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Is the Impact of Technological Innovations on Environment Quality Symmetric or Asymmetric? Vietnam and Switzerland Evidence

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ABSTRACT

Governments and corporations are investing progressively heavily in research and development for sustainable energy solutions that would increase capital goods efficiency and conserve energy, based on the idea that technological discoveries would successfully decrease deadly greenhouse gas emissions. From 1980 to 2019, the current study investigated symmetrical and asymmetrical relationships between environmental quality, patent, and trademark in Vietnam and Switzerland. ARDL approaches were used, both linear and nonlinear. The outcomes of the nonlinear analysis reveal that asymmetricity exit between technological innovations and environment quality in both Switzerland and Vietnam. In Switzerland, negative shock in the patent has a negative significance, and negative shock in trademarks has positive significant asymmetric effects on CO2 emissions in the short run. In Vietnam, positive shocks in technological innovations have substantial negative asymmetricity with the environmental pollution in the long run. Moreover, positive shocks in both trademark and patent have significant negative, whereas adverse shocks in trademark and patent have positive asymmetric effects on CO2 emissions in the long run. Public policy should fund technological innovations projects, including developing suitable technologies that can create complementarity between increased economic growth and reduced environmental impact.

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1. Introduction

The connections between growth in national output and ecological quality have been hotly contested in energy, development economics, and ecology system (Dinda, 2018; Sinha, Sengupta, & Alvarado, 2020). Global economic growth has surged to unprecedented heights since the commencement of business development under industrialization in the 18th century.

Similarly, various trajectories of expanding usage of energy and business at the expense of the diminishing of the ecological system have accompanied such rising growth out-of-date energy sources used in the production of goods and services cause environmental damage. In the above scenario, the relationship between economic development and the territory faces a trade-off, meaning that ecological degradation is unavoidable for further economic expansion. However, environmentalists, international organizations, and governments have lately increased their focus on clean energy and environmentally friendly technology on a national and worldwide scale (Chien, Hsu, Zhang, Vu, & Nawaz, 2021; Nawab, Bhatti, & Nawaz, 2021; Ozturk & Yuksel, 2016) in particular, it is reduced due to the Kyoto Protocol, which was kept in 1997 and executed in 2005. In the Paris Agreement, all economies promised to keep average worldwide temperatures far below 2 degrees Celsius (UNFCCC, 2015). Because of ecological system anxieties, reduction in emissions of the fatal and polluted gasses has become a worldwide strategy priority. The United Nations' Sustainable Development Goals (SDGs) concentrate on ecological protection. SDG 7 focuses primarily on renewable energy for long-term development.

Growing knowledge of clean manufacturing and the quality of the atmosphere may result in long-term development patterns. Furthermore, the private sector is rapidly seeking to create and design new technologies to promote clean and environmentally friendly manufacturing operations. As a result, such initiatives may result in higher growth while emitting fewer emissions, a process known as uncoupling economic progress from the atmospheric conditions (Khan & Majeed, 2019). As a result, there may be some steps to mitigate the trade-off between the ecosystem and economic growth globally (Gillani & Sultana, 2020). Besides, in the ahead stage of the Environmental Kuznets Curve (EKC), when a nation has reached a suitable degree of action, an inverse association between atmospheric dilapidation and output growth may be noticed. As a result of more developments, inventions, and innovations for clean and environmentally friendly technology, better growth in economic indicators leads to decreased atmospheric damage.

The preservation of environmental quality (EQ) recently held a worldwide priority. For many decades, innovation has been seen as a critical source of addressing ecological challenges (Liu, Zhang, & Bae, 2017). EQ has a vital aim of any nation since the situation is inextricably tied to a country's economic, political, and social challenges. For long-term sustainability, most firms may be abandoning reactive and short-term measures to adopt creative environmental habits (Fraj, Matute, & Melero, 2015; Runsen, Chunling, Ahmed Memon, Ali, & Nawaz). Hence, advanced technical breakthroughs, institutional changes, and ecological legislation address environmental challenges (Abdallh & Abugamos, 2017).

Environment proactivity entails a company regularly changing its goods, manufacturing techniques, and technology to enhance the green environment (Fraj et al., 2015). In other words, environmental problems may be addressed due to invention and development advancements. Thus, Product innovation (PI) refers to launching the latest or improved product in terms of its features (Hao, Shah, Nawazb, Barkat, & Souhail, 2020; Schumpeter, 1961). On either hand, PI represents introducing unique means of producing products via unique manufacturing methods and equipment. Product innovations are safeguarded by trademarks, whereas patents safeguard process innovations. A trademark protects a company's marketing assets, while a patent protects a company's technical expertise to protect inventions.

According to recent findings, PI is playing an essential role in the green economy (Ahmad, Khan, Rahman, Khattak, & Khan, 2021; Wang, Umar, Akram, & Caglar, 2021). However, in another study by Meirun, Mihardjo, Haseeb, Khan, and Jermsittiparsert (2021), Singapore achieves sustainable development through PI. Similarly, Ahmad et al. (2021) reported that technological shocks enhance OECD economies' environmental sustainability. The study also found that innovation shocks have an asymmetric impact on CO2 emissions. According to Rosa, Sassanelli, Urbinati, Chiaroni, and Terzi (2020), a circular economy uses technology to reduce the consumption of finite resources. Similarly, a circular economy has linked society, economy, and environment for long-term development, and technological innovation is critical to environmental sustainability (Sassanelli, Rosa, Rocca, & Terzi, 2019; Vinante, Sacco, Orzes, & Borgianni, 2021).

Abdallh and Abugamos (2017) stated that technological innovation, environmental legislation, and economic structural improvement are critical to environmental sustainability. Furthermore, ecological proactivity necessitates firms to change their products through technological innovation (Fraj et al., 2015). Product and process innovation, for example, can both stimulate ecological quality. The innovation process alters the manufacturing technique and installs new intelligent machinery and equipment. Furthermore, product innovation creates innovative products and services that save energy (Jianjun et al., 2021; Tidd & Bessant, 2020). As a result of the innovation process, copyright protection and copyright laws have protected the innovation. According to Boadu (2016), technological innovations are critical for managing manufacturing operations and environmental issues. Furthermore, new economic investment is required to install, maintain, and create new innovative technology. According to Schumpeter (1961), technological innovations improve overall environmental quality production stages.

EQ is a broad phrase that refers to natural environment qualities and characteristics. An increasing amount of literature is investigating how to maintain environmental quality (Hussain, Nawaz, Ahmad, & Bhatti, 2021). Previously, different studies emphasized the relationship between technological innovation and EQ for diverse locations and used a variety of old-fashioned econometrics approaches. Like Mensah et al. (2018) for OECD economies, Xu et al. (2020) for China, Sinha et al. (2020) for N11 economies, Demir, Cergibozan, and Ari (2020) for Turkey, where researchers studied the impacts of technological advancements on CO_2 emissions. Around all researchers employed ARDL and FMOLS for the econometric analysis. EQ is impacted by various social, economic, political, and financial factors. As a result, it produces either a positive or negative shift in technological innovation, with no symmetric influence on environmental quality. Past research has ignored technological innovation's good and bad elements in circumstances that produce biased outcomes. We used the nonlinear ARDL, and nonlinear causality testing methodologies developed by Shin, Yu, and Greenwood-Nimmo (2014) and Ullah, Ozturk, Majeed, and Ahmad (2021) to improve technological innovation and environmental quality literature.

To the best of our knowledge, no research has investigated the impact of technological innovation using asymmetric and symmetric approaches. To address this gap, the current research considers the nonlinear effect of technological innovations on pollution in Vietnam and Switzerland from 1990 to 2018. Vietnam and Switzerland are constructing a "knowledge-based economy" to ensure environmental sustainability. As a result, this study examined the positive and negative effects of technological innovation on emissions in Vietnam and Switzerland. Empirically, the study contributes significantly to clean manufacturing theory by looking at the impact of positive and negative fluctuation in technology on emissions in Vietnam and Switzerland. Furthermore, this world-leading research work in Vietnam and Switzerland highlights the linear and nonlinear influence and offers a new framework in ecological economics.

2. Literature Review

Existing theory and research provide plenty of empirical studies that look at the innovation-pollution nexus from multiple angles (Chishti & Sinha, 2022). Considering that technological innovations would successfully mitigate CO_2, governmental organizations and corporations are increasingly investing heavily in research and development for sustainable energy solutions to increase capital goods efficiency and save energy. Furthermore, technical advancements have been a primary engine of economic growth, and as a result, they are equally responsible for the environmental consequences that have resulted from the growth path (Ahmad et al., 2021). The relationship between ecological contamination, financial deepening, urbanization, energy consumption, and research and development expenditure was investigated by Shahbaz et al. (2018) and confirmed the importance of R&D investment in improving EQ by lowering CO_2emissions. These findings are consistent with a study conducted by Jin, Duan, Shi, and Ju (2017) in China to examine the relationship between technological progress and carbon emissions using research and development investment in the energy industry to indicate technological progress.

Fernández, López, and Blanco (2018) used the ordinary least squares technique to assess the impact of *innovations* activities on CO_2 emissions in developing countries. The researchers found an inverse relationship between innovation and the emissions of carbon dioxide. Moreover, recommended spending on R&D. Another study conducted by Churchill, Inekwe, Smyth, and Zhang (2019), using a non-parametric panel data model to analyse annual data on CO_2emissions and expenditure on research and development for the G7 countries over the period 1870 to 2014, indicated a negative relationship between environmental pollution and technological innovations . Similarly, the findings suggested that technological advancement in the energy sector reduced carbon emissions and increased energy efficiency. Similar evidence was found by Abbasi, Hussain, Haddad, Salman, and Ozturk (2022) in Pakistan, Cheng, Awan, Ahmad, and Tan (2021), and Wang et al. (2021) in China.

Similarly, (Álvarez-Herránz, Balsalobre, Cantos, & Shahbaz, 2017) employed panel regression analysis to investigate the influence of improvements in energy research development on atmospheric carbon emissions for 28 OECD nations from 1990–to 2014 under the phenomenon of the environmental Kuznets curve. The findings show that energy *innovations* regulation reduced per capita greenhouse gas emissions. Mensah et al. (2018) also identified similar outcomes for a few OECD countries and concluded that *innovations* was necessary for mitigating CO_2emissions. An examination of the influence of environmental *innovations* on environmental and economic performance in Korea revealed that environmental *innovations* activity had a more considerable affirmative effect on ecological performance than financial performance (Haq, Nawaz, Mahtab, & Cheema, 2012; Long, Chen, Du, Oh, & Han, 2017). Yu and Du (2019) also developed a Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model based on Chinese provincial panel data from 1997 to 2015 to investigate the impact of technical *innovations* on carbon dioxide (CO2) emissions. According to the researchers, technological advancements lowered CO_2emissions. Besides, Dinda (2018) and Zhang, Peng, Ma, and Shen (2017) also found a negative association between technological innovations and environmental degradation. Recently, Chishti and Sinha (2022) studied the impacts of technological and financial *innovations* shocks on carbon dioxide emissions in BRICS economies and found that positive economic *innovations* shocks significantly distorted CO_2 emissions.

In contrast, adverse shocks in financial innovations *innovations* stimulated environmental damage. Positive technological innovations shocks also figured in diminishing carbon EMI, while negative technological innovations shocks were insignificant. Suki, Suki, Sharif, Afshan, and Jermsittiparsert (2022) used the bootstrapped autoregressive distributed lag model to investigate the impact of renewable energy and technological innovations on Malaysia's environmental footprint and carbon dioxide emissions and found that technological innovations helped alleviate both carbon emissions and ecological consequences (Shafiq, ur Raheem, & Ahmed, 2020). Adebayo, Akadiri, Adedapo, and Usman (2022) used the environmental Kuznets curve (EKC) multivariate framework to analyze the relationship between technological innovations, renewable energy usage, and EQ in ten newly industrialized nations between 1990 and 2018. The researchers used the method of moments quantile regression and documented that technological progress and the use of renewable energy enhanced EQ in all quantiles.

In contrast to earlier literature, which found favourable results for technological innovations that reduce CO_2 emissions, Shaari, Abdullah, Alias, and Adnan (2016) concluded that excess R&D spending contributed to environmental damage. Climate change also effect the agricultural production of a country (Shafiq, Gillani, & Shafiq, 2021). The researchers employed panel co-integration and fully modified ordinary least squares for Germany, Russia, United Kingdom, United States, and Canada taking data from 1996 to 2011. Although the study found a co-integrated relationship between GDP, energy consumption, research and development, and CO_2 emissions, national income, energy consumption, and R&D might affect CO_2 emissions. Similarly, Adebayo and Kirikkaleli (2021) employed wavelet statistical tools and found that technological innovations Increase emissions. Another study Ali, Abdullah, and Azam (2016) used the ARDL model as an econometric technique for parameter estimation to examine the relation between CO_2 emissions and their determinants, such as energy consumption, financial development, economic growth, and technological innovations , for the Malaysian economy from 1985 to 2012. The empirical findings demonstrated that technological innovations had a negative but statistically insignificant relationship with environmental pollution in Malaysia. Moreover, the results of dynamic panel models for 13 OECD countries from 1980 to 2004 also confirmed the negligible impact of technological innovations on carbon dioxide emission (Garrone & Grilli, 2010).

The study looked at the impact of financial development, energy use, globalization, technological innovations, and economic development on consumption and territorial-based emissions in Pakistan from 1990Q1 to 2019Q4. The authors used Dynamic Autoregressive-Distributed Lag (ARDL) simulations and Frequency Domain Causality (FDC) methodologies and documented those technological innovations significantly reduced both emissions over time. Similarly, Ullah et al. (2021) used linear and non-linear ARDL on annual time series data from 1990 to 2018 to assess the symmetric and asymmetric effects of technological innovations on carbon emissions in Pakistan. The researchers used patents and trademarks as proxies for technological innovations. They discovered that patents had adverse short-run symmetric effects on carbon EMI, while trademarks had positive short-run symmetric effects. In contrast, trademark negative shock had significant adverse impacts on carbon emissions in the short run.

Petruzzelli, Maria Dangelico, Rotolo, and Albino (2011) compared the importance of ecological innovations to non-ecological innovations in terms of inter-and intra-organizational associations that lead to their development and technological traits such as complexity and novelty. Their findings indicated that green innovations were relatively more important than their conventional counterparts. The most valuable green innovations relied more heavily on collaborations among internal stakeholders. Álvarez-Herránz et al. (2017) confirmed these findings by exploring the relationship between firms' involvement in interfirm R&D collaborations to develop green solutions, revealing that firms' participation positively impacted the development of valuable green innovations. As public awareness of environmental issues grows, politicians are being compelled to support technical advancements that will improve environmental quality. Policymakers are concerned with building and fostering innovations capabilities and disseminating these breakthroughs so that the potential environmental advantages of these advances can be realized at various levels of the economy (Chishti & Sinha, 2022; Shaari et al., 2016).

Table 1.
Summary of the Literature

Study	Country	Time	Method	Variables for Technology Innovation	Effect on Environment
Adebayo et al. (2022)	10 Nations	1990 to 2018	MM Quantile Regression	Patents	Improve
Abbasi et al. (2022)	Pakistan	1990 to 2019	ARDL	Patents	Improve
Chishti and Sinha (2022)	BRICS economies	1987 to 2016	FMOLS	Patents	Improve
Suki et al. (2022)	Malaysia	1980 to 2018	Bootstrapped ARDL	Patents	Improve
Adebayo and Kirikkaleli (2021)	Japan	1990 to 2015	Wavelet Tools	Patents	Damage
Cheng et al. (2021)	China	2005 to 2018	FMOLS	% Of All Technologies	Improve
Ullah et al. (2021)	Pakistan	1980 to 2018	NARDL	Patents & Trademark	Existence of Asymmetricity
Wang et al. (2021)	China	1990 to 2018	OLS	% Of All Technologies	Improve
Dinda (2018)	USA	1963 to 2010	VEC Model	Utility Patent	Improve
Fernández et al. (2018)	EU, USA, China	1990 to 2013	OLS	R & D	Improve
Mensah et al. (2018)	OCED	1990 to 2014	STIRPAT Model	R & D Expenditure	Improve
Shahbaz, Nasir, and Roubaud (2018)	France	1955 to 2016	Bootstrap ARDL	Energy R&D	Damage
Yu and Du (2019)	China	1997 to 2015.	STIRPAT Model	R &D Expenditure	Improve
Álvarez-Herránz et al. (2017)	28 OECD countries	1990 to 2014	V-Lag Model	Energy RD &D	Improve
Jin et al. (2017)	China	1995 to 2012	OLS	Energy R&D	Improve
Long et al. (2017)	Korea	2017	Correlation	R & D	Improve
Ali et al. (2016)	Malaysia	1985 to 2012	ARDL	Patents	Improve
Shaari et al. (2016)	5 Nations	1965 to 2010	FMOLS	R &D Expenditure	Damage
Garrone and Grilli (2010)	13 Nations	1980 to 2004	OLS	Energy R&D	Insignificant relations

Liu et al. (2017) examined the impact of eco-friendly technological innovations on Carbon dioxide emission in 264 Chinese cities from 2006 to 2017 and found that green technology advances had a heterogeneous influence in different categories of towns. According to the empirical findings, cities with greater human capital levels had a relatively more substantial carbon reduction impact. Moreover, Ali et al. (2016) found a significant relationship between green innovation and environmental quality in BRICS Economies. Furthermore, Sinha et al. (2020) investigated the relationship between environmental regulation and green innovation in OECD countries from 1998 to 2018 using pooled regression, Random and Fixed effect models, and GMM models. They concluded that environmental law has a significant relationship with eco-friendly technical innovation and incentivizes the economy to implement newer green technologies.

3. Methodology

3.1 ADF Unit Root Tests

The augmented Dickey-Fuller unit root test, invented by Dickey-Fuller (1981), determines if a series has a unit root or not and the degree of integration in that series. It is essential to check the stationarity of the time-series data before proceeding with the empirical analysis. The following equation is employed to conduct the investigation.

$$\Delta y_t = \alpha + f y_{t-1} + \lambda_1 \Delta y_{t-2} + \lambda_2 \Delta y_{t-2} + \ldots\ldots + \lambda_m \Delta y_{t-m} + u_t \quad (1)$$

Where, t represents the time frame and Δ is denoted for the difference operator. The white noise error component is denoted by the u_t. Furthermore, y_t represents the series examined for stationarity during the stationarity analysis. Apart from that, the study used the Phillips and Perron unit root test, which differs from the ADF unit root test. It corrects for serial correlation and heteroscedasticity rather than ignoring them.

3.2 ARDL Estimation Technique

The study investigated long-run relationships among the variables after examining the stationarity of the variables. The auto-regressive distributed lag (ARDL) model, a well-established econometric method, is utilized. None of the variables in the ARDL model must be second difference stationary. As a result, stationarity at the first difference is required for each variable in the model. Nevertheless, the ARDL model can be used to model mixed order of integrated variables, such as I(0) and I(1) (Pesaran & Pesaran, 1997).Furthermore, research has employed the error correction mechanism (ECM) within the ARDL to determine the short-run relationship between variables. A simple linear transformation to derive the ECM from the ARDL to integrate the short-run adjustments without disrupting the long-run equilibrium. If there is any short-run disequilibrium, the error correction term (ECT) is employed to demonstrate the speed of adjustment towards the long run.

$$\Delta lco_{2t} = \beta_0 + \beta_1 lco_{2t-1} + \beta_2 gdp_{t-1} + \beta_3 ptt_{t-1} + \beta_4 trm_{t-1} + \sum_{i=1}^{p} \beta_{1i}\, \Delta lco_{2t-i} + \sum_{i=0}^{q} \beta_{2i}\, \Delta gdp_{t-i} + \sum_{i=0}^{r} \beta_{3i}\, \Delta ptt_{t-i} + \sum_{i=0}^{s} \beta_{4i}\, \Delta trm_{t-i} + \epsilon_t \quad (2)$$

Where Δlco_{2t} is first difference of carbon dioxide emission acting as a dependent variable,ϵ_t is disturbance term have zero mean and constant variance.Equation (2) would test the Null hypotheses (H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$) that would determine cointegration among the variables with alterative hypotheses (H_1:$\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq 0$). The above ARDL model is run for Switzerland and Vietnam separately.

Pesaran, Shin, and Smith (2001) proposed the ARDL-Bounds model used to investigate the presence of cointegration among variables. The estimated critical value is then used to identify the existence of short-run, and long-run cointegration relationships among the variables as usually a higher calculated value than the tabulate value confirms the connection. After establishing the model's long-run relationship, the model's short-run convergence is investigated by error correction term (ECM) (Pesaran et al., 2001), which demonstrates that if there is any shock in the short-run, whether there is any short-run, whether the model converges towards its long-run equilibrium or not. The negative and statistically significant value of ECM denotes convergence of the model. Moreover, serial correlation is checked by the LM test, and model stability is also reviewed by CUSUM and CUSUM square.

3.3 NARDL Econometric Method

The relationship between EQ and technological innovations indicators is assumed to be nonlinear. Because the environmental Kuznets curve demonstrates the nonlinearity between EQ and national income, it is possible that initially, *technological innovations* will cause an increase in CO_2 EMI. Still, due to increased efficiency in the manufacturing process and environmentally friendly innovations, greenhouse gas emissions will decrease after a certain point. Because they presuppose linearity and consistent changes across variables, traditional time series models such as ARDL (Pesaran et al., 2001) cannot give appropriate information about the nonlinear relationship. The recently created NARDL model is commonly used in the empirical literature to explore dynamic changes in the dependent variable in response to positive and negative changes or shocks in the independent variables. This technique distinguishes between CO_2 emissions short- and long-run asymmetric responses to the questions' explanatory. The change in the variable under consideration is expressed using the starting difference of the logarithmic transformation of the variable under examination. We extended Eq. (2) into the log form to account for these changes or shocks:

$$variableslco_{2t} = \beta_0 + \beta_1(lptt_t^+) + \beta_2(lptt_t^-) + \beta_3(ltrm_t^+) + \beta_4(ltrm_t^-) + \beta_5(lgdp_t) + + u_t \quad (3)$$

And where$(lptt_t^+)$ and $(lptt_t^-)$ represent positive and negative decomposition of patent while $ltrm_t^+$ and $ltrm_t^-$ denote positive and negative decomposition of trademark, the above ARDL model is run for Switzerland and Vietnam separately. The dynamics of both the long run and the short run can be incorporated in the following equation in a NARDL setting.

$$lco_{2t} = \beta_0 + \phi lco_{2t-1} + \beta_1(lptt_t^+) + \beta_2(lptt_t^-) + \beta_3(ltrm_t^+) + \beta_4(ltrm_t^-) + \beta_5(lgdp_t) + \sum_{i=1}^{p-1} f\, lco_{2t-i} + \sum_{i=0}^{q-1}(r_1^+ lptt_t^+ + r_2^- lppt_t^-) + \sum_{i=0}^{q-1}(r_1^+ ltrm_t^+ + r_2^- ltrm_t^-) \sum_{i=0}^{n} r_3 \Delta lgdp_{t-k} + u_t \quad (4)$$

Shin et al. (2014) presented an extension of the NARDL model called the asymmetric error correction model, which is described as follows:

$$lco_{2t} = \beta_0 + \phi lco_{2t-1} + \beta_1(lptt_t^+) + \beta_2(lptt_t^-) + \beta_3(ltrm_t^+) + \beta_4(ltrm_t^-) + \beta_5(lgdp_t) + \sum_{i=1}^{p-1} f\, lco_{2t-i} + \sum_{i=0}^{q-1}(r_1^+ lptt_t^+ + r_2^- lppt_t^-) + \sum_{i=0}^{q-1}(r_1^+ ltrm_t^+ + r_2^- ltrm_t^-) \sum_{i=0}^{n} r_3 \Delta lgdp_{t-k} + \alpha ECT_{t-1} + u_t \quad (5)$$

Where the Δ symbol signifies the short-run coefficient dynamics, variables without difference operator reflect long-run estimates, and p and q imply lag values entered in the model. The Wald test and Bound test, like the ARDL, can be used to determine the statistical significance of the estimated coefficient and the existence of cointegration. Furthermore, the presence of asymmetric relationship among the variables is tested using the proposition that no asymmetric LR relationship exists between the variables H_0: $\beta_i^{\pm} = 0$).

4. Data Description

The date of all variables is taken from the world development indicator (WDI) for the analysis. The study has used carbon dioxide emissions measured in thousand metric tons as a proxy for environmental quality. Similarly, GDP per capita is taken for economic growth measures in the US dollar. Furthermore, the total number of residential and non-residential patent (PPT) and trademark (TRM) applications Patent (PPT) and Trademark (TRM) are used as a proxy for technological innovations.

Some residential and non-residential patents were used to indicate technological innovations by various researchers (Abbasi et al., 2022; Adebayo et al., 2022; Adebayo &

Kirikkaleli, 2021; Ali et al., 2016; Chishti & Sinha, 2022; Suki et al., 2022). Similarly, Ullah et al. (2021) used many patents and trademarks as proxies of technological innovation to analyze their nexus with environmental quality. However, Cheng et al. (2021); Wang et al. (2021) took the percentage of technology for technical innovation analysis. Besides several researchers Fernández et al. (2018); Long et al. (2017); Mensah et al. (2018); Shaari et al. (2016); Yu and Du (2019) used investment/expenditure on research and development as an indicator for technical innovations.

Summary statistics of the variables for Switzerland and Vietnam are presented in Table 2. In the case of GDP per capita, Switzerland has one of the highest rankings, whereas Vietnam is a developing country with only 1291.6 US dollars average GDP per person. The average CO_2 emissions in Switzerland was 42197.64 thousand metric tons, which was around half of the average CO_2 emissions calculated for Vietnam (98474.46 thousand metric tons). Similarly, the arithmetic mean of the patent is greater in Switzerland (3503) than in Vietnam (2311). However, in terms of the average number of trademarks, Vietnam has a slightly more significant average number of TRM than Switzerland. This was why the Global Innovations Index-2021 declared Vietnam the highest innovated country among lower-middle-income group countries.

The calculated value of standard deviation (SD) for CO_2 emission is more excellent in Vietnam. SD for GDP is greater in Switzerland, SD for TRM is superior in Switzerland, and SD for PTT is greater in Vietnam than its counterpart. Moreover, the calculated value Kurtosis statistic is negative for all variables except for PPT in Switzerland. Similarly, variables like CO_2 and TRM in Switzerland are negatively skewed, whereas all of Vietnam and the other two variables in Switzerland are positively skewed. Last but not least, the number of observations for each variable is 40 and 32 for Switzerland and Vietnam, respectively, subject to the availability of the data. A graphical representation of the selected series is presented in figure 1, which exhibits the behavior of each time series in both countries. In Switzerland, initially, CO_2 emissions was 40,539 matric thousand tons in 1980 that were reduced to 36,630 in 1982 matric thousand tons, afterward, it had an increasing trend. It reached its maximum value of about 45700 metric tons in 1992 and 2000 with a minimal variation. However, it began to decrease after 2010 and reduced to 37,480 metric tons in 2019, near the emission value in 1980. This depicts that Switzerland adopted environment-friendly policies and achieved a lower carbon emission level. Nevertheless, in Vietnam, the level of CO_2 emission was 23,183 matric thousand tons in 1988, which had been increasing throughout the period and reached 257,860 matric thousand tons in 2019, which is eleven times more than that of Switzerland.

Table 2.
Summary Statistics of the Variables

Switzerland	**CO_2**	**GDP**	**Trademark**	**Patent**
Mean	42197.64	73361.46	21484.83	3503.075
Standard Deviation	2664.279	8905.727	8506.304	1958.278
Kurtosis	-1.06576	-1.24767	-0.5307	1.751477
Skewness	-0.39848	0.090675	-0.71134	1.463657
Minimum	36629.66	59373.74	4619	1615
Maximum	45850	88413.19	32541	9662
Count	40	40	40	40
Vietnam	**CO_2**	**GDP**	**Trademark**	**Patent**
Mean	98474.46	1291.663	21781.94	2311.938
Standard Deviation	75597.78	624.682	17582.29	2037.265
Kurtosis	-0.54899	-0.8407	-0.69405	-0.18405
Skewness	0.769193	0.531675	0.678693	0.811916
Minimum	17509.93	501.3865	1710	22
Maximum	257860	2604.224	62102	7520
Count	32	32	32	32

Source: Authors' calculations

As for as the proxies of *technological innovations* are concerned, the number of trademark applications has been increasing in both countries. In contrast, the number of patents grew in Vietnam and decreased in Switzerland. It can be observed that GDP per capita had been growing in both countries, but in 1988 the GDP per capita of Switzerland was 131 times higher than Vietnam's per capita GDP. Similarly, in 2019 GDP per capita of Switzerland was 33 times higher than Vietnam's per capita GDP, which indicates that growth in per-person GDP was relatively higher in Vietnam than in Switzerland.

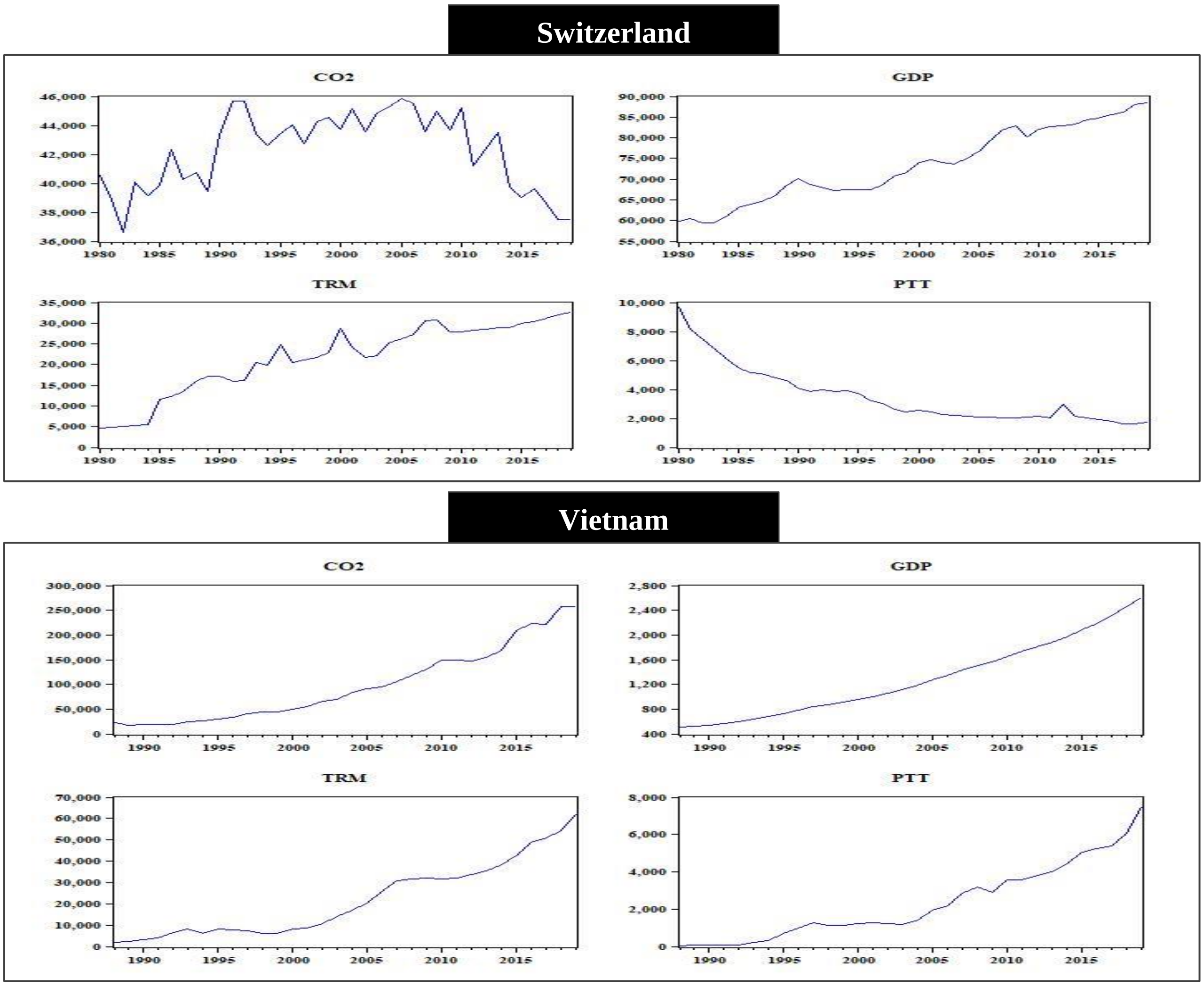

Figure 1: Graphical Representation of Data

5. Results

As discussed in the methodology section, the study would use two renowned tests ADF test and the PP test, for the stationarity analysis. The outcomes of these tests are represented in Table 3. Both tests conclude that both countries' CO_2 and GDP series are non-stationary at the level and become stationary after taking their first difference. Nevertheless, the trademark series of Switzerland and the Patent series of Vietnam are fixed at levels. However, Switzerland's ADF test patent series shows a different stationary process, whereas the PP test shows that it is fixed at the level. The unit root test summarizes that some variables are stationary at the level and other variables become stationary after taking their first difference. No series has integrated order two. These results support to application ARDL model for the empirical analysis.

Table 3.
Outcomes of the Unit Root Test

	ADF test statistic			**PP test statistic**		
Variables	Level	ΔX_i	Decision	Level	ΔX_i	Decision
Switzerland						
CO2	-1.751	-7.972***	I (1)	-1.581	-8.356***	I (1)
GDP	-0.444	-4.576***	I (1)	-0.424	-4.611***	I (1)
Trademark	-7.256***		I (0)	-4.381**		I (0)
Patent	-2.437	-7.72***	I (1)	-2.737*		I (0)
Vietnam						
CO2	0.23	-7.03***	I (1)	0.2	-8.33***	I (1)
GDP	-1.44	-3.99**	I (1)	-0.25	-2.81*	I (1)
Trademark	-1.98	-3.42*	I (1)	-1.8	-4.01**	I (1)
Patent	-3.57*		I (0)	-4.47**		I (0)

Source: Authors' calculations

5.1 Empirical Estimates of ARDL and NARDL

The outcomes of linear and non-linear ARDL approaches are given in three panels of Table 4. The study has run two models for each country. The results of the symmetric model for Switzerland found that patents, trademarks, and GDP per capita do not have any statistically significant relation with environment quality in the short-run and the long-run. Garrone and Grilli (2010) supported these results, where authors estimated the insignificant impact of expenditure in energy research and development on carbon emissions in 13 advanced nations.

In the third panel of Table 4, some diagnostics for the ARDL approach are calculated like F-Test/ ARDL Bounds Test, ECM parameter, Breusch-Godfrey Serial Correlation LM Test, and Reset test. The computed value of the Bound test favors the existence of cointegration in the model at 2.5%. A nominal value of the LM Test demonstrates that no autocorrelation exists in the model. Moreover, the estimated coefficient of error correction mechanism (ECM) is negative and significant, revealing that the model adjusts with the speed of 39 percent towards its equilibrium in case of any shock. Besides, the value of the Reset test is also statistically significant.

As for the linear model result for Vietnam, it confirmed a statistically significant positive relationship between patent and CO_2 emission in the short-run and in the long run that demonstrates that an increase in patent numbers leads to rising CO_2 emissions in Vietnam. However, the coefficient of the trademark variable in this model is insignificant in both periods, whereas GDP per capita significantly influences CO_2 emission in the long run. Moreover, ECM is also negatively significant, with a -0.483 magnitude. The results align well with Su and Moaniba (2017) outcomes. They used a panel dataset of 70 countries and employed various econometrics models for empirical analysis with patent as technological innovations variable. Their results revealed that the number of climate-change-related-I innovations responds positively to increasing levels of carbon dioxide emissions.

Ali et al. (2016) reported that *technological innovations* had a negative but statistically insignificant relationship with environmental pollution in Malaysia. Similarly, Shaari et al. (2016) concluded that excess R&D spending contributed to environmental damage. Diagnostics of the model are qualitatively similar to Switzerland, depicting the significant value of the Bound test (at 10%), with a nominal value of the LM test and a substantial value of the reset test. Both positive and negative parts of short-run and long-run estimated coefficients of the non-linear

ARDL model for Switzerland are different, revealing the existence of asymmetricity between innovations and carbon emissions. Numerically, in the long run, a one percent change in the positive part of the patent leads to a 0.910 percent decrease in CO_2 emissions, and a one percent change in the negative aspect of the patent leads to a 0.335 increase in CO_2 emission in Switzerland.

Table 4
ARDL and NARDL Coefficient Estimated

	Switzerland		**Vietnam**	
	Panel A: Short-run estimates			
Variables	**ARDL**	**NARDL**	**ARDL**	**NARDL**
$\Delta Patent_t$	0.011		0.106***(0.031)	
$\Delta Patent_{t-1}$	0.158**			
$\Delta Patent_t^+$		-0.084(0.098)		-0.060(0.083)
$\Delta Patent_{t-1}^+$		0.281(0.169)		-0.044(0.762)
$\Delta Patent_{t-2}^+$				-0.228**(0.097)
$\Delta Patent_t^-$		-0.424**(0.17)		-0.039(0.386)
$\Delta Patent_{t-1}^-$		-0.168(0.112)		
$\Delta Trade\ Mark_t$	-0.017		0.0423(0.085)	
$\Delta Trade\ Mark_{t-1}$	0.108**		-0.026(0.106)	
$\Delta Trade\ Mark_{t-2}$	-0.127***			
$\Delta Trade\ Mark_t^+$		-0.041(0.054)		-0.029(0.140)
$\Delta Trade\ Mark_{t-1}^+$		0.080(0.049)		-0.519***(0.14)
$\Delta Trade\ Mark_t^-$		0.127*(0.069)		-0.258(0.210)
$\Delta Trade\ Mark_{t-1}^-$				0.549*(0.298)
ΔGDP_t	-0.215(0.405)	-0.508(0.376)	0.636(0.299)	2.542*(1.397)
ΔGDP_{t-1}	-1.309**(0.605)	-0.676(0.444)		3.521**(1.495)
ΔGDP_{t-2}	1.399*** (0.371)			
	Panel B: Long-run Estimates			
$Patent_t$	-0.111(0.128)		2.510**(0.087)	
$Patent_t^+$		-0.910***(0.29)		-0.033***(0.012)
$Patent_t^-$		0.335*(0.183)		-0.271(0.166)
$Trade\ Mark_t$	0.057(0.078)		-0.032(0.131)	
$Trade\ Mark_t^+$		-0.081** (.042)		-0.200***(0.039)
$Trade\ Mark_t^-$		0.197*(0.104)		-0.223(0.149)
GDP_t	0.429(0.480)	0.087***(0.127)	1.317***(0.306)	1.237***(0.116)
	Panel C: Diagnostics			
F-Test/ ARDL Bounds Test	4.983[2.5%]	4.607[2.5%]	4.154[10%]	10.369[1%]
ECM	-0.397*** (0.119)	-0.643*** (0.223)	-0.483*** (0.150)	-2.359*** (0.339)
Breusch-Godfrey Serial Correlation LM Test	0.331	1.221	0.317	2.538 with 14% prob.
Reset	5.379**	0.553	3.16*	0.413
Wald-Patent SR		7.098***		15.032***
Wald-Patent LR		2.946*		11.439***
Wald-Trademark SR		3.054**		3.012*
Wald-Trademark LR		8.157***		4.908***

Note: *, **, *** represent 10%, 5%, 1% level of Significance, respectively. Standard errors of the estimates are given in parenthesis. The level of significance of the bound test is given in brackets.

Similarly, a one percent partial increase in the number of trademarks in Switzerland causes a fall in greenhouse gas emissions by 0.081 percent. A one percent partial decrease in the number of brands in Switzerland causes greenhouse gas emissions by 0.197 percent. This deduces an asymmetrical association between technological innovations (patent and Trademark) and carbon emissions only in magnitude but not in the direction in the LR period. The results are partially matched with those (Chishti & Sinha, 2022), who studied the impacts of technological innovations shocks on carbon dioxide emissions in BRICS economies and found that positive technological innovations shocks figured prominently in diminishing carbon EMI, while negative technological innovations shocks were insignificant. Moreover, several studies found that an increase in innovations leads to improved environment quality (Álvarez-Herránz et al., 2017; Churchill et al., 2019; Fernández et al., 2018; Jin et al., 2017; Mensah et al., 2018; Shahbaz et al., 2018). The bound test supports the cointegration notion in the model, and the estimated value of the LM test confirms no autocorrelation problem exists in the model. Furthermore, the coefficient of ECM is negative and significant, revealing that short-run short do does not diverge from the model, and it converges toward long-run equilibrium with 0.643 speed. Besides, short-run Wald and long-run Wald for both patent and trademarks are significant.

It can be noted that asymmetric relationships between technological innovations and environment quality exist in both periods due to significant differences in estimated parameters of positive and negative parts of patent and Trademark. The asymmetric results for Vietnam depicted in the last column of Table 4 show that GDP per capita significantly influences CO_2 emissions. Moreover, both positive and negative shocks in patent cause reduced CO_2 emission in the long run, but the estimated parameter is insignificant for adverse shocks. Similar impacts are observed in the case of Trademark, where the coefficient of positive shock is statistically significant with a negative sign. Moreover, the bound test supports cointegration, and the LM test confirms no autocorrelation in the model. Furthermore, ECM is negative and significant, with a very high value of the speed of adjustment (-2.359). Besides, short-run Wald and long-run Wald for both patent and trademarks are significant.

6. Conclusion

Governments and corporations are increasingly investing extensively in research and development for sustainable energy solutions that will boost capital goods efficiency and save energy because technical breakthroughs will successfully mitigate fatal greenhouse gases. Existing theories and research offer a plethora of scientific investigations on innovations pollution connection from several perspectives. The present study has looked into symmetrical and asymmetrical associations between environmental quality and *technological innovations* in highly innovative countries in their respective income group. According to the Global Innovation Index-2021, Switzerland is the most innovated country among wealthy nations, and Vietnam is the highest innovated country among lower-middle-income group countries. In light of the literature, many patent and trademark applications are used as proxies for technical innovations. Moreover, a relatively new and renewed econometric approach - ARDL and NARDL- have been employed for the empirical analysis.

The Linear ARDL model failed to capture a significant short-run and long-run relationship between Switzerland's technical innovations and environment quality. In other words, the study has not found substantial evidence for a linear relationship between *technological innovations* and CO_2 emanations, the most innovative country among wealthy nations. Nevertheless, in Vietnam, the study found linearity in patent and output concerning environmental quality. The outcomes of the non-linear analysis reveal that asymmetricity exit between technological innovations and environment quality in both Switzerland and Vietnam. Moreover, in Switzerland, negative shock in trademark contributes to CO_2 emanations, whereas negative shock in patent significantly reduces carbon discharges in the short run. Furthermore, Switzerland's long-run results favored the Kuznets curve phenomenon as a shock in both positive partial sum and negative partial sum significantly reduces CO_2 emissions. The outcomes of Vietnam demonstrate a short-run significant symmetric association of patent with CO_2 emission. However, GDP per capita is a substantial determinant of CO_2 emission in Vietnam for both time frames. Moreover, the positive partial sum of patent and trademark also significantly contributes to mitigating environmental destruction in the long run.

The basis on the findings, the outcome infers that PI is negatively connected with CO_2 emission in Switzerland and Vietnam. Thus, a rise in PI's level considerably declines CO_2 emission and stimulates environmental performance. However, the PI plays a vital role in the sustainability of the environment and is critical to high-quality economic development. The government should increase support for businesses researching technological innovation related to energy conservation and emission reduction and encourage firms to develop low-carbon technologies aggressively.

Authors Contribution

Zubair Tanveer: literature search, data collection, data interpretation
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Nabila Asghar: study design and concept, data interpretation, drafting
Hafeez ur Rehman: critical revision, incorporation of intellectual content

Conflict of Interests/Disclosures

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Reference

Abbasi, K. R., Hussain, K., Haddad, A. M., Salman, A., & Ozturk, I. (2022). The role of Financial Development and Technological Innovation towards Sustainable Development in Pakistan: Fresh insights from consumption and territory-based emissions. *Technological Forecasting and Social Change, 176*, 121444. doi:https://doi.org/10.1016/j.techfore.2021.121444

Abdallh, A. A., & Abugamos, H. (2017). A semi-parametric panel data analysis on the urbanisation-carbon emissions nexus for the MENA countries. *Renewable and Sustainable Energy Reviews, 78*, 1350-1356. doi:https://doi.org/10.1016/j.rser.2017.05.006

Adebayo, T. S., Akadiri, S. S., Adedapo, A. T., & Usman, N. (2022). Does interaction between technological innovation and natural resource rent impact environmental degradation in newly industrialized countries? New evidence from method of moments quantile regression. *Environmental Science and Pollution Research, 29*(2), 3162-3169. doi:https://doi.org/10.1007/s11356-021-17631-y

Adebayo, T. S., & Kirikkaleli, D. (2021). Impact of renewable energy consumption, globalization, and technological innovation on environmental degradation in Japan: application of wavelet tools. *Environment, Development and Sustainability, 23*(11), 16057-16082. doi:https://doi.org/10.1007/s10668-021-01322-2

Ahmad, M., Khan, Z., Rahman, Z. U., Khattak, S. I., & Khan, Z. U. (2021). Can innovation shocks determine CO2 emissions (CO2e) in the OECD economies? A new perspective. *Economics of Innovation and New Technology, 30*(1), 89-109. doi:https://doi.org/10.1080/10438599.2019.1684643

Ali, W., Abdullah, A., & Azam, M. (2016). The dynamic linkage between technological innovation and carbon dioxide emissions in Malaysia: an autoregressive distributed lagged bound approach. *International Journal of Energy Economics and Policy, 6*(3), 389-400.

Álvarez-Herránz, A., Balsalobre, D., Cantos, J. M., & Shahbaz, M. (2017). Energy innovations-GHG emissions nexus: fresh empirical evidence from OECD countries. *Energy Policy, 101*, 90-100. doi:https://doi.org/10.1016/j.enpol.2016.11.030

Boadu, F. O. (2016). *Agricultural law and economics in sub-Saharan Africa: cases and comments*: Academic Press.

Cheng, Y., Awan, U., Ahmad, S., & Tan, Z. (2021). How do technological innovation and fiscal decentralization affect the environment? A story of the fourth industrial revolution and sustainable growth. *Technological Forecasting and Social Change, 162*, 120398. doi:https://doi.org/10.1016/j.techfore.2020.120398

Chien, F., Hsu, C.-C., Zhang, Y., Vu, H. M., & Nawaz, M. A. (2021). Unlocking the role of energy poverty and its impacts on financial growth of household: is there any economic concern. *Environmental Science and Pollution Research*, 1-14. doi:https://doi.org/10.1007/s11356-021-16649-6

Chishti, M. Z., & Sinha, A. (2022). Do the shocks in technological and financial innovation influence the environmental quality? Evidence from BRICS economies. *Technology in Society, 68*, 101828. doi:https://doi.org/10.1016/j.techsoc.2021.101828

Churchill, S. A., Inekwe, J., Smyth, R., & Zhang, X. (2019). R&D intensity and carbon emissions in the G7: 1870–2014. *Energy Economics, 80*, 30-37. doi:https://doi.org/10.1016/j.eneco.2018.12.020

Demir, C., Cergibozan, R., & Ari, A. (2020). Environmental dimension of innovation: time series evidence from Turkey. *Environment, Development and Sustainability, 22*(3), 2497-2516. doi:https://doi.org/10.1007/s10668-018-00305-0

Dinda, S. (2018). Production technology and carbon emission: long-run relation with short-run dynamics. *Journal of Applied Economics, 21*(1), 106-121. doi:https://doi.org/10.1080/15140326.2018.1526871

Fernández, Y. F., López, M. F., & Blanco, B. O. (2018). Innovation for sustainability: the impact of R&D spending on CO2 emissions. *Journal of cleaner production, 172*, 3459-3467. doi:https://doi.org/10.1016/j.jclepro.2017.11.001

Fraj, E., Matute, J., & Melero, I. (2015). Environmental strategies and organizational competitiveness in the hotel industry: The role of learning and innovation as determinants of environmental success. *Tourism management, 46*, 30-42. doi:https://doi.org/10.1016/j.tourman.2014.05.009

Garrone, P., & Grilli, L. (2010). Is there a relationship between public expenditures in energy R&D and carbon emissions per GDP? An empirical investigation. *Energy Policy, 38*(10), 5600-5613. doi:https://doi.org/10.1016/j.enpol.2010.04.057

Gillani, S., & Sultana, B. (2020). Empirical Relationship between Economic Growth, Energy Consumption and CO2 Emissions: Evidence from ASEAN Countries. *iRASD Journal of Energy & Environment, 1*(2), 83-93. doi:https://doi.org/10.52131/jee.2020.0102.0008

Hao, W., Shah, S. M. A., Nawazb, A., Barkat, M. Q., & Souhail, A. (2020). COVID-19 epidemic spread and the impact on public health & safety policy: an analysis of the adoption of preventive measures and effective management: evidence from Pakistan. *Revista Argentina de Clínica Psicológica, 29*(4), 722-736.

Haq, M. A. U., Nawaz, M. A., Mahtab, N., & Cheema, A. K. H. (2012). Determinants of wage growth: An empirical analysis of private formal sector in Bahawalpur Division. *Business and Economic Research, 2*(1).

Hussain, M. S., Nawaz, M. A., Ahmad, T. I., & Bhatti, M. A. (2021). Environmental Governance and Green Energy: An Administrative Toolkit to Reduce Environmental Degradation. *iRASD Journal of Management, 3*(3), 329-338. doi:https://doi.org/10.52131/jom.2021.0303.0049

Jianjun, H., Yao, Y., Hameed, J., Kamran, H. W., Nawaz, M. A., Aqdas, R., & Patwary, A. K. (2021). The role of artificial and nonartificial intelligence in the new product success with moderating role of new product innovation: a case of manufacturing companies in China. *Complexity, 2021*. doi:https://doi.org/10.1155/2021/8891298

Jin, L., Duan, K., Shi, C., & Ju, X. (2017). The impact of technological progress in the energy sector on carbon emissions: an empirical analysis from China. *International journal of environmental research and public health, 14*(12), 1505. doi:https://doi.org/10.3390/ijerph14121505

Khan, S., & Majeed, M. T. (2019). Decomposition and decoupling analysis of carbon emissions from economic growth: a case study of Pakistan. *Pakistan Journal of Commerce and Social Sciences (PJCSS), 13*(4), 868-891.

Liu, X., Zhang, S., & Bae, J. (2017). The nexus of renewable energy-agriculture-environment in BRICS. *Applied energy, 204*, 489-496. doi:https://doi.org/10.1016/j.apenergy.2017.07.077

Long, X., Chen, Y., Du, J., Oh, K., & Han, I. (2017). Environmental innovation and its impact on economic and environmental performance: evidence from Korean-owned firms in China. *Energy Policy, 107*, 131-137. doi:https://doi.org/10.1016/j.enpol.2017.04.044

Meirun, T., Mihardjo, L. W., Haseeb, M., Khan, S. A. R., & Jermsittiparsert, K. (2021). The dynamics effect of green technology innovation on economic growth and CO2 emission in Singapore: new evidence from bootstrap ARDL approach. *Environmental Science and Pollution Research, 28*(4), 4184-4194. doi:https://doi.org/10.1007/s11356-020-10760-w

Mensah, C. N., Long, X., Boamah, K. B., Bediako, I. A., Dauda, L., & Salman, M. (2018). The effect of innovation on CO2 emissions of OCED countries from 1990 to 2014. *Environmental Science and Pollution Research, 25*(29), 29678-29698. doi:https://doi.org/10.1007/s11356-018-2968-0

Nawab, T., Bhatti, M. A., & Nawaz, M. A. (2021). Does Technological Innovation Advance Environmental Sustainability in ASEAN Countries? *Pakistan Journal of Humanities and Social Sciences, 9*(3), 425–434-425–434. doi:https://doi.org/10.52131/pjhss.2021.0903.0148

Ozturk, M., & Yuksel, Y. E. (2016). Energy structure of Turkey for sustainable development. *Renewable and Sustainable Energy Reviews, 53*, 1259-1272. doi:https://doi.org/10.1016/j.rser.2015.09.087

Pesaran, M. H., & Pesaran, B. (1997). Working with Microfit 4.0: Interactive Economic Analysis. In. US: Oxford University Press.

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics, 16*(3), 289-326. doi:https://doi.org/10.1002/jae.616

Petruzzelli, A. M., Maria Dangelico, R., Rotolo, D., & Albino, V. (2011). Organizational factors and technological features in the development of green innovations: Evidence from patent analysis. *Innovation, 13*(3), 291-310. doi:https://doi.org/10.5172/impp.2011.13.3.291

Rosa, P., Sassanelli, C., Urbinati, A., Chiaroni, D., & Terzi, S. (2020). Assessing relations between Circular Economy and Industry 4.0: a systematic literature review. *International Journal of Production Research, 58*(6), 1662-1687. doi:https://doi.org/10.1080/00207543.2019.1680896

Runsen, Y., Chunling, L., Ahmed Memon, J., Ali, M., & Nawaz, M. A. The Nexus between Fiscal Decentralization and Environmental Sustainability in Japan. *Frontiers in Environmental Science*, 579.

Sassanelli, C., Rosa, P., Rocca, R., & Terzi, S. (2019). Circular economy performance assessment methods: A systematic literature review. *Journal of cleaner production, 229*, 440-453. doi:https://doi.org/10.1016/j.jclepro.2019.05.019

Schumpeter, J. A. (1961). *The Theory of Economic Development; An Inquiry Into Profits, Capital, Credit, Interest, and the Business Cycle. Translated From the German by Redvers Opie*.

Shaari, M. S., Abdullah, D. N. C., Alias, N. S. B., & Adnan, N. S. M. (2016). Positive and negative effects of research and development. *International Journal of Energy Economics and Policy, 6*(4), 767-770.

Shafiq, M. N., Gillani, S., & Shafiq, S. (2021). Climate Change and Agricultural Production in Pakistan. *iRASD Journal of Energy & Environment, 2*(2), 47-54. doi:https://doi.org/10.52131/jee.2021.0202.0016

Shafiq, M. N., ur Raheem, F., & Ahmed, A. (2020). Does Adaptation of Renewable Energy and Use of Service Industry Growth Diminution CO2 Emissions: Evidence of ASEAN Economies. *iRASD Journal of Energy & Environment, 1*(2), 61-71. doi:https://doi.org/10.52131/jee.2020.0102.0006

Shahbaz, M., Nasir, M. A., & Roubaud, D. (2018). Environmental degradation in France: the effects of FDI, financial development, and energy innovations. *Energy Economics, 74*, 843-857. doi:https://doi.org/10.1016/j.eneco.2018.07.020

Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In *Festschrift in honor of Peter Schmidt* (pp. 281-314). New York: Springer.

Sinha, A., Sengupta, T., & Alvarado, R. (2020). Interplay between technological innovation and environmental quality: formulating the SDG policies for next 11 economies. *Journal of cleaner production, 242*, 118549. doi:https://doi.org/10.1016/j.jclepro.2019.118549

Su, H.-N., & Moaniba, I. M. (2017). Does innovation respond to climate change? Empirical evidence from patents and greenhouse gas emissions. *Technological Forecasting and Social Change, 122*, 49-62. doi:https://doi.org/10.1016/j.techfore.2017.04.017

Suki, N. M., Suki, N. M., Sharif, A., Afshan, S., & Jermsittiparsert, K. (2022). The role of technology innovation and renewable energy in reducing environmental degradation in Malaysia: A step towards sustainable environment. *Renewable Energy, 182*, 245-253. doi:https://doi.org/10.1016/j.renene.2021.10.007

Tidd, J., & Bessant, J. R. (2020). *Managing innovation: integrating technological, market and organizational change*: John Wiley & Sons.

Ullah, S., Ozturk, I., Majeed, M. T., & Ahmad, W. (2021). Do technological innovations have symmetric or asymmetric effects on environmental quality? Evidence from Pakistan. *Journal of cleaner production, 316*, 128239. doi:https://doi.org/10.1016/j.jclepro.2021.128239

UNFCCC. (2015). The Paris Agreement Retrieved from https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

Vinante, C., Sacco, P., Orzes, G., & Borgianni, Y. (2021). Circular economy metrics: Literature review and company-level classification framework. *Journal of cleaner production, 288*, 125090. doi:https://doi.org/10.1016/j.jclepro.2020.125090

Wang, K.-H., Umar, M., Akram, R., & Caglar, E. (2021). Is technological innovation making world" Greener"? An evidence from changing growth story of China. *Technological Forecasting and Social Change, 165*, 120516. doi:https://doi.org/10.1016/j.techfore.2020.120516

Xu, F., Huang, Q., Yue, H., He, C., Wang, C., & Zhang, H. (2020). Reexamining the relationship between urbanization and pollutant emissions in China based on the STIRPAT model. *Journal of Environmental Management, 273*, 111134. doi:https://doi.org/10.1016/j.jenvman.2020.111134

Yu, Y., & Du, Y. (2019). Impact of technological innovation on CO2 emissions and emissions trend prediction on 'New Normal'economy in China. *Atmospheric Pollution Research, 10*(1), 152-161. doi:https://doi.org/10.1016/j.apr.2018.07.005

Zhang, Y.-J., Peng, Y.-L., Ma, C.-Q., & Shen, B. (2017). Can environmental innovation facilitate carbon emissions reduction? Evidence from China. *Energy Policy, 100*, 18-28. doi:https://doi.org/10.1016/j.enpol.2016.10.005