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The impact of ESG practices on Carbon emissions: Insights and evidence from the CAC40 ESG

L'impact des pratiques ESG sur les émissions de carbone : Perspectives et éléments de preuve issus des entreprises ESG du CAC40

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Abstract: This research examines the effects of sustainable investment practices on environmental regulation by assessing the impact of ESG criteria on carbon dioxide (CO_2) emissions. A rigorous literature review and modeling are carried on in order to determine the relationship between ESG criteria and CO_2 emissions. We use empirical data from the Refinitiv database concerning CAC40 ESG companies over the period 2010-2020 to determine the relationship between ESG criteria and CO_2 emissions across different economic sectors. The methodology includes statistical analyses such as maximum likelihood, principal component analysis and factorial analysis method to measure the impact of sustainability practices on environmental degradation. By integrating these various disciplinary aspects, our research offers valuable insights into how financial decisions can contribute to reducing environmental degradation and promoting a sustainable economy.

Keywords : CO_2 emissions ; Sustainability ; Environmental degradation ; Finance ; ESG Rating

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1. Introduction

1.1. Context and research problem

The growing importance of environmental, social and governance (ESG) criteria in investment decisions and corporate management is attracting increasing interest from academics and practitioners alike. Nowadays, companies are no longer assessed solely on their financial performance, but also on their environmental and social impact. This evolution takes on a particular dimension in the context of CO2 emissions regulation, where sustainability mechanisms are becoming essential. Some research indicates that companies integrating sustainable practices into their strategy can reduce their carbon emissions while improving their overall performance (Khalil and al, 2022).

In addition, ESG rating agencies have a significant role to play in assessing the sustainability of companies. These assessments have an impact on the behavior of investors and managers, which can lead to a reduction in greenhouse gas emissions (López and al, 2023). However, the extent of the real impact of ESG criteria on the regulation of CO2 emissions remains to be determined. Although numerous studies have established a positive correlation between ESG performance and reduction of CO2 emissions, few have investigated the mechanisms underlying this relationship (Qureshi and al, 2019).

The central issue of this article is therefore: **To what extent do sustainability mechanisms, and in particular ESG criteria, contribute to regulating CO2 emissions in companies?** To answer this question, our study draws on empirical data and in-depth analyses of ESG practices in various sectors. We aim to shed light on this dynamic, providing insights into the impact of ESG criteria on companies' environmental performance and their role in combating pollution. In this paper, we begin with a detailed literature review, followed by a rigorous methodology. We will then present the results of our analysis and discuss their implications.

1.2. The expected outcomes

At the conclusion of this study, we anticipate obtaining interesting and significant results that will contribute to our understanding of the relationship between ESG ratings and CO2 emissions among companies listed on the CAC40 ESG index. By analyzing CO2 emissions data alongside ESG ratings, we aim to elucidate the correlation between companies sustainability practices and their environmental impact, as manifested through carbon dioxide emissions. This analysis has the potential to reveal patterns and trends that could inform investors and policymakers about the effectiveness of ESG criteria in mitigating environmental degradation. Additionally, we expect to uncover valuable insights into the role of corporate governance, social responsibility, and environmental management in shaping companies' carbon footprint. Ultimately, we hope that our findings will contribute to the ongoing discourse on sustainable business practices and provide practical guidance to decision-makers seeking to promote greater environmental responsibility within corporate sectors.

2. Literature review:

2.1. Relationship between ESG ratings and CO2 emissions: empirical foundations

In recent years, with the development of ESG factors, researchers have attached significant importance to developing the mechanism for integrating ESG factors into companies' business models (Cong and al, 2022). As a result, the concept of ESG factors needs to be precisely identified to understand its theoretical relationship with environmental degradation. Nowhere in the literature can we find a universally determined definition for the notion of ESG factors, which bring together environmental, social, and governance considerations (Alsayegh and al, 2020). Nevertheless, research (e.g. Hadiq and al, 2023) has shown that integrating ESG factors into organizations' business models could have a significant and positive impact on both environmental and economic performance. In addition, the current lack of universal definitions of ESG factors is an obstacle to the alignment of investment portfolios with sustainable development objectives relating to the natural environment and the effective management of energy transition risks (Alessi and al, 2022).

It is also worth noting that the emergence of ESG factors is the result of growing environmental concerns, such as climate change. Consequently, investors have attached increasing importance to ESG factors, which had an impact on organizations involved in environmental protection. In addition, environmental degradation is one of the major global problems (Desta, 1999; Aggrey and al, 2010, Tyagi and al, 2014) (quoted in Tuna, et al, 2023). Under the Paris Agreement, signed in 2015, adhering countries with rigorous climate policies are required to take action to reduce climate change and environmental degradation. Environmental deterioration is mainly due to greenhouse gas emissions consisting of CO2, methane, and nitrous oxide, the use of fertilizers, and fossil fuels such as coal, oil, and gas used by businesses.

At the same time, the sustainability concept requires companies to keep their CO2 emissions below an acceptable tolerance threshold. However, in our view, this tolerance could have negative effects on air quality and the environmental performance of organizations. Nevertheless, (Nguyen and, 2020) predict that an immediate suspension of CO2 emissions could negatively affect the performance of organizations. Therefore, the reduction of CO2 emissions by companies requires major reforms in their production and distribution strategies (Kump, 2021). At this stage, the integration of ESG factors aims to gradually push companies towards more responsible actions by addressing the concerns of all stakeholders. Thus, in recent years, companies have responded strongly to the Paris Agreement, which emphasizes the need to integrate ESG criteria to combat the effects of environmental degradation stemming mainly from CO2 emissions (Hoang, 2023).

The existing literature is still rather poor when it comes to determining the effects of ESG integration on CO2 emissions. For example, (Tuna and al, 2023) focus on the relationship between ESG funds and environmental degradation, mainly with regard to CO2 emissions. They examine the impact of ESG funds on CO2 emissions and economic activities. Their results show that there is no direct relationship between ESG funds and environmental degradation. Interestingly, the authors use a VAR model and causality tests to analyze the relationship between CO2 emissions, ESG fund prices and trading volume, and conclude that CO2 emissions values do not significantly explain variations in ESG funds.

On the contrary, (Cong and al. 2022) also investigated the relationship between ESG investments and carbon emissions in China. They specified in their findings that investments incorporating ESG factors have a significant and negative impact on CO2 emissions. This negative relationship suggests that an increase in ESG factor measurement units will result in a decrease in CO2 emission measurement units. More precisely, the authors results indicate that a 1% increase in ESG investments systematically leads to a decrease of 0.246% in CO2 emissions and a decrease of 0.558% in carbon emission intensity.

Other empirical studies indicate that higher ESG ratings are associated with lower carbon emissions. For example, (Yang and al, 2024) shows that a 1% increase in ESG scores correlates with a 0.076% decrease in carbon emissions, demonstrating a direct effect of ESG performance on CO2 emissions. This conclusion is supported by (Kong and al, 2024), who identifies a non-linear relationship between ESG performance and carbon emissions, uncovering that regions with greater availability of green credit experience a decline in emissions as ESG scores improve. In addition, the study by (Garifullina and al, 2024) suggests that carbon capture and utilization technologies can help companies meet their ESG objectives while reducing emissions. Integrating these technologies into corporate strategies not only improves ESG ratings, but also contributes to significant reductions in Scope 1, 2 and 3 emissions.

Indeed, (Zhang and al, 2023) indicates that carbon emissions trading policies could improve ESG performance, thereby facilitating emissions reductions. Additionally, (Cong and al, 2022) findings reveal that a 1% increase in environmental investments leads to a 0.246% decrease in CO_2 emissions, underscoring the financial benefits of ESG-focused investments. This is especially relevant in the light of growing investor awareness and demand for sustainable practices, as discussed in the wider literature on ESG investing (Jinga, 2022).

3. Methodology

Our study was conducted using panel data to analyze longitudinal observations from 2010 to 2020. This approach enables us to examine variations across time and individual effects within companies. The analysis was carried out using R software, which offers robust tools for handling complex data. This methodology enables us to better understand the relationships between variables, while considering the specificities of each company over time. By using panel data, we aim to provide precise, relevant answers to our research problem.

3.1. Analysis Framework

Our analysis focuses on studying the relationship between ESG ratings and CO_2 emissions, which represent the primary cause of environmental degradation. Therefore, we must rigorously apply appropriate measures to each binomial component in question. In this regard, we follow the studies conducted by (Tuna, and al, 2023), (Sarkodie and al, 2020) (Cong and al, 2022), which reflect ESG ratings as an indicator of measuring sustainable development practices, as well as environmental degradation represented by CO_2 emissions following the model of (Shahbaz, and al, 2019); (Kang, and al, 2016) (Ulucak and al, 2017).

In this study, a rigorous methodology was employed to analyze the data. First, a data cleaning process was conducted to eliminate outliers and errors. Next, winsorization was applied to mitigate the impact of extreme values on the analysis. The data was then standardized using a centered reduced matrix, allowing for a fair comparison between variables with different units of measurement.

Subsequently, a principal component analysis (PCA) was performed to reduce the dimensionality of the data while preserving essential information. A factor analysis followed this step to identify underlying relationships between the variables. Finally, a maximum likelihood estimation was used to evaluate the model. This approach enabled us to draw robust conclusions about the relationships between the variables of interest.

2.2. Data provider

This document aims to determine the relationship between ESG ratings and CO2 emissions, which constitute the primary cause of environmental degradation. To achieve this, we obtained the necessary data from the **Refinitiv database** including in particular data on CO2 emissions and ESG variables. For control variables, we utilized the Euronext database to identify companies' activities, calculate their size, and compute Return on Assets (ROA) and Return on Equity (ROE). The sample for this study comprises European companies listed on the CAC40 ESG. The chosen period for this study is longitudinal, spanning from 2010 to 2020. The methodology employed for this study will involve statistical analyses such as regression using various models, principal component analysis, and factor analysis method to explore the precise relationship between ESG scores and CO2 emissions. The findings of this study will contribute to a better understanding of the significance of sustainable development practices in mitigating environmental degradation, which could have significant implications for investors and policymakers.

2.3. Dependent variable

2.3.1. CO2 Emission: reflecting environmental degradation

This analysis will be based on CO2 emissions data for each company in the CAC40 ESG index (Badi H and al, 2019) (Hoang, H. V, 2023) (Johnson, J. A and al, 2022). This type of data, revealing the environmental degradation caused by the activities of these companies, will be rigorously incorporated into our research methodology. By integrating these quantitative measures, we aim to provide a scientifically robust assessment of the environmental impact associated with these companies' activities.

2.4. Independent variables

2.4.1. ESG rating end environmental score

Sustainability rating is a key instrument enabling investors and stakeholders to assess a company's performance in the area of sustainable development. It assesses a firm's practices concerning environmental, social, and governance factors, which are essential to the company's long-term success and value creation. The environmental factors include the company's impact on the natural environment, such as greenhouse gas emissions, water use, waste management, and biodiversity. In addition, social factors evaluate the company's relationships with its employees, customers, suppliers, and communities, including human rights, diversity and inclusion, labor standards, and community involvement. For Governance, we evaluate the company's internal controls, risk management, board structure, and executive compensation. As part of our research, we use ESG scores to measure the sustainability assessment of companies in the CAC40 ESG index.

2.5. Control variables

In accordance with the literature (Tuna and al, 2023), we use ROA determined by the combination of net profit/total assets, ROE calculated by the formula net profit/total equity, company size measured by the natural logarithm of the company's total assets, and GDP to control economic growth due to co2 emissions.

2.6. Econometric modeling

The relationship between ESG rating and environmental degradation represented by CO2 emissions, as well as its control variables (CVs), is based on the multiple non linear regression model “maximum likelihood estimation” presented below:

$$\mathbf{logL(\beta) = i = 1\sum n(-21log(2\pi) - log(\sigma) - 2\sigma 2(EMCO2i - f(Xi, \beta))2)}$$

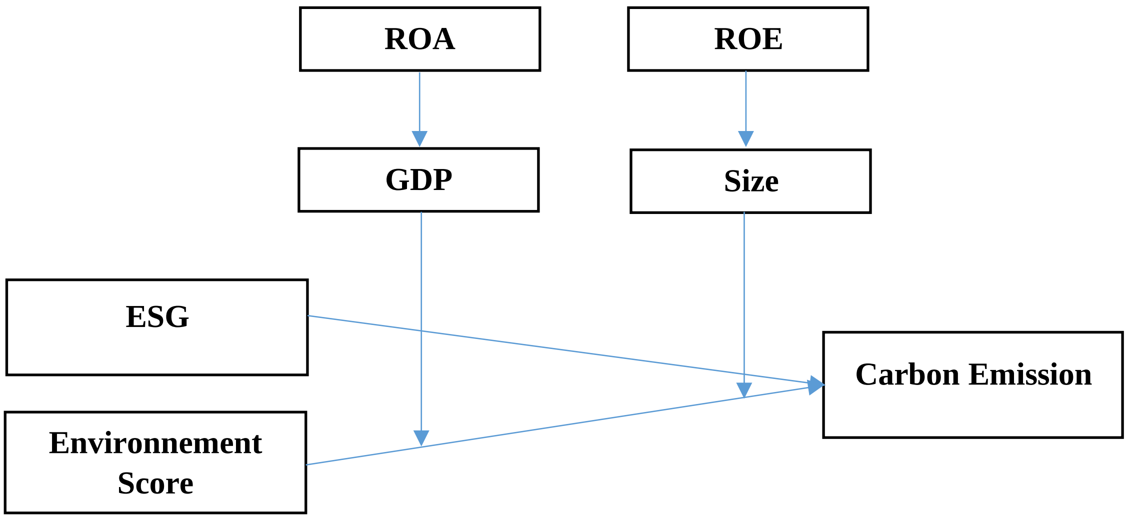
Where :

- **β**: vector of model parameters
- **σ. Sigma** : standard deviation of the residual error.
- **F (Xi,β) f (X_i, \beta) f (Xi,β)**: prediction function based on the explanatory variables and the model parameters.

2.7. Research model

In our article, we attempt to study the relationship between ESG scores and the CO2 emissions of CAC40 ESG-listed companies. This objective is part of the evaluation of the effect of responsible investment on environmental degradation. Accordingly, in line with the models in (Cong and al, 2022); (Tuna, and al. 2023); (Sarkodie and al, 2020), we present our research model as follows:

Figure 1: Research model



Source: compiled by us

3. Analysis and discussion of results

3.1. Preliminary statistical analysis

3.1.1. Descriptive statistics

Preliminary tests on the normality of the data revealed that they do not follow a normal distribution. This led to the selection of more suitable methods, including maximum likelihood estimation and principal component analysis. As indicated by the results presented in **(Table 1)** of the descriptive statistics, the ESG score has a mean of 68.54 and a standard deviation of 15.71, indicating a moderate dispersion around the median of 70.77. The E variable exhibits a higher mean of 77.17, with a similar moderate dispersion. Financial performance, measured by ROA and ROE, displays means of 0.04 and 0.12, respectively, accompanied by high coefficients of variation, suggesting notable variability. Company size shows a mean of 10.26

with a low coefficient of variation, indicating a low dispersion. Carbon emissions are particularly high, with a mean of 6.99 million and a very large standard deviation, highlighting significant variability. Finally, the CRPIB presents a mean of 0.61 and a high coefficient of variation, demonstrating a wide dispersion of values.

Table 1: descriptive statistics

Variable	Mean	Standard deviation	Median	Minimum	Maximum	IQR	CV
ESG	68.54	15.71	70.77	16.32	97.73	14.37	0.23
E	77.17	16.53	81.41	27.58	99.14	14.77	0.21
ROA	0.04	0.05	0.04	-0.21	0.42	0.03	1.25
ROE	0.12	0.11	0.11	-0.36	0.91	0.06	0.92
Size	10.26	1.17	10.29	7.06	16.38	0.97	0.11
EM.CO2	6,990,605.60	20,027,537.27	723,500.00	55,800	156,899,254	866,579.70	2.86
CRPIB	0.61	2.64	1.10	-7.50	2.30	1.19	4.33

Source: compiled by us using R software

In addition, the results of the winsorization process, as presented in **(Table 2)**, demonstrate the efficacy of this method in mitigating the effects of extreme values in our dataset, thereby yielding a more accurate and reliable representation. For instance, the ESG_winsorized score exhibits a mean of 68.67 with a moderate dispersion (CV = 0.22), and the median remains stable at 70.77. Similarly, the E_winsorized variable displays a mean of 77.22 with a low dispersion (CV = 0.21).

With regard to financial performance, winsorization has enabled the reduction of variability in ROA and ROE, with coefficients of variation of 0.75 and 0.64, respectively, indicating a decrease in dispersion. The size of the companies remains homogeneous, with a CV of 0.10, while the variability of CO2_winsorized emissions has also been reduced (CV = 1.28), although the median remains at 723,500. The interquartile range (IQR) has decreased for several variables, indicating a homogenization of the data. This approach has allowed us to neutralize the impact of aberrant values, thereby ensuring more robust and relevant results for analysis.

Table 2: descriptive statistics after winsorization

Variable	Mean	Standard deviation	Median	Minimum	Maximum	IQR	CV
ESG_winsorized	68.67	15.35	70.77	29.30	97.73	14.37	0.22
E_winsorized	77.22	16.40	81.41	36.11	99.14	14.77	0.21
ROA_winsorized	0.04	0.03	0.04	-0.03	0.11	0.03	0.75
ROE_winsorized	0.11	0.07	0.11	-0.06	0.28	0.06	0.64
Size_winsorized	10.23	1.02	10.29	7.61	12.65	0.97	0.10
EM.CO2_winsorized	2,406,250.96	3,069,844.22	723,500.00	55,800	8,195,848.12	866,579.70	1.28
CRPIB_winsorized	1.17	1.01	1.10	-1.35	2.30	1.19	0.86

Source: compiled by us using R software

3.1.2. Correlation

The correlation table below **(Table 3)** presents the relationships between the variables used to investigate the impact of sustainability on air pollution, measured by CO2 emissions. The primary explanatory variables are the ESG and environmental scores (E), while the other variables (ROA, ROE, company size, and GDP growth) serve as control variables.

Upon examining the correlations, we note that the dependent variable, CO2 emissions (EM_CO2_winsorized), exhibits a weak negative correlation with the ESG score (-0.196) and the environmental score (-0.021). This suggests that improvements in ESG and environmental performance are associated with modest reductions in CO2 emissions, although the effect of the environmental score is nearly negligible.

The explanatory variables (ESG and E) display a moderate correlation of 0.454, but this value remains sufficiently low to avoid serious multicollinearity issues. The company size is positively correlated with the environmental score (0.378), indicating that larger companies tend to have better environmental performance. However, this correlation does not directly interfere with the dependence of the variable EM_CO2.

The other control variables (ROA, ROE, and CRPIB) show acceptable correlations among themselves and with the explanatory variables, but none of these correlations is particularly concerning. This allows us to conclude that the chosen explanatory variables are largely independent, and the results of econometric models should be able to isolate the impact of sustainability on CO2 emissions without significant risk of multicollinearity.

Table 3: Correlations

	ESG_win	E_win	ROA_win	ROE_win	Size_win	EM_CO2_win	CRPIB_win
ESG_winsorized	1	0.454*	-0.002	-0.092	0.196	-0.196	-0.100
E_winsorized	0.454*	1	-0.224	-0.207	0.378*	-0.021	-0.050
ROA_winsorized	-0.002	-0.224	1	0.725***	-0.290	-0.159	0.206
ROE_winsorized	-0.092	-0.207	0.725***	1	-0.213	-0.156	0.237
Size_winsorized	0.196	0.378*	-0.290	-0.213	1	0.044	-0.081
EM_CO2_winsorized	-0.196	-0.021	-0.159	-0.156	0.044	1	-0.144
CRPIB_winsorized	-0.100	-0.050	0.206	0.237	-0.081	-0.144	1

Source: compiled by us using R software

3.2. Advanced analytical techniques

3.2.1. Principal component analysis (PCA)

The principal component analysis (PCA) presented in **(Table 4)** reveals that the first two dimensions collectively explain 54.60% of the total variance in the data. The first dimension (Dim.1) captures 33.12% of the variance, with an eigenvalue of 2.32. This dimension is primarily influenced by ROA_winsorized (cos2 = 0.681) and ROE_winsorized (cos2 = 0.679), indicating that financial performance plays a crucial role in this dimension.

Table 4: Eigenvalues PCA

Component	Variance	Percentage of Variance	Cumulative Percentage
Dim.1	2.318	33.12%	33.12%
Dim.2	1.504	21.48%	54.60%
Dim.3	1.024	14.63%	69.23%
Dim.4	0.794	11.34%	80.57%
Dim.5	0.682	9.74%	90.31%
Dim.6	0.486	6.94%	97.25%
Dim.7	0.193	2.76%	100%

Source: compiled by us using R software

The second dimension (Dim.2), which explains 21.48% of the variance, has an eigenvalue of 1.50 and is strongly associated with ESG_winsorized (cos2 = 0.541) and E_winsorized (cos2 = 0.308). This suggests that sustainability scores contribute significantly to the explanation of environmental effectiveness, particularly with regard to CO2 emissions.

The third dimension (Dim.3), with an eigenvalue of 1.04, explains 15.76% of the variance and is primarily influenced by CRPIB_winsorized (cos2 = 0.675) **(Table 5)**, highlighting the importance of economic fluctuations on CO2 emissions.

This eigenvalue analysis indicates that the three first dimensions are sufficient to explain a significant proportion of the total variance (69.23%), which justifies their use to interpret the results.

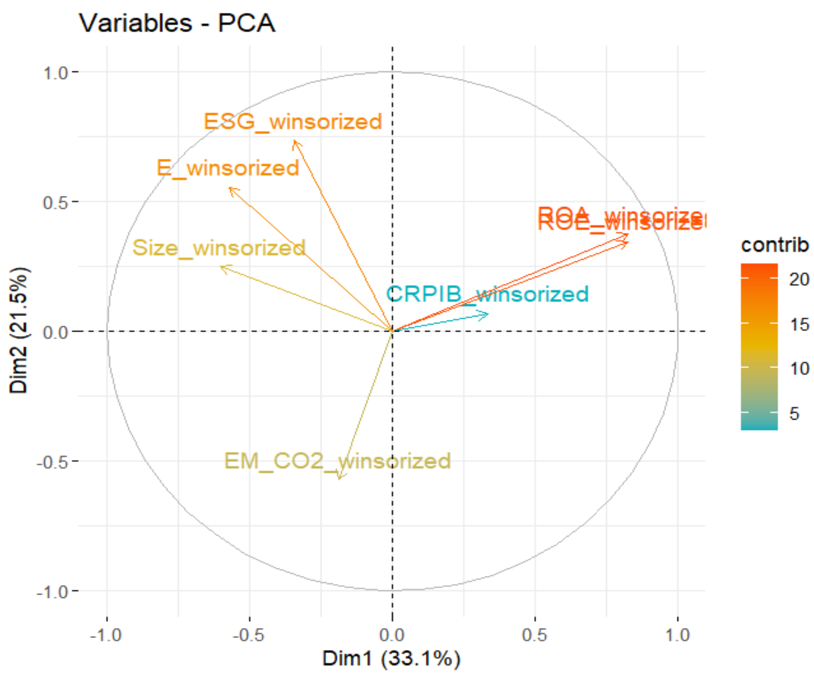
Table 5: The dimension of information derived from variables

Variable	Dim.1 (33.12%)	Cos2 (Dim.1)	Dim.2 (21.48%)	Cos2 (Dim.2)	Dim.3 (14.63%)	Cos2 (Dim.3)
EM_CO2_winsorized	-0.188	0.035	-0.572	0.327	0.405	0.164
ESG_winsorized	-0.347	0.120	0.736	0.541	-0.105	0.011
E_winsorized	-0.573	0.328	0.555	0.308	0.225	0.051
ROA_winsorized	0.825	0.681	0.375	0.140	0.034	0.001
ROE_winsorized	0.824	0.679	0.345	0.119	0.085	0.007
Size_winsorized	-0.603	0.363	0.250	0.063	0.339	0.115
CRPIB_winsorized	0.334	0.112	0.070	0.005	0.822	0.675

Source: compiled by us using R software

According to the results presented in **(Figure 2)**, the low correlations between the independent variables confirm the lack of multicollinearity, which increases the validity of the results. These results show that financial and sustainability aspects, as well as economic growth, are determining factors in the management of CO2 emissions.

Figure 2: PCA results graph



Source: compiled by us using R software

3.2.2. Factor analysis

The results obtained using the R software, presented in **(Tables 6)** confirm significant relationships between the factors and variables analyzed. The ROA_winsorized (0.76) and ROE_winsorized (0.85) scores, with high positive loadings on MR1, indicate a strong correlation between company profitability and this factor. In contrast, ESG_winsorized (-0.19) exhibits a low loading, suggesting that profitability is not directly linked to ESG criteria.

The second factor, MR2, shows a high loading of ESG_winsorized (0.86), highlighting a strong association with ESG sustainability practices. This correlation is crucial for studying the impact of sustainability on CO2 emissions. For MR3, the loadings of E_winsorized (0.63) and Size_winsorized (0.59) indicate a relationship between company size and environmental performance. Regarding model fit indices, the TLI (1.005) and RMSEA (0) indicate excellent model fit. The variance explained by the three factors is 50%, reinforcing the validity of the model.

The h^2, u^2, and Com indicators show that ESG_winsorized has a communality of 0.885, indicating that 88.5% of its variance is explained by the factors. The u^2 of 0.115 shows that only 11.5% of the variance remains unexplained. The complexity of variables, such as

ROA_winsorized (1.8) and ROE_winsorized (1.3), reveals that they are influenced by multiple factors, which reinforces the importance of multidimensional analysis for understanding the impact of sustainability on pollution.

Table 6: Factor loadings and explained variance

Variable	MR1	MR2	MR3	h^2	u^2	Com
ESG_winsorized	-0.19	0.86	0.34	0.885	0.11	1.4
E_winsorized	-0.10	0.25	0.63	0.470	0.53	1.4
ROA_winsorized	0.76	0.30	-0.36	0.798	0.20	1.8
ROE_winsorized	0.85	0.19	-0.27	0.827	0.17	1.3
Size_winsorized	-0.13	-0.03	0.59	0.363	0.64	1.1
CRPIB_winsorized	0.28	-0.07	0.00	0.086	0.91	1.1
EM_CO2_winsorized	-0.14	-0.27	0.02	0.092	0.91	1.5

Factor	SS Loadings	Proportion of Variance	Cumulative Variance	Proportion Explained	Cumulative Proportion
MR1	1.46	0.21	0.21	0.41	0.41
MR2	1.00	0.14	0.36	0.28	0.72
MR3	1.06	0.15	0.50	0.30	1.00

Source: compiled by us using R software

3.2.3. Likelihood estimation non linaire regression

Following the non-normality of the data, maximum likelihood estimation was used to obtain more robust results. The results, presented in **(Tables 7 and 8)**, show significant relationships between the variables studied and CO2 emissions.

The coefficient of ESG_winsorized (-0.2162) indicates that a one-point improvement in ESG score would lead to a 0.2162 tonne reduction in CO2 emissions, all else being equal (**Table 7)**. This result, with a p-value of 0.0001, confirms the impact of ESG sustainability practices on emissions reduction. However, it could mean that, in some cases, alignment with ESG criteria does not directly reduce emissions. This could indicate a potential case of greenwashing, or a delay between the adoption of ESG criteria and their actual impact on emissions.

Table 7 : Non-linear regression results (GLS)

Coefficient	Value	Erreur Std.	t-value	p-value
Intercept	0.0000	0.0484	0.0000	1.0000
ESG_winsorized	-0.2162	0.0557	-3.8852	0.0001
E_winsorized	0.0329	0.0583	0.5653	0.5722
CRPIB_winsorized	0.0442	0.0501	0.8825	0.3780
ROA_winsorized	-0.0580	0.0831	-0.6982	0.4855
ROE_winsorized	-0.1779	0.0812	-2.1910	0.0290
Size_winsorized	-0.0160	0.0544	-0.2938	0.7690

Source: compiled by us using R software

In contrast, E_winsorized (0.0329) shows a positive but insignificant effect, with a p-value of 0.5722, suggesting that this variable has no direct influence on CO_2 emissions. Furthermore, CRPIB_winsorized (0.0442) shows no significant link between GDP growth and emissions, with a p-value of 0.3780. However, this may reflect a trend often observed in developing countries, where economic growth is accompanied by an increase in polluting industrial activities.

The results for the financial variables show that ROA_winsorized (-0.0580) is not significant (p-value of 0.4855), while ROE_winsorized (-0.1779) displays a significant negative relationship (p-value of 0.0290), indicating that companies with higher ROE tend to reduce their CO_2 emissions. In contrast, Size_winsorized (-0.0160), with a p-value of 0.7690, has no significant effect on emissions.

Model fit criteria, such as AIC (1102.626) and BIC (1134.477) **(Table 8)**, confirm the model's good fit to the data. The residual standard error of 0.9541 is acceptable, with a sufficient number of 389 residual degrees of freedom.

Table 8: Reliability indicators and model adjustment

Indicator	Value
Chi-Square (empirique)	2.08
p-value (empirique)	< 0.56
RMSEA	0
90% CI RMSEA	[0, 0.079]
Tucker Lewis Index (TLI)	1.005
Root Mean Square of Residuals (RMSR)	0.01
df Corrected RMSR	0.03
Multiple R Square of Scores with Factors	MR1 : 0.80, MR2 : 0.85, MR3 : 0.57
Minimum Correlation of Possible Factor Scores	MR1 : 0.60, MR2 : 0.69, MR3 : 0.14
AIC	1102.626
BIC	1134.477
logLik	-543.3131
BIC (Factor Analysis)	-15.43
Résidu standard error	0.9541
Degrés de liberté total	396
Degrés de liberté résiduel	389

Source: compiled by us using R software

3.2.4. Statistical test

The results of the collinearity analysis using R software, presented in **(Tables 9)**, show that the variables in the model have acceptable VIF indices. The variables ESG_winsorized (VIF =

1.320), E_winsorized (VIF = 1.448), and CRPIB_winsorized (VIF = 1.070) display values well below the critical threshold of five, indicating low collinearity between these variables and the others. The VIFs of ROA_winsorized (2.946) and ROE_winsorized (2.808) are moderate, without suggesting problematic collinearity. The variable Size_winsorized (VIF = 1.262) is also well below this threshold. These results confirm that the variables selected in the model do not exhibit excessive collinearity, and allow a robust interpretation of the effects on CO2 emissions.

Furthermore, the results presented in **(Tables 9)** show that the elasticity of ESG_winsorized is 0.00288. This means that a 1% increase in ESG score leads to a 0.00288% increase in CO2 emissions. This low elasticity may suggest that the direct impact of ESG criteria on emissions reduction is limited, confirming the results of the research model.

On the other hand, the elasticity of E_winsorized is higher, at 0.02599. This indicates that environmental performance has a stronger influence on emissions. A 1% increase in this score would lead to a 0.02599% increase in emissions. This could suggest that there is an underlying relationship, even if the results of the previous model show a weak relationship. Secondly, CRPIB_winsorized has an elasticity of 0.01849, revealing an underlying positive correlation between economic growth and CO2 emissions. This confirms the trend observed in many developing economies, where GDP growth is associated with an increase in polluting activities.

In addition, financial variables such as ROA_winsorized (-0.00377) and ROE_winsorized (0.00438) show a moderate effect, but with a slightly opposite influence for ROA, which may indicate that profitability does not have a significant impact on CO2 emissions. Finally, the elasticity of Size_winsorized is low, at 0.00183, showing that company size has a negligible effect on emissions. These results point to a complex relationship between sustainability, economic growth and CO2 emissions.

Table 9: Table of VIF values and elasticity tests

Variable	VIF	Elasticity
ESG_winsorized	1.320	0.00288
E_winsorized	1.448	0.02599
CRPIB_winsorized	1.070	0.01849
ROA_winsorized	2.946	-0.00377
ROE_winsorized	2.808	0.00438
Size_winsorized	1.262	0.00183
Intercept	-	-2.49e-17

Source: compiled by us using R software

4. Discussion and conclusion

This study started with a rigorous data cleaning process. Non-normality tests were applied to assess the distribution of variables. The results showed that several variables had non-normal distributions. To resolve these issues, relevant methods were selected, including Winsorization, which eliminated outliers, Principal Component Analysis, Factor Analysis and Maximum Likelihood. This step is fundamental to the integrity and validity of the analyses that follow.

The purpose of this study is to explore the impact of sustainable practices on air pollution, as measured by CO_2 emissions. The results obtained through principal component analysis (PCA) and factor analysis show that both environmental and social dimensions are essential for understanding the dynamics of CO_2 emissions.

Using the PCA method, we were able to reduce the complexity of the data while retaining 54.60% of the variance. This reduction is significant and indicates that the ESG_winsorized and E_winsorized variables play a central role in achieving environmental performance. In particular, the first dimension (Dim.1), which explains 33.12% of the variance, is strongly associated with profitability indicators such as ROA and ROE. This suggests that companies that adopt sustainable practices not only reduce their CO_2 emissions, but also improve their financial profitability. This link between sustainability and financial performance is crucial for investors seeking to balance profitability and social responsibility.

The second dimension (Dim.2), accounting for 21.48% of variance, shows a strong correlation with ESG and E scores. These results underline the importance of environmental and social initiatives in reducing CO_2 emissions. Those companies that invest in sustainable practices appear not only to improve their environmental impact, but also to consolidate their market position. This paves the way for investment strategies that incorporate sustainability criteria, offering investors opportunities to support companies with a positive impact on the environment.

In a similar way, eigenvalue analysis revealed that the first component is predominant, with a value of 2.318, while the other components (Dim.2 and Dim.3) follow with values of 1.504 and 1.024 respectively. These values indicate that the first dimensions capture most of the information relevant to the analysis of the impact of Sustainability. In other words, sustainable practices have a direct and measurable effect on CO_2 emissions, which is fundamental to understanding how these variables interact in a sustainability- oriented economy.

However, the impact of GDP growth (CRPIB_winsorized) on CO_2 emissions deserves particular attention. The results indicate that economic growth can have contradictory effects. At one level, increased growth can generate higher emissions, but at another level, if this growth is accompanied by sustainable initiatives, it is possible to achieve a reduction in emissions. This suggests that decision-makers need to consider sustainability as a central factor in economic development. Consequently, this study makes an essential contribution to knowledge by providing empirical evidence on the need to integrate ESG dimensions into investment decisions.

4.1. Points to consider include

- **The central role of sustainable practices:** ESG and E-scores are key indicators influencing companies environmental performance. In fact, companies that actively engage in sustainable practices can reduce their CO_2 emissions.
- **Advanced interactions:** The interaction between profitability (ROA and ROE) and sustainability indicators reveals potential synergies. Those companies that improve their sustainability benefit from a positive corporate image and increased attractiveness to investors.
- **Policy implications:** The results underline the importance of adopting investment strategies that take ESG factors into account. Investors should focus on companies that implement sustainable practices to maximize both financial performance and positive environmental impact.

- **Economic and environmental impact:** Analysis shows that sustainability and economic growth are not mutually exclusive. An integrated approach, linking growth and sustainability, could benefit both companies and society as a whole.

5. Contributions to the knowledge base

This study contributes to the literature on sustainable finance by providing empirical evidence on the impact of sustainable practices on CO_2 emissions. It highlights the importance of ESG scores as indicators of environmental performance. By quantifying the effect of sustainability, this research offers innovative perspectives for investors and decision-makers.

Moreover, by establishing the link between profitability and sustainable practices, this study encourages companies to integrate environmental and social criteria into their strategies. The results call for an evolution in investment practices and a heightened awareness of environmental issues in the financial sector.

Finally, this research suggests a model that could be used for other studies on corporate sustainability and performance. By integrating financial and environmental data, researchers can better understand the complex dynamics underlying corporate performance in a sustainable context.

6. Future perspectives

In this context, the generalizability of the results could be enhanced by extending the sample to other sectors and geographical regions in the future. In addition, a pertinent research question concerns the influence of regulatory changes on companies' commitment to sustainability. This could open up new areas of study. It would highlight the need for public policies that promote the integration of sustainability into business practices. Future research should explore how these policies can encourage companies to adopt more sustainable and responsible strategies.

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