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Exploring the Influence of Innovation and Technology on Climate Change

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Abstract: Considering the negative effect of anthropological activities on climate in recent decades, all countries entailed a universal commitment to fight against climate change by boosting innovation and introducing new technologies. In this context, our paper aimed to investigate the impact of innovation input in terms of research and development (R&D) costs and technology expressed as technical equipment and machinery (TEM) on the reported greenhouse gas (GHG) emissions in chemical industry companies in five Central and Eastern European countries. This study employed a panel regression model with fixed effects and covered data from 2015 to 2020. The empirical results emphasize a negative relationship between R&D costs and GHG emissions, indicating the companies' commitment to developing innovative solutions that contribute to lower destructive emissions. Additionally, the findings related to the influence of TEM on GHG emissions reveal a positive impact, highlighting the need to improve manufacturing technologies. The practical implications of our findings can be meaningful for both policymakers and businesses operating in the chemical industry in developing countries. Policymakers should offer financial incentives to support research and investments in clean technologies, while businesses should prioritise such investments to mitigate GHG emissions.

Keywords: innovation; technology; greenhouse gas (GHG) emissions; research and development (R&D) costs; technical equipment and machinery; chemical industry; emerging countries; Central and Eastern Europe

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1. Introduction

Societies are restlessly searching for improved knowledge regarding how the Earth works and how they can adapt to be more responsible towards it [1] as a response to critical worldwide issues such as waste accumulation, water and air pollution, and water scarcity [2]. In recent years, climate change has become one of the most serious environmental concerns [3]. The interest in climate change is manifested in the academic literature as studies identifying the factors leading to increased carbon dioxide (CO_2) emissions. Prior studies have identified economic growth and/or energy intensity as playing a key role in increased carbon dioxide emissions [4–8]. In this context, fostering sustainable behaviour as a tactical option for development rather than considering it as a choice [9], searching for new and more efficient solutions to climate challenges [10], and promoting the long-term sustainable growth of the economy [11] represent valuable ways to face the risk of devastating our planet. A critical instrument for achieving sustainable development by simultaneously fostering economic growth and enhancing environmental quality through minimizing carbon emissions is represented by technological innovation [12], which is the subject of this study.

In the post-Kyoto Protocol [13] era, we witness a growing request for innovative technologies to address emissions mitigation. In 2015, the interest in sustainable development increased and resulted in the creation of a comprehensive framework for sustainable development through the introduction of Sustainable Development Goals and the adoption of the Paris Agreement [14], the international treaty on climate change. The Paris Agreement notes that "accelerating, encouraging and enabling innovation is critical for an effective, long-term global response to climate change". This is in line with the initiatives set by the European Commission through the European Green Deal [15] to make Europe climate-neutral in 2050. New technologies, sustainable solutions, and disruptive innovation are critical in achieving the objectives in 2030 and 2050. Some authors [16] show that the current climate policies are insufficient to meet the emission reduction goals for 2030 and considerable efforts should be made to impose climate mitigation measures in the economies. To achieve net-zero emissions across their value chain, companies from the chemical sector are required to engage in new partnerships, adopt business transformations, and most of all undertake substantial investments.

Numerous institutes and research centres massively invest in technological innovations that can help reduce greenhouse gas (GHG) emissions in various ways. For instance, they create new or improved technologies that enable devices to reduce energy consumption and use alternative energy equipment that emits lower GHG per unit in the production process. In this sense, some researchers emphasized the reductive effect of innovation on GHG emissions [17] and stated that decreases in CO_2 emissions are more obvious in highly innovative countries [18].

Traditionally, the main effects of innovation are considered to be the improved quality of the products offered for sale and the expanded variety of products [19]. However, advanced technologies create disruptive opportunities not only to transform the products and services the companies offer but also to enhance sustainable performance and behaviour [20]. In this context, technology has become a vital instrument for achieving the objectives of a green economy with zero pollution [21]. Whenever technology has been related to the environment, it has been suggested that certain technologies create environmental problems, or on the contrary, they help solve such problems. It is crucial to ensure that the new technologies work in the direction of responsible change by supporting the kind of innovation that is required nowadays, such as eco-innovation, that has an important impact on the mitigation of emissions [22]. Technological innovations regarding the environment evolve and become more efficient [23], reaching the eco-innovation potential to ensure that innovative technology serves sustainable development [24].

Technology development has always had a solid connection to industry, and it is continuously changing, as Industry 4.0 is the coming industrial revolution. Several opportunities are emphasized regarding how the 4th Industrial Revolution may contribute to cleaning the environment [25]. And of all industries, the chemical industry is essential in building a sustainable global economy [26] and a low-carbon future [27]. It provides plentiful materials to other major industries, but it has a notable influence on the environment.

Reducing the environmental footprint associated with GHG emissions is essential in the chemical industry and Central and Eastern Europe (CEE) countries. The European Environment Agency [28] data show that air pollution remains a problematic danger to health in this part of Europe, as solid fuel combustion results in large concentrations of harmful gases. The CEE region has unique characteristics such as high reliance on fossil fuels, dependency on energy imports, and heavy industry legacy. By investing in innovation and technology, CEE countries have great potential to face these significant environmental challenges, including air pollution and the degradation of natural resources. Furthermore, given its substantial contribution to GHG emissions, the chemical industry has a great environmental responsibility and plays an important role in mitigating climate change. By embracing innovation and new technologies, CEE chemical companies can demonstrate their commitment to eco-friendly practices. Innovation and new technologies drive modern industrial advancement and transformation [29], and the CEE chemical companies have the opportunity to achieve a sustainable competitive advantage by blending the above-mentioned synergetic factors [30].

In academic literature, the researchers' interest in this issue was manifested as investigations into the impact of innovation and technology on climate change mainly in developed countries. The mixed results along with the lack of studies on emerging countries and the chemical industry motivated the current study that aims to explore to what extent innovation and technology influence climate change in the case of companies from the chemical industry in emerging countries from Central and Eastern Europe covering 6-year time frame from 2015 to 2020.

To accomplish its objective, the paper is structured as follows: the literature review section emphasizes the relationship between innovation, technology, and GHG emissions; the methodology part describes the techniques and procedures used in the selection and analysis of the dataset, and the results and discussion section provides relevant findings related to the impact of the innovation and technology on GHG emissions disclosed by the analysed chemical companies. The study ends with final remarks, limitations, and a future research plan on this imperative topic.

2. Literature Review

Considering the negative effect of anthropogenic activities on climate in recent decades, all countries entailed a universal commitment to fight against climate change by embracing innovation and introducing new technologies in order to achieve a reduction in global warming. Although in the beginning the role of technological solutions was questioned, time has proved that technology and its components are playing a pivotal role in the direction of any transition towards sustainability [31].

Reaching CO_2 mitigation requires investments in innovation activities and clean technologies. Research and development (R&D) investments play a central role in the advancements in innovation [32,33] as the R&D costs represent a relevant indicator to assess the level of technology's input, innovative capability, sustainable development possibilities, and broad technology capacity [34]. At the company level, these expenditures can reflect the company's commitment to developing innovative solutions leading to GHG emissions reduction technologies.

Recent works in the academic field consider the research and development strategy as part of a climate policy portfolio but disclose different viewpoints. Some authors emphasized the negative impact of R&D costs on GHG emissions, strengthening the beneficial role of these costs in climate change mitigation [35–38]. Firms with more R&D activities have been discovered to be energy and CO_2-emission efficient [39]. The need for R&D to increase the accessibility of green energy sources for long-term reductions was emphasized by several authors [40,41], endorsing the constructive role of R&D in managing climate change.

In contrast, other authors highlighted the increasing effect of research and development expenditures on GHG emissions. They stated that an increase in R&D costs stimulates economic activity, production, and commerce, and hence raises GHG emissions through a scale effect, exerting a harmful influence on environmental quality [42,43]. Therefore, the long-term commitment regarding the reduction in pollution and carbon emissions should focus on environmental research and development investment [44] that leads to the innovation of environmentally friendly products [45–48].

Notably, some authors obtained mixed results in their studies, depending on the regions or countries they analysed. For instance, a study investigated the effect of R&D expenditure on CO_2 emissions in developed countries, showing that R&D costs for fossil energy have a growing impact on carbon emissions but emphasizing no significant relationship between R&D investments for renewable and nuclear energy and emissions of CO_2 [49]. Another study [36] estimated the effect of R&D costs on carbon emissions in European Union (EU) countries, the United States, and China. Empirical findings suggested that these costs have a decreasing effect on CO_2 emissions in the EU and the United States but have a growing impact in China.

Few authors indicated an insignificant influence of research and development costs on greenhouse gas emissions [43]. The miscellaneous standpoints regarding the assessment of R&D impact on GHG emissions may be explained by the different time frames used (long-run/short-run effect; past/present period), the development level of the analysed countries (developed/emerging countries), the quality of the R&D expenditures, and the industry. The prior studies explored the R&D impact on GHG emissions, especially in the United States, China, countries from OECD, and less in EU countries or countries from Central and Eastern Europe [18,50]. Also, to our best knowledge, just a few studies examined the impact of these costs in the chemical industry. To fill this gap, our research examines the R&D costs' impact on GHG emissions in companies from the chemical industry in Central and Eastern Europe. Based on the academic literature studied, a hypothesis has been defined as follows:

Hypothesis 1. *Innovation input, in terms of reported R&D costs, negatively influences the disclosed GHG emissions.*

Another area where investments are being made to reduce GHG emissions is represented by the incorporation of cutting-edge technologies. Technology, in general, and manufacturing technology, in particular, have a significant impact on GHG emissions. Obviously, energy-efficient manufacturing technologies, renewable energy equipment, and carbon capture and storage technologies can help reduce GHG emissions from companies' activities. On the other hand, inefficient equipment or equipment that uses fossil fuels generates more greenhouse gas emissions. Investing in more efficient and sustainable equipment can help mitigate the impact on climate change. In this context, researchers are providing increased attention to green manufacturing processes [51].

This transition to clean technologies is influenced by several factors such as government policies and regulations, advancements in technological innovation, access to financing and investment, and companies' social responsibility. Policymakers can incentivize companies to invest in efficient-energy equipment and clean technologies by creating policy frameworks and by offering proper financial support. On the other hand, managers can adapt their business strategy by integrating advanced technologies into their business models [52] but also by deliberately enhancing the development and implementation of creative solutions within their companies [53]. They can transform opportunities for sustainability into original sustainable initiatives [54]. For instance, low-carbon management initiatives have the potential to materialize within organizations where environmental management systems are in place [55]. As presented in [56], it has drawn attention to the risk that chemical companies, without proper management, are pose to the environment.

However, it is important to note that some equipment technologies may imply high initial costs or even assumptions of uncertainty regarding their effectiveness and reliability. As described above, the costs-related barriers can be removed by the proper financial support that policymakers can offer within an adequate policy framework. When these challenges are overcome, the opportunities are evident for the companies: cost savings in the long run, competitive advantage in a low-carbon economy, and enhanced public image, as companies are starting to be seen as environmentally responsible, gaining recognition from their customers, employees, and investors who prioritize sustainability practices. Moreover, chemical companies that do not adapt their product design and manufacturing practices will face increasing pressure from end-market customers [26].

Taking into account that equipment plays a central role in clean technologies adoption but also considering the fact that companies from developing countries have more rudimentary and less automated technologies [57], the second hypothesis of the current study emerged as follows:

Hypothesis 2. *Available technology measured as technical equipment and machinery positively influences GHG emissions.*

Investments in technological equipment and research and development expenditures can lead to improved energy efficiency of production processes and process optimisation in terms of waste. On the other hand, it should not be neglected that investments in energy-efficient equipment may enable higher production volumes, leading to an increase in emissions if the production process is not optimized or simply because it implies an increased production of raw materials.

As the existing literature lacks studies on the chemical industry in emerging countries, the current research is developed to empirically explore the effect of innovation input and technology on climate change based on a sample of companies from the chemical sector located in Central and Eastern Europe. The importance of this subject will continue to grow considering that the effects of climate change will be more severe in developing countries, although anthropogenic emissions of greenhouse gases are mainly from wealthy industrialized countries [58].

3. Research Methodology

The industry is still the primary contributor to air pollution, but some industries are more polluting than others. For removing the disadvantage of measuring the pollution emissions of companies operating in sectors characterized by relatively low pollution [59], the chemical industry is selected to be investigated, as it is one of the most polluting industries, according to the European Environment Agency [60]. Considering this important impact on climate change, the analysis undertakes chemical sector companies selected from five Central and Eastern European countries: Poland, Czech Republic, Romania, Hungary, and Slovakia. Countries' selection was based on their gross value added. Although in 2018 Poland was promoted from advanced emerging to developed market status, it is included in the sample based on its status for most of the analysed period.

The GHG data were analysed to assess the effect on climate, as these gases from human activities represent the most relevant driver of observed climate change [61].

3.1. Sample Description

This research study includes a sample of companies that consists of the first 20 chemical firms selected for each of the five Central and Eastern European countries from the database provided by ISI Emerging Markets Group's EMIS [62], based on firms' operating revenue. The analysed period includes a six-year time frame from 2015 to 2020, covering the exact period after the introduction of Sustainable Development Goals (SGDs) and the adoption of the Paris Agreement [14] that provides an appropriate framework for sustainable development. Thus, the analysis manages to capture the immediate effects of these measures until 2020, which marks the COVID-19-mandated lockdown. The selection of companies was followed by data collection.

The data were manually collected from all types of companies' reports, from sustainability to annual financial reports available on their websites. When individual reports were not accessible, the group ones were used instead. In order to avoid any biased translation, we used English reports. To ensure the data's accuracy, we performed a cross-checked test. The major problems in collecting the data from the unlisted companies' reports are due to the lack of information (related to either the financial data or the non-financial measurements) or the relatively low comparability of information [63]. The existence of an unstandardized reporting structure in the case of sustainability reports permits entities to disclose GHG emissions as increases or decreases instead of absolute values. Due to these aspects, the initial sample of 100 companies was reduced to 37 companies leading to 171 firm-year observations.

3.2. Research Design

The objective of this study is to analyse the extent to which innovation and technology employed by chemical companies from emerging countries influence climate change.

The dependent variable is GHG emissions as a climate change measure similar to prior studies [64–67]. These emissions consist of seven gases directly affecting climate change, from which CO_2 is the main contributor to climate change. The reported GHG emissions values are gathered considering the three scopes according to SDGs. The values are converted into 1000 t CO_2 equivalent (CO_2e), as a metric measure to ensure the GHG emissions comparability.

Considering the global trend that is in favour of technology-oriented international agreements that focus on advancing research and development of low-carbon technologies [68], the research and development costs reported by chemical companies in their annual reports are set as one of the independent variables of the model presented in [36,37]. There are lots of studies that recognise reported R&D expenditure as the most widely or common proxy used for innovation or innovation input [69–72].

Furthermore, as the role of technology development in planning an efficient solution to the growing GHG emissions has become essential, the study uses TEM for modelling the effect of available technology on GHG emissions. As a proxy for TEM, this study uses the values of equipment and machinery reported by chemical companies in their annual reports. The choice of this independent variable is justified by the fact that this item covers major capitalized machinery and equipment acquired for use in the performance of R&D [73] and can be designed as a proxy for technological adoption [74].

In order to strengthen the internal validity of the research model used, control variables that may impact the level of GHG emissions are considered, such as an annual change in sales (GROWTH, computed as annual change in sales divided by total sales) similar to [75] and return on assets (ROA, computed as net income divided by total assets) being in line with other authors [76–79].

The financial data are extracted from annual reports and the GHG data are collected from non-financial reports as presented in Table 1.

Table 1. Variables description.

Variables	Acronym	Measurement	Source
Greenhouse gas emissions	GHG	CO_2e	Non-financial reports
Research and development costs	R&D	Monetary units	Annual reports
Technical equipment and machinery	TEM	Monetary units	Annual reports
Annual change in sales	GROWTH	Decimal	Annual reports
Return on assets	ROA	Decimal	Annual reports

3.3. Data Analysis

This study employed a panel regression model. In order to check the variables' stationarity it is used the Levin, Lin, and Chu—LLC [80], Im, Pesaran, and Shin W-Stat—IPS [81], ADF-Fisher Chi-Square, and PP-Fisher Chi-Square tests. The existence of structural breaks was investigated on single cross-section units and also on the whole panel dataset [82].

In the case of the static panel data model, there are three different methods: common constant, fixed effects, and random effects. According to the literature [83], fixed effect models consider a specific set of entities, and the random effect model is based on entities randomly drawn from a large sample.

Choosing between random and fixed effects was based on the Hausmann test and the redundant fixed effects test, detecting the presence of statistically significant unobserved fixed effects [84]. Robustness checks were conducted by the Wooldridge autocorrelation test [85] and Wald test (heteroskedasticity of residues), Pesaran test (dependence of residues between the panels) [86], Greene heteroscedasticity test [87], and LM test (autocorrelation of residues).

The results of the above-mentioned tests confirmed the regression model's statistical validity. The software used was EViews student version, and the results are disclosed in the further section.

4. Empirical Results and Discussions

The empirical findings from this study are expected to complement the theoretical literature. The outcomes of this investigation are detailed below. For providing an overview of the data characteristics, descriptive statistical analysis was used. Table 2 presents summary statistics such as mean, minimum, maximum, and standard deviation for the panel regression model variables.

Table 2. Summary of statistics of dependent and explanatory variables.

Variables	Mean	Min.	Max.	Std. Dev.
GHG	23,106.38	0.016	424,513.0	62,120.66
R&D	1.849×10^9	0	1.2×10^{10}	3.14×10^9
TEM	3.88×10^9	100,561.6	1.99×10^{10}	4.79×10^9
GROWTH	0.023	−0.928	1.502	0.194
ROA	0.056	−0.233	0.293	0.063

Regarding the GHG emissions, the mean value is 23,106.38, ranging from a minimum value of 0.016 to a maximum value of 424,513.0, showing a considerable degree of pollution with a negative impact on the environment. In the case of R&D costs, the range from 0 to the maximum value of 1.2×10^{10} underlines the varying levels of commitment and focus on R&D within companies.

The variables' stationarity was tested through unit root tests using the augmented LLC, Dickey–Fuller, and PP unit root tests. All variables are stationary at a 10% level for a probability of 90% (Table 3).

Table 3. Unit root tests for the full sample.

Variables	Levin, Lin, and Chu		ADF-Fisher Chi-Square		PP-Fisher Chi-Square	
	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
GHG	−2.529	0.057 *	11.272	0.337	13.934	0.176
R&D	−2.631	0.004 **	11.420	0.179	21.986	0.005 **
TEM	−0.317	0.038 **	7.715	0.066 *	8.011	0.063 *
GROWTH	−4.525	0.000 ***	24.361	0.007 **	42.016	0.000 ***
ROA	−3.328	0.0004 ***	16.974	0.075 *	16.653	0.082

Note: * significance at the 10% level; ** significance at the 5% level; *** significance at the 1% level.

The static results using fixed/random effect estimations are prescribed by the Hausman specification test and the redundant fixed effects test (Table 4), highlighting that fixed effect estimates are appropriate.

Table 4. Redundant fixed effects test.

Test Summary	Statistic	d.f.	Prob.
Cross-section F	5.144	4.21	0.005
Cross-section Chi-Square	20.490	4	0.000

Static results (Table 5) indicated the relationship between independent variables and GHG emissions. The independent variables have a significant impact on GHG for the countries in the sample. GHG emissions are positively influenced by TEM, GROWTH, and ROA, and negatively influenced by the R&D costs. Thus, both hypotheses are validated.

Table 5. Static panel results.

Test Summary	Coefficient	Std. Error	t-Statistic	Prob.
R&D	-9.98×10^{-9}	1.36×10^{-8}	6.60	0.000
TEM	4.7×10^{-9}	8.68×10^{-9}	−4.132	0.000
GROWTH	2.418	215.125	0.011	0.9911
ROA	2896.851	701.023	−4.132	0.000
Constant	252.397	68.182	3.702	0.001
R^2	0.640			
F-statistic	11.093			
Prob. (F-statistic)	0.0000			

Since the fixed effects model was used, it is considered that the influence of the variables analysed on the GHG is similar for all countries, regardless of the period analysed.

The robustness was checked, being verified with the following assumptions: heteroskedasticity of residues (Wald test); dependence of residues between the panels (Pesaran test); and autocorrelation of residues (LM test) [88]. The results indicated no autocorrelation and heteroscedasticity problems.

The empirical results emphasize a negative influence of research and development costs on GHG emissions, indicating the companies' commitment in developing innovative solutions that contribute to lower GHG emissions. These findings are in line with the results of the prior studies [35–38]. In this context, chemical companies from developing countries should be encouraged to increase their R&D investments as they increase the accessibility of carbon-free technologies.

In the case of TEM, the empirical results show a positive and statistically significant influence on GHG emissions. On the one hand, this is consistent with [89] who state that the influence of technology on carbon emissions is more complex. In the first phase is positive, but afterwards, the impact is negative due to technological improvement, and obviously, the developing countries are still in the first phase. On the other hand, these findings may show the effect of old and pollutant equipment used by firms from this industry in emerging countries, emphasizing that improvements are needed in manufacturing technologies so that fewer CO_2 emissions are experienced worldwide [90]. These companies should consider replacing their actual equipment with more efficient and sustainable technologies that can help mitigate GHG emissions and result in cost savings in the long run. But this transition to clean technologies requires massive investments, representing a challenge, especially for small- and medium-sized companies that should receive proper financial support from the policymakers.

Furthermore, the chemical sector companies from these developing countries should not only invest in new plants with new technology [91] but also take a step towards the transformation of technology to benefit from achieving depletion in GHG emissions through the use of specific reduction technologies [48] that is still under development.

The variables GROWTH and ROA positively influence the dependent variable GHG emissions, although GROWTH is not statistically significant. In the case of these companies from the chemical industry, an increase in sales volume requires more energy, water, and raw material resources, which can contribute to a larger carbon footprint. Regarding the positive relationship of ROA with GHG emissions, it shows the inadequate implementation of emission reduction strategies or the lack of environmental focus, with companies being concentrated primarily on financial performance rather than on the adoption of sustainable practices or on investments in clean technologies.

This investigation leads to valuable practical implications. Firstly, the outcomes underline the importance of increasing R&D expenditures to reduce GHG emissions in the chemical industry. Secondly, this research points out that the currently available technology in companies located in emerging countries from CEE is unsatisfactory and investments in equipment and machines suitable for low-emission production processes, monitoring, and reduction in GHG emission are desirable. It is a good practice to conduct sampling and analysis whenever a company makes important progress that would affect the generation of GHG. In addition, the specific technologies employed by companies should be annually assessed, since technologies may improve over time [92].

5. Conclusions

Many agreements aim at stimulating research and fostering innovations in decarbonizing the economy for future sustainable development. In this context, studying the interaction between innovation, technology, and greenhouse gas emissions has important implications for both policymakers and businesses aiming to promote environmental protection.

There is a lack of studies related to these aspects in emerging countries, especially on chemical companies that have motivated this research. Consequently, the main objective was to investigate the effect of innovation and technology on climate change in the chemical industries of five countries (Poland, Hungary, Slovakia, Czech Republic, and Romania) of Central and Eastern Europe. The used panel regression model has the following variables: the GHG emissions as a dependent variable (as a measure of climate change); the research and development costs and the technical equipment and machinery as independent variables, incorporating innovation input and available technologies employed by the companies within the chemical sector, and two control variables for return on assets and change in sales. All the statistical tests were performed to guarantee the validity of the panel regression model.

The results regarding the R&D costs' impact on GHG emissions are consistent with the previous studies that pointed out a negative relationship, underling the companies' efforts made in innovation advancements. Chemical companies from emerging countries should be encouraged to invest in R&D, as by investing in research and development, they actively contribute to addressing climate change.

The findings related to the influence of TEM on GHG emissions reveal a statistically significant positive impact. These findings may show the effect of old pollutant technical equipment used by chemical companies from developing countries, highlighting the need to improve the manufacturing technologies to achieve a reduction in GHG emissions. Companies that successfully follow the new transformation framework are prepared to drive innovation strategies for competing in the rapidly evolving market conditions determined by customer expectations, new technologies, and environmentally sustainable goals.

This study makes several contributions to the scientific literature on technology and climate change. It fills the gap in the literature by investigating the influence of innovation and technology on climate change in developing countries. Starting from the theory advanced in the academic literature, this study also extends the current literature by developing a panel regression model where R&D costs and technical equipment and machinery capture innovation input and available technology, respectively. The study reveals practical implications for policymakers who have to promote technology upgradation. From the managerial perspective, the study underlines the need to improve the manufacturing technologies used by chemical industry companies to mitigate GHG emissions in developing countries. This implies significant financial resources and the need that these companies should receive financial support to overcome the high initial costs of introducing low-carbon technologies.

This paper has assessed climate change in the chemical industry with a particular focus on innovation and technology as facilitators for the reduction in GHG emissions and concludes that these factors can be part of the problem and also part of the solution.

This research is subject to several limitations that could inspire future research directions. The limitations relate to the manual collection of data and the limited availability of metric information reported by selected companies, leading to a significant reduction in the sample.

Further work will concentrate on expanding the database as follows: an extended analysis period and many companies from an expanded region that results in a larger sample for examining the role of new technologies adoption in climate change.

As a final point, managing GHG emissions in the chemical sector should be viewed as an opportunity rather than a challenge. While this industry is one of the main global emitters of GHG emissions, companies can implement innovative results obtained through R&D investments and modern technologies to reduce their emissions and meet key targets.

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