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Relationship between greenhouse gas emissions and accounting variables according to the Environmental Kuznets Curve Hypothesis

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Abstract

Objective: Considering that entities' activities are reflected and represented in their financial-accounting statements, this study aimed to analyze the relationship between greenhouse gas emissions and the entities' operating income and the accounting variables net intangible, amortization, net property, plant and equipment, depreciation, and research and development (R&D), considering the environmental Kuznets curve.
Method: The sample comprises 682 companies from 40 countries belonging to 11 different sectors, which have disclosed their scope 1 greenhouse gas emissions from 2012 to 2019 in the Thomson Reuters Refinitiv Eikon database.
Results: The results found by panel regression indicate a relationship between greenhouse gas emissions, as predicted by the Environmental Kuznets Curve Hypothesis (EKCH). These emissions graphically draw an inverted U-shaped curve, in which, due to the scale effect, there is an increase in greenhouse gas emissions as the entity's operating income increases. However, according to the composition effect, as companies use a greater amount of net intangibles and fewer net property, plant and equipment (captured by the "depreciation" variable), their emissions decrease. Nevertheless, with the technique effect, it was not possible to identify a significant relationship with greenhouse gas emissions.
Contributions: This understanding of the relationship between accounting variables and greenhouse gas emissions can help regulatory bodies in developing metrics and disclosure standards for climate-related business information, improving quality, comparability and their reliability. This fact can influence the assessment of the value of entities when considering the risks and opportunities related to their environmental impacts.

Keywords: Environmental Kuznets Curve, Greenhouse Gas Emissions, Accounting Variables

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Introduction

The risk factors brought about by anthropic actions on the environment, such as economic, financial, physical and reputational risks fuel growing discussions regarding the importance of companies adopting strategies to address global warming (Lima & Benke, 2021; Souza et al., 2018). Therefore, understanding the determinants of companies' actions to mitigate or adapt their environmental impacts helps contribute to their evidence process (De Faria et al., 2018).

There is a line of thought which holds that economic growth is essential for reducing environmental damage, even though companies can negatively impact the environment as their operations and results increase. Due to social, legal, or market pressures, they would sometimes tend to modify their operational structure to decrease their environmental impacts and continue to generate increasing operating income. Such environmental strategies can act synergistically with financial performance by creating opportunities to increase revenue and cut costs (Seles et al., 2018, 2019).

Eccles et al. (2014) have already found that more sustainable companies perform better when considering accounting rates of return, such as return on equity (ROE) and return on assets (ROA). Furthermore, those that have voluntarily integrated social and environmental issues into their business models and daily operations (i.e., their strategy) represent a distinct type of modern corporation. Such companies are characterized by having a governance structure aimed at financial performance. Moreover, they are concerned with their responsibility for environmental and social impact, have a long-term approach to maximizing intertemporal profits, have an active stakeholder management process, and have more developed measurement and reporting systems.

Balancing the scales of this trade-off between economic development and climate change is a challenging and heated topic. This relationship is analogous to two sides of the same coin in the social welfare and environmental impacts issue (Ma & Jiang, 2019).

Based on the Environmental Kuznets Curve Hypothesis (EKCH) of Grossman and Krueger (1991), there would be an inverted U-shaped relationship between environmental impact and economic development. As a result, it would be possible to decrease the pressure on the environment even with economic growth, where, in the first phase (by the scale effect), economic growth would increase environmental degradation. However, the last two phases (by the composition and technique effects) would result in less environmental pressure, decreasing environmental degradation even with economic growth.

Given the presented context, the question is: What is the relationship between greenhouse gas emissions and the operating income of entities and their accounting variables, considering the environmental Kuznets curve? This study aimed to analyze the relationship between Scope 1 Greenhouse Gas Emissions (GHGE1) and the operating income (EBIT - Earnings Before Interests and Taxes) of the entities and their accounting variables. Furthermore, it aimed to identify an inverted U-shaped relationship, as predicted by the EKCH, and to verify the scale, composition, and technique effects using the accounting variables net intangible, amortization, net property, plant and equipment, depreciation, and R&D.

Most surveys seeking to identify this relationship predicted by EKCH have been conducted at the macro level (Ahmad et al., 2021; Arnaut & Lidman, 2021; Aslam et al., 2021; Chang, 2015; Lapinskienė et al., 2017; Ma & Jiang, 2019; Oliveira et al., 2011; Tang & Tan, 2015; Zavalloni et al., 2014). They verify the economic development (using Gross Domestic Product for the scale effect, urbanization rate, industrialization rate for the composition effect, and R&D spending rate for the technique effect as the most common variables) of cities or countries and the relationship with environmental degradation, which is represented by water and energy consumption from fossil sources, deforestation, and greenhouse gas emissions in their different scopes 1, 2, and 3.

According to EPA (2021), GHG Protocol (2015) and Tian et al. (2013), scope 1 emissions are the direct responsibility of the entities' operations, which occur from sources controlled or owned by them (for example, associated burning fuel in boilers, furnaces, vehicles, etc.).

Scope 2 emissions focus on the energy source used by the entity, such as those associated with the purchase of electricity, steam, heat or refrigeration, for which the producers of the energy sources would be responsible for the emissions (EPA, 2021; GHG Protocol, 2015; Tian et al., 2013).

Finally, scope 3 emissions, according to the same authors, are carried out in sources that are not controlled by the entity, but are part of its value chain, including all those that are not within the limits of scope 1 and 2 of an organization.

However, few studies have examined the relationship between financial performance and environmental performance at the enterprise level under the EKCH perspective. Vinayagamoorthi et al. (2015) tested variables such as ROA (return on assets), ROE (return on equity), ROCE (return on capital employed), and ROS (return on sales) in Indian firms. They found a U-shaped relationship for the ROE, ROCE, and ROS variables and an EKCH relationship using an inverted U-shaped curve for ROA. Alshehhi et al. (2018) analyzed the literature on the impact of corporate sustainability on corporate financial performance. They found only one study with a methodological approach to the Environmental

Kuznets Curve Hypothesis. However, the analysis was not at the level of the accounts presented in the balance sheet.

This study aims to fill the gap in GHG emissions from a corporate perspective. Considering that only scope 1 emissions are directly responsible for the entities' operations because they occur from sources controlled or owned by the entity (Ryan & Tiller, 2022) and provide better measurement conditions, this study will be restricted to scope 1.

Applying macro concepts of EKCH at the enterprise (micro) level and trying to identify determinants that can explain the relationship of companies with the environment can generate inputs for formulating sustainability disclosure standards and metrics. Furthermore, testing the existence of the EKCH standard at the enterprise level will make it possible to understand which accounting variables could explain companies' intensification or mitigation of greenhouse gas emissions. In addition, it could assist in investment assessments, a very relevant fact at this time when market analysts and investors, in general, are becoming concerned regarding the impact of social responsibility stances on the continuity of organizations. Moreover, understanding the characteristics of the companies in terms of scale (operating income), composition (production structure), and technique (technology) can also serve as a reference to encourage management practices that will ultimately be reflected in the accounting statements, with less environmental impact, at least regarding GHG emissions.

2 Theoretical references

2.1 Environmental Kuznets Curve

In the 1990s, the Kuznets Curve, as it became known, according to Dinda (2004), had a new application with three independent empirical studies (Grossman & Krueger, 1991; Panayotou, 1993; Shafik & Bandyopadhyay, 1992). These studies tested the relationship between economic growth and levels of environmental quality. Grossman and Krueger (1991) found an inverted U-shaped relationship between pollutants (SO2 and smoke) and per capita income. However, it was Panayotou (1993) who first coined it as the Environmental Kuznets Curve (EKC).

The standard approach to the EKCH holds that as a country develops and GDP (Gross domestic product) per capita grows environmental degradation initially increases but eventually it reaches a turning point where environmental degradation begins to decline (Badunenko et al., 2023). The Environmental Kuznets Curve is a statistical tool for examining the cointegration and causality link between economic growth and carbon emissions or environmental degradation and per capita income. The EKCH is widely used in energy and environmental economics studies (Koondhar et al., 2021; Ma & Jiang, 2019; Stern, 2017).

According to Sarkodie and Strezov (2019) and Leal et al. (2021), the systematic relationship between economic development and the environment provides the premise for the Environmental Kuznets Curve (EKC) hypothesis, which has been employed in various contexts, for diverse countries, with different environmental indicators, and including numerous determining factors.

The links between economic development, environmental degradation, and institutional quality have gained greater relevance recently as the results provide evidence supporting the EKCH hypothesis and confirming the impact of financial development and institutional quality (Pincheira & Zuniga, 2021), economic complexity, renewable energy use, foreign investment, GDP, trade openness (Bunnag, 2023; Esmaeili et al., 2023; Hossain et al., 2023; Rasool et al., 2020, Bekun et al., 2023), population density (Jaeger et al., 2023), green finance (Tariq & Hassan, 2023), technological innovation (Udeagha & Breitenbach, 2023), research and development expenses (Aydin, Degirmenci, Gurdal, et al., 2023; Aydin, Degirmenci & Yavuz, 2023) and education (Balaguer & Cantavella, 2018; Gheraia et al., 2023) on environmental performance.

Financial development can affect the relationship between pollution and per capita income as it can influence countries' capacity to adopt cleaner technologies and implement stricter environmental policies. Furthermore, financial development can impact governments' ability to implement environmental policies, such as pollution taxes or incentives for the adoption of cleaner technologies (Udeagha & Breitenbach, 2023).

Li (2023) asserts that initially, as the economy grows, environmental degradation also increases (scale effect), but as the economy continues to grow, society begins to value environmental quality more and adopt cleaner technologies (composition and technique effect), leading to a reduction in environmental degradation. Therefore, the EKC takes the form of an inverted "U."

However, Wang et al. (2023) describe that the relationship between economic growth and carbon emissions can be altered from an inverted "U" shape to an "N" shape due to income inequality. The authors explain that economic growth significantly increases carbon emissions during periods of low-income inequality; however, as income inequality increases, economic growth starts to suppress carbon emissions. On the other hand, during periods of high-income inequality, economic growth inhibits the rise of carbon emissions. Nevertheless, with the increase in income inequality, the impact of economic growth on carbon emissions changes from inhibitor to promoter.

Pincheira and Zuniga (2021) criticize the EKCH estimation model by using the GDP variable in its original value, squared and sometimes cubed, because this can cause multicollinearity or collinearity problems among the variables and, consequently, econometric limitations. However, in this study, the multicollinearity tests presented no impediment to analyzing the results.

Stern (2017) states that the EKCH model is typically estimated with panel data, most commonly using the fixed effects estimator. However, time series and cross-section data are also used. Furthermore, many estimation methods have been tried, including non-parametric methods. However, these generally do not produce radically different results from parametric estimates.

Nevertheless, Sarkodie and Strezov (2019) reinforce that regardless of the different methods employed in existing studies on EKCH, almost all follow a similar model specification. When using a panel data series, the nexus between environmental pressure or pollution level and income level is expressed in reduced form as:

Equation 1: Empirical estimation model of EKCH

$$\gamma_{i,t} = \alpha_{i,t} + \beta_1 \chi_{i,t} \times \beta_2 \chi^2{}_{i,t} + \beta_3 \chi^3{}_{i,t} + \beta_4 Z_{i,t} + \varepsilon_{i,t}$$

Source: Sarkodie and Strezov (2019)

Even though EKCH is an essentially empirical phenomenon, most model estimates are not statistically robust. Moreover, although the concentrations of some local pollutants have decreased in developed countries, there is still no consensus on the causes of the changes in emissions. In addition, there are inconclusive and controversial results of the growth-environment nexus, one possible reason being that they may not have used panel data with long time series (Koondhar et al., 2021; Maneejuk & Yamaka, 2022; Stern, 2017).

Dinda (2004) states that there is mixed evidence on the relationship between economic growth and environmental quality. There is no unanimity among researchers as to whether an EKCH-compliant relationship with economic development can explain the different types of environmental impacts.

With that said and based on Koondhar et al. (2021), Ma and Jiang (2019), Sarkodie and Strezov (2019), and Stern (2017), we developed this study's first hypothesis (H1). In order to capture the inverted U-shaped relationship of emissions, the squared independent variable "operating income" ("Ebit2"), corresponding to the gross domestic product (GDP) used at the macro level, is considered as the production factor of the entities.

H1: There is an inverse relationship between the squared operating income variable (Ebit2) and the GHGE1 variable.

Where: GHGE1 stands for the scope 1 greenhouse gas emissions generated by the entities.

2.2 Relationship between the entities' operational activities and environmental impacts

The emission of greenhouse gases comprises one of the many ways in which the operational activities of entities impact the environment. However, social, economic, and legal pressures have led to modifications in strategies and operations to decrease environmental impacts.

In the short term, climate change impacts projected in the production and consumption chain provoke changes in companies since they can jeopardize their survival in the long term (De Faria et al., 2018). Some companies began to respond to such pressures by making sustainability increasingly important as a response to the rapid depletion of natural resources and concerns regarding environmental issues (Yong et al., 2020).

Entities must then adapt or focus on mitigating the impacts generated by their operations. Organizations mobilize internally, adopting environmental management initiatives and low-carbon operations practices. These can significantly impact the environment by reducing the amount of waste and pollutants generated by companies (Giannetti et al., 2020; Seles et al., 2018, 2019). Cleaner business practices can include: implementing environmental management systems; reducing the use of raw materials and energy; reusing and recycling materials; using more energy-efficient technologies; developing more durable and repairable products; promoting financial savings by reducing resource consumption; and minimizing the costs associated with waste disposal (Giannetti et al., 2020).

Even Sahoo et al. (2023) work with the concept of green knowledge, referring to it as the knowledge and skills needed to develop and implement environmentally sustainable practices and technologies. This includes knowledge about environmental regulations, green technologies, environmental management practices, among others. The authors argue that the acquisition of green knowledge is fundamental to improve corporate environmental management and performance.

Thus, sectors may be indirectly affected by regulatory, public, and market pressures that require focusing on climate change mitigation and adaptation (Seles et al., 2018, 2019).

When given the appropriate economic signaling, carbon-intensive sectors can modify their production functions through innovation and devise processes with a lower carbon footprint, achieving dynamic competitiveness vis-à-vis their competitors (Machado & Almeida, 2020). For example, when considering a supply chain (supply chains), the demand for a certain product implies exploiting a natural resource related to it. Thus, there is a need to understand the social, environmental, and financial impacts on the entity when meeting the market demand (Lopes de Sousa Jabbour et al., 2017; Mani et al., 2020).

Faced with the possibility of environmental resource scarcity increasing the company's costs, the company could restructure itself to maintain or increase its margin (revenue minus total operating expenses). Moreover, the company faces legal and social pressure that demands a less polluting production process with lower greenhouse gas emissions and environmental impact.

In a literature review comprising 132 articles, Alshehi et al. (2018) aimed to verify the relationship between entities' financial/operating income and their environmental impacts. They analyzed the relationship between corporate sustainability and financial performance. However, only one article used a methodological approach to the EKCH relationship, and the ROA was the most used financial performance measure, followed by ROE and Sales. However, the authors have not reached a consensus on the best environmental performance measure. Instead, they say that the complexity of measuring corporate sustainability comes from the multidimensional nature of the concept itself and how different corporate contexts influence it.

Vinayagamoorthi et al. (2015) analyzed ROA (Return On Assets), ROE (Return On Equity), ROCE (Return On Capital Employed), and ROS (Return On Sales) in Indian firms. They found an inverted U-shaped relationship, as predicted by EKCH, only for the ROA variable and energy intensity.

Boaventura et al. (2012) described that the variables ROA, ROE, ROS, Sales Growth and Contribution Margin are used in studies that verify the relationship between the financial performance and the socio-environmental performance of entities and highlighted that the ROA indicator is the most used among them. However, he emphasizes that, although ROA is an accounting variable by nature, it should be used with caution, as this variable represents short-term performance and does not reflect long-term performance.

Even though calculating such indicators (ROA, ROE, ROCE, and ROS) requires using net income divided by total assets, total equity, total capital employed in assets, or total sales, respectively, this study uses operating income as a variable to analyze the scale effect. Moreover, based on (Alshehhi et al., 2018; Boaventura et al., 2012; Koondhar et al., 2021; Ma & Jiang, 2019; Sarkodie & Strezov, 2019; Stern, 2017; Vinayagamoorthi et al., 2015), we developed hypothesis H2.

H2: There is a direct relationship between the operating income variable (Ebit) and the GHGE1 variable.

Regarding the composition effect, we consider the non-current assets related to the entity's operating activities, such as fixed and intangible assets.

Based on (Alshehhi et al., 2018; Boaventura et al., 2012; Seles et al., 2018, 2019; Vinayagamoorthi et al., 2015), we used the accounting groups net property, plant and equipment, accumulated depreciation, net intangible, and accumulated amortization to consider the composition effect. Therefore, they would be more related to this restructuring by socio-environmental strategies to mitigate or adapt and could affect the entity's environmental performance. Thus, we developed hypotheses H3a, H3b, H3c, and H3d.

H3a: There is an inverse relationship between the net intangible (NetInt) variable and the GHGE1 variable.

H3b: There is an inverse relationship between the amortization variable (Amort) and the GHGE1 variable.

H3c: There is a direct relationship between the net property, plant and equipment variable (NetPPE) and the GHGE1 variable.

H3d: There is a direct relationship between the depreciation variable (Deprec) and the GHGE1 variable.

Meanwhile, to consider the technical effect, as predicted by EKCH, we used firms' R&D spending because, according to Shahbaz and Sinha (2019), the technique effect on the environment occurs "when industries begin to incorporate technologies to increase energy efficiency by investing more in research and development-based activities, and obsolete and polluting technologies begin to be replaced".

Innovation coming from R&D can be decisive in mitigating the adverse effects of climate change (Alvarado et al., 2021; Wang et al., 2022; Aydin, Degirmenci, Gurdal, et al., 2023; Aydin, Degirmenci and Yavuz, 2023) since there is a negative correlation between carbon emissions and R&D variables (Lee & Min, 2015). However, even though R&D input remains one of the most important approaches to mitigating carbon emissions, the marginal effect of technological progress in reducing these emissions tends to decrease. However, despite this, there is an inverted U-shaped relationship between R&D and carbon emission reduction (Li et al., 2021).

Thus, based on Wang et al. (2022), Li et al. (2021), Shahbaz and Sinha (2019), Alvarado et al. (2021), and Lee and Min (2015), we developed hypothesis H4.

H4: There is an inverse relationship between the R&D variable and the GHGE1 variable.

However, innovation is much broader than technological change or R&D spending. Moreover, not all companies that are successful in developing or implementing innovation are necessarily R&D performers. Thus, measuring R&D spending may not effectively characterize the innovative performance of companies or industries (Galindo-Rueda & Verger, 2016).

It should also be noted that R&D and emissions occur at different moments. Research and development may result in reduced emissions in the future. However, its existence may reflect the concern regarding reducing these emissions. This adoption of technologies not developed by companies is an important factor in the detachment between economic growth and environmental degradation. There are clean technologies focused on the reduction at the generating source, implying lower costs. On the other hand, there are end-of-pipe technologies, for example, that burn methane from landfills through a flare to turn methane into CO2 without reducing GHG emissions. However, they reduce the heating potential of the gas and thereby earn the right to receive carbon credits.

The analysis considers the depreciation ("Deprec") and amortization ("Amort") variables as control variables to capture the effect of the entity's operations by relating depreciation to net property, plant and equipment and amortization to net intangibles.

Table 1 shows a summary of the developed hypotheses to be tested for the main base sample:

Table 1: Summary of the study's hypotheses

Effect		Hypotheses
Kuznets	H1	There is an inverse relationship between the squared operating income variable (Ebit2) and the GHGE1 variable.
Scale	H2	There is a direct relationship between the operating income variable (Ebit) and the GHGE1 variable.
Composition	H3a	There is an inverse relationship between the net intangible variable (NetInt) and the GHGE1 variable.
	H3b	There is an inverse relationship between the amortization variable (Amort) and the GHGE1 variable.
	H3c	There is a direct relationship between the net property, plant and equipment variable (NetPPE) and the GHGE1 variable.
	H3d	There is a direct relationship between the depreciation variable (Deprec) and the GHGE1 variable.
Technique	H4	There is an inverse relationship between the R&D variable and the GHGE1 variable.

Source: Prepared by the authors (2022).

3 Methods

We use data collected from the Thomson Reuters Refinitiv Eikon database (TRRE) from 2010 to 2019 out of an initial total of 61,312 companies from 141 countries. However, companies with missing values were removed from the sample. Since there are missing data for the average total assets in 2010 and 2011, the time horizon of the sample is from 2012 to 2019. Moreover, not all companies presented data for all years. Thus, we have an unbalanced data panel duly treated in the statistical procedures.

It is worth noting that the period has been restricted to 2019 due to the assumption that the crisis generated by the Covid-19 pandemic may have significantly altered results for 2020 and 2021. As a result, the main sample base has expanded to 682 companies from 40 countries and 11 economic sectors. We chose to cover ten years of time horizon in data collection since these are scarce, and even so, the sample was reduced to eight years of analysis due to the non-disclosure of data in 2010 and 2011.

Table 2 shows the number of companies and observations in each specific sector.

Table 2: Groups per economic production sectors

Production Sectors	Companies	Observations
Utilities	12	51
Basic Materials	112	437
Industries	110	423
Energy	45	169
Non-Cyclical Consumption	63	279
Technology	151	646
Academic and Educational Services	1	6
Real Estate	7	19
Financial	5	9
Cyclical Consumption	79	277
Medical Assistance	97	382
Total	**682**	**2698**

Source: Prepared by the authors (2022).

The reason for the difference between the number of observations and the number of firms is that some firms did not have data for all observed years. The technology sector has the largest number of companies and the ones that most disclose the information on the variables addressed here, followed by the basic materials and industrial sectors. On the other hand, the academic and educational services sector is represented by only one company, with six years of observation.

Using the United Nations classification for countries as a reference (UN, 2022), we grouped the companies according to Table 3.

The developed countries group comprises 22 countries, while the developing countries group includes 18 countries.

Table 3: Number of countries per group

	Developed	Developing		Developed	Developing
1	Sweden	China	12	Japan	Israel
2	Australia	India	13	Denmark	South Africa
3	Canada	Hong Kong	14	Finland	Malaysia
4	France	Taiwan	15	Germany	Russia
5	United Kingdom	South Korea	16	Switzerland	Saudi Arabia
6	Netherlands	Thailand	17	Greece	Gibraltar
7	Republic of Ireland	Brazil	18	Belgium	Cayman Islands
8	Austria	Turkey	19	Luxembourg	
9	Norway	Indonesia	20	Italy	
10	Spain	Philippines	21	Malta	
11	United States	Chile	22	New Zealand	

Source: Prepared by the authors (2022).

When separating the companies already classified in their respective sectors, we can see that in Table 4, in the "developed" countries group, 478 companies were classified with 1930 observations in total. Meanwhile, in the "developing" countries, there are 204 companies with 768 observations.

Table 4: Sample grouped by country

Production Sectors	Developed		Developing		Total	
	Companies	Observ.	Companies	Observ.	Companies	Observ.
Utilities	4	18	8	33	12	51
Technology	97	420	54	226	151	646
Academic and Educational Services	1	6	0	0	1	6
Basic Materials	82	323	30	114	112	437
Industries	77	298	33	125	110	423
Real Estate	3	13	4	6	7	19
Financial	4	8	1	1	5	9
Energy	26	109	19	60	45	169
Non-Cyclical Consumption	46	207	17	72	63	279
Cyclical Consumption	54	180	25	97	79	277
Medical Assistance	84	348	13	34	97	382
Total	**478**	**1930**	**204**	**768**	**682**	**2698**

Source: Prepared by the authors (2022).

In the developed countries group, the largest number of companies belongs to the technology sector, followed by medical assistance, basic materials, and industries. The technology sector also has the most companies in the developing countries group. However, it is followed by the basic materials and industries sectors.

The data will be analyzed using unbalanced panel regressions, considering the following variables in the model:

Equation 2: Proposed Model

$$\mathrm{EGEE1}_{i,t} = \beta_0 + \beta_1 \mathrm{Ebit^2}_{i,t} + \beta_2 \mathrm{Ebit}_{i,t} + \beta_3 \mathrm{IntLiq}_{i,t} + \beta_4 \mathrm{Amort}_{i,t} + \beta_5 \mathrm{ImobLiq}_{i,t} + \beta_6 \mathrm{Deprec}_{i,t} + \beta_7 \mathrm{PD}_{i,t} + \varepsilon_{i,t}$$

Where:
GHGE1 (Greenhouse Gas Emissions); $Ebit^2$ (Squared Operating Income); Ebit (Operating Income); NetInt (Net Intangible Assets); Amort (Amortization); NetPPE (Net Property, Plant and Equipment); Deprec (Depreciation); R&D (Research and Development)

Studies that have worked with EKCH have used the "independent variable" of greatest interest squared (as explained in Section 2.2) because, to obtain an inverted U-shaped curve, mathematically, a second-degree equation with the constant value "a" negative is required.

The data were normalized by the average total assets (average calculated by adding two sequential years divided by two) of each entity.

Regarding the treatment of accounting variables, when performing the normalization of "Ebit" by the average value of total assets, we obtain the ROA indicator (Return On Assets). Boaventura et al. (2012) and Vinayagamoorthi et al. (2015) report that the ROA variable, which is of an accounting nature, is the most widely used in studies verifying the relationship between financial performance and the social and environmental performance of entities. However, they point out that this fact should be observed with caution insofar as this variable represents short-term performance but does not reflect long-term performance.

This study performed a panel regression analysis to test the proposed hypotheses. However, to ensure the quality and accuracy of the results, before the analysis itself, the statistical pre-test procedures of winsorization, Shapiro-Wilk normality, normality of residuals, Spearman correlation, multicollinearity VIF, heteroscedasticity, Ramsey variables omission, Breusch-Pagan, Chow's test, Breusch-Godfrey/Wooldridge serial correlation test, serial correlation in the residuals Wooldridge-Parm test, cross spatial dependency Beck-Katz test, Driscoll and Kraay standard errors test, and Hausman specification were performed.

4 Results and discussion

Table 5 presents a summary of all obtained results.

Table 5: Summary of obtained results

Hypotheses	Variables	Expected	Obtained Results
H1	Ebit	+	0.0001838**
H2	Ebit2	-	-0.0005621**
H3a	NetInt	-	-0.0000676*
H3b	Amort	-	0.0001529
H3c	NetPPE	+	7.24e-06
H3d	Deprec	+	0.0003222*
H4	R&D	-	-0.0000131
	Constant		0.0000683***
	Prob > chi2		0.0060
	Regression		Efeitos Fixos
	Observations		2698
	Groups		682
	Overall (R-squared)		0,0238

Source: Prepared by the authors (2022).
*10% significance; **5% significance; ***1% significance

The descriptive statistics presented on Table 6 demonstrate that, after winsorization to 1% of the data with 2,698 observations, most variables exhibited means and standard deviations extremely close to zero. This result indicates that the distribution of observations was adjusted in such a way that the majority of values are concentrated around the mean, with relatively low variation in relation to this mean. However, the 'NetPPE' variable stands out, which presents a considerably higher mean compared to the other variables and a significant standard deviation. This suggests that 'NetPPE' has a wider distribution of values relative to the mean and that there is greater variability in the data for this particular variable.

Table 6: Descriptive statistics after winsorization

Variables	Obs.	Average	Stand. Dev.	Min	Max
GHGE1	2698	.0000864	.0002463	2.71e-08	.0018748
Ebit	2698	.0889042	.0652438	-.0608758	.3071699
Ebit2	2698	.0125046	.017501	8.55e-06	.100859
NetInt	2698	.0796087	.0888296	.000477	.4751883
Amort	2698	.0087702	.0105208	0	.0609321
NetPPE	2698	.2617461	.188329	.0107805	.8313079
Deprec	2698	.03236	.0230616	.0008738	.1236128
R&D	2698	.0333881	.0374234	.0000302	.1849789

Source: Prepared by the authors (2022).

It is worth noting that the minimum negative value is identified only in the "Ebit" variable because the companies in the sample can present negative results in their operations (operating loss).

According to Table 5, the model can explain the behavior of the dependent variable by 2.38% (overall) with Chi2 and the constant with significance at 10%.

The variables "Amort", "NetPPE", and "R&D" were not significant in the model. However, "Ebit" and "Ebit2" showed a significant relationship at 5% with greenhouse gas emissions ("GHGE1"), and "NetInt" and "Deprec" had a significant result at a 10% confidence level.

The significant result of the "Ebit2" variable signals the possibility that at some point, even if the entity generated a higher operating income, there would be a lower emission of greenhouse gases. Thus, it draws a curve in the shape of an inverted "U", thereby accepting hypothesis H1, converging with the statements of Koondhar et al. (2021), Ma and Jiang (2019), Sarkodie and Strezov (2019) and Stern (2017).

The results of the relationship between "Ebit" and "GHGE1" indicate that EKCH predicts a scale effect. In other words, the more the company generates operating income, the higher its GHG emissions would be, and therefore hypothesis H2 is accepted, thus supporting the work of Alshehhi et al. (2018), Boaventura et al. (2012), Koondhar et al. (2021), Ma and Jiang (2019), Sarkodie and Strezov (2019), Stern (2017) and Vinayagamoorthi et al. (2015).

This situation could be explained by the composition effect, which we consider to be the relationship between the entities' fixed and intangible assets with their gas emissions. The results obtained for the variables "Deprec" and "NetInt" indicate the possibility of this effect. Thus, we accept hypotheses H3a and H3d and reject hypotheses H3b and H3c since the variables "Amort" and "NetPPE" did not present significant results.

The variable "Deprec" showed a positive sign, indicating that the higher the amount of depreciation, the higher the amount of greenhouse gas emissions.

The opposite occurs for the variable "NetInt". The larger the number of intangibles, the lower the environmental impact caused by the entity when considering greenhouse gas emissions.

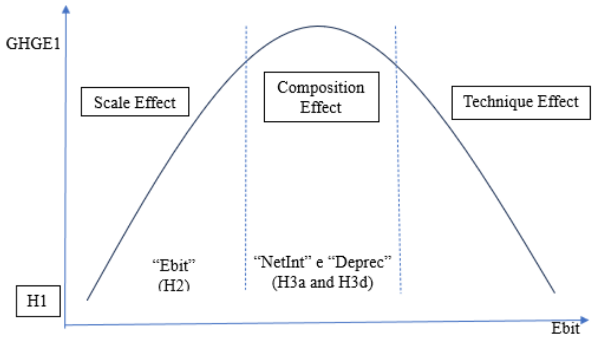
In this way, it is possible to reinforce the statements made in the works of Alshehhi et al. (2018), Boaventura et al. (2012), Seles et al. (2018, 2019) and Vinayagamoorthi et al. (2015) when they mention a) the complexity of measuring business sustainability; b) how different business contexts can influence their relationships with the environment; c) that ROA must be used with caution and; c) that companies tend to modify their operational structure to reduce their environmental impacts and continue to generate increasing operating income.

The technical/technique effect predicted by EKCH was not confirmed since the variable "R&D" did not show a significant result. Thus, we rejected hypothesis H4. In this case, although Li et al. (2021) state that there is an inverted U-shaped relationship between R&D and reduction of carbon emissions, Galindo-Rueda and Verger (2016) highlight that many companies are successful adopters of technology they did not develop and therefore measuring R&D expenditure may not effectively characterize the innovative performance of companies or sectors.

Furthermore, R&D does not necessarily represent all the effort for new developments, since regulations require that expenses in the initial phase cannot be recorded in assets, but rather in the result of the period in which the disbursement occurs.

Thus, the results with panel regression suggest an inverted U-shaped curve, as shown in Figure 1.

Figure 1: Representation of the EKCH for the entities in the main sample base



Source: Prepared by the authors based on results and Shahbaz and Sinha (2019)

At first, due to the scale effect, entities tend to emit more greenhouse gases as their operating income increase. However, due to the composition effect, when the entity has more intangibles and uses more of its fixed assets captured through depreciation, the GHGs are stabilized and tend to decrease.

The results converged with what was expected in the hypotheses, pointing out that it is possible to find the behavior predicted by EKCH. At first, companies with a significant result for the "Ebit" variable, in a direct relationship with the "GHGE1" variable due to the scale effect, emit more greenhouse gases as their operating income increases. Thus, we accepted hypothesis H2. However, due to the significant result for the "Ebit2" variable and confirming hypothesis H1, their emissions, at some point, tend to decrease, drawing an inverted U-shaped curve.

This behavior occurs as entities change their asset structure by the composition effect, using less fixed assets (variable "Deprec") and more intangible assets (variable "NetInt"). Thus, according to the significant results, we accepted hypotheses H3a and H3d. Such action leads companies, in general, to decrease their greenhouse gas emissions even while their operating income continues to increase.

There were no significant results for the variables "Amort", "NetPPE", and "R&D". Thus, we did not accept hypotheses H3b, H3c, and H4.

5 Conclusion

This study's results statistically confirmed the inverted U-shaped curve between operating income and greenhouse gas emissions. Under the scale effect, there is an increase in gas emissions as the companies' operating income increases. However, under the composition effect, as they use more net intangibles and fewer net property, plant and equipment (captured by the "Deprec" variable), their emissions decrease. However, ultimately, we did not find the technique effect. This non-significant result for the variable "R&D" may be due to problems in capturing the technology developed or used by the entities through the current accounting in accounting guidelines.

Also identified in the accounting variables the characteristics of companies that lead them to emit more (operating income, net property, plant and equipment, and depreciation) or less (net intangibles and research and development) greenhouse gases. Furthermore, it brought a new perspective on entities' interaction with the environment to accounting and its financial statements. This interaction goes through how organizations act to adapt or mitigate (Sahoo et al., 2023; Giannetti et al., 2020; Lopes de Sousa Jabbour et al., 2017; Machado & Almeida, 2020; Mani et al., 2020; Seles et al., 2018, 2019) the environmental impacts caused by their production processes. In other words, by adopting cleaner production processes, these will be reflected in their financial-accounting statements, promoting a better evaluation of the entity's performance and value when being analyzed by different stakeholders within society.

This understanding of the relationship between accounting variables and greenhouse gas emissions can help develop metrics and disclosure standards for climate-related corporate information, improving the quality, comparability, and reliability of such information. Such a fact can influence the entities' value assessment when considering the risks and opportunities related to their environmental impacts.

Furthermore, it must be considered that the innovation issue, considered here as R&D spending, may not effectively characterize the innovative performance of companies or sectors (Galindo-Rueda & Verger, 2016). Therefore, this spending on technologies not developed by companies is an important factor in the detachment between economic growth and environmental degradation.

In practice, it sheds light on the need for accounting statements to reliably and transparently show the interaction between entities and socio-environmental issues. In other words, it helps regulatory bodies to develop metrics and disclosure standards for climate-related corporate information, improving the quality, comparability, and reliability of such information.

For future research, we suggest expanding the sample, trying to equalize the groups to have more precise results in the detailing between countries and sectors. Moreover, we recommend checking if there are other possible relationships between the companies' accounting variables and greenhouse gas emissions, for example Wang et al. (2023). Another suggestion comprises extending the period to confirm the results of Caraka et al. (2020), El Zowalaty et al. (2020), Mostafa et al. (2021) and Sadiq et al. (2021) regarding GHGE reduction and the projects previously planned in renewable energies, environmental conservation, mitigation, energy efficiency, and green projects during the pandemic period, considering the Kuznets curve. Furthermore, we suggest adopting the different greenhouse gas emission scopes, 2 and 3, to verify whether the relationship according to EKCH can still be observed in the different sectors and countries. Finally, future studies can separate the sample by economic production sector, countries, or life cycle.

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