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Moderating Effects of Environmental Governance on Environmental Innovations and Carbon Dioxide Emissions

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The objective of this study was to examine the moderating effect of environmental governance (ENVGOV) on the relationship between environmental innovation (ENVINN) and carbon dioxide emissions (CO2E) in Saudi Arabian companies. The data was obtained from Eickon and annual reports spanning the years 2010 to 2021. The use of a longitudinal research design coupled with a quantitative research approach is recommended. Panel data was employed for the purpose of conducting data analysis. The empirical findings from the panel data analysis reveal a statistically significant and negative relationship between ENVINN and CO2E. The findings regarding the indirect moderating effect also demonstrate that environmental governance has a significant and negative moderating role in the relationship between environmental innovation and carbon dioxide emissions. The findings pertaining to robustness also indicate a detrimental impact of ENVINN on carbon dioxide emissions. This research is regarded as a pioneering study that explores the extended framework of the moderating effect of ENVINN on the relationship between ENVINN and CO2E, specifically within the context of Saudi Arabia. The findings of our study hold considerable relevance for both businesses and policymakers, as they pertain to the adoption of environmentally sustainable technologies and the enhancement of environmental governance with the aim of reducing carbon dioxide emissions. This study additionally demonstrates the significance of environmental innovations in enhancing a company's environmental and operational performance through the mitigation of carbon dioxide emissions.

Keywords: environmental innovation, carbon dioxide emissions, Saudi Arabia.

INTRODUCTION

In the present-day context, the adoption of novel or modified manufacturing protocols initiates endeavours that yield innovative and environmentally sustainable products, thereby playing a pivotal role in attaining noteworthy environmental performance, particularly in terms of carbon dioxide emissions (CO2E) (Cheng, Shi, Yi, & Fu, 2020). This response is prompted by the numerous adverse consequences of climate change and its overarching detrimental effects on human civilization (Hashmi & Alam, 2019; Zandalinas, Fritschi, & Mittler, 2021). Hence, the implementation of technological advancements is imperative for the effective operation of environmental management systems, encompassing various aspects such as pollution prevention, "recycling and plastic reuse, energy efficiency, and carbon emissions management" (Shi, Huang, Han, & Xu, 2021). Several authors have put forth arguments suggesting that the adoption of technological environmental innovation (ENVINN) plays a significant role in improving an organisation's environmental sustainability, particularly in relation to reducing CO2 emissions (Shi, Huang, Han, & Xu, 2021).

In recent decades, numerous scholars have concurred that technological innovation is indispensable for achieving economic growth (Swainson & Mahanty, 2018). There has been a growing recognition of the importance of green technology improvement, also known as eco-innovation, in achieving sustainability goals, enhancing energy efficiency, reducing the impacts of resource consumption, and mitigating pollution and other hazards (Abdulqadir, 2022). In order to attain enhanced environmental and economic outcomes, numerous companies employ ENVINN as a prevalent environmental strategy (Khan, Dhir, Parida, & Papa, 2021). This entails the process of cultivating, implementing, and utilising innovative resource utilisation products, procedures, services, organisational plans, and industry strategies that mitigate environmental risks and damage (Iqbal et al., 2021). Recent research has emphasised the importance of technological advancements, specifically ENVINN, in the pursuit of sustainability goals (Liu, Yang, Shen, & Štreimikienė, 2022; Sinha, Sengupta, & Alvarado, 2020). The utilisation of green energy and the reduction of fossil fuel consumption by technological ENVINN may have a positive impact on the environment (Hernandez, Jordaan, Kaldunski, & Kumar, 2020).

In addition, it is plausible that these technologies could potentially aid nations in enhancing the efficiency of their manufacturing processes. Goyal et al. (2022) conducted a study that highlights the significance of ethical corporate behaviour and explores how technological advancements within organisations can lead to the development of environmentally friendly technologies, thereby helping to alleviate the adverse impacts of industrialization. Indeed, technology plays a substantial role in the global endeavour to achieve net zero emissions (Dwivedi et al., 2022). There has been a noticeable increase in the level of interest regarding environmentally sustainable production methods and the availability of eco-friendly goods and services (Hole & Hole, 2019). Nevertheless, the

connection between investments in research and development (R&D) by businesses and advancements in environmental protection is inherently intertwined. It is crucial to acknowledge that the impacts of eco-innovation may not manifest immediately (Li, Zhang, Ali, & Khan, 2020). Developing environmentally-friendly products that are both commercially viable and ecologically sustainable poses a substantial obstacle for corporations (Ashfaq et al., 2023). Other empirical evidence pertaining to business performance is necessary to initiate the process of formulating "win-win" strategies aimed at reducing carbon emissions through innovation. The ongoing and inconclusive nature of the discourse surrounding the potential relationship between eco-innovation and financial performance indicates that the deliberation will persist. In the context of economic development, the innovation-driven mode can be of significant importance in altering emerging drivers and patterns to enhance performance optimisation (Jiang, Lyu, Ye, & Zhou, 2020). Achieving a world with no net carbon emissions would necessitate significant effort, considering the past relationship between ENVINN and CO2E. However, it is currently premature to ascertain the specific areas within the various innovation revolutions where possibilities may arise, as well as how to effectively leverage innovation to reduce carbon emissions. In order to enhance the environmental performance of guide and advice company executives, additional research is necessary to investigate the impact of ENVINN on CO2E. Prior research has also posited that in cases where organisations are unable to allocate sufficient resources towards investment in ENVINN, the literature suggests that the role of environmental governance in enhancing environmental sustainability may be diminished (Heikkila, Villamayor-Tomas, & Garrick, 2018). Hence, the primary objective of environmental governance is to regulate the actions of both individuals and groups, with the aim of advancing shared environmental objectives and societal aspirations (Heikkila et al., 2018). Environmental governance can be implemented through diverse mechanisms, including formal co-management agreements and informal networks comprising individuals and groups, as well as through hierarchical, participatory, and collaborative decision-making processes involving governmental bodies, private citizens, and other relevant stakeholders (Partelow et al., 2020). There has been a growing interest in investigating the impact of various governance characteristics and components on social and ecological outcomes, with the aim of deriving conclusions that can be applied universally (Bennett & Satterfield, 2018). Previous research has demonstrated a direct relationship between ENVINN and CO2E (Hashmi & Alam, 2019; Shi, Huang, Han, & Xu, 2021). However, there has been limited focus on the indirect moderating effect of environmental governance on CO2E. Moreover, prior research has predominantly focused on countries other than Saudi Arabia, with limited attention given to companies within the Saudi Arabian context. Hence, additional research is required to elucidate the causal connections between environmental innovation (ENVINN), CO2 emissions, and the potential moderating influence of environmental governance, particularly within the context of Saudi Arabia.

Hence, this study contributes to the existing body of literature in multiple ways. This study diverges from previous research (Afrifa, Tingbani, Yamoah, & Appiah, 2020; Hashmi & Alam, 2019) by focusing on environmental technologies. These technologies showcase a company's inclination to diminish its environmental footprint and related expenses while also fostering prospects for novel business ventures. Furthermore, this study makes a valuable contribution to the ongoing discourse surrounding the underlying factors behind carbon dioxide (CO2) emissions by shedding light on the significant role that ENVINN plays in this phenomenon. According to the available information, this study is unique in the United Kingdom as it investigates the impact of environmental governance on the relationship between ENVINN and CO2E. Our organisation offers a valuable research opportunity to investigate the potential of ENVINN for reducing CO2 emissions. Additionally, we highlight the significant role of environmental governance in this context. The reduction of carbon dioxide emissions (CO2E) holds significant implications for businesses and policymakers, as indicated by our research. It is imperative for them to embrace environmentally sustainable technologies and enhance their environmental governance practices. The study was divided into five distinct sections, namely: introduction, literature review, methodology, data analysis, findings, discussions, and recommendations.

LITERATURE REVIEW

Theoretical Background

The stakeholder theory argues that the interests of shareholders should not be prioritised over the interests of other stakeholders. One of the primary objectives for managers within a shareholder approach is to establish shared goals among multiple shareholders rather than focusing on trade-offs (Hashmi & Alam, 2019). By addressing both social and environmental challenges, technological innovation has the potential to offer benefits that align with the values of the firm, its shareholders, and the wider society (Albitar, Borgi, Khan, & Zahra, 2023). Nevertheless, certain elements of stakeholder theory highlight the necessity of choosing and potentially giving precedence to specific stakeholders, thereby casting doubt on the attainability of mutual advantages for all noteworthy stakeholders (Hiebl & Pielsticker, 2023; Tiggeman, 2020). Such businesses that emit excessive amounts of greenhouse gases are prone to receiving criticism from stakeholders (Chithambo et al., 2020). For example, it is plausible that customers and business partners may exhibit reluctance to purchase carbon-intensive products, thereby resulting in a decline in sales and earnings for the manufacturing companies involved. It is plausible for stakeholders to hold the belief that companies that contribute to environmental degradation will ultimately encounter substantial market consequences (Vera-Muñoz, Gaynor, & Kinney, 2020).

Furthermore, numerous governments worldwide, including the United Kingdom, are currently undertaking efforts to

mitigate the excessive release of carbon emissions and incentivize corporate engagement through the implementation of more stringent carbon regulations and protocols (Karim, Albitar, & Elmarzouky, 2021; Mahajan, Tingley, & Wagner, 2019). This could potentially impede regular business operations. In the present context, the significance of company stakeholders in exerting influence on businesses has become increasingly pivotal, thereby rendering stakeholder theory more indispensable than ever before. In order to achieve their long-term objectives, companies must prioritise the needs and desires of all stakeholders rather than solely focusing on those deemed most significant. These groups will possess different levels of legal influence. According to the resource-based view (RBV), the construction of unique, environmentally friendly goods and services requires key abilities that are effective, environmentally safe, financially viable, and widely accessible (Marín-Vinuesa, Scarpellini, Portillo-Tarragona, & Moneva, 2020). Furthermore, numerous governments worldwide, including the United Kingdom, are currently undertaking efforts to mitigate the excessive release of carbon emissions and incentivize corporate engagement (Jang, 2013) through the implementation of more stringent carbon regulations and protocols (Karim, Albitar, & Elmarzouky, 2021; Mahajan, Tingley, & Wagner, 2019). This could potentially impede regular business operations. In the present context, the significance of company stakeholders in exerting influence on businesses has become increasingly pivotal, thereby rendering stakeholder theory more indispensable than ever before. In order to achieve their long-term objectives, companies must prioritise the needs and desires of all stakeholders rather than solely focusing on those deemed most significant. These groups will possess different levels of legal influence. According to the resource-based view (RBV), the construction of unique, environmentally friendly goods and services requires key abilities that are effective, environmentally safe, financially viable, and widely accessible.

In response to the growing concerns surrounding environmental degradation and the ongoing global discourse on environmental issues, various international entities, including the United Nations and the European Union, along with regulatory bodies across the globe, have set forth environmental targets aimed at reducing their overall carbon emissions (van Emous, Krušinskas, & Westerman, 2021). Likewise, Zhang, Liang, Jin, and Shen (2020) propose that the utilisation of ENI represents a viable approach to effectively mitigate environmental concerns, such as the reduction of CO2 emissions. At a more detailed level, businesses may be motivated by a range of factors to decrease their overall carbon emissions, primarily through responding to the diverse demands of multiple stakeholders who demonstrate an awareness of the critical significance of environmental preservation (van Emous, Krušinskas, & Westerman, 2021). Technological advancements in the environmental sector may be associated with the integration of renewable energy sources, such as solar power. These endeavours are commendable manifestations of environmental advancement as they effectively reduce energy consumption and mitigate carbon emissions (Töbelmann & Wendler, 2020). According to Barbieri et al. (2017), it is asserted that ENI exerts a significant adverse impact on pollution emissions within the American manufacturing industry. In their recent study, Konadu, Ahinful, Boakye, and Elbardan (2022) look at the relationship between board diversity, carbon emissions, and the potential moderating effect of environmental and social governance (ESG) factors, specifically the Environmental, Social, and Governance (ESG) Net Impact (ENI) metric. The authors use data from the United States to explore this relationship and assess whether ENI plays a moderating role in the correlation between board diversity and carbon emissions.

Numerous studies examining the relationship between CO2 emissions and innovation often fail to consider the potential impact of energy and natural resource intensity (ENI) as a significant determinant that could effectively mitigate CO2 emissions. Some studies incorporate ENI as a factor (Ganda, 2019; Mensah et al., 2019), while others primarily concentrate on the national level (e.g., Ma). According to Zhang, Peng, Ma, and Shen (2017), the effectiveness of ENI as a potential means to significantly reduce CO2 emissions will be estimated. The findings presented in their study provide evidence supporting the effectiveness of China's Environmental and Energy Intensity (ENI) policies in reducing carbon emissions on a global scale. There is a notable association between heightened energy efficiency and reduced carbon emissions. Furthermore, they develop an appreciation for the importance of innovation resources and knowledge innovation in the efforts to combat climate change.

Environmental Innovation and Carbon Dioxide Emissions

The utilisation of a resource-based approach offers a comprehensive theoretical framework to examine the importance of resources in various aspects of ENVINN, as well as their inherent value. The success of a company in the competitive market is contingent upon its capacity to acquire resources that possess distinct value, are challenging to imitate, and are essential for its operations (Lee & Min, 2015). Previous studies have provided evidence to support the notion that innovation has a substantial impact on reducing carbon dioxide emissions (Ganda, 2019; Tnani, 2018). Zafar, Saud, and Hou (2019) conducted a study to examine the potential impact of investments in innovation and technology on carbon dioxide equivalent emissions (CO2E) within the member countries of the Organisation for Economic Co-operation and Development (OECD). The results of this study suggest that investments in research and development (R&D) have a significant and adverse effect on carbon dioxide equivalent emissions (CO2E). Furthermore, the number of patents has a substantial and positive impact on carbon emissions. Mensah et al. (2019) argue that innovation plays a crucial role in the reduction of carbon dioxide emissions (CO2E) within the majority of OECD countries.

Moreover, the study conducted by Erdoğan, Yıldırım, Yıldırım, and Gedikli (2020) arrives at the finding that the

presence of innovation, increased investment in research and development (R&D), and the exportation of high-tech goods all contribute to a reduction in carbon dioxide emissions (CO2E). Other studies place greater emphasis on the examination of how technological advancements influence carbon dioxide emissions across various nations. Investments in advanced, eco-friendly technologies have been shown to significantly mitigate carbon dioxide equivalent emissions (CO2E) and improve overall environmental conditions (Ali, Abdullah, & Azam, 2016). According to the study by Meirun et al. (2021), there is a 0.017% decrease in carbon dioxide emissions (CO2E) for every 1% increase in the presence of ecologically efficient patents. In another study conducted by Fethi and Rahuma (2019), an investigation was carried out to analyse the response of the top 20 exporters of refined oil from 2007 to 2016 towards eco-innovation, specifically in relation to carbon dioxide emissions (CO2E). Researchers have discovered that eco-innovation has a detrimental impact on the environment through the amplification of carbon dioxide equivalent emissions (CO2E). In the year 2021, Mongo, Laforest, Belaïd, and Tanguy (2022) conducted a study to examine the impact of environmental advancements on carbon dioxide equivalent emissions (CO2E) in 15 European countries over a period of 23 years. The results of their study indicate that ENVINN interventions generally result in a reduction of CO2 emissions over a longer period of time.

However, in the short term, the observed effects appear to be the opposite, indicating a temporary increase in emissions. To examine the impact of ENVINN on carbon dioxide emissions (CO2E), Töbelmann and Wendler (2020) conducted an analysis utilising various environmental patentability measures as a proxy for ENVINN. These findings elucidate the reasons behind the reduction of carbon dioxide equivalent emissions by ENVINN. Zhang, Jin, and Shen (2020) assert that a significant proportion of environmental innovation (ENVINN) endeavours in China effectively mitigate carbon emissions. The enhancement of energy efficiency significantly contributes to the reduction of carbon emissions. Furthermore, it has been found that the availability of resources for innovation and the development of knowledge in the field of innovation are crucial factors in effectively reducing carbon emissions. Albitar, Abdoush, and Hussainey (2022) have presented supplementary evidence indicating a significant and adverse impact of ENVINN on CO2E. It was also discovered that ENVINN had a notable influence on CO2E (Sinha, Sengupta, & Alvarado, 2020). Subsequent investigations have revealed the lack of a significant impact of ENVINN on CO2E (Enciso-Alfaro & García-Sánchez, 2023). Previous discussions have suggested a potential association between ENVINN and CO2, although the results have been inconclusive. Therefore, it is recommended that further research be conducted to investigate this relationship. In light of this, the following research hypothesis is proposed.

H1: environmental innovation has significant effect on CO2 emissions.

Moderation effect of environmental governance

Previous research has primarily focused on the direct impact of innovation on carbon dioxide emissions (CO2E) (Fethi & Rahuma, 2020; Hashmi & Alam, 2019; Mongo, Laforest, Belaïd, & Tanguy, 2022). The aforementioned findings lack conclusive evidence, although ENVINN has identified a noteworthy influence on carbon dioxide equivalent emissions (Salehi et al., 2022). Subsequent investigations have revealed the lack of a significant impact of ENVINN on CO2E (Albitar, Borgi, Khan, & Zahra, 2023). The preceding discourse has indicated a potential correlation between ENVINN and carbon dioxide; however, the findings are inconclusive. Consequently, it is advisable to pursue further investigation in alternative contexts. According to Spencer, Zanna, and Fong (2005), the presence of inconsistent results necessitates the consideration of moderating variables. In theory, the implementation of effective governance practices, guided by a stakeholder-oriented approach, can effectively communicate to the market the extent to which enterprises are committed to safeguarding the interests of their diverse stakeholders (Cormier, Lapointe-Antunes, & Magnan, 2015). This may also have an impact on the relationship between ENVINN and CO2E. The resource-based approach posits that companies can gain a competitive advantage by demonstrating a high level of commitment to meeting stakeholder expectations through the implementation of robust governance and environmental policies, such as the ability to provide more impactful environmental innovations. This could potentially necessitate a positive moderating impact on the relationship between ENVINN and a reduction in CO2E. In contemporary times, firms are facing heightened difficulties in fostering enhanced environmental innovation (ENVINN) skills. This predicament arises from the escalating environmental limitations imposed by both the market and governmental entities (Lee, Kuo, & Liu, 2023). According to Barney et al. (2011), the proposition is made to extend the "Resource-Based View" (RBW) framework by integrating natural advantages and limitations. This integration would enable a company to leverage its valuable, non-imitable, scarce, and inflexible resources, thereby establishing a sustainable competitive advantage.

In essence, it is imperative for businesses to give precedence to long-term resource allocation as opposed to short-term profit maximisation, which has detrimental effects on the environment. The attainment of a competitive advantage by a corporation may be facilitated by its ability to envision and construct sustainable goods and technology (Fethi & Rahuma, 2020). The study by Afrifa, Tingbani, Yamoah, and Appiah (2020) examines the connection between innovation contribution and CO2E as well as the potential moderating effects of country-level governance factors. The study utilises a dataset consisting of 725 observations across different countries and years, focusing specifically on a sample of 29 emerging nations. The primary findings of the study indicate that there is a negative relationship between innovation input, as quantified by the proportion of research

and development (R&D) expenditures to gross domestic product (GDP), and carbon dioxide (CO2) emissions. If a corporation has incorporated board-level considerations regarding global warming, it is possible to ascertain its dedication to addressing climate change at a more detailed level. The commitment of boards can be assessed by their capacity to regulate carbon emissions, the formation of a collective body to address global warming issues, or the acknowledgment of senior executives who successfully attain sustainability and carbon reduction objectives (Ioannou, Li, & Serafeim, 2016). To date, there has been a dearth of research investigating the moderating influence of sustainable governance on the relationship between ENVINN and CO2E. Therefore, this study provides a valuable opportunity to contribute to the existing scholarly literature. In light of the discussion above, environmental governance as a moderating effect between ENVINN and CO2E is hypothesized below,

H2: Environmental governance significantly moderates between environmental innovations and carbon dioxide emissions.

The preceding discourse serves as the basis for the construction of a research framework. The existing body of literature primarily concentrates on the direct influence of environmental innovation (ENVINN) on carbon dioxide emissions (CO2E), while giving comparatively less consideration to the indirect moderating effects. In a similar vein, prior research has predominantly concentrated on countries other than Saudi Arabia, with limited attention given to the latter. Hence, taking into consideration the aforementioned gaps, the following research framework is proposed, comprising three types of variables: environmental innovation as an independent variable, environmental governance as a moderating variable, and CO2E as a dependent variable. The variables depicted in Figure 1 below are anticipated.

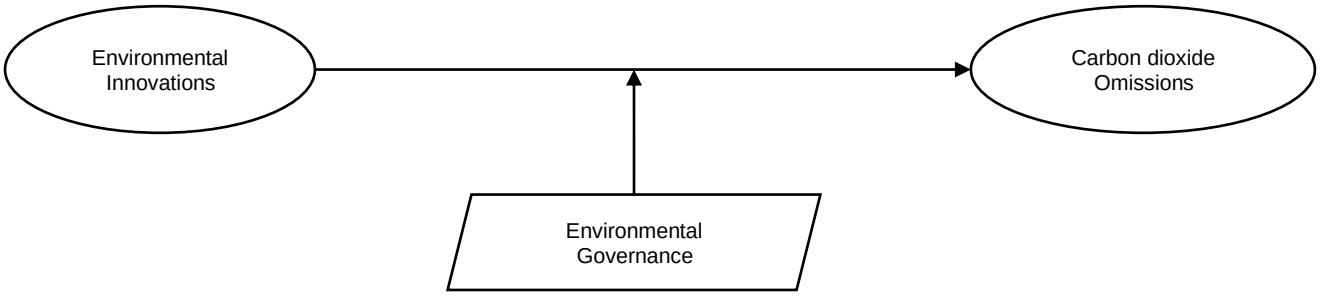

Figure 1. Conceptual Framework

RESEARCH METHODOLOGY

This study employs two research methodologies, specifically the quantitative and qualitative research approaches. Qualitative research is a methodology employed in the field of human and social sciences with the objective of elucidating individuals' deepest thoughts and emotions. The primary objective of quantitative research is to generate numerical data and objective facts by employing statistical, logical, and mathematical methodologies (Dimitrov, 2008). The sample consists of all companies from Saudi Arabia that are included in the Bloomberg database and for which data are available for the period spanning from 2010 to 2021. A total of one hundred companies were listed on the Bloomberg platform. Bloomberg is a comprehensive financial services platform that offers extensive financial and economic data across global market sectors. It incorporates environmental governance indicators sourced from annual reports and the Bloomberg sustainability survey. Hence, the present study has employed a quantitative research methodology (Bloomfield & Fisher, 2019). The longitudinal nature of the current study is attributed to the fact that data was collected at various time intervals (Carlson, Alan sroufe, & Egeland, 2004).. In line with previous research (Nadeem, Bahadar, Gull, & Iqbal, 2020; Zaman et al., 2021), the independent variable in this study is the participants' environmental innovation (ENVINN) scores. These scores were obtained from the Eikon database. The corporation's ability to improve existing ENVINN systems and practices, as well as efficient and environmentally friendly products and activities, with the aim of reducing environmental costs and responsibilities for consumers, thereby achieving new opportunities in the market, is indicated by the ENVINN score. The ecological innovation index is quantified on a scale ranging from zero to one hundred. Furthermore, the assessment of a company's environmental governance encompasses the examination of the subsequent criteria.

To commence, an examination is conducted to ascertain the presence of an environmental committee (ENC) within the organisation's board structure, which convenes on a regular basis to deliberate and advance matters pertaining to the environment. In the event that an Error Correction Code (ENC) is detected, the binary variable ENC will assume a value of 1; otherwise, it will assume a value of 0. Next, we examine the correlation between executive compensation (ENCOM) and environmental performance. In order to ascertain whether the business offers incentives for individual environmental risk management, ENCOM can be assigned a binary value of either 1 or 0. A parameter is used as a metric, denoted as 1 when a company introduces sustainability initiatives and 0 otherwise, to ascertain its classification as a sustainability reporting company (SUSR). In conclusion, the utilisation of an indicator variable is employed to ascertain the presence of external assurance in the sustainability report (SUSA). A value of 1 signifies the existence of external assurance, while a value of 0 denotes the absence of external assurance. Hence, the summation of the aforementioned four factors is conducted in order to assess the comprehensive efficacy of a company's environmental

governance. Nevertheless, the current study employed two control variables. Return on assets was determined by dividing net income by total assets, while liquidity was assessed using the current ratio. In the concluding phase, the investigation ascertained the aggregate amount of carbon dioxide (CO2) emissions, measured in metric tonnes, generated by the organisation (Bui, Houqe, & Zaman, 2020; Gerged, Matthews, & Elheddad, 2021). Greenhouse gas emissions, referred to as carbon dioxide (CO2) emissions in scholarly literature, encompass carbon dioxide, methane, and nitrous oxide (Bui, Houqe, & Zaman, 2020). In the present context, it can be stated that an organisation's aggregate emissions would encompass the entirety of its greenhouse gas emissions. To achieve data standardisation, we performed a conversion of the quantity of carbon dioxide emissions released into the Earth's atmosphere to its corresponding natural logarithm.

Econometrics Models

This section represents the econometric model of the study which is discussed below in two models.

CO_2 emission= $\beta_0+ \beta_1 ENVINN+\beta_2 BOI+\beta_3 ROA+\beta_4 Liquidity+\epsilon$ **(M-1)**

CO_2 emission= $\beta_0+ \beta_1 ENVINN+ \beta_2 ENVINN*ENVGOV+\beta_3 BOI+\beta_4 ROA+\beta_5 Liquidity+\epsilon$ **(M-2)**

Equation 1 and 2 introduce the variables CO2E, ENVINN, BOI, ROA, Liquidity, and ENVGOV. CO2E is the dependent variable, representing carbon dioxide emissions. ENVINN is the independent variable, while BOI, ROA, and Liquidity are control variables. Lastly, ENVGOV is a moderating variable that represents environmental governance.

Descriptive statistics

"Descriptive statistics for the dependent, independent, and control variables" remain existing within Table 1 for all sampled businesses. The mean carbon dioxide (CO2) emissions amount to 32,720 metric tonnes, while the average ENVINN score stands at 23, which represents 21 points out of a total of 88,890 possible points. The ENVGOV score typically falls within the range of 0 to 5, with an average value of approximately 1.87. This value serves as an indicator of the effectiveness of environmental governance. On average, boards consist of 8.221 members, with 42% of these members serving as independent directors. Additionally, approximately 21.56% of board members are women. Finally, it is worth noting that the average return on assets (ROA) is 0.073, while the average liquidity ratio remains at 1.707. Table 1 presents the projected values for all of the aforementioned variables.

Table 1. Descriptive statistics

	Mean	Standard deviation	Minimum	Maximum
CO2E	32.720	6.341	2.121	44.246
ENVINN	23.21	22.42	0	88.890
ENVGOV	1.87	2.11	0	5
BI	0.420	0.125	0	0.600
BS	8.221	2.523	1	16
BD	21.557	12.570	0	64.556
BM	8.272	3.734	0	45
ENC	0.476	0.462	0	1
ENCOM	0.319	0.345	0	1
SUSR	0.602	0.41	0	1
SUSA	0.474	0.451	0	1
ROA	0.073	0.153	0.871	2.93
Liquidity	1.707	1.486	0.357	11.72

Correlation analysis

The correlation matrix for the variables included in the analysis is presented in Table 2. The presented correlation matrix illustrates the association between CO2E (carbon dioxide emissions) and contemporary ENVINN (environmental innovation). Additionally, the interrelationships among the different factors are taken into consideration. The objective of this study is to ascertain that none of the variables under investigation exhibit multicollinearity. The correlation analysis conducted in Table 2 does not reveal any statistically significant evidence of multicollinearity in relation to the model. Furthermore, the "variance inflation factor" (VIF) is computed, with values ranging from 1.205 to 3.131 and a mean of 2.11. Moreover, the analysis does not reveal any significant evidence of substantial multicollinearity issues, as suggested by the Pearson correlation coefficients and Variance Inflation Factor (VIF) statistics.

Table 2. Correlation Analysis

	CO2E	L.ENVINN	ENVGOV	BOI	Liquidity	ROA
CO2E	1.000					
ENVINN	0.044	1.000				
ENVGOV	0.332	0.181	1.000			
BOI	0.197	0.097	0.099	1.000		
Liquidity	0.372	0.100	0.068	0.082	1.000	
ROA	0.059	0.029	0.095	0.045	0.016	1.000

Note: CO2E-carbon dioxide emissions, ENVINN-environmental innovations, ENVGOV-environmental governance, BOI-board independence, ROA-return on assets

HYPOTHESIS TESTING

Diagnostics Test

In order to evaluate the presence of multicollinearity in the data, the variance inflation factor (VIF) is also computed. It is suggested that the values for the Variance Inflation Factor (VIF) should ideally be below 5 or 10 (Romero-Gonzalez et al., 2018). The test results indicate that the Variance Inflation Factor (VIF) does not exceed a value of 5, suggesting the absence of multicollinearity in the dataset. The anticipated outcomes are presented in Table 3 below.

Table 3. Variance Inflation Factor

	M-1 (VIF)	M-2 (VIF)
ENVINN	1.607	1.205
ENVGOV	2.384	2.234
BOI	1.532	3.132
Liquidity	2.136	3.322
ROA	1.321	3.131

Furthermore, an assessment of heteroskedasticity was conducted for both models. According to Romero-Gonzalez et al. (2018), the criterion for heteroskedasticity is that the values should exceed 0.05. The predicted values in Table 4 indicate that the values of the entire model consistently exceed 0.5, suggesting the absence of heteroskedasticity issues.

Table 4. Heteroskedasticity Results

	M-1	M-2
ENVINN	0.071	0.092

Regression Results

This section of the paper presents the anticipated results of the hypothesis. The results of the hypothesis remain

consistent with the predictions made in both the direct and indirect effect models, which will be further elaborated upon in the following discussion.

Direct Effect

After conducting the diagnostic testing, the Bruach pagan tests continue to be utilised in order to ascertain whether the aggregated and randomised effects of Model-1 were deemed acceptable as models. The P-values were found to be less than 0.05, indicating the validity of a "random effect model (REM)" that allows for conducting a Hausman test to compare the random effect model with the fixed effect model (FEM). The Hausman test was utilised to assess the appropriateness of the model for this dataset. If the p-value exceeds 0.05, it is necessary to accept the null hypothesis and apply the REM (Random Effects Model). On the contrary, if the P value remains below 0.05, the use of the Finite Element Method (FEM) becomes valuable for analysing the data. The findings indicate that the P value is less than 0.05, suggesting that the use of the FEM (Fixed Effects Model) is appropriate. The results of the regression analysis, which investigates the impact of environmental innovation (ENVINN) on CO2 emissions, are presented in Table 5. The results obtained from estimation models, where total CO2 emissions are considered endogenous variables at a significance level of 1%, reveal that the overall CO2 emissions factor exhibits statistical significance and a negative relationship. This suggests that ENVINN has a significant impact on reducing CO2 emissions. The aforementioned findings are consistent with prior research that has identified a robust negative correlation between innovation and carbon dioxide equivalent emissions (CO2E) (Ali, Abdullah, & Azam, 2016; Fethi & Rahuma, 2019). Töbelmann and Wendler (2020) conducted a study that did not establish a significant correlation between ENVINN and greenhouse gas emissions.

However, recent scholarly investigations present contrasting findings on this matter. Companies have the potential to mitigate their adverse environmental impacts, particularly in terms of reducing carbon dioxide (CO2) emissions, through the adoption of novel pollution and resource management approaches. Furthermore, fixed-effects are employed to account for unobservable organisational heterogeneities over time that are likely to be consistent but may influence the relationship between predictors and outcomes, which may be disregarded when using ordinary least squares (OLS) estimation, as suggested by Wooldridge (2002). The organisation variables that were not identified maintained a significant correlation with the other businesses in our sample, as indicated by the Hausman test. Consequently, we opted to utilise a random-effects estimation method rather than a fixed-effects approach. The fixed-effects model demonstrated superior performance compared to the random-effects model in our analysis. There exists a statistically significant inverse correlation between ENVINN and CO2 emissions (p =.00604**, Table 5, fixed-effects model). The results from Model 1 in Table 4 show that heterogeneity at the firm level doesn't have a big effect on the results from using ordinary least squares (OLS) methods. The data collected up to this point provides support for the acceptance of the initial null hypothesis. The stakeholder theory provides a conceptual framework that elucidates the significance of board members' actions in meeting the needs and expectations of shareholders and other significant stakeholders. Directors may feel compelled to fulfil stakeholder expectations regarding ENVINN outcomes due to the requirement of obtaining stakeholder approval for the availability and accessibility of essential resources. Consequently, the emission of carbon dioxide into the atmosphere is expected to diminish as a consequence of this phenomenon.

The findings of the study demonstrate a correlation between effective environmental governance and reduced carbon dioxide emissions on a broader scale. The quality of the board index has a significant impact on carbon emissions, as evidenced by the control variables. The direction of the relationship suggests that an increase in the board index is associated with negative effects on carbon emissions. Furthermore, in contrast to a company's liquidity or return on assets (ROA), businesses have the potential to derive advantages from augmenting their CO2 emissions through the utilisation of leverage. The results obtained from the aforementioned discussion will be presented in Table 5 below.

Table 5. Direct effect results

	Pooled Effect CO2E	Fixed Effect CO2E
ENVINN	-0.0122 (0.0031)	0.00403 (0.00173)
BOI	-0.0122 (0.0210)	0.0218 (0.00294)
ROA	-0.0217 (0.0130)	0.138 (0.0813)
Liquidity	-0.527 (0.0510)	0.00825 (0.00256)
Constant	-4.017 (1.321)	2.522 (1.264)
R2	0.252	0.194

Indirect Effect Results

After looking at the direct effect model, the next step is to look at how the relationship between environmental innovation (ENVINN) and CO2 emissions (CO2E) is affected by environmental governance (ENVGOV). Table 6 presents the moderating effect of ENVGOV on ENVINN. The findings of this study suggest that the variable ENVGOV plays a significant and negative moderating role in the relationship between ENVINN and CO2E. As a result, it is evident that ENVINN influences the association between ENVINN and CO2E. Businesses that possess robust environmental governance structures experience greater advantages from environmental innovation (ENVINN), resulting in a subsequent reduction in their carbon dioxide emissions (CO2E). The level of ENVGOV can increase the explanatory capacity of the relationship between ENVINN and CO2E, which is currently limited. The results validate the findings. According to the resource-based view (RBV), organisations can maintain a competitive advantage when their resources and competencies possess characteristics such as value, limited imitability, rarity, and inimitability (Hart, 1995; Lee & Min, 2015). Companies that possess robust environmental governance (ENVGOV) structures are more inclined to effectively decrease their carbon dioxide (CO2) emissions by leveraging the resources at their disposal, thereby gaining a sustainable competitive

advantage. A comparable moderating effect pertaining to governance factors at the national level was identified by Afrifa, Tingbani, Yamoah, and Appiah (2020).

To the best of the writers' knowledge, there is a lack of corporate-level analyses that have examined the potential moderating influence of environmental governance (ENVGOV) on environmental innovation (ENVINN) and carbon dioxide emissions (CO2E). As a result, the findings presented in this study make a substantial contribution to the existing body of knowledge on CO2E. The aforementioned outcomes are presented in Table 6 below.

Table 6. Moderating affect Results

	CO2E
ENVINN	-0.00214 (0.0014)
ENVGOV	-0.138 (0.0694)
ENVINN*ENVGOV	-0.00231 (0.00123)
BOI	-0.0225 (0.00608)
ROA	-0.0240 (0.0127)
Liquidity	-0.118 (0.0434)
Constant	8.299 (1.253)

Robustness

In order to mitigate the potential impact of endogeneity on the results, researchers continue to employ a "generalised method of moments (GMM)" estimator. This is because the variable ENVINN has the potential to be endogenous, meaning it may be influenced by other factors that have not been accounted for in the analysis. Gerged, Albitar, and Al-Haddad (2023) identified two distinct processes as a result of their research. By employing a sensitivity analysis, it is possible to implement a Generalised Method of Moments (GMM) model in order to evaluate the potential existence of endogeneity issues. According to earlier studies (Ağazade, 2023; Ganda, 2019), our primary measure of CO2 emissions is a lagging indicator. Based on our research findings, it is evident that there continues to exist a significant inverse correlation between ENVINN and CO2 emissions, as indicated by the aggregate scores. Table 7, presented below, provides a forecast of the previously mentioned results.

Table 7. Robustness Results

	CO2E
ENVINN	-0.0144** (0.00280)
ENVGOV	-0.0165** (0.0361)
BOI	-0.00616* (0.00516)
ROA	0.0339 (0.0346)
Liquidity	0.126 (0.130)
Constant	0.182 (1.774)

The significance of environmental innovation (ENVINN) lies in its potential to effectively mitigate carbon emissions, thereby contributing to environmental sustainability. This, in turn, facilitates businesses' environmental performance (Töbelmann & Wendler, 2020). This research utilises a dataset comprising a specific group of companies listed on the London Stock Exchange during the period from 2016 to 2020. The objective is to investigate the impact of environmental innovation (ENVINN) on carbon dioxide emissions (CO2E), while also considering the moderating effect of environmental governance. The findings indicate that the implementation of ENVINN has the potential to effectively mitigate carbon emissions in both Scope 1 and Scope 2 categories. In a similar vein, it is observed that environmental governance plays a moderating role in the relationship between environmental innovation (ENVINN) and carbon dioxide emissions. The data confirmed our hypothesis that the implementation of environmentally friendly technological advancements has a discernible impact on carbon dioxide emissions. Furthermore, we argue that there exists a positive correlation between enhanced environmental governance within businesses and increased environmental innovation (ENVINN). The results of our study indicate a compelling rationale for the implementation of ENVINN, highlighting its potential to contribute to a decrease in carbon emissions. These outcomes hold significant promise for generating positive global outcomes. The endogeneity concern is effectively mitigated through the application of Generalised Method of Moments (GMM) techniques, leading to consistent findings.

PRACTICAL AND THEORETICAL IMPLICATION

This study is regarded as a pioneering research endeavour that expands upon the existing framework by examining the moderating influence of "environmental innovation" (ENVINN) on the relationship between ENVINN and carbon dioxide emissions, particularly within the specific context of Saudi Arabia. The inclusion of this supplementary compilation of literature may contribute to enhancing the research by augmenting the findings of the expanded theoretical framework. The findings of this study also carry significant implications for businesses seeking to improve their environmental innovation (ENVINN) efforts and reduce their carbon emissions. Managers are encouraged to adopt innovative strategies for addressing environmental degradation, encompassing the utilisation of current environmentally friendly technologies that result in reduced carbon dioxide emissions. Additionally, it is imperative for managers to allocate increased financial resources towards the advancement and implementation of both existing and future environmental technologies. This encompasses both individual funding for academic pursuits as well as collective expenditure on educational endeavours. The intended meaning of this is "the pooling of financial resources to invest in high-technology, developing firms that are at the forefront of the 'green' technology movement."

If this strategy were to be executed, it would possess the capability to expedite the dissemination of pioneering technologies that have the capacity to enhance energy efficiency and foster the production of alternative energy on a sectoral or industry-wide level. Policymakers, including state governments, localities, and regulatory agencies, ought to formulate comprehensive strategies that encompass medium- and long-term objectives. These plans should aim to provide financial and practical support to businesses, enabling them to effectively adopt and implement state-of-the-art innovations that promote resource conservation. One potential strategy for achieving this objective could involve the provision of financial

assistance, such as grants or subsidies, to enterprises with the aim of supporting their research and development endeavours. Despite potential reluctance from policymakers and businesses to augment expenditures amidst the aftermath of the COVID pandemic and the European conflict, such action could yield substantial long-term consequences. Specifically, it has the potential to invigorate the global economy and advance progress towards the objectives outlined by COP26, aimed at mitigating the acceleration of global warming. Furthermore, the government has the potential to foster green innovation through the implementation of environmental policy instruments, including but not limited to subsidies for emissions taxes, environmental credits, green procurement practices, pollution mitigation measures, and regulatory frameworks (Li, Liao, & Albitar, 2020).

LIMITATIONS AND RECOMMENDATION

The paper presents a variety of recommendations and utilises appropriate research methodologies. However, it is imperative to bear in mind that research possesses notable constraints that necessitate consideration when interpreting the findings. Firstly, it is important to note that the sample used in this study was limited to companies operating exclusively within the borders of Saudi Arabia. In order to enhance the comprehensiveness of the study, it may be beneficial to juxtapose the findings with potential outcomes observed on other prominent international stock exchanges, such as "international stock exchanges like the Dow Jones, DAX, Tokyo," etc. The task at hand necessitates a significant investment in terms of time, financial resources, and exertion. Nevertheless, employing the methodology outlined in this study holds promise for future research endeavours aimed at achieving this objective. Acquiring access to such information may also present challenges. Furthermore, the scope of this study was limited not only to the geographical context of Saudi Arabia but also to a relatively narrow temporal range spanning from 2010 to 2021.

Future research could potentially derive substantial benefits from conducting a longitudinal analysis encompassing a more extensive time period. By extending the scope of investigation to encompass earlier years, researchers may have the opportunity to identify discernible patterns in the progression of eco-innovation. The utilisation of research findings from 2021 and 2022 can provide valuable insights into the influence of ENVINN both prior to and during the COVID era, as well as in the post-COVID period. Furthermore, the current study has certain limitations regarding the utilisation of a quantitative research approach and its exclusive reliance on data collected from annual reports. It is important to acknowledge that there are alternative sources for data collection. Therefore, future research endeavours could explore the possibility of employing survey-based or interview-based methods, as these approaches have the potential to enhance the overall generalizability of the study results. Therefore, further inquiry could be conducted on the utilisation of mixed methods in order to enhance the generalizability of research findings.

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