were eliminated.

The dataset used in this study contained 218 variables representing ESG issues. These variables were carefully selected to ensure that they were not correlated and specific to any particular industry. Owing to the large number of variables, the dataset was divided into two parts. One part contained all the Boolean variables, whereas the other contained numeric and categorical variables transformed into numeric values. The dataset contained 36 quantitative variables and 185 Boolean variables. As the Boolean dataset did not provide useful information, it was removed from further analysis, and all analyses were conducted based on the numerical dataset.

3.2. Model and Feature Selection

Feature selection is the process of selecting the most important variables that can affect the outcome. XGBoost is a model used for feature selec-

Figure 1
Dataset Regularization



tion. This is particularly useful for high-dimensional data with many features, as was the case in this study. XGBoost is based on the random forest algorithm that uses the F-score to measure the average improvement caused by a variable when used in the trees of the ensemble model (T. Chen & Guestrin, 2016). The F-score helps classify the variables in the function based on their importance for the outcome. This indicates the frequency at which each feature is used to split the data across the decision trees within the XGBoost model. Features with higher F-scores are more significant for the target variable. XGBoost ranks variables based on their F-scores, allowing for the effective prioritization of features. This enables researchers to focus on the most impactful variables when building or interpreting models (Abdurrahman & Sintawati, 2020). However, it is important to note that variables with the same F-score are equally important because of the random nature of the underlying XGBoost algorithm. The importance of each feature lies in the difference between the F-score of the variables; the bigger the gap, the more important it is.

The XGBoost model was optimized with automatic hyperparameter tuning through Hyperopt.

Hyperopt is a Python library for serial and parallel optimization over awkward search spaces, which may include real-value, discrete, and conditional dimensions (Bergstra et al., 2013). Hyperparameters tuning and the different models were run on Google Collab, and all the scripts were written in Python using the XGBoost package.

4. Results

The heuristic approach applied to the model allowed for a segmented classification defined by the three pillars of ESG, as shown in Table 1. This presentation follows the normal structure of ESG scores. Environmental sustainability metrics are designed to scrutinize an organization's ecological footprint and encompass elements such as energy consumption, emissions, and the incorporation of environmental management systems. These variables fall into the E of ESG when the score is aggregated by the data provider to produce the ESG score.

The social pillar of ESG can be classified as internal social responsibility and external social responsibility (Becchetti et al., 2022). When analyzing the internal social responsibility metrics, it was observed that there is minimal focus on external social responsi-

bility. The only external social responsibility metric pertains to the organization's efforts to give back to the community by redistributing its resources.

Finally, corporate governance metrics encompass variables instrumental to the architecture and operational efficacy of the corporate board and its committees, thereby influencing the quality of governance practices. These variables fall into the G of ESG when the score is aggregated.

These results show that while environmental metrics are well covered, the social impact of the business on society lacks coverage in the present dataset, as only donations are tracked. Furthermore, the environmental metrics include the impact of business on the planet by measuring different kinds of interactions between businesses and society, such as water and energy use, among others. “Corporate governance and internal social responsibility,” are more related to the governance of the business. They reflect information from within the business and are less directly linked to its impact on the planet.

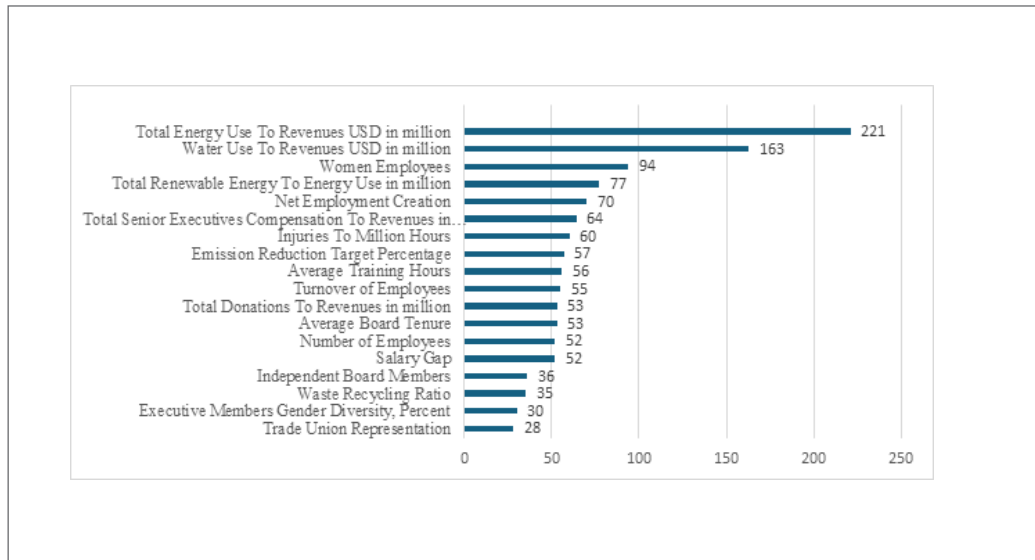
4.1. CO₂ emissions on revenue in \$

CO2 intensity was the target variable in this model and was divided into carbon intensity quantiles. The primary focus of this model was to identify the extra-financial variables with the most significant impact on CO2 intensity. Data on the CO2 intensity of 2258 businesses were integrated, and the shape of the quantitative dataset was (2258, 36). The accuracy score of the model was 0.76.

Figure 2 presents the variables with the greatest impact on CO2 intensity. The results of the analysis identify the key drivers of CO2 intensity in corporations based on an algorithmic procedure and feature selection from XGBoost. The results identify, in descending order, the variables that influence CO2 intensity the most. “Total energy use to revenues” is the most important predictor for CO2 intensity in a business, however it is also the expected outcome. This finding supports our understanding of how operational resources, particularly energy, are correlated with corporate emissions. The predominance of energy use as a determinant of CO2 emissions supports the notion that re-

Table 1
Classification of ESG Variable into Themes

1. Environmental Sustainability Metrics	2. Internal Social Responsibility	3. External Social Responsibility	4. Corporate Governance Metrics
<ul style="list-style-type: none">• CO2 Estimation Method• Emission Reduction Target Percentage• ESG Reporting Scope• ISO 14000 or EMS• Total CO2 Equivalent Emissions To Million Revenues USD YoY• Total CO2 Equivalent Emissions To Revenues USD in million• Total Energy Use To Revenues USD in million• Total Renewable Energy To Energy Use in million• Waste Recycling Ratio• Water Use To Revenues USD in million	<ul style="list-style-type: none">• Average Training Hours• Board Gender Diversity, Percent• Board Specific Skills, Percent• Employee Fatalities• Executive Members Gender Diversity, Percent• Injuries To Million Hours• Net Employment Creation• Number of Employees• Salary Gap• Total Senior Executives Compensation To Revenues in million• Trade Union Representation• Turnover of Employees• Women Employees	<ul style="list-style-type: none">• Total Donations To Revenues in million	<ul style="list-style-type: none">• Anti-Takeover Devices Above Two• Audit Committee Independence• Audit Committee Non-Executive Members• Auditor Tenure• Average Board Tenure• Board Member Term Duration• Board Structure Type• Compensation Committee Independence• Independent Board Members• Nomination Committee Independence• Nomination Committee Involvement• Voting Cap Percentage

Figure 2*Quantitative Data Set, CO₂ Emission/Millions of \$*

source efficiency, particularly energy efficiency, is key to reducing corporate carbon intensity. A business's carbon intensity is determined by its energy consumption and production, which are often based on electric grid power from fossil fuel power plants (Murshed et al., 2021). The second highest influential variable is found to be "water used." Water usage is a crucial factor in determining the carbon footprint of a business. The link between water consumption and CO₂ intensity implies that businesses that are resource-intensive in one area (water) may also exhibit inefficiencies in other areas (energy), ultimately contributing to higher emissions. "Women employees," the third variable from the top, is the only variable not represented by a resource used to run a company. This variable represents the proportion of women in the workforce within a business. Test 1 confirmed that resource-use metrics, such as energy and water consumption, are the most relevant variables affecting CO₂ intensity, while introducing new insights into the role of workforce composition in corporate environmental performance.

4.2. CO₂ by Sector of Activity

Additional tests were conducted using the same procedure, but with the MSCI ACWI data set de-

composed into sectors. The sectors used were those provided by the MSCI and related to the Global Industry Classification Standard (GICS) sectors. Owing to this decomposition, the number of examples in each category was significantly reduced.

The "utilities," "oil and gas," and "real estate" sectors were found to have limited data points, eliminating these sectors from the XGBoost model. Additionally, the high emissions present in both the "utilities" or oil and gas" sectors prevented variability in the data points and would therefore prevent the model from aggregating toward a solution.

The results presented in Table 2 indicate that certain variables consistently have a high impact across sectors. The accuracy in models maintained a range of 0.62 to 0.69. Complete randomness is equal to 0.25, and models below 0.5 were rejected. The varying accuracy rates of the XGBoost models among the different sectors imply that some sectors are more easily explained by the model than others.

Some features consistently had a high F-score across multiple sectors, indicating their importance and confirming the results of the previous test. For instance, the "total energy use to revenues USD in million" feature shows significant importance

in nearly every sector, especially in the energy-intensive sectors. Therefore, businesses with higher energy consumption relative to their revenues may be viewed as less sustainable. Certain variables are more significant for particular sectors than for others. For instance, "net employment" is a crucial factor in the healthcare industry, but it was not identified as critical in other sectors. Net employment creation refers to the number of instances of hiring or licensing in a business.

It has been observed that women play a crucial role in traditionally male-dominated sectors such as industry, information technology, and materials. This interesting finding can be attributed to the fact that women are naturally inclined toward taking into consideration the interests of various stakeholders.

Various other factors affect a company's CO₂ intensity but with less certainty. Governance-related factors, such as "audit committee independence," "board gender diversity, percentage," and "nomination committee independence," have a moderate influence on CO₂ intensity. As these factors have less impact on operational and resource-related features, these results were expected. Factors related to social responsibility and employee well-being, such as "trade union representation" and "salary gap," also show moderate importance. These factors could indicate a company's overall ethical stance, which may correlate with its environmental impact initiatives.

4.3. CO₂ by Continent

A final test was conducted to examine cultural and geographic differences. In this study, the MSCI ACWI dataset was separated by continent location based on the country of origin of a company's headquarters. Country data were provided by the MSCI, and mapping between the countries and continents was performed manually. This analysis, conducted by continent, produced a significant reduction in examples for some continents. Therefore, the results for areas such as Africa reduced the accuracy of the model and yielded no results. The accuracy results for South America were also low; however, as the accuracy score remained above 0.5, the results remained consistent. Table 3 shows the model

statistics and the four higher variables for our location-based mapping. The accuracy of the models ranges from 0.55 to 0.77.

Table 3 shows similarities to Table 2 with women being a top variable in multiple countries. What is interesting here is the difference between countries reflecting differences in culture and lifestyle. Women employees is the second highest variable for Europe, but is lower in Asia and the Americas, while being absent in Oceania. A common understanding is that Europe is years ahead of trends concerning climate change disclosure and regulation, and these results are not surprising. A metric that was unexpected was "total donations to revenue," which topped the list in North America. Further, net employment creation in Asia indicates that businesses are expanding or shrinking, which can in turn affect CO₂ intensity during the transition.

5. Discussion

Understanding how metrics and management decisions affect CO₂ intensity would allow businesses to make decisions that can positively affect their future. The identification of the most important variables in extra-financial data can narrow the focus to a subset of key drivers, providing clarity on the factors that most significantly impact CO₂ emissions. This study aimed to answer the following research questions: What are the primary extra-financial variables linked to CO₂ intensity, and how can businesses use these insights to effectively reduce their carbon footprint? The objective of this research was to utilize AI, specifically the XGBoost algorithm, to identify these key variables and offer practical insights into managing corporate CO₂ emissions.

Three tests were conducted to achieve these objectives. By systematically analyzing three dimensions—general drivers, industry-specific factors, and geographic disparities—this study provides a comprehensive view of the determinants of CO₂ intensity. Consistently throughout the tests, some redundant themes emerged as the key drivers of CO₂ intensity in corporations based on XGBoost.

The first test focused on identifying the drivers of CO₂ emissions relative to revenue across businesses. This analysis revealed that resource use

Table 2
Result of CO2 Intensity by Industry

Communication Services		Consumer Discretionary		Consumer Staples		Financials		Energy	
Model accuracy score: 0.6667 Shape : (120, 36)		Model accuracy score: 0.7234 Shape : (234, 36)		Model accuracy score: 0.6258 Shape : (182, 36)		Model accuracy score: 0.8378 Shape : (369, 36)		Model accuracy score: 0.8947 Shape : (95, 36)	
F-score		F-score		F-score		F-score		F-score	
Total Energy Use To Revenues USD in million	15*	Total Energy Use To Revenues USD in million	22*	Water Use To Revenues USD in million	19*	Water Use To Revenues USD in million	37*	Water Use To Revenues USD in million	30*
Water Use To Revenues USD in million	5*	Women Employees	18*	Total Renewable Energy To Energy Use in million	18*	Emission Reduction Target Percentage	36*	Total Energy Use To Revenues USD in million	27*
Number of Employees	3	Salary Gap	16	Total Energy Use To Revenues USD in million	17	Waste Recycling Ratio	25*	Women Employees	22*
		Average Board Tenure	16	Salary Gap	17	Total Senior Executives Compensation To Revenue...	21	Audit Committee Non-Executive Members	20
		Total Senior Executives Compensation To Revenue...	15	Waste Recycling Ratio	16	Salary Gap	20	Turnover of Employees	20
		Total Renewable Energy To Energy Use in million	14	Women Employees	14	Women Employees	18	Emission Reduction Target Percentage	17
		Total Donations To Revenues in million	13	Emission Reduction Target Percentage	13	Number of Employees	17	Trade Union Representation	12
		Water Use To Revenues USD in million	13	Number of Employees	12	Total Energy Use To Revenues USD in million	15	Independent Board Members	10

*: significant results



Table 2
Result of CO2 Intensity by Industry (Continued)

Health Care		Industrials		Information Technology		Materials	
Model accuracy score: 0.7949 Shape : (192, 36)		Model accuracy score: 0.7191 Shape : (363, 36)		Model accuracy score: 0.8043 Shape : (230, 36)		Model accuracy score: 0.8222 Shape : (224, 36)	
	F-score		F-score		F-score		F-score
Net Employment Creation	25*	Total Energy Use To Revenues USD in million	21*	Water Use To Revenues USD in million	39*	Total Energy Use To Revenues USD in million	41*
Total Energy Use To Revenues USD in million	22*	Total Renewable Energy To Energy Use in million	16*	Women Employees	25*	Water Use To Revenues USD in million	26*
Total Donations To Revenues in million	20*	Water Use To Revenues USD in million	16*	Total Energy Use To Revenues USD in million	21*	Total Renewable Energy To Energy Use in million	19*
Women Employees	19*	Women Employees	16*	Net Employment Creation	19	Women Employees	14*
Salary Gap	16	Net Employment Creation	12	Total Renewable Energy To Energy Use in million	19	Emission Reduction Target Percentage	12
Emission Reduction Target Percentage	11	Total Donations To Revenues in million	12	Turnover of Employees	13	Salary Gap	10
Total Renewable Energy To Energy Use in million	11	Emission Reduction Target Percentage	12	Average Training Hours	13	Trade Union Representation	6
Turnover of Employees	10	Salary Gap	10	Emission Reduction Target Percentage	13		

*: significant results

variables, particularly energy and water consumption, were the most significant predictors of CO2 intensity. The presence of women in the workforce was also highlighted, which was surprising. To explore this further, that is, understand the result of the variable "women employees," a second test was performed to analyze the dataset, but this time by segmenting CO2 intensity by industry sectors. This allowed the identification of sector-specific factors influencing emissions, demonstrating that energy-intensive industries, such as the industrial, information technology, and material industries, showed distinct patterns compared to other sectors. Finally, the third test examined CO2 intensity by geographic location. This test revealed that cultural and regional differences may play a role in the significance of certain ESG topics such as corporate philanthropy and gender diversity.

The themes that emerged consistently throughout the tests can be split into categories consisting of resources used, business practices, and human management. The resources used directly affect CO2 emissions (Murshed et al., 2021), and the results of previous tests showed that these variables are highly important for CO2 emission in business. The second theme is corporate philanthropy. Corporate philanthropy can be linked to CO2 emissions because businesses that actively manage their CSR or promote sustainable practices are more inclined to do better in terms of CO2 emissions (Kudlak, 2019). Finally, CO2 emissions affect variables related to human resources, such as hiring women employees and net employment creation.

5.1. Linkage between CO₂ Intensity and Resources Used

Most sectors and their businesses use resources such as water, electricity, and minerals in the production process. Therefore, the first theme that emerges is resources used, which comprises three important factors regarding the CO2 intensity of a business: energy used, renewable energy used, and water used. The most important group of variables linked to CO2 intensity across industries and worldwide is "energy usage." Energy used was highest in 7 of 9 industry sectors and 4 of the 5 continents tested. This result was expected, as it aligns

with the literature indicating that the energy sector is the largest producer of CO2. Energy is used to power operational and production processes, and can be directly converted into GHG emissions. The same logic applies to the "renewable energy is used" metric. Businesses that use renewable energy will have positive outcomes through lesser CO2 emissions (Murshed et al., 2021).

Water used can be seen as unrelated to CO2, but businesses that use more water generally use more resources and thus produce more CO2 (B. Du et al., 2022). Therefore, companies proven to be efficient in terms of water usage are generally more efficient with most of their resources. Technological innovation is the most effective method for reducing water use and businesses that use technological innovation generally have lower CO2 emissions (Du et al., 2022). The variables under the resources used are linked to the amount of activity present in the business and resource-intensive activities, and, as a result, produce more CO2.

Resource usage is a crucial variable influencing CO2 levels. Energy consumption remains a key determinant of a company's carbon intensity, supporting the existing literature that highlights the link between energy use and environmental harm. Thus, H1 (on resource usage) is validated. Consistent with H1, both total energy consumption relative to revenue and water usage relative to revenue were identified as primary predictors, indicating that increased dependence on essential resources is associated with elevated CO2 intensity.

5.2. Linkage Between CO2 Intensity and Corporate Philanthropy

Corporate philanthropy can be interpreted as a good business practice that goes beyond regulations and obligations. The variable "total donations to revenue" expresses the good intention of the business resulting from their voluntary action and the firm's intention to remain close to social value. Implementing corporate philanthropic strategies improves a company's environmental performance. Wang et al. (2008) and Trespeuch and Robinot (2023) have shown that up to a certain threshold, corporate philanthropy has a positive impact on a company's performance. Through donations, busi-

nesses express their awareness of an issue and are generally more aware of the other negative impacts they might have.

Globally, good business practices and philosophy, improving business relationships with society through donations, and reducing the pay gap between upper management and the workforce show business social value and the ambition to do better than their peers. Business actions toward giving to society or advocating equality can be genuinely undertaken to promote CSR or to remain competitive with their peers (Cha & Rajadhyaksha, 2021). The link between the variables in this category and the CO2 emissions of a business is the result of the good intentions of the business globally, positively affecting CO2 emissions.

Hence, corporate philanthropy correlates with CO2 emissions because companies that are aware of their environmental impact also consider their CO2 output. Thus, H2 (on corporate philanthropy) is confirmed. Corporate donations in relation to revenue show an important connection with CO2 intensity, and indicate a relationship between these two concepts. This relationship aligns with the notion that philanthropic activities are generally accompanied by lower emissions, although the effect size was less pronounced compared to that for resource intensity validated by H1.

5.3. Linkage Between CO2 Intensity and Human Resources

The management of human capital includes human resources within a company and the variables associated with employee satisfaction, development opportunities, diversity, and pay. Multiple internal social responsibility variables are found to have important links with CO2 intensity. Variables such as net employment creation can be explained as proxies for business growth. The hypothesis is that companies experiencing substantial growth, manifested through net employment creation, are likely to increase their operational scale and, consequently, their consumption of resources, thereby impacting their CO2 intensity. Nonetheless, the variable flagged most often in this study was the number of women employees in the workforce.

Women employees remained at the top of the

list, regardless of the tests conducted. Further tests conducted by industry confirm this trend. The results by country show that this variable was most important in Europe. It was expected that this variable would have a high score in North America and Europe, as both these regions are known to have good programs for women, such as child daycare and maternity leave. Unfortunately, these benefits are not universal in the United States, which could be one of the reasons why this variable did not score as high in the United States as in Europe. The inclusion of women employees as a top influential metric to CO2 intensity was not the initial expectation; the expectation was around another variable named “executive members’ gender diversity.”

“Executive members’ gender diversity” tracks the gender diversity in upper management. This variable did not reveal important results, regardless of previous studies (Bernardi & Threadgill, 2010; del Carmen Valls Martínez et al., 2022; Mehmood, 2022; Setó-Pamies, 2015) showing that women in executive positions are more prone to environmental and social considerations of their organization. Previous findings have indicated that having women in top management is linked to a clear enhancement in environmental performance. Yet, this study could not confirm whether increasing diversity within executive teams leads to better carbon intensity management. Consequently, H3 is rejected. This is likely because the statistical significance attributed to female participation in the model is being captured by women employees.

The variable of women employees emerged strongly in all the studies conducted in this research. This variable indicates the proportion of women employees in the workforce and remains important, especially in male-dominated industries. Based on the results of Test 2, it was observed that women play a crucial role in traditionally male-dominated sectors, including industry, information technology, and materials, for CO2 emissions. This interesting finding can be attributed to the fact that women are naturally inclined to take into consideration the interests of various stakeholders. This tendency can significantly improve the environmental considerations in these industries. Women have been found to be better than men in balancing the

performance-driven concerns of shareholders with the diverse interests of other stakeholders such as communities, employees, suppliers, and customers (Brammer et al., 2007; Harrison & Coombs, 2012). The centrality of stakeholder-oriented leadership is key for advancing eco-friendly initiatives, given that corporate sustainability endeavors strive to satisfy both direct stakeholders, such as investors, and indirect stakeholders, such as clients and local communities (Dyllick & Hockerts, 2002).

From a philosophical perspective, the ethics of care (Tronto, 2022) can help explain the effect of women employees in the workforce on business CO2 emissions. The ethics of care posits that moral decision-making is not solely a matter of applying abstract principles but involves a nuanced understanding of the specific needs and circumstances of individuals involved. This perspective contrasts with the individualism prevalent in many traditional ethical theories, which often prioritizes autonomy and impartiality. The ethics of care argues that ethical actions arise from an empathetic understanding of others' perspectives and needs, thus fostering a more compassionate and context-sensitive approach to moral dilemmas. This emphasis on care and connectedness shifts the ethical focus from abstract rights and duties to the concrete responsibilities and wellbeing of others. Moreover, the ethics of care (Tronto, 2022) highlights the importance of emotions in ethical deliberation. While traditional ethical theories often regard emotions as potential sources of bias, the ethics of care sees them as essential for understanding and responding to the needs of others. Empathy, compassion, and sensitivity to others' suffering play a crucial role in guiding moral actions and fostering ethical relationships.

The role of emotion and purpose reflected in women's morale could explain the link between CO2 intensity and the workforce. A simple understanding is that, statistically, women care more about others and results that are not monetary than men. It shows not only in their day-to-day ways of living but also their choices. According to this theory, women tend to be more concerned with environmental governance (Glass et al., 2015). Further, in line with the findings of Stern et al. (1993), women generally exhibit greater sensitivity toward the

interconnectedness of environmental degradation and individual well-being than men. This observation is further corroborated by research conducted by Andreoni and Vesterlund (2021) regarding the gender dynamics of altruistic behavior. This study revealed that women are more inclined to act altruistically when the cost of such actions is high, whereas men are more prone to altruism when the associated costs are low. Therefore, their participation in organizational decision-making could serve as a catalyst for environmentally conscious policies, ultimately leading to reduced emissions. It can be argued that corporations that demonstrate proactive gender diversity initiatives may be more vigilant in adhering to existing environmental regulations (Lu et al., 2019). As a result, women could choose to work in businesses that are more in line with their environmental values, and businesses with good management of their CO2 may attract more women, especially in male-oriented industries. However, further exploration is needed to establish causality, but this is consistent with previous links established by Konadu et al. (2022) and Streimikiene, (2023), who call for more research on the role of women in low carbon economy transition. Thus, H4 (on women's workforce representation) is confirmed. A noteworthy finding is the consistent importance of gender composition within the workforce. The percentage of female employees consistently emerged as a key variable influencing CO2 intensity, often surpassing other governance metrics. This indicates that companies with a higher proportion of women tend to exhibit lower carbon intensity, possibly reflecting a broader interest for them to work in organizations that perform well in terms of environmental performance.

5.4. International Social Responsibility: Implications

GHG emissions continue to become an important issue as climate change awareness continues to increase. Managers must consider CO2 emissions in addition to CSR practices in the current business climate. This awareness has been amplified by the COVID-19 pandemic (Tosun & Köylüoglu, 2022; Trespeuch et al., 2021), as people have realized the role of human development in the emergence of the pandemic (Barouki et al., 2021). From a manage-

rial perspective, the insight of the current research allows decision makers to understand how various practices can impact CO2 emission intensity. Furthermore, it enables the measurement of practices and ranks in importance the hundred extra-financial variables available, which allows us to focus on a subset of available data highly linked to CO2 emissions.

Resources used is the most important group of variables affecting CO2 emissions. This theory is widely accepted, particularly regarding the energy consumption of businesses, which is generally produced from non-reusable sources (Murshed et al., 2021). Workforce gender diversity is another indicator that can be measured and tracked, with a significant relationship between emissions intensity and business impact. Research has shown that women are more interested in working in positive environments and in businesses with socially responsible objectives (Konadu et al., 2022), especially in male-oriented industries. Finally, businesses that engage in corporate philanthropy and, more broadly, promote social value externally through donations or internally by reducing the pay gap are more likely to achieve improved CO2 emissions performance. Corporate philanthropy allows businesses to express their values and shape their social profiles (Polonsky & Jevons, 2009). Reducing CO2 emissions is an additional benefit of the broader inclusion of CSR values in the business DNA.

The results demonstrate that resource-use metrics, particularly energy and water consumption, are the most significant predictors of CO2 intensity. This finding is consistent with existing literature, which underscores the role of resource efficiency, especially energy use, in mitigating corporate carbon emissions. The analysis revealed a significant correlation between gender diversity within an organization and its carbon intensity, warranting further exploration to establish causality. This finding implies that companies that prioritize diversity may demonstrate a broader pattern of socially responsible behavior. This also suggests a complex relationship between social factors and environmental performance, indicating that diversity may play a role in promoting sustainable corporate behavior. Finally, firms that actively engage in philanthropic

activities or demonstrate a broader commitment to societal well-being also exhibit superior environmental performance, suggesting synergy between socially responsible behavior and sustainability outcomes.

This study has some limitations. Feature selection cannot identify missing variables that would better explain the outcome. In addition, variables with the same F-score are equally important for the model. In addition, the F-score method may not consider the combined effects of the variables on the target variable. Therefore, two variables with low individual F-scores may significantly affect the target variable when considered together. Finally, the F-score method needs to be calibrated; although it can rank variables, it does not provide an absolute measure of their importance. It is crucial to exercise caution when interpreting F-scores and using other techniques to gain a more comprehensive understanding of variable importance. Further research is necessary to establish a causal link between the variables before generalizing the findings. Notwithstanding these limitations, the main contribution of this study is that it sheds light on a subset of variables for further exploration and causality research.

6. Conclusion

The objective of this research was to use AI to identify the most important and relevant extra-financial variables linked to CO2 emissions in a business. Through the feature selection process applied to a large dataset encompassing more than 600 extra-financial metrics, this study systematically identified the key drivers of CO2 intensity across diverse sectors and geographical regions. This study offers intriguing insights into the relationship between the CO2 emissions of companies and additional financial data. The most important variables are classified into the following themes: resources used, human resources, and corporate philanthropy.

This research provides a new perspective on business CO2 cause and management. Although the feature selection results must be interpreted and used cautiously, this technique makes it possible to find the most important variables for an outcome and rank them by relative importance. This provides a baseline for more research to explore other different variables

and the links between them. This would help reinforce the causality link and provide a clear understanding of the importance of these variables. Some links to the resources used and, to a certain extent, those related to corporate philanthropy, are easy to explain; however, there is a lack of literature on those related to the workforce. Nevertheless, this research provides a novel way to analyze the possible links between CO2 and business. For firms, efforts to reduce CO2 emissions should not only focus on optimizing resource use but also on the strategic incorporation of social governance practices, particularly those related to workforce diversity and corporate social engagement.

In conclusion, mitigating the adverse impacts of climate change is urgent and requires the identification of meaningful metrics upon which companies can act. Although the CO2 intensity metric is comprehensive, an understanding of its determinants is crucial. This study contributes to addressing this issue by providing a mathematical perspective of the situation through the lens of AI. The results have implications for business practitioners seeking to improve their sustainability efforts and for those seeking to establish more robust environmental governance frameworks. The complex relationship between governance and environmental metrics emphasizes the multifaceted nature of CSR that companies must manage. This suggests that companies with strong governance frameworks are likely to be better equipped to implement successful sustainability initiatives.

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