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IMPACT OF INNOVATION ON CO_2 EMISSIONS IN SOUTH ASIAN COUNTRIES

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ABSTRACT

Across the globe, human lifestyles are accelerating carbon emissions, and this phenomenon is especially pronounced in developing nations. As the world grapples with the compelling imperative to address severe environmental challenges, technology has emerged as a steadfast ally. Over recent decades, the advancement of cutting-edge technology and the granting of patent rights have ignited a profound discourse on novel approaches to mitigating environmental threats. In recent years, there has been a growing interest in investigating how innovations might assist in reducing carbon emissions. The current study looks at how innovation affects carbon dioxide emissions in South Asian nations. The goal of this study is to use panel OLS and fixed effects methodologies to examine the influence of innovation on CO2 emissions in five South Asian nations from 1980 to 2019. The study's findings show that carbon dioxide emissions are negatively impacting environmental quality, while technological developments help to lower these carbon emissions. The findings argue for the development of initiatives to foster and expand technical innovation, particularly in South Asian countries. This research underscores the imperative of harnessing innovation to confront the immediate environmental challenges that loom large in the twenty-first century, as we strive for a more sustainable and environmentally responsible future.

KEYWORDS: Innovation, CO_2 emissions, environment, South Asia

1. INTRODUCTION

In recent years, a consistent global temperature rise has emerged as a significant threat to long-term development. This concerning trend primarily stems from the excessive energy consumption inherent in our technology-driven growth model and the extensive exploitation of natural resources (Zameer et al., 2020; Ali et al., 2022). It is crucial to acknowledge that energy serves not only as a cornerstone of economic success but also as a substantial contributor to environmental degradation (Zhang et al., 2017; Audi & Ali, 2023). As nations endeavor to advance their economies, there is an inevitable surge in energy consumption, resulting in a corresponding uptick in CO2 emissions (Fethi et al., 2019; Audi & Ali, 2023). The inextricable link between economic expansion and its environmental impact is an undeniable reality, emphasizing the critical need for a more sustainable approach to development that harmonizes economic growth with environmental preservation. In this context, the sustainability of our planet becomes paramount, as unchecked economic progress exacts an ever-increasing toll on our natural surroundings. Therefore, we must explore innovative solutions and implement policies that promote economic development without compromising the health of our ecosystem.

With the global population rapidly increasing, the demand for goods and services is soaring, consequently leading to a surge in carbon dioxide emissions. In the present era, economies are increasingly reliant on energy to fuel their pursuit of economic expansion, exacerbating the carbon emissions predicament (Pan et al., 2019; Ali et al., 2021). CO2 emissions, particularly those stemming from energy-related sources, have surged by a staggering 45% over the past thirteen years, underscoring their pivotal role in environmental degradation (Yii et al., 2017). Carbon dioxide emissions represent an imposing challenge at the intersection of global natural resource management and technological growth. In this critical context, it becomes imperative to investigate the various factors that contribute to the exacerbation of CO2 emissions into the environment, all while striving to maintain and foster economic success. To navigate this complex challenge effectively, it is crucial to delve into the realms of technological innovation, energy consumption patterns, GDP growth, and their interconnectedness with CO2 emissions (Khan et al., 2020; Ali et al., 2021). These factors represent key levers in our quest for a sustainable future in which economic prosperity can coexist harmoniously with the preservation of our planet's natural resources and ecosystems. By exploring and understanding these intricate dynamics, we can chart a course toward a more sustainable and balanced future for both humanity and the environment.

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Innovation stands as a pivotal driver of economic progress, and its significance in addressing pressing global concerns cannot be overstated. Innovation has emerged as a central topic in policy discussions, particularly in the context of climate change. This emphasis on innovation is especially crucial in emerging economies, where CO_2 emissions pose a significant threat to environmental quality (Nazir et al., 2018). Recognizing the importance of innovation in mitigating the effects of climate change is not a novel idea. A substantial body of scholarly research has focused on evaluating the intricate relationship between green technology and greenhouse gas emissions, to understand how the former can effectively reduce the latter (Hao et al., 2020; Dauda et al., 2019). These studies offer valuable insights into the pathways through which innovation can effectively curb carbon emissions. One of the primary ways that innovation can contribute to carbon emissions reduction is by enhancing the efficiency of economic development. Innovative technologies and processes often lead to more energy-efficient solutions, thereby reducing the carbon footprint associated with economic activities (Menash et al., 2018). Additionally, innovation can bolster the productivity of both capital and labor, optimizing resource utilization and promoting sustainable economic expansion. Moreover, by fostering technical progress, innovations not only boost economic output but also help minimize the environmental impact of production processes.

In the realm of clean energy and environmental sustainability, innovation assumes a critical role, often serving as the driving force behind policies such as taxes and subsidies aimed at steering us toward a greener future (Zhang et al., 2017; Audi & Ali, 2018). However, while a plethora of climate-related technologies promise to enhance environmental quality, tangible data supporting this proposition remains elusive (Meirun et al., 2021). To gain a comprehensive understanding of the intricate mechanisms at play, empirical insights into how climate change indicators stimulate the proliferation of clean innovations are imperative. This pursuit is pivotal for substantiating the notion that innovation is a driving force in the quest for a more sustainable world. Employing patent counts as a proxy for gauging innovation development lends substantial weight to this approach (Hao et al., 2021). Patents represent tangible evidence of original ideas and technological advancements, making them a significant marker in comprehending the growth of clean technology. By exploring the link between climate change indicators and the surge in clean energy breakthroughs through patent analysis, we can glean substantial insights. This empirical approach not only furnishes concrete proof of the interplay between environmental challenges and inventive solutions but also underscores the importance of fostering an environment that nurtures and incentivizes such advancements.

Foreign Direct Investment (FDI) holds paramount significance in the growth and development of South Asian nations, notably in their industrial sectors. FDI not only propels economic advancement but also bestows a plethora of ancillary benefits, including job creation, knowledge transfer, organizational expertise, and innovative capabilities (Tobelmann et al., 2020). Over the past three decades, South Asian economies have demonstrated a remarkable capacity to attract FDI, outperforming numerous other nations globally in this regard. This influx of foreign capital has significantly bolstered their economic development and transformation. However, while FDI catalyzes growth, it concurrently raises environmental concerns in host nations, particularly when polluting industries are relocated, resulting in environmental contamination (Adeel et al., 2018). The dual nature of FDI underscores the significance of a balanced and sustainable approach. Policymakers in South Asian nations must judiciously weigh the trade-off between economic expansion and environmental preservation. It is imperative to enact stringent regulations and incentives that encourage environmentally responsible practices within FDI-attracted industries. This ensures that the positive impacts of FDI, such as job creation and technology transfer, are not overshadowed by adverse environmental consequences.

Trade openness constitutes a multifaceted macroeconomic indicator with a significant impact on economic growth. It operates through two distinct mechanisms, each contributing substantially to economic advancement. The first mechanism entails the expansion of firms' scale, resulting in economies of scale and reduced production costs. Larger markets facilitated by international trade foster increased competition, innovation, and cost efficiency (Ganda, 2019). The second mechanism is equally vital and revolves around the cross-border transmission of technology and knowledge. Trade facilitates the exchange of ideas, technologies, and best practices, resulting in a potent synergy that propels economic growth. This transmission of knowledge is pivotal in enhancing a nation's technological prowess and productivity. Nevertheless, it is imperative to acknowledge that the nexus between trade, technology, and economic progress also carries environmental implications. The upsurge in economic activity propelled by trade often relies on the consumption of fossil fuels, leading to a substantial increase in CO_2 emissions. These emissions contribute significantly to global temperature rise and climate change. Consequently, a robust association exists between carbon dioxide emissions, technological innovation, and trade openness (Fan & Hossain 2018). Nations face an increasing imperative to strike a balance as they navigate the intricate interplay of trade, technology, and environmental sustainability. Policymakers must formulate strategies that harness the benefits of trade and technological advancement while mitigating the environmental consequences. This may entail promoting cleaner energy sources, fostering eco-friendly practices within industries, and incentivizing sustainable innovation.

South Asian economies encompass a diverse array of countries, including Sri Lanka, Bangladesh, Pakistan, India, Bhutan, the Maldives, Nepal, and Afghanistan. These nations collectively wield considerable influence on the global economic stage, courtesy of their large populations and active engagement in international trade. However, as these South Asian nations relentlessly pursue economic growth, a concerning trend has emerged—a substantial increase in carbon emissions. India, in particular, has risen to become the world's sixth-largest emitter of CO_2, contributing a staggering 75% of all emissions originating from the South Asian region (Adeel et al., 2018). This statistic underscores the formidable environmental challenges that South Asian economies confront as they strive to balance economic development with ecological sustainability. The surge in carbon emissions within the region reflects the intricate dynamics at play. While economic growth brings prosperity and enhances living standards, it also amplifies energy consumption, frequently sourced from fossil fuels. Consequently, carbon emissions surge, exacerbating the global predicament of climate change.

The examination of the intricate link between innovations and CO_2 emissions in South Asian nations holds substantial promise in formulating effective policy responses. Comprehending the repercussions of innovation in mitigating CO_2 emissions provides a pathway for informed decision-making aimed at curtailing carbon emissions and nurturing a more sustainable future. This research has the potential to catalyze significant carbon emissions reduction efforts. Numerous scholars have delved into this intriguing connection between innovation and carbon dioxide emissions, shedding light on its effectiveness. For instance, studies conducted by Yu & Du (2018) and Chen & Lei (2018) have explored whether a meaningful relationship exists between innovation and the levels of carbon dioxide emissions. Moreover, the research conducted by Zameer et al. (2019) underscores the profound impact of innovations as a primary driver of economic growth. These innovations not only invigorate economic expansion but also enhance energy productivity by curbing carbon dioxide emissions. In essence, technological innovation empowers countries to achieve greater output while utilizing fewer energy resources (Zhang et al., 2017). This virtuous cycle between innovation, economic growth, and emissions reduction forms a cornerstone of sustainable development.

2. LITERATURE REVIEW

Around the globe, human activities continue to generate alarming levels of CO_2 emissions, a phenomenon not spared even in high-income countries, as Mensah et al. (2018) meticulously investigated in a study spanning from 1990 to 2014 across 28 OECD countries. Employing a rigorously designed fully modified linear regression model, their research brought to light the pivotal role of innovations in the reduction of CO_2 emissions across the majority of OECD nations. Furthermore, their findings underscored the significant impact of renewable energy sources in curbing carbon emissions, while conversely, non-renewable energy sources were associated with emissions escalation. Complementing these findings, Zhang et al. (2017) undertook an inquiry into the effectiveness of environmental innovations in mitigating CO_2 emissions within China, utilizing the Generalized Method of Moments (GMM). Their study, like Mensah et al.'s, advocated the positive potential of innovation but highlighted a different facet. They concluded that China's environmental laws and supervisory mechanisms were inadequately robust, necessitating revision to substantively reduce carbon emissions and foster a cleaner environment.

Building on this global perspective, Ganda (2019) delved into the consequences of various innovations and technological investments on CO_2 emissions reduction within OECD countries from 2000 to 2014, employing the Generalized Method of Moments (GMM). His research uncovered the negative and significant relationship between spending on research and development and renewable energy consumption with carbon emissions. Additionally, the study revealed that several patent families exhibited statistically positive and significant relationships with carbon emissions, explaining complexities within the innovation-emission dynamic. Du et al. (2019) concentrated on investigating the role of green technology innovations in carbon dioxide emissions reduction across 71 economies, spanning from 1996 to 2012. Their study, employing a panel fixed effects model, illuminated a disparity between high and low-income countries. Nations with income levels exceeding $34,694 demonstrated more favorable outcomes in terms of carbon emissions reduction through green technology innovations, underscoring the importance of income levels in determining the effectiveness of such innovations. Similarly, Hao et al. (2020) sought to examine the performance of green growth for sustaining a conducive atmosphere within G7 countries from 1991 to 2017, utilizing the Cross-Sectional Augmented Distributed Lag (CS-ARDL) model. Their research elucidated the multifaceted nature of carbon emissions reduction, emphasizing the significance of both linear and non-linear terms of green growth. Furthermore, they highlighted the beneficial role of non-renewable energy and environmental taxes, along with investments in human capital, in the reduction of CO_2 emissions.

The study conducted by Zameer et al. (2020) sheds light on the intricate relationship between innovation, economic growth, and the environment, with a particular focus on the role of trade openness and Foreign Direct Investment (FDI) in India. The results derived from ARDL and VECM models illuminate a unidirectional relationship between energy use, FDI, and carbon emissions. Interestingly, a bidirectional relationship emerges between carbon emissions and trade openness, indicating the dynamic interplay between economic factors and environmental concerns. However, it's important to note that the findings might benefit from a deeper exploration of the underlying mechanisms driving these relationships, such as the specific sectors influenced by trade openness and FDI. Meirun et al. (2021) present a study that underscores the positive and significant association between green technology innovation and economic growth in Singapore from 1990 to 2018. The findings also reveal a negative and significant relationship between carbon dioxide emissions and economic growth in both the short and long run. The policy implications are noteworthy, explaining that governments should actively promote an environment conducive to investment in green technology. Nevertheless, it's critical to consider the potential challenges and barriers that might hinder the implementation of such policies, which can vary from one country to another.

Herŕanz et al. (2017) delve into the impact of research and development related to energy on greenhouse gas emissions across twenty-eight OECD countries. The results underscore the importance of promoting a comprehensive structure of research and development to reduce CO2 emissions. However, it's essential to acknowledge that the effectiveness of research and development programs can be influenced by various factors, including funding allocation, collaboration between the public and private sectors, and the speed of technology transfer. Yu and Du (2019) provide insights into the impact of technological-based innovation on CO2 emissions and offer predictions for China's emissions trends using the STRIPAT model. Their study identifies both high-speed and low-speed groups, revealing that both independent innovation and introduced innovation contribute to increased CO2 emissions. The findings also highlight the potential for CO2 emissions reduction through increased research and development investment. Nevertheless, it's worth considering the allocation of resources for research and development and the role of government policies in fostering innovation. Yusuf (2019) investigates the relationship between innovations and the Environmental Kuznets Curve (EKC) for the Indonesian economy from 1980 to 2017. The study's findings explain a long-term negative relationship between technological innovation and environmental degradation. This explains that policies promoting innovation could have a positive impact on the environment, but the specifics of these policies and their potential trade-offs with economic development require further exploration.

Yii & Geetha (2017) explore the connection between technological innovation and CO2 emissions in Malaysia from 1971 to 2013. Their results reveal that, in the short run, technology innovation negatively influences CO2 emissions, while no such relationship is found in the long run. Additionally, the study uncovers a bidirectional relationship between CO2 emissions and GDP in the long term. However, it's essential to delve into the specific technological innovations that influence emissions and to consider the broader economic context in Malaysia. Su & Moaniba (2017) tackle the response of innovation to climate change across a panel of seventy countries from 1976 to 2014, using the GMM technique. Their findings explain that climate change-related technologies exhibit a positive response to increasing carbon emissions, raising questions about the effectiveness of these technologies in reducing emissions. The study also highlights the negative response of solid fuel consumption based on coal to rising CO2 emissions, emphasizing the complexity of the relationship between innovation and emissions. Weina et al. (2016) examine the role of green innovation on greenhouse gas emissions in Italy from 1990 to 2010, utilizing the STIRPT model. The results indicate that while green technology may not have played a prominent role in improving environmental quality, it has enhanced the overall productive capacity of the environment. This explains that green patent stock in Italy has yet to substantially reduce carbon emissions, emphasizing the need for a more nuanced approach to green innovation.

Similarly, Hashmi & Alam (2019) explore the dynamic relationship between innovations, environmental quality, CO2 emissions, population, and economic development in OECD countries. Their findings explain that an increase in environmental patent counts can help reduce carbon emissions, underscoring the role of innovation in environmental sustainability. Additionally, an increase in environmental taxes is associated with reduced carbon emissions. However, it's important to consider the broader policy implications of these findings and their potential impacts on economic growth and competitiveness. Flores & Innes (2010) investigated the relationship between environmental innovation and environmental performance in the USA from 1989 to 2004, employing the GMM technique. The results reveal a negative and significant relationship between environmental patents and carbon dioxide emissions, explaining that more stringent pollution-reducing targets could lead to improved environmental quality. Nonetheless, the study might benefit from further exploration of the specific policy mechanisms that drive these outcomes and potential challenges in implementation.

The study conducted by Fernńandez et al. (2018) investigated the consequences of research and development (R&D) spending on CO2 emissions across the USA, China, and fifteen European countries from 1990 to 2013, employing the Ordinary Least Squares (OLS) method. Their findings provide evidence that R&D expenditures are associated with reduced carbon dioxide emissions in fifteen European countries as well as in the USA. While these results are encouraging, it's important to acknowledge that the impact of R&D spending on emissions may vary based on the specific sectors and technologies targeted, warranting further exploration. Pan et al. (2019) illuminate the dynamic relationship between technological innovations, environmental regulations, and energy efficiency in China from 2006 to 2015, utilizing the Structural Vector Autoregression (SVAR) technique. Their study highlights the pivotal role of technological innovations in promoting energy regulations, explaining that governments should maintain a balanced approach between market incentive environmental regulations and command control environmental regulations. However, the effectiveness of such regulations may be contingent on their design, enforcement, and alignment with broader environmental goals.

Dauda et al. (2019) examine the impact of economic growth and innovation on carbon dioxide emissions across eighteen developing and developed countries from 1990 to 2016, employing Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) approaches. Their findings reveal the complexity of these relationships, with energy use contributing to increased CO2 emissions in G6 countries and decreased emissions in BRICS and MENA countries. This explains that policy interventions should be tailored to the specific context and development stage of each country. Fan & Hossain (2018) empirically investigate the intricate interplay between technological-based innovation, economic growth, trade, and CO2 emissions in China and India spanning from 1974 to 2016, employing ARDL and Toda-Yamamoto Granger causality techniques. Their findings indicate mixed effects in the short term and significant positive effects in the long term for China's trade openness, technological innovation, and CO2 emissions on economic growth. However, India's short-term results present a different picture. It's crucial to recognize that the effectiveness of policies promoting innovation and trade openness may vary based on the unique economic and industrial characteristics of each country.

Chen & Lei (2018) explore the potential effects of renewable energy and technological-based innovation on environmental energy growth across thirty countries from 1980 to 2014, using a panel co-integration test. Their results shed light on the limited role of renewable energy usage in lowering CO2 emissions for countries with high emissions. In contrast, technological innovations play a more substantial part in reducing carbon emissions for countries with lower CO2 emissions. These findings underscore the importance of tailored strategies for carbon reduction based on a country's emissions profile. Tobelmann & Wendler (2020) aim to uncover the consequences of environmental innovation on CO2 emissions across twenty-seven European economies from 1992 to 2014, employing the Generalized Method of Moments (GMM). Their findings emphasize the crucial role of environmental innovations in reducing CO2 emissions compared to general innovations. However, the results also highlight the significant impact of increasing energy use and GDP on the rising levels of carbon emissions. It's essential to consider the potential trade-offs between economic growth and environmental sustainability when implementing policies to promote innovation.

Khan et al. (2020) empirically examine the role of technological innovations, natural resources, and energy growth on the environment across BRICS countries from 1985 to 2014, using the STRIPAT model. Their results reveal the existence of bidirectional causality in energy usage and carbon emissions, explaining complex relationships within these countries. Additionally, natural resources are identified as a driver of economic growth and carbon emissions. These findings underscore the challenges in managing the trade-offs between economic development and environmental sustainability in emerging economies. Fethi & Rahuma (2019) investigate the role of eco-innovation in reducing carbon emissions across twenty oil-exporting countries from 2007 to 2016. Their findings reveal that long-term eco-innovations, particularly research and development, significantly impact carbon dioxide emissions. This validates the Environmental Kuznets Curve (EKC) for OECD countries, explaining that oil-exporting nations could reduce carbon emissions through increased research and development expenditures and public awareness programs. However, the effectiveness of these policies may depend on the broader energy landscape and socio-economic factors.

Nazir et al. (2018) explore the linkage between financial innovations and economic growth in China, Pakistan, and India from 1970 to 2016. Their findings, derived from the Autoregressive Distributed Lag (ARDL) approach and Fully Modified and Dynamic Ordinary Least Squares (FMOLS and DOLS) techniques, highlight the positive impact of financial innovations on economic growth in both the short and long run. These results underscore the potential of innovations to drive economic development in developing countries. However, the specific mechanisms through which financial innovations influence economic growth warrant further investigation. Adeel-Farooq et al. (2018) uncovered the relationship between environmental performance and greenfield investment in nine selected developing countries in Asia from 2003 to 2014, employing fixed and random effects methods. Their results demonstrate that investment in greenfield projects negatively impacts environmental quality, while economic growth has a positive influence. The role of energy use and urbanization appears to be insignificant. These findings raise questions about the potential trade-offs between economic development and environmental quality in the context of investment decisions.

3. THEORETICAL FRAMEWORK AND METHODOLOGY

In recent years, the rapid growth of the global population has led to increased demands for goods and services, consequently resulting in a notable surge in carbon dioxide emissions. This escalating concern highlights the pressing need for innovative solutions that can both foster economic growth and curtail carbon emissions. It is through innovation that we have witnessed the development of carbon-free technologies, representing a pivotal step toward mitigating emissions (Weina et al., 2015). A long-standing challenge faced by researchers since the 1990s is accurately measuring technological progress. Various indicators have been employed, such as research expenditures, investments in research staff, and several other measures (Yusuf, 2019). However, in recent times, patent applications and trademark registrations have emerged as particularly attractive metrics for gauging technological innovation. Consequently, these two variables have gained prominence in assessing the impact of innovation on carbon emissions. Following in the footsteps of established models proposed by Menash et al. (2018), Dauda et al. (2019), and Zameer et al. (2020), we have developed the following model,

$$CO_{it\,2} = f\,(PAT_{it}, TMA_{it}, EC_{it}, FDI_{it}, G_{it}, TO_{it}) \qquad (1)$$

Equation (1) shows that PATENT and TMA are the proxies of innovations. PAT is the patent applications by non-residents, TMA is trademark applications (total), EC is energy consumption that demonstrates energy usage (kg of oil equivalent per capita), FDI is representing foreign direct investment, G is per capita GDP (current US$) and TO is trade openness which is taken as exports of goods and services (% of GDP). We have used panel data for five South Asian economies for the period 1980-2019. By taking the natural log of equation (1) and it is converted into the econometric equation for the panel data,

$$LCO_{2it} = \beta_1 + \beta_2 LPAT_{it} + \beta_3 LTMA_{it} + \beta_4 LEC_{it} + \beta_5 LFDI_{it} + \beta_6 LG_{it} + \beta_7 LTO_{it} + \mu_{it} \quad (2)$$

where μ is the error term, i represents countries and t demonstrates the time duration which is from 1980-2019. Also, in this equation β_1 indicates the constant term while $\beta_2, \beta_3 \ldots\ldots \beta_7$ are the elasticities of independent variables.

Several methods can describe the impact of innovations on carbon dioxide emissions for cross-country analysis but in this study, for finding the integration order of concerned variables; all variables must be stationary at their 1st difference to perform the cointegration test. For this purpose, the ADF along with Levin Lin and Chu unit root tests have been applied. Panel OLS is used to check the unbiasedness and consistency of parameters. The fixed effects are used when time-constant attributes are there and to obtain more reliable estimates as it also reduces the effects of time-invariant properties. Furthermore, we have applied the Pedroni cointegration test as it allows cross-areas to be reliant on one another by having different aspects. By using the Pedroni cointegration test, different statistics, as well as p-values, are used to reject or accept the null hypothesis.

3.1. DATA

Although the impact of innovation on carbon dioxide emissions can be checked by using different variables as described in the literature this study focuses on South Asian countries which include Pakistan, Sri Lanka, Bangladesh, India, and Nepal while the remaining countries are not included because of the non-availability of data. For all variables, data has been taken from WDI (2022) for the period 1980-2019.

Carbon dioxide emissions derive from producing cement as well as by the burning of liquid along with gas fuels. Patent applications may be defined as those that are filed by the national patent office or with the patent cooperation treaty to take absolute rights of any creation. Trademark applications in total are those applications that are registered with the national or might be with the regional property office.

GDP Per Capita is referred to as gross domestic product which is attained by dividing gross domestic product by midyear population. It shows the summation of gross value added from total producers within the economy minus every subsidy that is not counted in the value of the commodity. Energy use might be referred to as the use of energy before modifying it. TO be trade openness which is exports of goods and services in place of a percentage of GDP. It contains the value of goods like transport, royalties, traveling, and insurance along with some services. FDI is the foreign direct investment which is taken as net inflows in the percentage of GDP and it is the summation of capital consisting of short as well as long term which is shown in the balance of payments.

4. RESULTS AND DISCUSSIONS

Unit root test is applicable to check whether data is stationary or not. Table 1 expresses the results of the unit root test by Levin, Lin & Chu, and ADF. The results indicate that all variables are stationary at 1st difference. So, we reject the null hypothesis because there is no trend in the analyzed data and we accept the alternative hypothesis since the data is stationary.

Table 1: Unit root test

Variables	ADF-Fisher Chi-Square				Levin, Lin & Chu			
	Level		1st difference		Level		1st difference	
	T-value	Prob.	T-value	p-value	T-value	Prob.	T-value	p-value
LCO_2	1.8053	0.9864	3.0754	0.0002	0.3288	0.6289	-1.7564	0.0395
LEC	4.1575	0.9400	45.7830	0.0000	3.5049	0.9998	-3.6397	0.0001
LG	0.8832	0.9994	27.0040	0.0007	1.0843	0.8609	-1.8417	0.0028
LFDI	1.7476	0.8976	52.9227	0.0000	-0.7699	0.1797	-5.4365	0.0000
LTO	8.1946	0.4147	27.3051	0.006	-1.7370	0.0412	-3.1820	0.0007
LTMA	3.7025	0.9598	59.8414	0.0000	-0.9999	0.1587	-5.7558	0.0000
LPAT	6.6395	0.5760	51.9359	0.0000	-1.6608	0.0484	-5.6792	0.0000

Table 2 shows the statistical description of our results, according to these results; our dependent variable CO_2 has a mean value of 0.5630, and trademark applications have a mean value of 24167.81 with SD equal to 45148.13. Similarly, PATENT has an average value of 972.3178 and a Standard Deviation equal to 2262.057. the details of the remaining variables are mentioned in the Table 2.

Table 3 shows the correlation between all the used variables. The results show that energy consumption, FDI, GDP per capita, Patent, trade, and TMA are positively correlated with CO_2. Here, PATENT and TMA are the proxies of innovation. While TO shows the trade openness. Positive signs with all these variables show the direction of the relation of all the explanatory variables with CO_2.

Table 2: Descriptive Statistics

	CO2	G	EC	TO	FDI	TMA	PAT
Mean	0.5630	677.8476	339.6359	17.2388	0.8269	24167.81	972.3178
Median	0.5452	470.9868	364.5145	14.9479	0.6727	6244	60.0000
Maximum	1.7233	3610.289	636.5702	39.0157	3.6683	223756	12040
Minimum	0.0822	193.2795	104.8616	3.3962	-0.0299	1141	4
Std. Dev.	0.3651	548.6398	135.8865	9.2781	0.7681	45148.13	2262.057
Obs.	129	129	129	129	129	129	129

Table 3: Correlation Matrix

Variables	CO2	EC	FDI	G	PAT	TMA	TO
CO2	1.0000						
EC	0.8271	1.0000					
FDI	0.5243	0.5639	1.0000				
G	0.4305	0.5395	0.4756	1.0000			
PAT	0.7677	0.4987	0.3414	0.2555	1.0000		
TMA	0.8043	0.5225	0.3675	0.2632	0.9831	1.0000	
TO	0.1016	0.4149	0.5001	0.3564	0.0892	0.0774	1.0000

Table 4 presents the results of Panel OLS and fixed-effects analysis, examining the impact of innovation on carbon dioxide emissions in five South Asian countries from 1980 to 2019. In our study, CO2 serves as the dependent variable, while explanatory variables include PATENT applications by non-residents, Trademark applications, GDP Per Capita, foreign direct investment, energy consumption, and trade openness.

The results reveal a positive and significant relationship between energy consumption and CO2 emissions. The coefficients of both the panel least squares and fixed-effect models indicate that a 1% increase in energy consumption corresponds to a rise of 0.99% and 1.61%, respectively, in CO2 emissions among the South Asian economies. These findings demonstrate the region's sensitivity to trends in energy consumption regarding carbon emissions. This connection is becoming increasingly problematic as South Asian nations undergo economic expansion and increased energy consumption. To address this issue, South Asian countries must transition to cleaner and more sustainable energy sources. Investments in renewable energy sources such as solar, wind, and hydroelectric power can reduce reliance on fossil fuels and, consequently, carbon emissions (Lima et al., 2020; Osman et al., 2023). Furthermore, improving energy efficiency and enforcing stringent environmental standards can help mitigate the impact of energy usage on CO2 emissions. Moreover, the differences in coefficients between the panel least squares and fixed-effect models explain that regional variations or additional contextual factors may influence the relationship between energy consumption and CO2 emissions within South Asian economies (Murshed, 2021). When developing measures to minimize carbon emissions, these nuances should be carefully considered. The identified positive and substantial link between energy consumption and CO2 emissions aligns with prior research findings (Lima et al., 2020; Osman et al., 2023), underscoring a significant environmental challenge for South Asian countries. This relationship underscores the undeniable fact that increased energy consumption, often driven by economic growth and industrialization, directly contributes to rising CO2 levels. These emissions, primarily resulting from the burning of fossil fuels, carry far-reaching environmental and climatic consequences. The resultant increase in greenhouse gases in the atmosphere is a significant driver of global warming and related climate change impacts, including elevated temperatures, extreme weather events, and sea-level rise (Dauda et al., 2019). Unmitigated CO2 emissions have global and regional ramifications, adversely affecting the health and well-being of South Asian communities.

Regarding foreign direct investment, the panel least squares results demonstrate a positive and significant relationship with CO2 emissions, while this relationship is found to be insignificant in the fixed effect model. The coefficient from the panel least squares analysis explains that a 1% increase in foreign direct investment leads to a 0.029% rise in CO2 emissions among the South Asian economies. Foreign investment can provide economic advantages such as job creation and technical transfer, but it can also result in the migration of companies with greater carbon footprints to host countries (Adeel et al., 2018). However, the relative insignificance of the FDI-CO2 relationship in the fixed effect model necessitates a more in-depth analysis of the contextual elements that may influence this correlation (Tobelmann et al., 2020). It is critical to remember that the environmental impact of FDI varies depending on the industry and type of investment. While some businesses may embrace cleaner technology, others may exacerbate environmental issues (Adeel et al., 2018). Furthermore, strict environmental rules and policies in some South Asian nations may impact emissions associated with foreign investments (Tobelmann et al., 2020). Policymakers should prioritize sustainable FDI practices to reconcile these contradictory findings. This entails attracting investments in industries that support green technology and environmentally friendly manufacturing processes. Furthermore, stringent environmental laws and incentives for cleaner manufacturing methods are required to ensure that FDI does not result in uncontrolled carbon emissions (Adeel et al., 2018; Tobelmann et al., 2020).

GDP exhibits a positive and significant relationship with CO2 emissions according to both the panel least squares and fixed effect models. The coefficients indicate that a 1% surge in GDP corresponds to a 0.081% and 0.072% increase in carbon emissions, respectively. These findings are consistent with previous studies (Pan et al., 2019; Dauda et al., 2019), indicating that economic growth in these economies may be associated with greater carbon emissions. The positive association means that when GDP expands, so does the demand for energy and industrial output, which frequently results in increased emissions (Dauda et al., 2019). This result aligns with the basic Environmental Kuznets Curve (EKC) concept, which states that as countries grow, environmental degradation increases, but then improves when nations reach higher economic levels and adopt cleaner technology (Pan et al., 2019). Economic development is critical for raising living standards and eliminating poverty; however, our findings highlight the critical need for more sustainable and environmentally friendly growth patterns in South Asian nations (Dauda et al., 2019). Policymakers should prioritize methods that decouple economic development from carbon emissions to overcome this challenge (Pan et al., 2019). This includes increasing energy efficiency, transitioning to renewable energy sources, and implementing green technology across various industries (Dauda et al., 2019). Furthermore, environmental regulations and incentives to promote clean and sustainable manufacturing practices are required to mitigate the environmental impact of GDP growth (Pan et al., 2019).

PATENT applications by non-residents are found to have a negative and significant relationship with CO2 emissions in both the panel least squares and fixed effect models. The coefficients reveal that a 1% increase in Patent applications results in a reduction of CO2 emissions by 0.1028% and 0.078%, respectively. These findings are consistent with previous studies highlighting the critical importance of PATENT applications by non-residents in lowering carbon emissions (Weina et al., 2016; Zameer et al., 2020). The negative connection indicates that as clean technology, energy efficiency, and sustainable practices improve, so do the emissions linked with economic activity (Zameer et al., 2020). This finding aligns with the notion that technical advancements frequently result in more efficient resource utilization and lower environmental impact (Weina et al., 2016). These findings underscore the importance of prioritizing technology breakthroughs, as they can lead to significant reductions in carbon emissions, aligning with global efforts to address climate change. South Asian nations should focus on policies and investments that promote PATENT applications by non-residents in clean energy, green technology, and sustainable practices to harness this connection (Weina et al., 2016). This includes incentives for research and development in these areas, promoting the adoption of eco-friendly technology, and supporting startups and businesses that prioritize sustainability (Zameer et al., 2020). Furthermore, to maximize the impact of PATENT applications by non-residents on lowering CO2 emissions, a supportive regulatory framework that facilitates the deployment of new solutions is required (Weina et al., 2016).

Trademark applications show a negative and significant relationship with CO2 emissions in both the panel least squares and fixed effect models. The coefficients demonstrate that a 1% increase in trademark applications leads to a reduction in CO2 emissions by 0.347% and 0.121%, respectively. These findings are consistent with earlier research that has highlighted the possibility of intellectual property-related elements, such as trademarks, being connected to environmental consequences (Dauda et al., 2019). The negative association implies that when trademark applications grow, so do carbon emissions linked with economic activity (Dauda et al., 2019). This finding explains that branding and intellectual property protection may be linked to cleaner, more ecologically friendly manufacturing processes and commercial practices. This research implies that firms and sectors that prioritize brand recognition, quality, and customer trust are more likely to implement sustainable and environmentally friendly practices. South Asian governments may utilize this link by encouraging firms to invest in branding and intellectual property protection while emphasizing the significance of sustainable and ecologically responsible practices (Dauda et al., 2019). Green branding, eco-certification, and sustainable production practices may all be promoted by government rules and incentives. This strategy is consistent with worldwide trends that emphasize the importance of sustainable branding and its ability to attract environmentally concerned customers (Gale and Burda, 1998; Nayak et al., 2019; Lambin et al., 2020).

The estimated results show that PATENT applications by non-residents and trademark applications have a negative and significant impact on CO2 emissions. This shows that the level of innovation hurts CO2 emissions among the South Asian economies. This finding indicates that as the number of patent applications filed by non-residents increases, CO2 emissions tend to decrease (Smith et al., 2020). Similarly, the analysis reveals a negative and significant impact of trademark applications on CO2 emissions. This implies that a higher number of trademark applications is associated with reduced CO2 emissions in South Asian economies. These results collectively explain that the level of innovation, as measured by patent and trademark applications, hurts CO2 emissions among South Asian economies. This finding aligns with prior research that has emphasized the role of innovation in promoting environmental sustainability and reducing carbon emissions (Zhang et al., 2022; Albitar et al., 2023). It is important to note that innovation, as evidenced by patent and trademark applications, can lead to the development and adoption of cleaner technologies and more efficient production processes, which ultimately contribute to lower emissions. This result underscores the potential for innovation-driven policies and practices to mitigate environmental challenges in the South Asian context.

Trade openness exhibits a positive and significant relationship with CO2 emissions in the panel least squares analysis, while this relationship is insignificant in the fixed effect model. The coefficient from the panel least squares analysis explains that a 1% increase in trade openness results in a decrease of CO2 emissions by 0.265%. These findings, which are consistent with earlier studies (Dauda et al., 2019; Zameer et al., 2020), show that as trade openness grows, so do carbon emissions associated with economic activity. This result highlights the environmental implications of increased international commerce and global economic integration, particularly within South Asian nations. The disparity in the relevance of the trade openness-CO2 emissions link between the panel least square and fixed effect models illustrates the issue's complexities. The fixed effect model, which accounts for each country-specific impact, reveals that the link may not be statistically significant, highlighting the necessity of taking country-specific factors into account when analyzing the trade-environment nexus. While greater economic activity may result in increased emissions, trade openness may also encourage the transfer of cleaner technology, sustainable practices, and environmental policies (Dauda et al., 2019; Zameer et al., 2020). South Asian nations should focus on leveraging the benefits of trade openness for environmental sustainability, such as encouraging environmentally responsible trade practices and assuring compliance with international environmental standards.

Table 4: Estimated Outcomes

	Results of Panel OLS		**Results of fixed effect model**	
Variable	Coefficient	Std. Error	Coefficient	Std. Error
LEC	0.9922***	0.0360	1.6058***	0.1728
LFDI	0.0297**	0.0119	-0.0045	0.0121
LGDPPC	0.0809***	0.0272	0.0726**	0.0754
LPATENT	-0.1028***	0.0168	-0.0781***	0.0258
LTMA	-0.3474***	0.0245	-0.1213*	0.0628
LTO	-0.2650***	0.0360	-0.0817	0.0587
C	-8.8705	0.2821	-8.7502	1.1625
R-squared	0.911077		0.9218	

Note: *, **, *** represents here 1%, 5% and 10% level of significance

Table 5 indicates the findings of the Pedroni cointegration test. Pedroni co-integration test is used mostly for panel data regression analysis as this test takes care of cross-sectional dependence and it is suitable for those countries that have the same outlook either economically, politically, or socially allowing for considerable heterogeneity. The findings prevail that all variables are cointegrated in the long run as in our model, four p-values are significant out of seven, consequently, we reject our null hypothesis of no cointegration in South Asia.

Table 5: Results of Pedroni co-integration test

	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Stat	-0.7486	0.773	0.3518	0.3625
Pan. rho-Stat	0.5704	0.7158	0.7558	0.7751
Pan. PP-Stat	-1.7318*	0.0417	-2.4778***	0.0066
Pan. ADF-Statistic	-1.893*	0.0292	-2.9742***	0.0015
Alternative hypothesis: individual AR coefs. (between-dimension)				
	Statistic	Prob.		
Group rho-Stat	1.3139	0.9056		
Gro. PP-Stat	-3.4350***	0.0003		
Gro. ADF-Stat	-3.6831***	0.0001		

Note: *, **, *** represents here 1%, 5% and 10% level of significance

5. CONCLUSION

In recent years, the world has witnessed an accelerated pace of technological innovation that not only drives economic growth but also plays a crucial role in mitigating carbon dioxide emissions and improving environmental quality. This study seeks to address critical environmental concerns by examining the influence of innovation on CO2 emissions within the context of five South Asian countries during the period spanning from 1980 to 2019. The study utilizes both panel ordinary least squares and fixed effect models to comprehensively assess this relationship. Our analysis centers on environmental quality indicators, with a particular emphasis on the pressing issue of CO2 emissions. These emissions have emerged as a primary indicator of environmental degradation and are at the forefront of global environmental concerns. Consequently, this study meticulously investigates the impact of innovation on CO2 emissions across South Asian nations. Our empirical findings unveil a striking connection between innovation and CO2 emissions. Specifically, we find that patent applications, serving as a proxy for technological innovation, are significantly and negatively correlated with CO2 emissions. This suggests that as innovation advances, there is a simultaneous reduction in CO2 emissions. Additionally, trademark applications exhibit a similar negative correlation with CO2 emissions, reinforcing the critical role of innovation in environmental preservation. Conversely, our analysis reveals contrasting results for energy consumption and per capita GDP. Both factors display positive correlations with CO2 emissions, implying that an increase in energy consumption and higher per capita GDP levels are associated with elevated carbon dioxide emissions. These outcomes underscore the challenges posed by economic growth and energy utilization in the context of environmental sustainability. Thus, South Asian nations opt for a set of policy recommendations tailored. These policy measures should prioritize and promote technological innovation as a central component of environmental preservation strategies. By fostering an environment conducive to innovation, these nations can effectively curtail CO2 emissions and mitigate their environmental impact.

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