Does higher innovation intensity matter for abating the climate crisis in the presence of economic complexities? Evidence from a Global Panel Data

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Summary of Literature Review

Table 1: Does higher innovation intensity matter for abating the climate crisis? Evidence from a Global Perspective Innovation-Induced Environmental Kuznets Curve: Does higher innovation intensity matter for abating the climate crisis?						
S/ N	Author(s)	Title	Country/ Period.	Variables	Theoretical Framework / Methodology	Main findings.
1	An *et al.* (2021)	The role of technology innovation and people's connectivity in testing environmental Kuznets curve and pollution heaven hypotheses across the Belt and Road host countries: new evidence from Method of Moments Quantile Regression.	Belt and Road host countries. 2003 – 2018	Carbon emission = GDP, FDI, People Connectivity Index, Innovation.	Environmental Kuznets Curve (EKC) hypothesis, Pollution Haven Hypothesis. Method of Moments Quantile Regression (MMQR), Panel Estimation; FE-OLS, DOLS and FMOLS.	The results confirmed the existence of the acclaimed inverted U-shaped relationship between economic growth and carbon emissions, but this was only evident in lower to medium emission countries, attesting to the EKC hypothesis. The Chinese outward FDI flows were found to increase carbon emissions at the observed medium to high emission countries, thus confirming Pollution Haven Hypothesis. The results also showed the contributory effects of people's connectivity to increasing emissions while innovation was found to mitigate carbon emissions in lower to medium polluted countries. Finally, the results of the Granger causality tests confirmed the presence of a one-way causality between; economic growth and carbon emissions, FDI and CO2 emissions, people's connectivity and CO2 emissions, and between innovation and CO2 emissions.
2	Nyiwul, L (2021)	Innovation and adaptation to climate change: Evidence from the water sector in Africa.	African Countries 1990 – 2016	Patents = Climate-induced water vulnerability score, Research and Development, Trade Openness, Institutional Quality, H; Country Size and Absorptive Capacity.	Porter Hypothesis. Summary Statistics, Binomial Regression.	It was discovered that the most exposed countries to water stress were innovating at lower rates. Although counterintuitive, this is premised on the fact that these supposed countries had meagre investments in the research and development of the required infrastructure needed to advance the much-needed quality innovations, that will attract patenting. The study showed that African countries experiencing water stress need to consider prioritizing investing and designing

						water-related adaptation measures to climate change.
3	Razzaq *et al.* (2021)	Asymmetric role of tourism development and technology innovation on carbon dioxide emission reduction in the Chinese economy: Fresh insights from QARDL approach.	China. 1995 – 2017	Carbon Emissions = Tourism Development (TOR), Technology Innovation Index (TII), GDP, (GDP^2 = EKC), Globalization.	Environmental Kuznets Curve (EKC) hypothesis. Quantile Autoregressive Distributive Lag Approach and Granger causality-in-quantiles.	The results showed that tourism development and technology significantly mitigated the level of carbon dioxide emissions in the long run at higher-highest and lower-higher emissions quantiles and emissions quantiles, respectively. Economic growth and globalization exerted a positive asymmetric influence on carbon emissions at medium-higher and lower-medium emissions quantiles, respectively. In the short run, technology and the metric for Environmental Kuznets Curve; GDP^2, possessed an insignificant impact across all emissions levels, while tourism development showed a positive influence on carbon emission at the lowest-lower emissions quantiles. The study also confirmed the presence of the EKC hypothesis at lower-higher emissions quantiles in the long run. In addition, the Granger causality in quantiles confirmed an asymmetric bidirectional quantile causality between tourism development, technology globalization and carbon emission albeit a unidirectional causality running from economic growth to carbon emissions.
4	Gomez and Rodriguez (2020)	The Ecological Footprint and Kuznets Environmental The curve in the USMCA Countries: A Method of Moments Quantile Regression Analysis.	The member countries of the United States, Mexico, Canada Agreement (USMCA). 1980 – 2016	Ecological Footprint = GDP, Renewable Energy, Trade Openness, Patent Applied.	Environmental Kuznets Curve Hypothesis. Panel Data Econometrics. Method of Moments Quantile Regression, Fully Modified Ordinary Least Squares.	The results suggested a cointegrated and cross-section dependent characterization, integrated of order one for the variables under consideration. The fully modified ordinary least squares (FMOLS) method showed that renewable energy sources reduced environmental degradation- validating the Environmental Kuznets Curve Hypothesis. In contrast to this, this research returned a statistically insignificant relationship. These findings were confirmed by the Moments Quantile Regression Analysis as reported by the reduced environmental degradation in quantiles

						from 4 to 6, which was ultimately corroborated by the Environmental Kuznets Curve Hypothesis, which saw a reduction in quantiles from 3 to 9.
5	Aziz *et al.* (2020)	The role of natural resources, globalization, and renewable energy in testing the EKC hypothesis in MINT countries: new evidence from Method of Moments Quantile Regression approach.	MINT Countries. 1995 – 2018	Carbon emission = Economic Growth, Renewable Energy, Globalisation.	Environmental Kuznets Curve Hypothesis. Panel Data Analysis, Method of Moments Quantile Regression approach, FMOLS, DOLS and FE-OLS.	The result validated the EKC hypothesis between economic progress and carbon emissions from the third quantile to the highest quantile. In addition, natural resources increased CO2 emissions at the lowest quantile and which then became insignificant from the middle to the highest quantiles. This was credited to the use of resources in a sustainable manner. The renewable energy mitigated CO2 emissions at the lower half quantiles while upper quantiles returned unexpected results implying that the countries' total energy mix heavily depended on fossil fuels.
6	Ahmad *et al.* (2020)	Innovation, foreign direct investment (FDI), and the energy–pollution–growth nexus in OECD region: a simultaneous equation modelling approach	24 OECD Economies. 1993 – 2014	Innovation (measured by R&D expenditures), FDI (measured by cross country technology transfer), and energy-environment-growth, energy consumption, carbon emission and environmental pollution with GDP per capita.	Environmental Kuznets Curve Hypothesis. Simultaneous Equation Modelling.	The results were in stark contrast to the Environmental Kuznets Curve (EKC) hypothesis in the OECD economies. In addition, there was evidence of a two-way causality between GDP per capita and energy consumption per capita, showing that the pollution levels are yet to attain their maximum threshold. Fossil-fuel consumption, innovation, and FDI were also discovered by this study as the primary sources of CO2 emissions.
7	Afrifa *et al.,* (2020)	Innovation input, governance and climate change: evidence from emerging countries.	29 emerging countries.	Carbon emission = Governance, innovation input, Domestic Credit to Private Sector, Market Capitalization, Inflation and Net Domestic Credit.	Descriptive Statistics, Person Correlation Matrix, Regression Analysis.	A negative relationship was discovered between innovation input and CO2 emissions which points to the fact that countries invested in R&D, innovation combat climate change crisis After separating the samples into low and high innovative countries, it was discovered that reduction to carbon emissions rates was more pronounced in countries with high innovation input. It was further established that factors

			1990 – 2018			like; country-level governance; including political stability, rule of law, government effectiveness, regulation quality, and control of corruption all negatively affected the impact of innovation input on CO2 emissions.
8	Yao *et al.* (2019)	Renewable energy, carbon emission and economic growth: A revised environmental Kuznets Curve perspective	17 major developing and developed countries, 6 geo-economic regions. 1990 – 2014	Carbon emissions = GDP, GDP Per Capita, Renewable Energy Consumption Rate.	Environmental Kuznets Curve Hypothesis, Renewable Energy Kuznets Curve. Fully Modified Ordinary Least Squares (FMOLS), and Dynamic Ordinary Least Squares (DOLS) techniques.	The results showed that a long-run relationship exists between economic growth, RER and carbon emission. The results attested to the EKC and RKC hypotheses, indicating that a 10% rise in RER will lead to a 1.6% decrease in carbon emission. In addition, the study found that the Renewable Environmental Kuznets Curve turning points of sample countries and the population considered as a whole took place in time before the turning points of the individual EKC's for individual countries.
9	Churchill *et al.* (2019)	R&D intensity and carbon emissions in the G7: 1870–2014.	G7 Countries. 1870 – 2014	Carbon emissions = R&D, GDP, M2; a ratio of broad money to GDP, Population, Trade	Endogenous Growth Theory, Environmental Kuznets Curve Hypothesis. Parametric and Non-Parametric Data Analysis.	The result showed a varying relationship between innovation and CO2 emissions over time. The non-parametric panel data estimates exhibited a negative relationship between R&D and CO2 emissions with a major exception between 1955 and 1990. In addition, it was also discovered that R&D intensity and CO2 emissions were increasingly positive between the mid-1950s and mid-1970s, which ultimately decreased and maintained negative values from the start of the 1990s.
10	Dinda, S (2018)	Production technology and carbon emission: long-run relation with short-run dynamics	United States 1963 – 2010	Carbon emissions per dollar = Utility Patent (UTPAT) (proxy of the production technology supposed to reduce carbon emissions), Per Capita CO_2 emissions, Per Capita GDP.	Production Function, Pollution and Clean Technology. Vector Error Correction Model.	The findings supported the existence of technological progress as the driver of economic growth. CO_2 emission per unit of output was significantly reduced over the period in view although there was a negative effect in the 1970s, 1980s and 1990s due to the oil crisis of the 1970s. The study also discovered a long-run relation albeit short-run dynamics between technological progress, carbon emission intensity and economic growth. This study ultimately shows that income reduces CO2

						emission intensity which translates to an increased utility patent in the long run.
11	Mensah *et al.* (2018)	The effect of innovation on CO2 emissions of OECD countries from 1990 to 2014.	28 OECD Countries. 1990 – 2014	Carbon Emissions = Per Capita GDP, Renewable energy consumption, Non-renewable energy consumption, Patent per capita, Patent per capita Research and development per capita.	EKC Hypothesis, Growth theories. Fully Modified Linear Regression (FMOLS), STIRPAT model, the economic-EKC growth model, and the innovation-EKC model	The findings revealed that innovation played a key role in carbon emissions in the observed OECD countries. Its impact, however, varied across countries and was dependent on stated factors as observed in the variables elucidated in the study. Additionally, it was asserted that improvement in GDP per capita leads to increased emissions in most OECD economies, although ameliorated emissions in few OECD; hence, the economic-EKC model was not valid for most OECD countries. Non-renewable energy was found to accelerate emissions while renewable energy sources mitigated emissions. Also, research and development improved environmental quality and the EKC hypothesis for both economic growth and innovation, remained valid for a few economies of the OECD countries.
12	Alvarez-Herranz *et al.* (2017)	Energy Innovations-GHG Emissions Nexus: Fresh Empirical Evidence from OECD Countries.	28 OECD Countries. 1990 – 2014	Per Capita Pollution = GDP Per Capita Income, other auxiliary carriables over environmental quality.	Environmental Kuznets Curve Hypothesis. Panel Data Analysis.	The result indicated that energy innovation measures required a gestation period to attain their full effect i.e., innovation applied to measures for environmental correction takes ample time to reach its whole effect, requiring yield periods to arrive at the desired result. The EKC analysis exhibited an N-shaped relationship between per capita income and contamination levels implying that at the first stage of economic growth, per capita greenhouse gas emissions decreased with increased income level, but once the scale effect exceeded the technological effect (as justified by the existence of obsolete technology) the countries in question experienced pollution increase. Also, energy innovation was found to positively affect environmental quality.
13	De Stefano *et al.,*	A natural resource-based view of climate	European Union	Carbon emission = product stewardship,		The study employed a socio-technical transition perspective to understand how companies have

	(2016)	change: Innovation challenges in the automobile industry.	2000 – 2008	clean technology, euro standard anticipation, model restyling, vehicle weight, firm size and firm profitability.	___________ Descriptive Statistics, Correlation Matrix, Random-effects Regression Analysis,	developed technologies to carbon emissions from their products during a period of regulatory uncertainty. The Natural-Resource-Based View was employed to dichotomize technological innovations into product stewardship and clean technology. It was discovered that the significant reduction in carbon emissions from vehicles was due to clean technology innovations. Albeit short term, the study concluded that continuous innovation in product stewardship is essential to survive a carbon-constrained market.

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Abstract

Industrial development generally entails a structural transition from resource-based and low-technology activities to medium- and high-tech industrial (MHT) activities that represent higher innovation intensity. A modern, highly complex production structure creates better opportunities for skills development and technological innovation. The present study examines the relationship between innovation intensity and climate change crises by incorporating the factor of economic complexities. For this purpose, we used panel data pertaining to 120 global economies from 1996 to 2019 and applied the CS-ARDL estimation technique to achieve empirically valid results. The outcomes of the estimations revealed that real GDP, trade openness, energy use, and economic complexities have a positive and significant relationship with climate change crises in these economies, whereas innovation intensity has a negative and significant relationship with climate change crises. However, the joint effect of the interaction between innovation intensity and real GDP with economic complexities is positive and significant in terms of climate change crises. Thus, the study concludes that higher innovation intensity has a significant role in determining climate change crises in the presence of complex economic structures.

Keywords: Innovation Intensity, Climate Change Crises, Economic Complexities, CS-ARDL

1. Introduction

Climate change is, without a doubt, one of the most pressing issues of the twenty-first century. It is one of several dramatic, large-scale environmental changes afflicting our planet. These changes have brought about the overburdening of various of the earth's biophysical and ecological systems as a result of the combined influence of an increasing human population and increased economic activity. Environmental changes are now impacting whole countries and disturbing the atmosphere's life-sustaining mechanisms, although the extent to which this impacts human well-being and health differs greatly around the globe. Generally, adverse environmental exposure does not *de facto* result from climate change, however the aftermath effects of carbon emission, greenhouse gas emission, ecological footprinting, fossil fuels, coal, and excessive consumption of non-renewable energy instead of sustainable energy, increase global warming. The increasing variability of weather patterns can also lead to intensify the effects of climate-related environmental changes, degrading our environment and affecting human life on earth.

In as much as every country seeks to be more developed, as things stand no country in the world can achieve zero carbon emissions rapidly, although the emissions rate varies between developing and developed countries. As such, there have been several research initiatives, across a range of countries and categorizable groups of countries, seeking to better understand the factors contributing to climate change and the ways in which they may be mitigated. For instance, early papers by Grossman and Krueger (1991, 1995) made the case for an initial increase in emission rates, subsequently followed by improved environmental quality due to an incremental rise in average income, as defined by the Environmental Kuznets Curve (EKC) hypothesis. The EKC hypothesis, as defined by Panayotou (1993), states that economic growth has three effects on environmental emissions, and the most prominent effect is the technical effect, which pertains to the adoption of energy-saving techniques, resulting from innovations and the ongoing technological process, thus leading to a net reduction in total emissions irrespective of the degree of economic growth and expansion. Joint efforts by countries and institutions in ameliorating the after-effects of greenhouse gases – the methane, nitrous oxide, and carbon dioxide that have skyrocketed over the last 150 years – orientate around innovation. Innovation has remained a vital instrument through which economic development and market competitiveness can be improved.

However, while increased innovation is claimed to be essential as a major tool in reducing the harmful effects of carbon emissions through eco-innovations by industries and governmental agencies that make R&D investments, it is important to be aware of the downsides. For one thing, there is the obvious cost to the environment of eco-innovation itself, as evidenced by Ali *et al.* (2016), who posited that increased innovation designed to abate the climate change crisis will ultimately lead to an increased cost to the environment. Secondly, it has been discovered that a nonsignificant albeit negative relationship exists between carbon emissions and innovation in some countries (Santra, 2017). In this research, taking the BRICS bloc as a case study, investment in innovation led to increased energy consumption which, in turn, ultimately exacerbated climatic change in these countries through an increase in carbon emissions. Other recent studies (Liu, Zhang & Bae, 2017, Liobikiene & Butkus, 2017, Gómez & Rodríguez, 2020) have nevertheless found that increased renewable energy products and their derivatives created through innovation processes can significantly hinder environmental degradation and excessive dependence on fossil fuels.

Many studies have been based on this argument which corroborates the narrative of reduced carbon emissions emerging from increased use of renewable energy sources. This has prompted the more recent and widespread adoption of the Renewable Energy Environmental Kuznets Curve (RKC) as an improved hypothesis vis-à-vis the former EKC hypothesis. Among the 2300+ research articles on the EKC hypothesis in the web of science database (Sarkodie & Strezov, 2019), international trade, income, technical progress, foreign direct investment, and emissions regulations stood out as key drivers. In recent years, however, many studies have revised the EKC, ultimately culminating in the Renewable Energy Environmental Kuznets Curve (RKC), first introduced by Boluk and Mert (2014). This is arguably because it considers and incorporates renewable energy as a major factor in depicting the U-shaped interaction that exists between renewable energy consumption as an indicator and per capita GDP across countries. This advanced curve model maintains that increased renewable energy consumption can accelerate the traditional EKC to reaching its turning point. This lends credence to other existing literature, in which combined consumption of renewable and non-renewable energy sources converge in the RKC hypothesis, that then hits its turning point faster than the traditional Kuznets curve (that refers only to non-renewable energy sources). Furthermore, this has brought about an advanced renewable energy consumption rate which has ultimately become the index for observing renewable energy consumption alongside the EKC (Yao *et al*., 2019).

Moreover, pollutant emissions can be reduced via the development of patents designed to prevent pirate seizures of innovations. Popp (2005) has argued that patents offer more benefits when analysing the effects of technological change on the environment. This is due to the widely available detailed invention records and their respective patents' bibliographic data, and due to this availability, they can be used to measure innovative levels across countries. Patents are grants of ownership to innovators, issued once an invention is deemed to improve the market status quo and (in these cases) reduce pollutant emissions (Cheng *et al*., 2019).

Assessments of the impact of climate change on the world have resulted in the creation of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, leading to the adoption of the core UNFCCC goal: "the stabilization of greenhouse gas concentrations in the atmosphere to prevent dangerous anthropogenic interference in the climate system." This goal has been ratified by 197 member countries and has since been adopted as national policy in many states. This is made evident from the mapping out of various pathways through which greenhouse gases can be significantly reduced. What is common to all pathways, however, is the drastic change to the energy system that will ultimately take a larger chunk of the overall changes solely attributed to the energy sector as a dominant contributor to climate change. It is these multiple pathways that this study seeks to investigate within the context of innovation as it relates to the medium- and high-tech sectors. Moreover, this study contributes significantly to the existing literature by assessing the role of economic complexities in the realms of innovation and climate change crises, as well as analysing the roles and interacting effects of economic complexities and real GDP in the innovation intensity and climate change crises relationship. The results will help form direction for policymakers. The proceeding sections present a review of the pertinent literature, the gap that this study seeks to redress, the data and variables used, the econometrics methods employed, the estimations and discussion of the results, and a conclusion that provides iterative direction for policy and practice moving forwards.

2. Literature Review

2.1 Innovation Intensity and Climate Change Crises

Innovation is the execution of a novel plan that either creates a new product or leads to the improvement of an existing product or process, and that has a meaningful impact on the market or on society. Innovation, as defined by Maranville (1992), refers to the application of better alternatives that provide improved results to existing market needs or unarticulated needs through the supply of more effective products, processes, services, or technologies. Innovation is classified into product innovation, service innovation and organizational innovation. All in all, the focal point here is the fact that distinct improvements lead to innovation, and this is driven by, and reinforcing of, the patent system. There are many patents across different fields, one of which pertains to environment-related technologies. The objective of the patent is to protect these innovations or new technologies from being unjustly used or pirated. As observed by Serrat (2009), firms simultaneously improve their product offerings through innovation whilst maintaining reduced production costs through process innovation. Product innovation comprises an improvement to an existing product, whereas process innovation constitutes the introduction of an obvious improvement to a method or equipment used in producing a product or service. Guan and Cheng (2020) investigated the productivity-complexity linkage in a large sample of Chinese manufacturing sector firms. They found that product complexity drives up productivity levels. Ivanova *et al.* (2017) argue that ECI can analytically be elaborated into the Triple Helix Complexity indicator of the innovation system. Abbasi *et al.* (2022) found that technological innovations decreased emissions substantially in the long-term for Pakistan.

Ausubelle (1991) pointed out the necessity of technical innovation as it relates to climate change given that it can preserve our climate and proliferate new inventions, in many forms, across various sectors of any typical economy. A study by Dechezleprêtre *et al.* (2011) observed some patented innovations according to climate-related technology classes. It was observed that innovation in climate change was highly concentrated in selected OECD countries, such as the USA, Germany and Japan, and this lends credence to the efforts made by developed countries to alleviate carbon emissions. Wang and Wang (2012) observed that patenting energy innovations drive economic activity and leads to the development of better energy technologies. For instance, improved solar technologies have drastically reduced environmental damage. As found by Raiser *et al.* (2017), renewable energy sources and carbon capture storage are advanced technologies built on previous climate mitigation technologies seeking to attain economic efficiency. Su and Moaniba (2017) observed that an increase in climate change technologies has multiple effects on carbon dioxide emissions from different sources. However, Raiser *et al.* (2017) found that patents seem to restrict development and hamper the alleviation of climate change issues.

The rise in greenhouse gases such as carbon emissions, amongst other gases, has necessitated the production of climate mitigation technologies to help redress the effects of these greenhouse gases. This supports the acknowledged role that tech innovation will play in attaining the goal set by the International Panel for Climate Change (IPCC), which is to completely phase out fossil fuels by 2100. It is important to note that current technologies may attain this target by the said date, but these technologies also come with high costs which necessitates additional research to arrive at lower costs while circumventing existing barriers to implementation flagged up in the findings of prior research (Raiser *et al.*, 2017). Several studies have explored the interrelations between innovation and climate change, some of which have been cited above. More recent additions to the literature are presented in Table 1 (see supplementary file).

2.2 Factors Contributing to Global Climate Change Crises

Asides from the conventional EKC hypothesis, another important element in the theoretical archive, as it relates to climate change, is the Pollution Haven Hypothesis which theorizes that, in free trade conditions, multinational corporations transfer the manufacturing processes of pollution-intensive products to developing countries to leverage the advantages of less stringent environmental regulations in those countries, which ultimately has a negative effect on the global climate.

The Pollution Haven Hypothesis, within the context of globalization and the encouragement of free trade, has both positive and negative externalities in some economic regions. This has been extensively researched in terms of carbon emissions in several groups of countries. For instance, a study by Shahbaz *et al.* (2015) observed that globalization is a beneficial factor to the Australian economy considering the environment's quality. In the Indian economy, however, the same study reported a non-beneficial environmental effect of increased globalization, akin to Khan *et al.*'s (2019) findings in Pakistan, who concluded that Pakistan's ties with trading partners who sought to invest in Pakistan resulted in a corresponding rise in emission rates due to the agglomeration of pollution-intense industries.

Some authors have investigated this phenomenon across countries using a panel data method, which has resulted in a mix of results. Salahuddin and Gow (2019) studied a sample of sub-Saharan African countries and reported that globalization's effect on environmental quality was insignificant, but urbanization seemed to worsen the state of environmental quality across these countries. As found by Kalaycı and Hayaloğlu (2019), the EKC hypothesis holds for NAFTA member countries where a positive relationship emerges, ultimately pointing to the fact that increased energy demand due to growing trade activities increases carbon emissions. Neagu (2019) used the economic complexity index in place of GDP per capita to measure the EKC, and he found that CO_2 emission patterns exhibit an inverted U-shaped curve depending on economic complexity. He argued that initially pollution increases when countries enhance the complexity of the products they export, but after a turning point a rise in economic complexities lowers pollutant emissions. According to Huang *et al.* (2022), from the E-7 countries' perspective, empirical results reveal that ICT, economic complexity, and human capital increase pollution levels, while renewable energy significantly reduces them.

Within country categories, Shahbaz *et al.* (2019) posited that middle- to higher-income countries seek to encourage investments (domestic and foreign) to boost aggregate income, which is detrimental to the environment. You and Lv (2018) claim that globalization impacts carbon emissions indirectly. These indirect effects were attributed to the ripple effect from neighbouring countries' pursuit of globalization. It was found that as economic developmental activities increased in these countries, carbon emissions correspondingly increased in the domestic region. This validates the finding of Haseeb *et al.* (2018) that an insignificant and negative relationship exists between globalization and carbon emissions in BRICS countries, stemming from the unsustainable economic choices available in those countries. Again within the pollution haven hypothesis framework, investments – both foreign direct and trade liberalization – lead to shifts in the production process of pollution-intensive products in regulatorily weak economies (Aklin, 2016). While there is evidence to attest to the detrimental effects of foreign direct investment in countries with weak environmental regulations due to the production of pollution-intensive goods, the benefits in the form of increased trade figures is the blind spot which is unsustainable, especially when viewed through the lens of long-term cost-benefit analysis. The pollution haven hypothesis used by Pethig (1976) employed a simple two-Ricardian trade model to compare two identical economies. The northern economy maintained a stricter policy in taxation rates than the southern economy. It was observed that both economies had distinct advantages albeit also having distinct disadvantageous access to alternatives. The northern economy thrived in cleaner production conditions while the southern economy thrived in pollution-intensive production conditions. In the long run, however, it can be argued that pollution-intensive production will have far-reaching consequences on environmental quality and health indicators.

Another explanation that appears to be subsumed within globalization as a factor is industrial growth, its corresponding growth in energy demand and the resultant effect of increased emission rates (Shahbaz, Solarin, Sbia, & Bibi, 2015). In the Asia Pacific Economic Cooperation Countries, Zaidi *et al.* (2019) found a negative relationship between increased globalization and carbon emission rates. This negative relationship was due to international pacts whereby the countries agreed to import green technologies under binding protectionist rules, which appears to connect three variables: innovation, globalization, and carbon emission rates. The same outcome was identified by Liu *et al.* (2020) in the G7 countries. It was found that globalization and the EKC hypothesis comprise two different concepts that help to improve environmental quality amongst trading partners and the markets they operate in.

Tourism economics is another aspect that has been considered concerning environmental quality. Despite being worth approximately 1.5 trillion dollars, the sector has been reported by Robaina-Alves, Moutinho, and Costa (2016) to account for a sizeable chunk of billable costs in terms of global carbon emissions. The social benefits to economies are well captured in the economic indicators, such as international tourist arrivals (Sharif, Afshan, & Nisha, 2017), tourism flows receipts (Balli, Uddin, & Shahzad, 2019), and international tourism expenditure (Aslan, 2016). However, the downsides to this, as documented in the literature, concern a partial correlation with increased carbon emissions. However, there have been advancements regarding these indicators (Shahzad, Shahbaz, Ferrer, & Kumar, 2017; Chishti et al; 2020; Razzaq, Sharif, Ahmad, & Jermsittiparsert, 2021) in studies that have employed principal component analysis to combine them as a single weighted index. The results, as discerned by Razzaq *et al.* (2021), show that tourism has a positive relationship with carbon emissions at the lowest-lower emission short-term quantiles, but tourism and technology innovation jointly and significantly mitigate long-term carbon emissions levels at the lower-higher emission quantiles.

Furthermore, a study by Lenzen *et al.*, (2018) reported that tourism-related carbon emissions at the global level, over the 2009 to 2013 timeline, grew from 3.90 to 4.55 GtCO2e, accounting for over 8% of global carbon emissions. This figure had quadrupled in that period. Similarly, an earlier report by UNWTO (2008) pointed at transportation and hospitality sectors as major drivers of global carbon emissions with respective contribution shares of 75% and 21%. In conclusion, numerous studies show that variables such as innovation, foreign direct investment, globalization, and renewable energy have measurable effects on climate change proxies, across both individual countries and economic blocs. Given the results of these studies, the importance of variables such as innovation, foreign direct investment, globalization, and natural resources in abating emissions rates is important in identifying strategies for emissions reduction and sustainable development. This nexus of relationships should be looked into, especially in underdeveloped economic blocs, to devise a global and encompassing strategy.

2.3 Research Gap

Previous studies focused on climate change have posited and tested a range of hypotheses. Explanatory variables used to understand causal factors responsible for increased emission rates have ranged from foreign direct investment, innovation, and globalization to the energy sector. While some studies have analysed these variables separately in terms of their impacts on climate change, other studies have focused on the joint effects of these variables on various economies. What appears obvious from the review, however, is the absence of clear-cut studies that have investigated a mix of these variables at the global and regional levels, and such studies could produce comparative reports across economic zones. Considering this, the present study assesses the degree to which innovation affects climate change at the *global* level while accounting for the effects of innovation on climate change. Moreover, this study investigates economic complexities and GDP as variables in the innovation-climate crises relationship. Papers providing robust analyses of a wide range of econometric methods that depict the relationship between innovation and climate change are in short supply. This study therefore calls for an ongoing scholarly inquiry that applies a mix of these econometric methods.

3. Research Methodology

3.1 Data and Variables

In this research, the data, covering 120 global countries from 1996 to 2019, are drawn from three databases: the World Development Indicators (WDI) database, the United Nations Industrial Development Organization (UNIDO) database, and the Competitive Industrial Performance (CIP) database. From the WDI, we isolated climate change crises (CCC) – the dependent variable estimated by measuring carbon emissions (kt) – along with several independent variables such as real GDP proxied by GDP (constant 2010 US $), trade openness (TO) defined as a percentage of GDP, energy use (EU) measured as kg of oil equivalent used per capita, and economic complexities (EC) (measured by the Economic Complexity Index (ECI) developed by Harvard Growth Lab). Moreover, innovation intensity (INOVINT) proxied as medium- and high-tech industry (% manufacturing value-added) were taken from UNIDO/CIP. We also included two interaction terms. These were the combined effect of innovation intensity and ECI on climate change crises, and the effects of real GDP and ECI on climate change crises.

3.2 Econometric Model

The sole aim of this study is to examine the interrelation between climate change crises and the aforementioned independent variables. Hence, the ideal empirical model for the analysis, as described in equation 1 below, is

$$\mathrm{CCC} = \mathrm{f(TO, GDP, \ LEU, \ INOVINT, EC, INOVINT * EC, \ GDP * EC)} \quad [1]$$

$$\mathrm{lnCCC_{it}} = \alpha_o + \alpha_1 \mathrm{lnTO_{it}} + \alpha_2 \mathrm{lnGDP_{it}} + \alpha_3 \mathrm{lnLEU_{it}} + \alpha_4 \mathrm{lnINOVINT_{it}} + \alpha_5 \mathrm{lnEC_{it}} + \alpha_6 \ln(\mathrm{INOINVT} * \mathrm{EC}) + \alpha_7 \ln(\mathrm{GDP} * \mathrm{EC}) + \tau_{it} \quad [2]$$

Where t and i denote the period of the data and the countries respectively. $\mathrm{lnCCC_{it}}$ is the natural logarithm of climate change crisis, $\mathrm{lnTO_{it}}$ is the natural log trade openness, $\mathrm{lnGDP_{it}}$ is the natural log of real GDP, $lnLEU_{it}$ is the natural log of energy use, $lnINOVINT_{it}$ is the natural log of innovation intensity, and $lnEC_{it}$ is the natural log of economic complexity. Furthermore, α_0 is the coefficient of the constant term, and $\alpha_j, j = 1,2, \ldots, 7$ is the coefficient of the independent variables. τ_{it} is the error term.

3.2.1 Cross-Sectional Dependence Test

Since the data are based on cross-sectional data for different countries, there may be mutual relationships between one or more of the countries, and this may lead to the countries experiencing similar patterns that ultimately occur as a part of spatial dependence, idiosyncratic pairwise dependence, and error term in the disturbances, without specific design of spatial dependence or general components (Pesaran, 2004; Robertson & Symons, 2000; Baltagi, 2008; Anselin, 2001). Moreover, some countries have sample-integrated economies via trading and financial links. These links enhance the contribution of potential spillovers among them. Therefore, we apply the cross-sectional dependence (CD) test of Pesaran (2004) to probe the coexistent correlation across the countries and gauge the cointegration tests and unit root categories that are the most appropriate for our dataset. The cross-sectional independence test of Pesaran (2004) was used to measure the CD test, which has the null hypothesis of no cross-sectional interdependence amongst the countries included in the sample. The underlying equation for the test is as follows:

$$D = \left(\frac{TN(N-1}{2}\right)^{1/2} \bar{\hat{\rho}} \quad [3]$$

Where $\bar{\hat{\rho}} = \left(\frac{2}{N(N-1)}\right) \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}$ and $\hat{\rho}_{ij}$ specifies the combined coefficient of cross-sectional correlation of the residuals obtained from the ADF regression. T designates the time dimension, and N signifies the cross-sectional dimension.

3.2.2 Panel Unit Root Test

After the computation of the CD statistics as described in the former section, we apply the cross-sectional augmented Dickey-Fuller (CADF) test to calculate the time trend in the unit root test:

$$\Delta y_{it} = \alpha_i + T_i \ + \beta_i y_{it-1} + \gamma_i \bar{y}_{t-1} + \phi_i \Delta\bar{y}_t + \varepsilon_{it} \qquad [4]$$

Here, $t = 1, \dots, T,\ i = 1, \dots, N$ and $\overline{y}_t$ is the mean of the cross-sectional y_{it} that is obtained from $\overline{y}_t = N^{-1} \sum_{i=1}^{N} y_{it}$. Equation (1) $H_0: \beta_i = 0$ presents the null hypothesis for all i and $H_a: \beta_i < 0$ indicates the alternative hypothesis for some i. It is assumed that the errors term is independent across the sample units. The null hypothesis is 0 and the alternative hypothesis is <0. This alternative hypothesis is restrictive since it implies that the autoregressive parameters are identical across the panel.

The cross-sectionally augmented panel unit root (CIPS) test of Pesaran (2007) computes statistics using the following equation:

$$CIPS(N,T) = N^{-1} \sum_{i=1}^{N} t_i(N,T) \qquad [5]$$

where $t_i(N,T)$ shows the β_i t-statistics.

3.3 CS-ARDL Test

A robust potential dependence cross-sectionality is found between the core dependent variable (i.e., carbon emissions) and the core independent variables (economic complexity index, innovation intensity) and the other variables. This is because globally countries are integrated through financial and trade liberalization, neighbouring, globalization, and other networking factors. Therefore, the Cross-Sectional Augmented Distributed Lag (CS-ARDL) estimation framework developed by Pesaran and Chudik (2014) has been applied to estimate the long-run and short-run relationships in the model stated in equation 2. Pesaran and Tosetti (2011) indicate that this estimation framework is important for controlling the cross-sectional dependence error process. They argue that cross-correlations occur because of common omitted elements, financial integration, interactions within socioeconomic networks, and spatial spillovers. CS-ARDL approach is impartial asymptotically as N→∞ for both fixed T and T→∞. CS-ARDL is very useful in the occurrence of common influences that are unobserved (Chudik, Mohaddes, Pesaran, & Raissi, 2016). CS-ARDL addresses the possible cross-sectional bias in both cases – the long-run and the short-run, as it has been developed under the framework of error correction to capture dynamic behaviour. CS-ARDL delivers coefficients for the short-run and long-run besides the coefficient of error correction. Both short-run and long-run homogeneity restrictions can be imposed under this framework. Moreover, CS-ARDL tackles the issue of endogeneity and serial correlation.

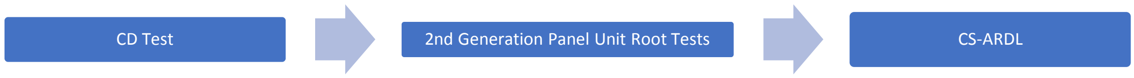

Figure 1: The Flow of methodology

The key disadvantage of calculating the long-run coefficients using CS-ARDL specifications is the possible emergence of lagged dependent variables in the regressions. This requires moderately large time measurement for suitable small sample performance, particularly when the sum of the AR coefficients in the specifications of ARDL is close to one. In the context of heterogeneous slope specifications, individual cross-sectional units of outlier estimates can influence the estimation of CS-ARDL coefficients. Three versions of CS-ARDL have been applied in this dissertation, which addresses the possible cross-sectional bias, both in the short-run and long-run. Therefore, the baseline regression equation is as follow:

$$\Delta CCC_{it} = \mu_i + \varphi_i(CCC_{it-1} - \beta_i X_{it-1} - \phi_{1i}\overline{CCC}_{t-1} - \phi_{2i}\bar{X}_{t-1}) + \sum_{j=1}^{p-1}\lambda_{ij}\Delta CCC_{it-j} + \sum_{j=0}^{q-1}\zeta_{ij}\Delta X_{it-j} + \eta_{1i}\Delta\overline{CCC}_t + \eta_{2i}\Delta\bar{X}_t + \varepsilon_{it} \quad [6]$$

Where ΔCCC_{it} is the dependent variable, $\overline{CCC}_{t-1}$ is the dependent variable mean for the long-run, X_{it} signifies all independent variables throughout the long-run, $\bar{X}_{t-1}$ independent variables mean for the long-run, ΔCCC_{it-j} the short-run dependent variable, $\Delta\overline{CCC}_t$ the mean of a dependent variable throughout the short-run, ΔX_{it-j}, independent variables in the short run, $\Delta\bar{X}_t$ independent variables mean throughout the short run, and ε_{it} is the error term. Where t=1 t presents time dimension, j denotes the cross-sectional dimension j=1 …. J, λ_{ij} is the dependent variable coefficient in the short-run, βj implies the coefficients of the independent variables, ζ_{ij} the short-run independent variables coefficients, and $\eta_{1i}\ and\ \eta_{2i}$ indicates dependent and independent variables means during the short-run. We estimated three different models.

4. Results and Discussions

4.1 Descriptive Analysis and Correlation Matrix

The summary statistics of the variables included in the model are presented in Table 2. The average value and standard deviation of CCC are 10.66kt and 1.79kt respectively. TO has an average value of 4.32 and its standard deviation is 0.50 which indicates less variability over the years across the sample of countries. Likewise, the average value of innovation intensity is 2.97 and its standard deviation value is 0.93. EC has an average value of 0.15 and its standard deviation is 0.97 which also indicates less variability. Minimum and maximum values show the range of data across the sampled countries. Skewness measures the extent of asymmetries in the series. The values of skewness show that variables CCC, LGDP, LEU, and EC are normally distributed as the skewness values are close to 0. The TO and INOVINT show a negative skew, with a long tail on the left side. Kurtosis shows the peakness or flatness of the series. The variables CCC, LGDP, LEU, and EC show mesokurtic distribution as their values are close to 3. The variables TO and INOVINT show leptokurtic distribution as the kurtosis values are higher than 3.

Table 2: Descriptive Statistics

Variable	Mean	Median	Std. Dev.	Min	Max	Skewness	Kurtosis
CCC	10.6612	10.6247	1.7903	6.3556	16.3937	0.3772	2.6859
TO	4.3202	4.3391	0.5009	2.0918	6.0806	-0.2328	3.9222
LGDP	25.2808	25.0966	1.8057	21.4873	30.4990	0.3989	2.4861
LEU	7.3397	7.3393	1.0008	4.9122	10.0042	0.09403	2.2323
INOVINT	2.9788	3.1614	0.9312	-2.6193	4.5047	-1.5182	6.7271
EC	0.1582	0.0633	0.9790	-2.6921	2.8951	0.1923	2.5255
N	2,760	2,760	2,760	2,760	2,760	2,760	2,760
Source: Author Compilation							

Table 3 shows the Pearson correlation matrix along with significant variables included in the model. Our findings indicate a positive and significant relationship between real GDP, energy use, innovation intensity, and economic complexity and climate change crises (CCC). Trade openness showed a negative and significant relationship with climate change crises. The scatters of the relationships between the major variables focused upon – innovation intensity and climate change crises, and economic complexities and climate change crises – are presented in Figure 2 and Figure 3 respectively.

Table 3: Correlation Matrix

	CCC	TO	LGDP	LEU	INOINT	ECI
CCC	1.0000					
TO	-0.2962***	1.0000				
LGDP	0.9134***	-0.3243***	1.0000			
LEU	0.5083***	0.2404***	0.4940***	1.0000		
INOVINT	0.6012***	-0.0201	0.6419***	0.5705***	1.0000	
EC	0.4325***	0.1684	0.5357***	0.5357***	0.6165***	1.0000
Note: *** shows a 1 % level of significance. Source: Authors compilation						

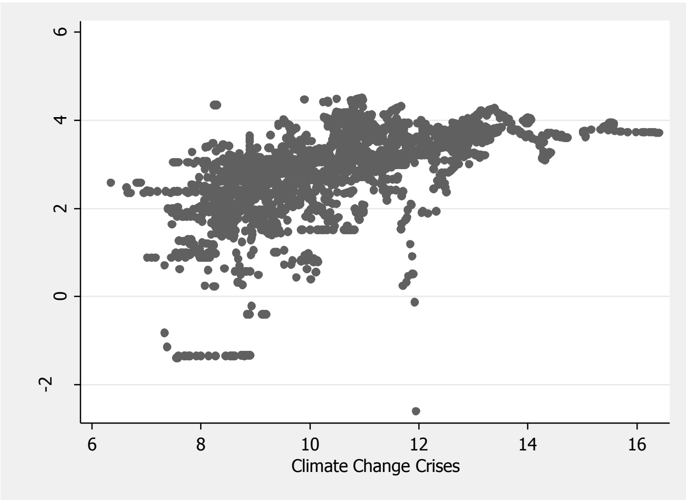

Figure 2: Innovation Intensity and Climate Change Crises

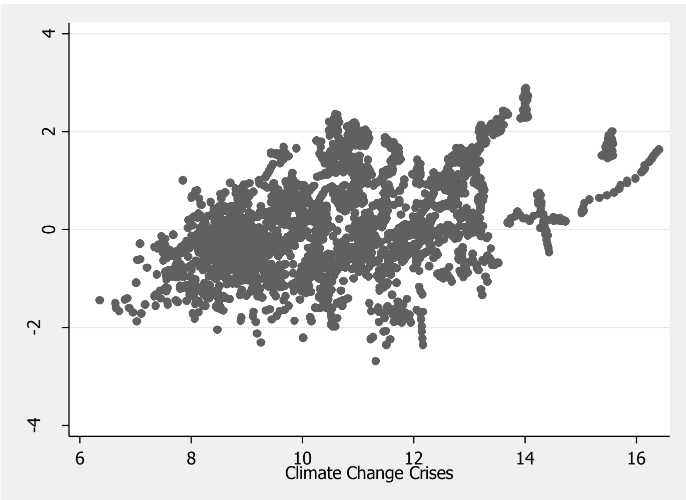

Figure 3: Economic complexities and Climate Change Crises

4.2 Results of Cross-Sectional Dependence and Panel Unit Root

As discussed in the methods section, we applied the CD test developed by Pesaran (2004) to check for the existence of common correlations in the sampled countries as the countries have been integrated via finance flows, trade, FDI, R&D, and globalization (Sadorsky, 2013). The CD tests are calculated from the common correlation across the cross-sections in the panel framework and obtained via OLS regression. Besides estimating the CD statistics, we used the 2nd generation panel unit root developed by Pesaran (2007) to identify the order of integration of all variables included in the study.

Table 4 shows the estimated values of the CD test along with the common correlation coefficients for the variables. The second column shows the existence of CD at 1% and 5% significance. The third column depicts that real GDP has the highest cross-country correlation and innovation intensity has a lower level of cross-country correlation. The fourth and fifth columns present the findings for the order of integration, with intercept included, of variables included in the model. The findings from CIPS show that climate change crises (CCC), real GDP (LGDP), energy use (LEU), and innovation intensity (INOVINT) are stationary at a level showing an integration order of 1(0). However, trade openness (TO) and economic complexities (EC) must be stationary at first difference with an integration order of 1(1). The mixed order of the integration of variables validates the application of the CS-ARDL framework to estimate the empirical model (Chudik *et al.*, 2016)

Table 4: Results of CD test and 2nd Generation Panel Unit Root Test

Variable	CD-test	abs(corr)	CIPS Level	CIPS 1st Diff
CCC	78.63***	0.694	-3.077***	-4.918***
TO	76.13***	0.551	-2.038	-4.369***
LGDP	360.76***	0.934	-2.613***	-3.639***
LEU	41.77***	0.590	-2.656***	-4.861***
INOVINT	38.23***	0.245	-2.383***	-4.490***
EC	-1.87 **	0.566	-2.020	-5.250***
Note: **, *** shows the level of significance at 5 % and 1 % respectively. Source: Author Compilation				

4.3 Impact of Innovation Intensity on Climate Change Crises

Table 5 presents the impact of innovation intensity on climate change crises based on the CS-ARDL estimation technique. We resolved the CD bias under three conditions namely by addressing the CD issue for short-run coefficients (model 1), removing CD bias for long-run coefficients (model 2) and resolving the CD bias both for short-run and long-run coefficients (model 3). We selected the findings from model 3 to interpret estimated coefficients, as common correlation effects exist in each variable across the sampled countries over the time horizon. The error correction coefficient is negative and significant in model 3 (see Table 5, last column), which confirms a long-term relationship between innovation intensity and climate change crises when incorporating the roles of real GDP, trade openness, energy use, economic complexities, and adjusting shocks in the short-run. The speed of adjustment is 24.99 % per period towards the equilibrium level during the long run.

It is interesting to note that after addressing the CD bias in all three models, we noticed that the rate of adjustment becomes slightly higher in model 3 after resolving the issue of CD during the short-run and long-run. Real GDP, trade openness, energy use, and economic complexities have a positive and significant relationship with climate change crises across economies, whereas innovation intensity has a negative and significant relationship with climate change crises. This inverse relationship between innovation intensity and climate change crises points to the fact that in countries invested in R&D, innovation can combat climate change. This argument is supported by Afrifa Tingbani, Yamoah, & Appiah, (2020) and Többelmann and Wendler (2020). A positive and significant relationship between real GDP and trade openness and climate change crises indicates that an increase in real GDP and trade openness spurs an increase in economic development which enhances carbon emissions and further stimulates climate change crises (You and Lv, 2018). Energy use also has a positive and significant relationship with climate change crises. We argue that an increase in energy use indicates that economies are performing well in terms of industrial production, hence generating more carbon emissions which worsens climate change crises. We find that innovation intensity has an inverse relationship with climate change crises. Short-run results are consistent with long-run results.

Table 5: Impact of Innovation Intensity on Climate Change Crises

	CD in SR (Model 1)	CD in LR (Model 2)	CD in both SR and LR (Model 3)
ECM	-0.2329***	-0.2141***	-0.2499***
	(-9.13)	(-9.97)	(-9.85)
	Long Run Coefficients		
$LGDP_{t-1}$	0.3737***	0.6419***	0.7083***
	(38.88)	(28.32)	(33.75)
TO_{t-1}	0.0017	0.0002	0.0006***
	(1.76)	(1.22)	(4.19)
LEU_{t-1}	0.8348***	0.8211***	0.7079***
	(50.87)	(33.50)	(32.71)
$INOVINT_{t-1}$	-0.0368***	-0.0212*	-0.0287**
	(-3.56)	(-1.98)	(-2.77)
EC_{t-1}	0.1335***	0.0653***	0.0765***
	(14.97)	(7.42)	(8.37)
	Short Run Coefficients		
$\Delta LGDP$	0.4496***	0.3197***	0.4716***

	(5.00)	(4.57)	(5.31)
ΔTO	0.0001	0.0000	0.0004
	(0.24)	(0.02)	(1.15)
ΔLEU	1.2163***	1.2325***	1.1849***
	(5.68)	(5.73)	(5.54)
$\Delta INOVINT$	0.3277	0.3031	0.3600
	(0.89)	(0.80)	(0.97)
ΔEC	0.0124	0.0103	0.0086
	(1.00)	(0.85)	(0.71)
Constant	-1.0682***	-0.7572***	-0.7814***
	(-8.43)	(-9.49)	(-8.69)
Observations	2645.0000	2645.0000	2645.0000
Cross Sections	120	120	120
Note: *, ** and *** presents level of significance at 10 %, 5 % and 1 % respectively. Source: Author compilations			

4.4 Innovation Intensity and Climate Change Crises: The Role of Economic Complexity

Table 6 shows the results pertaining to innovation intensity and climate change crises while incorporating the role of economic complexities. The findings from model 3 show that the error correction term is negative and significant. The speed of adjustment is 25.38 % per year to reach towards equilibrium level. Real GDP, trade openness, and energy use have a positive and significant relationship with climate change crises. This finding is supported by Shaari, Abidin, Ridzuan, and Meo (2021). It is interesting to note that when we introduced the interaction term between innovation intensity and economic complexities, the effect of innovation intensity on climate change crises turns to being positive, whereas economic complexities showed a negative and significant relationship with climate change crises across the sampled countries. This might be due to the increased use of innovative and clean energy technologies in the production process. The joint effect of both innovation intensity and economic complexities is positive and significant in terms of climate change crises. Short-run results are consistent with long-run results in terms of economic complexities and the interaction term between economic complexities and innovation intensity. Economic complexities have an inverse relationship with climate change crises and the joint effect of both innovation intensity and economic complexity is negative but insignificant. The inverse relationship between the economic complexity index and emissions is evidenced in some European regions, as shown by Adedoyi et al. (2021).

Table 6: **Innovation Intensity and Climate Change Crises: The Role of Economic Complexity**

	CD in SR (Model 1)	CD in LR (Model 2)	CD in both SR and LR (Model 3)
ECM	-0.2251***	-0.2256***	-0.2538***
	(-9.08)	(-9.67)	(-9.83)
Long Run Coefficients			
$LGDP_{t-1}$	0.3739***	0.5889***	0.7107***
	(45.95)	(31.47)	(36.71)
TO_{t-1}	0.0001	-0.0001	0.0005***
	(0.70)	(-0.94)	(3.45)
LEU_{t-1}	1.0064***	0.8693***	0.7110***
	(56.11)	(41.30)	(33.60)
$INOVINT_{t-1}$	0.0250	0.0152	0.0277***
	(1.95)	(1.60)	(3.43)
EC_{t-1}	-0.3131***	-0.2624***	-0.4075***
	(-6.67)	(-15.58)	(-18.23)
$INOVINT * EC_{t-1}$	0.1145***	0.0208**	0.1631***
	(8.48)	(2.78)	(3.79)
Short Run Coefficients			
$\Delta LGDP$	0.4212***	0.3198***	0.4574***
	(4.45)	(4.50)	(4.99)
ΔTO	0.0004	-0.0000	0.0005
	(0.85)	(-0.15)	(1.11)
ΔLEU	1.2169***	1.2471***	1.1807***
	(5.65)	(5.80)	(5.47)
$\Delta INOVINT$	-0.9759	-0.8739	-0.2193
	(-0.60)	(-0.72)	(-0.23)
ΔEC	15.0210	10.0549	7.8402
	(0.94)	(0.89)	(0.91)
$\Delta INOVINT * EC$	-4.7610	-3.2910	-2.4504
	(-0.93)	(-0.90)	(-0.88)
Constant	-1.3564***	-1.0353***	-0.8359***
	(-9.08)	(-9.55)	(-8.77)
Observations	2645.0000	2645.0000	2645.0000
Cross Sections	120	120	120
Note: *, ** and *** presents level of significance at 10 %, 5 % and 1 % respectively. Source: Author compilations			

4.5 Innovation Intensity and Climate Change Crises: The Roles of Economic Complexity and Real GDP

Table 7 presents the findings pertaining to innovation intensity and climate change crises, incorporating the roles of economic complexities and real GDP. The finding from model 3 shows that the error correction term is negative and significant. The speed of adjustment per year is 20.70 % to reach towards equilibrium level. Real GDP, trade openness, energy use, and economic complexity have a positive and significant relationship with climate change crises. These results are consistent with our earlier findings. Innovation intensity has a negative and significant relationship with climate change crises. As the use of innovation technologies increases in the production process, this reduces climate change crises. However, the joint effect of real GDP and economic complexity has positive and significant effects on climate change crises in the long run. The short-run results show that real GDP, energy use, and innovation intensity have a positive and significant effect on climate change crises. Trade openness has insignificant effects on climate change crises during the short-run. Economic complexities have an inverse relationship with GDP during the short-run, however the joint effect of real GDP is positive and significant on climate change crises during the short-run.

Table 7: Innovation Intensity and Climate Change Crises: Role of Economic Complexity and Real GDP

	CD in SR (Model 1)	CD in LR (Model 2)	CD in both SR and LR (Model 3)
ECM	-0.2436***	-0.1569***	-0.2070***
	(-9.18)	(-9.45)	(-9.09)
Long Run Coefficients			
$LGDP_{t-1}$	0.3193***	1.1874***	1.0228***
	(36.98)	(39.60)	(33.32)
TO_{t-1}	0.0001	0.0003	0.0002
	(0.92)	(0.94)	(0.02)
LEU_{t-1}	1.0936***	0.1776***	0.3404***
	(63.00)	(5.88)	(13.80)
$INOVINT_{t-1}$	-0.0325**	-0.0252*	-0.0019***
	(-2.61)	(-2.50)	(-8.46)
EC_{t-1}	0.0289***	1.9850***	1.6189***
	(4.86)	(6.19)	(7.40)
$GDP * EC_{t-1}$	-0.6242***	-0.0837***	-0.0722***
	(-4.10)	(-6.50)	(-8.10)
Short Run Coefficients			
$\Delta LGDP$	0.5461***	0.3743**	0.6366***
	(3.83)	(3.05)	(4.41)
ΔTO	0.0002	-0.0004	0.0001
	(0.36)	(-1.16)	(0.21)
ΔLEU	1.2598***	1.1723***	1.1478***
	(6.13)	(6.12)	(6.19)
$\Delta INOVINT$	0.2974	0.3685	0.4032
	(0.79)	(0.93)	(1.01)
ΔEC	-1.8176	-0.9278	-0.7120
	(-0.95)	(-0.45)	(-0.33)
$\Delta GDP * EC$	0.0849	0.0421	0.0399
	(1.13)	(0.52)	(0.47)
Constant	-1.2723***	-0.4137***	-0.7884***
	(-8.58)	(-9.02)	(-9.06)
Observations	2645.0000	2645.0000	2645.0000
Cross Sections	120	120	120
Note: *, ** and *** presents level of significance at 10 %, 5 % and 1 % respectively. Source: Author compilations			

5. Conclusion and Policy Implications

This study has analyzed the relationship between innovation intensity and climate change crises by factoring in the roles of economic complexities and real GDP. To investigate this phenomenon, we collected empirical data from 120 economies globally. The analysis shows the presence of a strong common correlation effect across all variables included in the study. The results of second-generation unit root tests validated the use of the CS-ARDL estimation technique. Our empirical investigation flags up several interesting results. Innovation intensity and economic complexities both have impacts on climate change crises. We find that innovation intensity has an inverse relationship with climate change crises and economic complexities have a positive relationship with climate change crises (see Table 5). The impact of these two variables changed when we included an interaction term between innovation intensity and economic complexities to examine the joint effect of both on climate change crises (see Table 6). We find that innovation intensity has a positive and significant relationship with climate change crises and economic complexities have a negative relationship with climate change crises.

The joint effect of both innovation intensity and economic complexities has, however, a positive and significant effect on climate change crises. The impact of innovation intensity and economic complexities again changed when we included the interaction term between innovation intensity and real GDP (see Table 7). Innovation intensity has an inverse and significant relationship with climate change crises whereas economic complexities have a positive and significant effect on climate change crises. The joint effect of both innovation intensity and real GDP is positive and significant on climate change crises. Concerning the effects of real GDP, trade openness, and energy use, these variables contribute positively and significantly to augmenting climate change crises in the sample of economies studied here.

These findings provide a few iterative policy implications. Higher innovation intensity reduces climate change crises so more funds should be reserved for innovation and research and development such that climate change crises can be contained or minimized. We find that a high level of economic complexities fosters climate change crises. This finding suggests that global emerging economies are trying to expand their production base by diversifying exports and this has an indirect impact on climate change. These global emerging economies should diversify exports production by using new and more efficient methods of production so that climate changes crises can be prevented or minimized. We also find that the innovation intensity and climate change crises relationship is sensitive to economic complexities. This indicates that global emerging economies should focus on diversifying export bases, adopting new technologies for production purposes, and promoting innovation and research and development, in order to combat climate change crises.

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