



THE IMPACT OF TRADE, TECHNOLOGY AND GROWTH ON ENVIRONMENTAL DETERIORATION OF CHINA AND INDIA



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ABSTRACT

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The aim of this study is to investigate the impact of Trade openness, Technological Innovation, and Economic growth on the Environmental deterioration of China and India over the period of 1974–2016. These two largest transitional and emerging countries of Asia have gained miraculous development in many sectors but at the cost of Environmental deterioration. We have applied the ARDL Bounds Test methodology and Toda- Yamamoto Granger Non-Causality test to determine the short-run and long-run relationships of the variables. The results of the study illustrate that Technological innovation has a significant positive impact and Economic growth has a strong 0adverse effect on the Environmental deterioration of China in the long-run. But it is not so strong in the short-run. In the case of India, Trade openness and Economic growth have a significant positive impact and Technological innovation has a strong negative effect on Environmental deterioration in the long-run. The selected macro-economic explanatory variables have a significant impact on the Environmental deterioration of India in the short-run as well. The results of ARDL bounds test are also supported by Toda- Yamamoto Granger Non-Causality test. To compare China and India, Trade openness has a significant impact on the Environmental deterioration of India, but it is not factual for China. In addition, Technological innovation and Economic growth have an inverse relationship on the Environmental deterioration of both the Countries. The findings of this study have an important policy implication for China and India.

Contribution/ Originality: The contributions of this study in the existing literature are: it has examined the impact of Trade, Technology, and growth on the Environmental deterioration of the two largest transitional and emerging economies of Asia: China and India. We have applied the ARDL Bounds method and Toda-Yamamoto Granger Non-Causality test and illustrated that Trade has a significant impact on the Environmental deterioration of India, but it is not factual for China. Technology and growth have an inverse relationship on the Environmental deterioration of both the Countries.

1. INTRODUCTION

Climate change and environmental deterioration which was ignored by the western developed countries in the 1970's and 1980's; has now become an important policy issue not only in the regional level but also in the international level. World leaders and policymakers are giving strong and important emphasis on the improvement of environment equivalent to economic growth. In these days, Nations want economic development of the country but not at the cost of environmental deterioration. China and India are the two biggest developing and transitional economies of Asia. Both the countries are large enough having one-third population of the world but they are in two separate stages of economic development, energy use, structural change, technological innovation, trade as well as differences in culture, customs and religious beliefs. Both the countries belong the nuclear power. China is a permanent member of the United Nations Security Council with 'Veto' power and India is a big power in South and South-East Asia. So these two countries are playing an essential and crucial role in the politics and economy in this region as well as in the world.

The Population of China and India is 1,382.7 million and 1,309.3 million (April-2017) respectively; which refers about one-third population of the world live in this two countries. GDP per capita of China is \$8,118.3 and of India is \$1,723.3, means China's GDP per capita is 4.71 times than that of India. So India is far behind of China in the case of economic development. In accordance with the economic structure, China had been a manufacturing-based economy and India was a more balanced mix of manufacturing and services based economy in 2015 (Schwab). From 1989 to 2018 China has achieved 9.61 percent, and from 1951 until 2018 India has gained 6.15 percent economic growth (Economics, 2018). Both the countries have made dramatic progress not only in the economic sector but also in the poverty alleviation. Especially the Chinese economic growth is a wonder to the scholars, academicians and International organizations like the World Bank and the IMF.

It is a fact that the Economic development is not a fresh blessing; it is coming at the cost of environmental deterioration of the countries. The reason is that the vast amount of primary energy (oil, coal etc.) is used to gain economic development, which is playing a vital role in environmental deterioration. China and India are among the biggest consumers and users of energy as well as the heaviest emitters of CO₂. BP Statistical Review of World Energy 2018, published by British Petroleum revealed that in 2017, the use of global primary energy raised strongly which was directed by renewable energy and natural gas, with coal's portion of the mix of energy persisting to go down. It was stated in the report that average growth of primary energy consumption was 2.2% in 2017, the highest since 2013. According to fuel, natural gas was the highest in energy consumption followed by renewable energy and oil is coming later. In China, energy consumption grew by 3.1% which contributed over a third of world growth and China was the largest market for energy. It was driven by the output of some of China's most energy-exhaustive sectors such as crude steel, iron, and non-ferrous metals. Around 60% of the raise in primary energy was provided by renewable energy and natural gas (wind and solar power) (Report, 2018).

In 2017, total primary energy consumption in China was 3132.2 Million tons oil equivalent (Mtoe) which was 23.2% of the world total, making China the major energy consumer in the world. In line with it, CO₂ emissions from energy consumption increased by 1.6% in 2017. This year China emitted 9232.6 million tons CO₂ accounting for 27.6% of the world total, which is the also largest in the world. On the other hand, India consumed 753.7 Mtoe of total primary energy. This volume accounted for 5.6% of the world total in 2017. The energy consumption grew 4.6% from the last year. In the case of CO₂ emissions, India emitted 2344.2 Million tonnes of CO₂, which contributed 7% of the world total. CO₂ emissions in India increased by 4.4% to compare with last year (Report, 2018). So, total CO₂ emissions by China and India were 34.6% in 2017 which contributed more than one-third of the world total.

In line with it, Coal is another essential element of CO₂ emissions. In 2017, India's coal consumption was 424.00 Mtoe which was 11.4% of the world total whereas, China's coal consumption was 1892.60 Mtoe which was 50.7% of the world total. In 2017, Global coal consumption increased by 1% (25 Mtoe) whereas, India's coal consumption

grew by 4.8% (18 Mtoe), the fastest growth in the world. The reason behind is the increased demand for coal in India from the power sector. In the case of China, coal consumption grew by 0.5% (4 Mtoe) after three years of successive declines. Though there had been the extensive transformation from coal-to-gas in the residential and industrial sector, increased demand of power in China absorbed the additional coal. The coal statistics given above indicates that China and India consumed 62.1% of the total coal of the world (Report, 2018). It is documented that the consumption of coal has a drastic impact on the environment. The use of coal adds more CO₂ in the atmosphere than any other fossil fuels.

The International Energy Outlook 2018 commented that the economy of India is a service-oriented economy, benefitting from technological advancement transferred from other countries, and by utilizing energy-efficient equipment and practices. Infrastructural limitations, low investment in the energy sector, and the use of conventional, non-marketed fuels like charcoal are the reason behind India's low energy use per capita. China's enlarged, the goods-oriented economy is more energy intensive than that of the primarily service-oriented economy of India (Report2, 2018).

The above discussion indicates that the speedy economic growth of China and India has been accompanied by increasing levels of energy use and emissions. The use of fossil fuels such as coal, oil, and gas produces CO₂ and CO₂ emissions by different industrial sectors such as transportation, electricity, steel, and cement contribute to climate change (global warming). It is a serious anxiety for the two countries themselves and rest of the world. With a view to prevent disastrous damage of the earth, the last Paris Agreement (2015) on Climate change fixed up the target to keep the increase in global average temperature below 2°C in relation to pre-industrial stages, and try to limit the temperature increase to 1.5°C compared to pre-industrial levels (Pradhan *et al.*, 2017). Since China and India are among the biggest emitters of CO₂ in the world, they have to play a superior role to fight against global warming.

If we look from the environment to the other macroeconomic variables, it is astonishing to observe how trade openness, technology, economic growth, urbanization, and atmosphere are working collectively, also, to against one another at the same time (Ameer and Munir, 2016). Technological development has reduced the cost of communication and transportation. The study of Kang *et al.* (2016) and Brock and Taylor (2010) revealed that technology is a means of bringing the world closer and facilitates to mitigate the problems. It is documented that environmental deterioration goes up with economic growth but descends with technological development. Globalization is distinguished by rigorous trade openness and trade integration, and it is related to the technological revolution. Development of telecommunications, transport, and technology have generated prospects for a restructuring of the global manufacturing and distribution procedure (Were, 2015). So there has been a significant association between trade, technology, use of energy, and the environment.

From partial overview in our selected variables, let's have a look into the related literature of China and India. There are a good number of studies which investigated the impact of different variables on China and India. Among them, Bosworth and Collins (2008) examined the patterns of economic growth; Qureshi and Wan (2008) checked export performances and specialization patterns; Bansal (2011) compared the growth of e-commerce and internet development; Agrawal and Khan (2011) documented the role of FDI on GDP; Lema and Lema (2012) examined technology transfer; Sun *et al.* (2012) documented the role of MNEs; Nguyen *et al.* (2017) showed the impact of investment on use of energy, CO₂ emissions, and income; Adhikari and Ganguly (2017) explained comparative green industrial policies; Pradhan *et al.* (2017) examined carbon prices; Wolde-Rufael and Idowu (2017) showed income inequality and CO₂ emissions; Shahbaz *et al.* (2017) showed that financial development accelerates economic growth; Sun *et al.* (2018) compared the manufacturing trade and the total energy use; Shahbaz *et al.* (2018) investigated the impact of industrialization, service sector growth, and urbanization on financial development; Bharadwaj (2018) examined the technical aspects of green technologies of both countries; etc.

There has been relatively little literature which has investigated the relationships of trade openness and CO₂ emissions exclusively. Some of the studies found trade openness has a negative impact on the quality of environment by intensifying CO₂ emissions (Ertugrul *et al.*, 2016; Shahbaz *et al.*, 2017; Mohammed, 2018; Niu *et al.*, 2018). Several studies found the mixed or negative effect of trade openness on CO₂ emissions which refers that trade develops the quality of environment (Dogan *et al.*, 2017; Hasson and Masih, 2017; Kim *et al.*, 2018; Vale *et al.*, 2018).

A considerable amount of literature has been published on the technology - CO₂ emissions association and most of the investigator found the negative effect of technology on CO₂ emissions. It indicates that technology is improving environmental quality by reducing CO₂ emissions. The investigations conducted by Ang (2009); Sohag *et al.* (2015); Ameer and Munir (2016); Salahuddin *et al.* (2016); Yan *et al.* (2017); Kahouli (2018); Khan *et al.* (2018); Mensah *et al.* (2018); Miao *et al.* (2018); Xu and Lin (2018) revealed that different proxies of technology have a positive effect on environmental quality. Some of the scholars discovered the mixed or negative impact of technology on environmental quality (Choi and Han, 2018; Park *et al.*, 2018).

Many of the studies have been conducted in the relationships of Economic growth and CO₂ emissions. Grossman and Krueger (1991) and Selden and Song (1994) developed the EKC hypothesis which illustrates that economic growth and environmental deterioration (measured by CO₂ emissions) is non-linear and inverted-U shaped. It refers that economic growth leads to a gradual deterioration of the environment but after a definite stage of economic growth, it starts to improve again. The same result were found in the study of Ayeche *et al.* (2016); Ertugrul *et al.* (2016); Ahmad *et al.* (2017); Jamel and Maktouf (2017); Aslan *et al.* (2018); Hanif (2018); Rauf *et al.* (2018); Raza and Shah (2018); Shahbaz and Sinha (2018); Zhang *et al.* (2018). Different proxies of economic growth increases CO₂ emissions has been documented in many studies such as Hossain (2011); Al-Mulali *et al.* (2015); Omri *et al.* (2015); Ali *et al.* (2016); Dogan and Turkecul (2016); Kang *et al.* (2016); Mohammadi (2017); Ahmed and Ahmed (2018); Balsalobre-Lorente *et al.* (2018); De Souza *et al.* (2018); Mardani *et al.* (2018); Shahbaz *et al.* (2018).

Some of the researchers documented the mixed or negative effect of economic growth on CO₂ emissions (Liu *et al.*, 2007; Hossain, 2012; Chandran and Tang, 2013; Farhani and Ozturk, 2015; Acheampong, 2018; Chapman *et al.*, 2018).

This research has the following particular objectives:

- i. With a view to investigate and compare the impact of three most essential macroeconomic variables: Trade, Technology, and Economic growth on the Environmental deterioration of China and India.
- ii. To analyze the structure of the short-run and long-run relationships (Unidirectional, no directional or feedback/bidirectional) between Trade, Technology, Growth, and Environment on each other of the two countries.
- iii. To indicate the policy implication for the Government of China and India to formulate national trade, technology, and economic growth policy to maintain the present economic growth without hampering the environment.

From the summarized discussion in the existing literature, we detect that numerous researcher accomplished lots of investigation on different variables and they have used diverse methods to compare China and India. Few types of research have been performed about the impact of trade, technology, and growth on the environment of these two countries but these studies were individual. By our findings, we have studied the impact of trade, technology, and growth on the environment of China and India together for the first time. The principal contributions of this empirical research in the current literature are: (I) it examined the long-run and short-run impact of trade, technology and growth on the environment of the two largest emerging economy China and India for the period of 1974–2016 applying ARDL cointegration bound test and Toda- Yamamoto Granger non-Causality test in an augmented VAR framework with structural break unit root test. (II) Most recent and longest time series data from a highly dependable source - World Development Indicators of the World Bank - have been applied in

this study, (III) we have included technology for the first time in determining the impact of it on the environment of these two countries, and (IV) the obtained results of this study would provide policy makers of these two countries to understand the impact of trade, technology and growth on the environment as well as to formulate national trade policy, technological policy, and energy policy to foster economic growth by saving the environment. As a result, this study holds immense importance in the literature arena and it will cover the gap in the present economic literature.

The remaining portion of this paper is designed in the following way: Section 2 presents the review of the past literature; Section 3 illustrates data and econometric model; Section 4 documented the estimation, findings, result in analysis and discussion; in conclusion (section 5), we have compared the major findings and suggested some important policy implications of this study for both the countries.

2. LITERATURE REVIEW

A considerable amount of literature has been published in China and India, but the number of empirical research is very small. Several studies have analyzed the impact of Trade openness, Technological innovation, and Economic growth on Environmental Deterioration of China and India separately. In order to have a sound review of the past literature, we have discussed it in groups: first, the literatures which have studied on China and India; second, the relationship of Trade openness and CO₂ emission; third, the relationship of technological innovation and CO₂ emission; fourth, the relationship of Economic growth and CO₂ emission as well as with other macroeconomic variables.

2.1. Literature on China-India

The study of Qureshi and Wan (2008) showed that China is the competitor of India in the third markets exclusively in clothing, textile, and leather products. China is a challenge for the US, the European countries and the East Asian region especially in medium-technology industries; India is the competitor mainly for South Asian countries. In the study of Bosworth and Collins (2008) revealed that China achieved tremendous economic growth in the industrial sector for its eagerness to reduce trade barriers and to attract FDI in the country. In contrast, India's growth has been capitalized by the quick expansion of service-producing industries. The researchers Singh *et al.* (2009) found that China and India have implemented numerous promotional schemes for SMEs. Bansal (2011) compared the growth of e-commerce and internet development in China and India. They reveal that despite China was linked to the Internet later than India; it is now well ahead of India due to the completion of several special "Golden Projects" and the quick improvement of the Internet infrastructure of China.

The study conducted by Marelli and Signorelli (2011) revealed that openness, FDI and integration in the world economy have a significant positive effect on economic growth of these two countries. Agrawal and Khan (2011) documented that a 1% increase in FDI would result in a 0.02% increase in GDP of India and 0.07% increase in GDP of China. Lema and Lema (2012) illustrated that traditional technology transfer process like FDI and licensing was essential for industry formation and take-off initially for China and India. But, since these sectors are catching up, new unique technology transfer methods like R&D partnerships and acquisition of foreign firms have become important. Incorporating the comparative advantage theory with Dunning's OLI paradigm on China and India's MNEs, Sun *et al.* (2012) showed that MNEs from developing economies have gone for aggressive cross-border mergers and acquisitions (M&As).

Jayanthakumaran *et al.* (2012) illustrated that CO₂ emissions in China had been influenced by structural changes, per capita income, and energy consumption. On the contrary, the same relationship cannot be established for India. The reason is an informal economy of India is larger than that of China. India has a good number of micro-enterprises which consumes low energy. In an empirical study to compare growth and productivity between China and India Wu *et al.* (2017) revealed that during the post-reform period from 1981 to 2011 the growth of

China in value added was over 50 percent faster but in total factor productivity (TFP) 25 percent slower than that of India. In a review article, [Adhikari and Ganguly \(2017\)](#) explained the comparative green industrial policies of China and India.

[Pradhan et al. \(2017\)](#) revealed that carbon prices are higher in China than India because of the differences in emission intensity and the rate of deployment of new technologies. The study by [Yao and Whalley \(2017\)](#) documented that China was adversely affected by the crisis than India and India is recovering more rapidly in economic performance. India has diversified its exports, and China's share has dropped. India has a more competitive advantage in the service sector. [Wolde-Rufael and Idowu \(2017\)](#) showed that there been had no strong association between CO₂ emissions and income inequality both in the short-run and the long-run in India and China. The researchers [Shahbaz et al. \(2017\)](#) exposed that financial development accelerates economic growth in China and India. Their study documented that globalization increases economic growth in India but not in China.

Applying ARDL model [Pal and Mitra \(2017\)](#) revealed that there is a short-run effect of energy use on CO₂ emissions and a long-run impact of trade and economic activity. Their study also documented the N-shaped association between CO₂ emissions and economic growth between India and China. [Nguyen et al. \(2017\)](#) demonstrated that investment plays a crucial role in the relationship between energy consumption, CO₂ emissions, and income in China but not in India. They also showed that trade openness plays a major role in the short-term in China, but it has no effect on the emissions-energy-growth scenario in India. [Solarin et al. \(2017\)](#) proved the existence of the EKC hypothesis in both the countries. Their study documented that urbanization and GDP have a long-run positive effect on emission, but hydroelectricity consumption has a negative impact on it in the long-run in both countries. The Granger causality test revealed that there had been a long-run bidirectional relationship between the variables.

In a study, [Sun et al. \(2018\)](#) documented that the total use of energy in bilateral trade and net embodied energy imports in India's manufacturing increased by 11 times and 40 times respectively. The manufacturing sector of India lost its advantage of energy conservation gradually followed by the trade deficit. India's light industries had reduced trade profits and increased energy demands, but it had been the heavy industries in the case of China. The study conducted by [Shahbaz et al. \(2018\)](#) revealed that industrialization, urbanization, and service sector growth helped in the financial development of China and India. The study added that trade openness increases Indian financial development which is not documented for China and the institutions and governments might play major role for both countries in enlarging finance and growth. [Nazir and Tan \(2018\)](#) confirmed that financial innovation has a positive and significant effect on economic growth in the short-run and long-run. It was also revealed in the study that trade openness and gross capital formation plays a vital role in economic growth.

2.2. Literature on Trade – CO₂ Emissions:

There has been considerably little literature which revealed the impact of trade openness on CO₂ emissions that has been mentioned in the introduction section. Investigating in 105 low, middle and high income countries [Shahbaz et al. \(2017\)](#) illustrated that Trade openness hinders environmental quality for the high, middle and low-income countries but the impact is different from country to country. The feedback effect exists between carbon emissions and trade openness at the global level and the middle-income countries. On the other hand, trade openness Granger-causes CO₂ emissions for high and low-income countries. In an investigation on Bahrain, [Mohammed \(2018\)](#) documented international trade have a significant negative impact on the environment in the long-run.

[Niu et al. \(2018\)](#) demonstrated that trade openness and political stability have a significant negative impact on the environmental performance in 126 countries and the non-OECD countries, while, trade openness leads a positive influence on the environment in OECD countries. Their VECM results indicated negative causalities are running from trade openness and political stability to environmental performance in the long-run for both full

samples and the sub-samples countries. Ertugrul *et al.* (2016) revealed that the EKC hypothesis exists in Turkey, India, China, and Korea. The research work also showed that trade openness, energy consumption, and real income are the principal determinants of carbon emissions in the long-run.

Some of the studies found that trade decreases CO₂ emissions and develops the environmental quality or mixed effect. In research on South Africa, Hasson and Masih (2017) illustrated that trade decreases CO₂ emissions by improving environmental quality and there is a positive association between energy consumption and economic growth. Dogan *et al.* (2017) indicated that trade improves the environment by decreasing emissions in the OECD member countries. On the contrary, tourism and energy consumption increases emissions. They also showed that the EKC hypothesis is not supported for GDP.

The study conducted in the South-South, North-North, North-South, and South-North context by Kim *et al.* (2018) revealed that trade with the North boosts CO₂ emissions while, trade with the South mitigates it. The trade of advanced countries with the North or the South lessens CO₂ emissions. Trade of developing countries with the North intensifies CO₂ emissions; whereas, trade with the South alleviates CO₂ emissions. The study to investigate the relationships between the environment and international trade at a global level, Vale *et al.* (2018) indicated that both the North and the South have become less pollution-intensive over the years. On the contrary, South has specialized in comparatively more pollution-intensive activities.

2.3. Literature on Technology-CO₂ Emissions:

A volume of studies has documented the impact of technology on CO₂ emissions. In a study on China, Ang (2009) revealed that there is a negative relationship of CO₂ emissions to research strength, transfer of technology, and the soak up the capability of the economy to incorporate foreign technology. They also indicated that higher income, more use of energy and greater trade openness intensify CO₂ emissions. In an investigation to realize the function of technologies and infrastructure in the processes of urbanization, Chester *et al.* (2014) positioned these progressively more complex systems for low-carbon (CO₂) growth. The study about the effects of technological innovation on energy use in Malaysia, Sohag *et al.* (2015) documented that increasing trade openness and GDP per capita generate an inverse effect of technological innovation on energy use.

In a working paper series of the United Nations Industrial Development Organization (UNIDO) on developing countries, Massa (2015) commented that technological innovation has a strong impact on the socio-economic factors as well as could develop the environmental quality. On the other hand, it might also create severe challenges for the human welfare, the economy, and the environment. Similar kind of policy paper by The Centre for International Governance Innovation (CIGI), Bak (2015) commented that environmental goods, as well as clean technologies, are playing a vital role in the sustainable growth in a carbon-constrained world. The investigation conducted in the Asian countries (India, Bangladesh, Hong Kong, Indonesia, Iran, Pakistan, Malaysia, Philippines, Singapore, Sri Lanka, and Thailand) Ameer and Munir (2016) demonstrated that there is a significant impact of technology and growth on the CO₂ emissions.

Irاندoust (2016) indicated that there is unidirectional causality from renewable energy to CO₂ emissions for Finland and Denmark as well as a bidirectional relationship between these variables for Sweden and Norway. Their research also documented a unidirectional causality running from technological innovation and growth to renewable energy for the four Nordic countries. Ali *et al.* (2016) demonstrated that technological innovation has a negative but insignificant association with environmental pollution in Malaysia. They documented that higher economic growth and financial sector development increase the environmental quality in the long-run. Also, bidirectional causality is running between economic growth and CO₂ emissions and between technological innovation and CO₂ emissions in the long-run.

Utilizing OECD panel data, Salahuddin *et al.* (2016) documented that the quick growth in Internet usage is not a threat for the environment in this region. They also showed that economic growth is not significant in the long-

run and short-run on CO₂ emissions. In addition, the use of the Internet has a positive impact on both financial development and trade openness. The study conducted by Yan *et al.* (2017) in 15 major economies, did not reveal the positive impact of low-carbon innovation on CO₂ emissions. In contrast, they found a significant negative effect of clean innovation on it, and the impact of gray innovation is not apparent. By using the panel data of 21 industrial segments, Miao *et al.* (2018) confirmed that technological innovation plays a significant positive impact on the energy utilization efficiency of emerging industries. Xu and Lin (2018) demonstrated that the high-tech industries are reducing CO₂ emissions in China.

In a study, Kahouli (2018) revealed the significant feedback relationships between CO₂ emissions, electricity, R&D stocks and economic growth in the Mediterranean Countries (MC) as well as unidirectional causality is running among R&D stocks and economic growth and R&D stocks and CO₂ emissions. The study in emerging countries, Khan *et al.* (2018) illustrated that ICT has a significant effect on CO₂ emissions, and the rational impact of ICT and financial development is to increase the level of CO₂ emissions. Economic growth increases CO₂ emission as well as the interaction between ICT and GDP diminishes the intensity of pollution. The study by Mensah *et al.* (2018) indicated that innovation (R&D) has a significant positive impact in reducing CO₂ emissions in most OECD countries. Additionally, GDP intensifies CO₂; in contrast, EKC is not applicable for most economies.

Some of the studies found the mixed or negative impact of technological innovation on CO₂ emissions. In a study of a panel data of 33 high-income and 36 middle-income countries, Choi and Han (2018) demonstrated that environmental innovations lessen CO₂ and SO₂ emissions in high-income countries whereas, it is not the fact for middle-income countries. Their investigation also revealed that trade increases SO₂ and CO₂ emissions in middle-income countries. Park *et al.* (2018) indicated that Internet use has been lowering the environmental quality by raising CO₂ emissions in selected European Union (EU) countries and it is raising the threat to the sustainable development. Additionally, both financial development and economic growth have a diminishing negative impact on CO₂ emission.

2.4. Literature on Economic Growth - CO₂ Emissions and Mixed Literature

There has been a good number of literature which indicated the positive relationship between economic growth and CO₂ emissions. Most of the researcher used other variables such as trade, technology, energy, urbanization, etc. to determine the impact of growth on CO₂ emissions. Grossman and Krueger (1991) and Selden and Song (1994) developed the EKC hypothesis. The existence of EKC hypothesis was also documented in the study of Aslan *et al.* (2018); Hanif (2018); Rauf *et al.* (2018); Raza and Shah (2018); Zhang *et al.* (2018).

Hossain (2011) revealed that there has been no existence of the long-run relationship, in contrast, unidirectional short-run relationship is present from economic growth to energy consumption, economic growth and trade openness to CO₂ emissions, from trade openness to economic growth. Al-Mulali *et al.* (2015) revealed that financial development, economic growth, and urbanization intensify CO₂ emissions in the long-run whereas, trade openness reduces it. The VECM Granger causality test reported that economic growth is the reason of CO₂ emissions in the long-run exclusively. The research in a panel of 12 MENA countries, Omri *et al.* (2015) showed the bidirectional causality running between Economic growth and trade openness and between CO₂ emissions and economic growth. Unidirectional causality was also documented from trade openness to CO₂ emissions. Ohlan (2015) illustrated that economic growth, population density, and energy consumption have a strong positive effect on CO₂ emissions both in the short-run and long-run.

In a study on 40 European countries, Ayeche *et al.* (2016) revealed the existence of the environmental Kuznets curve. They also confirmed that bidirectional causality is running between economic growth and financial development, trade and CO₂ emissions; between financial development and trade, and between trade and CO₂ emissions. Dogan and Turkekul (2016) showed the non-existence of the EKC hypothesis in the USA. They revealed that trade has a negative effect on environmental deterioration as well as energy policies reduce CO₂ emissions.

The partial similar result was found in the study of [Javid and Sharif \(2016\)](#); [Kang et al. \(2016\)](#) for Pakistan and China. [Ali et al. \(2016\)](#) expressed that economic growth and energy consumption has a positive and significant impact on CO₂ emissions in Nigeria. On the contrary, Trade openness has a negative and significant impact on CO₂ emissions.

The study conducted by [Jamel and Maktouf \(2017\)](#) on 40 European countries revealed the validity of the environmental Kuznets curve hypothesis. They also demonstrated the bidirectional causality is running between economic growth, environmental deterioration, financial development, and trade openness. [Mohammadi \(2017\)](#) confirmed that energy use and GDP have a significant positive effect on CO₂ emission in the 16 middle-income countries. [Ahmad et al. \(2017\)](#) revealed the existence of an inverted U-shape association between economic growth and CO₂ emissions in the long-run which validates the EKC in Croatia. They also confirmed bi-directional causality between economic growth and CO₂ emissions in the short-run and unidirectional causality from economic growth to CO₂ emissions in the long-run.

The study of [De Souza et al. \(2018\)](#) revealed that economic development has a positive effect on CO₂ emissions in the five MERCOSUR member countries: Brazil, Argentina, Paraguay, Venezuela, and Uruguay. Reviewing the past literature by single-country and cross-country contexts [Shahbaz and Sinha \(2018\)](#) documented that the EKC has an inverted U-shaped relation between economic growth and CO₂ emissions for the panel. But both single-country and cross-country, the results of EKC estimation for CO₂ emissions are inconclusive. [Shahbaz et al. \(2018\)](#) indicated that financial development and economic growth have a significant positive impact on CO₂ emissions, refers, environmental deterioration. In a study, [Fan et al. \(2018\)](#) illustrated that Technological innovation has an adverse effect on Industrial growth (proxy of economic growth) in the long-run as well as Infrastructure and technological innovation both have a significant positive impact on Industrial growth in the short-run. In a study of [Balsalobre-Lorente et al. \(2018\)](#) revealed the presence of an N-shaped association between economic growth and CO₂ emissions in the EU-5 countries. They also showed that trade openness and economic growth intensify CO₂ emissions.

[Islam et al. \(2018\)](#) suggested bringing more depth to the financial system of China to accelerate prospective innovative environment in the course of FDI. [Wang et al. \(2018\)](#) illustrated that CO₂ emissions are growing and there is a severe polarization of CO₂ emissions in China. From the geographic, adjacent, and economic distance point of view, technological energy progress has a strong positive impact on an emissions reduction of China. [Dong et al. \(2018\)](#) documented that economic growth and population size have a significant positive effect in increasing CO₂ emissions at both the global and regional level in 128 countries. [Boukhelkhal and Bengana \(2018\)](#) illustrated that economic growth and electricity consumption plays a positive role in the environment deterioration in Egypt and Morocco in the long-run. [Abdouli and Hammami \(2018\)](#) revealed that there had been a bidirectional causality running between CO₂ emissions and economic growth, between FDI inflows and CO₂ emissions, and between FDI inflows, economic growth, and financial development for the Middle East countries.

[Mahmoodi and Mahmoodi \(2018\)](#) documented the feedback association between CO₂ emissions and GDP and the existence of unidirectional causality from renewable energy and trade openness to CO₂ emissions for nine Asian developing countries and six European developing countries. [Rasoulinezhad and Saboori \(2018\)](#) demonstrated the bidirectional long-run relationship between economic growths and CO₂ emissions in the Commonwealth of Independent States (CIS). In addition, they also documented that unidirectional short-run panel causality running from financial openness, economic growth, and trade openness to CO₂ emissions. [Liu and Hao \(2018\)](#) confirmed that there is a bidirectional relationship running among energy use, industry value added, carbon emissions, and GDP per capita in the long-run in 69 countries along the Belt and Road Initiative (BRI).

Some of the researchers documented the mixed or negative impact of economic growth on CO₂ emissions. [Liu et al. \(2007\)](#) revealed the existence of an EKC for Shenzhen. They documented that production-induced pollutants supported EKC, but consumption-induced pollutants did not support it. [Hossain \(2012\)](#) demonstrated that more

utilization of energy intensifies environmental pollution, on the contrary, trade openness, economic growth, and urbanization does not affect environment in the long-run in Japan. Chandran and Tang (2013) illustrated that economic growth has a crucial role in enlarging CO₂ emission in ASEAN-5 countries. They documented that the bidirectional causality is present between economic growth and CO₂ emissions in Thailand and Indonesia in the long-run, while unidirectional causality exists from GDP to CO₂ emissions in Malaysia. The inverted U-shape EKC hypothesis is not applicable in Malaysia, Thailand, and Indonesia.

Farhani and Ozturk (2015) showed that the relationship between CO₂ emissions and GDP is inconclusive and it is deviated from the EKC hypothesis in Tunisia. The study conducted in six Northeast Asian countries (Republic of Korea, China, Japan, Mongolia, Democratic People's Republic of Korea, and Russia) by Chapman *et al.* (2018) illustrated that major driving forces of CO₂ emissions change among Northeast Asian countries. It is motivated by economic growth in Korea and China, decreased by energy efficiency enhancements in Russia and the DPRK, in contrast, relatively soft in Japan and Mongolia because of the amalgamation of these factors. The study in 116 countries, Acheampong (2018) confirmed that economic growth lessens carbon emissions at the global level, and Caribbean-Latin America but carbon emissions positively influence economic growth.

Reviewing the past literature, we experienced that many investigators operated lots of research on different variables to compare China and India. But there is no direct empirical study about the impact of Trade, Technology and growth on the environment of these two countries. In accordance with our findings, we have investigated the associations between these three variables on environment for the first time. So this study has a great significance in the literature domain, and it will fill up the gap in the existing economic literature.

3. DATA AND ECONOMETRIC MODEL

In this study, we would use Trade openness, Technological innovation, and Economic growth as the proxy of trade, technology and growth consequently; and CO₂ emission would be utilized as the proxy of environmental deterioration. In order to investigate and compare the long-run and short-run impact of Trade openness, Technological innovation, and Economic growth on the CO₂ emission of China and India, data have been derived from the world highly reliable data source - World Development Indicators (WDI) of the World Bank - published in 2017. The period covers from 1974 to 2016. It is the longest time series data been used so far as our knowledge. For Trade Openness, we will apply the sum of Export and Import as % of GDP; for Economic growth, we would utilize GDP per capita (constant 2010 US\$); for CO₂ emissions, we will take CO₂ emissions (kg per 2010 US\$ of GDP); and for Technological innovation (TI), we have used the number of patents registered by residents and non-residents (sum) as a proxy of the variable. It is documented that Technological innovation indicates the interest of industrial and private organizations of a country in absorbing the new technology and could be estimated by a quantitative indicator, like the number of patents. Following the empirical studies of Schmoch (2007); Ang (2009); Tang and Tan (2013); Sohag *et al.* (2015); Cederholm and Zhong (2017); Fan *et al.* (2018) we have also taken the number of patents as a proxy for technological innovation in our research. We have converted all time series data to their natural logarithm form except Trade openness because it is in the percentage (ratio) form (Fan *et al.*, 2018).

In our research, we are going to apply CO₂ emission (CO₂) as the dependent variable and Trade openness (TO), Technological innovation (TI), and GDP per capita (GDP) as the explanatory variables. To documenting the major objective of our research, the functional form of the model has been designed in the following way:

$$CO_2 = f(TO, TI, GDP) \text{ ----- (I)}$$

In accordance with the review of the existing literature and following the study of Bhattacharya *et al.* (2017); Pal and Mitra (2017); Wolde-Rufael and Idowu (2017); Shahbaz *et al.* (2018) the linear econometric form of the above model is as follows:

$$CO_2_t = \alpha_0 + \alpha_1 TO_t + \alpha_2 TI_t + \alpha_3 GDP_t + \varepsilon_t \text{ ----- (II)}$$

In the above equation, α_0 is the intercept and α_1 , α_2 , and α_3 are coefficients of the explanatory variables. ε refers the error term, and the subscript t explained the period. By taking the natural logarithm of the variables in both sides except, 'Trade openness' (because it is in the ratio form), the equation stands as follows:

$$\ln CO2_t = \alpha_0 + \alpha_1 TO_t + \alpha_2 \ln TI_t + \alpha_3 \ln GDP_t + \varepsilon_t \quad \text{----- (III)}$$

3.1. Unit Root Testing

In ARDL approach, unit root test is not essential, because of it could function the unit root test in the presence of cointegration among the variables of order I(0) or I(1) or a mix of these two. But the study of Pesaran and Shin (1998) and Pesaran *et al.* (2001) illustrated that none of the variables should be integrated in the order I(2) in ARDL Bounds test. The methodology of the test will be invalidated if the variables are integrated in the order I(2). In addition, random shocks might have short-term effects and may not affect in the long-run in the economy according to the traditional unit root testing approach. It is believed that economic rise and falls are not short-term and random shocks have a permanent effect on the economy. The study of Barros *et al.* (2011) revealed that macro-economic variables like trade, economic growth (GDP), and energy consumption (CO₂ emission), etc. experience the structural changes mainly in the developing countries. Besides, if structural break exists, traditional unit root tests such as ADF presents biased results to the non-rejection of the null hypothesis of a unit root (Perron, 1989). Taking these matters into Consideration, we would find out structural break points using (Bai and Perron, 2003) multiple break point tests, and again operate structural break unit root tests in the modified ADF and PP test.

3.2. Test of Cointegration in ARDL Bounds

There are numerous approaches to test the existence of the cointegration and the short-run and long-run relationships between or among the variables. We will utilize the ARDL Bounds Testing method in this research. The ARDL bound testing approach carries a good number of smart characteristics over the traditional cointegration testing technique. The characteristics are: (i) this technique has the supremacy on other techniques and allows to examine the data in the existence of cointegration of I(0) or I(1); (ii) it has the flexibility as well as for single equation set up it could easily be illustrated and utilized; (iii) this procedure could be used for small observations; (iv) diverse lag-lengths for different variables could be utilized in this approach; (v) neutral result of short-run and long-run relationships of the variables are presented in this method, and (vi) it eradicates the endogeneity and auto-correlation problems as long as possible.

The results of the error correction model (ECM) reveal the speed of adjustment back to the long-run equilibrium after a short-run shock in the ARDL approach. The ECM includes the short-run coefficient with the long-run without affecting the long-run information. In this method, the long-run causality is expressed by the negative and significant value of the ECT coefficient and the short run causality is illustrated by the significant value of coefficients of other explanatory variables (Pal and Mitra, 2017; Rahman and Kashem, 2017; Shahbaz *et al.*, 2018; Zhang *et al.*, 2018). Following the study of above mentioned researchers, the ARDL model for bounds testing of cointegration is as follows:

$$\begin{aligned} \Delta \ln CO2_t = & \\ & \alpha_0 + \sum_{i=1}^{\rho_1} \alpha_1 \Delta \ln CO2_{t-i} + \sum_{i=1}^{\rho_2} \alpha_2 \Delta \ln TI_{t-i} + \sum_{i=1}^{\rho_3} \alpha_3 \Delta TO_{t-i} + \sum_{i=1}^{\rho_4} \alpha_4 \Delta \ln GDP_{t-i} + \\ & \beta_1 \Delta \ln CO2_{t-1} + \beta_2 \Delta \ln TI_{t-1} + \beta_3 \Delta TO_{t-1} + \beta_4 \Delta \ln GDP_{t-1} + \varepsilon_t \\ & \text{----- (4)} \end{aligned}$$

The model (4) is a distinctive type of ECM, and the coefficients of the model are not constrained. In this model, ε_t is well-behaved random disturbance terms which is normally distributed, serially independent, and homoskedastic. The researcher Pesaran *et al.* (2001) stated this unique type of ECM as the conditional ECM. The terms with \sum signs demonstrate the error correction dynamics for the short-run and the terms with β depicted to the long-run relationships among the variables (Rahman and Kashem, 2017; Fan *et al.*, 2018). The maximum lag lengths $\rho, \rho1, \rho2$ and $\rho3$ would be determined by using one or more of the 'information criteria' such as AIC, SC, HQ, etc. The null and alternative hypotheses of the model would be as follows:

H0: No cointegration exists.

H1: Cointegration exists.

The null hypothesis of the model will be determined by applying F-test for the joint significance of the coefficients of the lagged values of the variables. Thus the null and alternative hypothesis for the model is:

$$H0 : \beta_1 = \beta_2 = \beta_3 = 0$$

$$H1 : \beta_1 \neq 0, \beta_2 \neq 0, \beta_3 \neq 0$$

The critical values of the F-statistic for the asymptotic distribution about the bounds testing technique was developed by Pesaran *et al.* (2001). They initiated lower and upper bounds on the critical values for various situations in this method. According to their suggestion, there is no cointegration between or among the variables whether the computed F-statistic falls beneath the lower bound. If it crosses the upper critical value, a long-run association is running. Whether it remains inside the bounds, the result is indecisive.

In this study, short-run parameters will be estimated by utilizing the regular error correction mechanism (ECM) expressed in equation (4) (Rahman and Kashem, 2017). This model is designed in the following way:

$$\begin{aligned} \Delta \ln CO2_t = & \alpha_0 + \sum_{i=1}^{\rho} \alpha_1 \Delta \ln CO2_{t-i} + \sum_{i=1}^{\rho1} \alpha_2 \Delta \ln TI_{t-i} + \sum_{i=1}^{\rho2} \alpha_3 \Delta TO_{t-i} + \sum_{i=1}^{\rho3} \alpha_4 \Delta \ln GDP_{t-i} + \\ & \gamma ECT_{t-1} + \varepsilon_t \end{aligned} \tag{5}$$

ECT is the special error correction term under the error correction model here.

3.3. Diagnosis Test of the MODEL

We will utilize the usual technique to diagnosis our designed model. It is necessary assumptions that the errors of equations (4) and (5) must be independently and identically distributed to the ARDL Bounds test. To examine the Normality of the errors of the model 'Jarque-Bera' technique; to determine the Serial Correlation problem 'Breusch-Godfrey Serial Correlation LM test' would be applied. At last, 'Breusch-Pagan-Godfrey' test will be utilized to test the heteroscedasticity of the model.

3.4. Stability Test of the Model

The model which has autoregressive characteristics in nature is necessary to test the stability. Following the suggestion of Pesaran and Pesaran (1997) and according to the study of Brown *et al.* (1975) we would apply recursive CUSUM and CUSUM of squares tests to check the stability of the model.

3.5. Toda-Yamamoto Granger Non-Causality Test

In this study, we would apply the ARDL method to examine the cointegration, the long-run and short-run associations. But Granger (1969) revealed that it is not sufficient only to calculate the correlation among or between the variables. The reason is that a third variable may exist and the findings of correlations might be spurious and worthless. If two or more-time series variables are cointegrated, bi-directional, unidirectional, or neutral causality may exist. In addition, only correlation does not authenticate causation between or among variables. Therefore, we should go for a cross-check of our results. In this research, we would apply the Toda-Yamamoto Granger non-Causality technique to establish the associations and the directions of our variables again (Fan *et al.*, 2018).

Toda and Yamamoto (1995) brought in a technique to examine the existence of non-causality irrespective of the variables are $I(0)$, $I(1)$ or $I(2)$, cointegrated or not cointegrated of arbitrary order. It could be utilized by a normal lag selection system of VAR as the order of integration of the procedure does not surpass the actual lag length of the model. In this process, after determining a lag length k , $(k+d_{max})$ the order of VAR is calculated. In this case, d_{max} is the maximal order of integration which can be occurred in the procedure. They added that the coefficient matrices of the last d_{max} lagged vectors in the model are overlooked because of these are considered as zero, and it can be tested linear or nonlinear restrictions on the first k coefficient matrices using the standard asymptotic theory. In accordance with the Toda and Yamamoto procedure, the causality model is set-up in the following VAR system:

$$\Delta \ln CO2_t = \alpha_0 + \sum_{i=1}^{\rho} \alpha_{1i} \Delta \ln CO2_{t-i} + \sum_{j=\rho+1}^{d_{max}} \alpha_{2j} \Delta \ln CO2_{t-j} + \sum_{i=1}^{\rho_1} \alpha_{3i} \Delta \ln TI_{t-i} + \sum_{j=\rho_1+1}^{d_{max}} \alpha_{4j} \Delta \ln TI_{t-j} + \sum_{i=1}^{\rho_2} \alpha_{5i} \Delta TO_{t-i} + \sum_{j=\rho_2+1}^{d_{max}} \alpha_{6j} \Delta TO_{t-j} + \sum_{i=1}^{\rho_3} \alpha_{7i} \Delta \ln GDP_{t-i} + \sum_{j=\rho_3+1}^{d_{max}} \alpha_{8j} \Delta \ln GDP_{t-j} + \varepsilon_{1t}$$

--- (6)

$$\Delta TO_t = \beta_0 + \sum_{i=1}^{\rho} \beta_{1i} \Delta TO_{t-i} + \sum_{j=\rho+1}^{d_{max}} \beta_{2j} \Delta TO_{t-j} + \sum_{i=1}^{\rho_1} \beta_{3i} \alpha_{3i} \Delta \ln TI_{t-i} + \sum_{j=\rho_1+1}^{d_{max}} \beta_{4j} \alpha_{4j} \Delta \ln TI_{t-j} + \sum_{i=1}^{\rho_2} \beta_{5i} \alpha_{5i} \Delta \ln GDP_{t-i} + \sum_{j=\rho_2+1}^{d_{max}} \beta_{6j} \alpha_{6j} \Delta \ln GDP_{t-j} + \sum_{i=1}^{\rho_3} \beta_{7i} \alpha_{7i} \Delta \ln CO2_{t-i} + \sum_{j=\rho_3+1}^{d_{max}} \beta_{8j} \alpha_{8j} \Delta \ln CO2_{t-j} + \varepsilon_{2t}$$

--- (7)

$$\Delta \ln TI_t = \gamma_0 + \sum_{i=1}^{\rho} \gamma_{1i} \Delta \ln TI_{t-i} + \sum_{j=\rho+1}^{d_{max}} \gamma_{2j} \Delta \ln TI_{t-j} + \sum_{i=1}^{\rho_1} \gamma_{3i} \alpha_{3i} \Delta \ln GDP_{t-i} + \sum_{j=\rho_1+1}^{d_{max}} \gamma_{4j} \alpha_{4j} \Delta \ln GDP_{t-j} + \sum_{i=1}^{\rho_2} \gamma_{5i} \alpha_{5i} \Delta TO_{t-i} + \sum_{j=\rho_2+1}^{d_{max}} \gamma_{6j} \alpha_{6j} \Delta TO_{t-j} + \sum_{i=1}^{\rho_3} \gamma_{7i} \alpha_{7i} \Delta \ln CO2_{t-i} + \sum_{j=\rho_3+1}^{d_{max}} \gamma_{8j} \alpha_{8j} \Delta \ln CO2_{t-j} + \varepsilon_{3t}$$

--- (8)

$$\Delta \ln GDP_t = \delta_0 + \sum_{i=1}^{\rho} \delta_{1i} \Delta \ln GDP_{t-i} + \sum_{j=\rho+1}^{d_{max}} \delta_{2j} \Delta \ln GDP_{t-j} + \sum_{i=1}^{\rho_1} \delta_{3i} \alpha_{3i} \Delta \ln TI_{t-i} + \sum_{j=\rho_1+1}^{d_{max}} \delta_{4j} \alpha_{4j} \Delta \ln TI_{t-j} + \sum_{i=1}^{\rho_2} \delta_{5i} \alpha_{5i} \Delta TO_{t-i} + \sum_{j=\rho_2+1}^{d_{max}} \delta_{6j} \alpha_{6j} \Delta TO_{t-j} + \sum_{i=1}^{\rho_3} \delta_{7i} \alpha_{7i} \Delta \ln CO2_{t-i} + \sum_{j=\rho_3+1}^{d_{max}} \delta_{8j} \alpha_{8j} \Delta \ln CO2_{t-j} + \varepsilon_{4t}$$

--- (9)

The above mentioned four equations are designed to accomplish Toda-Yamamoto Granger non-causality test to find out the relationships and the directions of the variables. The null hypothesis of no-causality is rejected when the p-values fall within the desired 1% to 10% level of significance. In equation (6), Granger causality is running from TO, TI, and GDP to CO₂ refers that $\alpha_{3i} \neq 0$, $\alpha_{5i} \neq 0$, and $\alpha_{7i} \neq 0$ respectively. The similar test will be used for the equation (7), (8) and (9). We will find out the appropriate maximum lag length for the variables in the VAR by using the standard methods, such as AIC.

4. ANALYSIS OF RESULTS AND DISCUSSION

We have inaugurated our investigation with the traditional statistical tools like descriptive statistics and correlation matrix. The results are presented in Table: 1.

Table-1. Descriptive Statistics and correlation matrix

Country	China				India			
	CO ₂	TO	TI	GDP	CO ₂	TO	TI	GDP
Mean	2.6697	33.273	205564.8	1902.30	1.1996	26.229	4260.20	781.015
Median	2.2941	33.809	51906.00	1173.02	1.1731	21.694	826.000	622.303
Std. Dev.	1.2375	16.566	298286.6	1851.34	0.1174	15.202	5228.48	428.286
Jarque-Bera	4.1575	1.7450	20.41586	10.2537	2.9410	5.3714	.242910	7.93605
Probability	0.1250	0.4179	0.0000	0.0059	0.2298	0.0681	0.0162	0.0189
Correlation								
Country	China				India			
Variables	CO ₂	TO	TI	GDP	CO ₂	TO	TI	GDP
CO ₂	1.0000				1.0000			
TO	-0.7808	1.0000			-0.4888	1.0000		
TI	-0.5972	0.4799	1.0000		-0.5839	0.9703	1.0000	
GDP	-0.7701	0.6749	0.9486	1.0000	-0.4551	0.9694	0.9685	1.0000

Source: Author's own calculation in EViews-9.

The table above indicates the mean, median and standard deviation of the series. The results of the Jarque–Bera test reveals that GDP and Technological innovation data of China and India are significant, refers they are not normally distributed. In order to avoid this problem, we will convert these data into their natural logarithm form, and we would take the first difference. In addition, since we will cross-check it after running our model, we could proceed in the investigation. The correlation matrix illustrates a negative correlation of Trade openness, Technological innovation, and Economic growth on CO₂ Emission of both the countries.

4.1. Unit Root Testing

A good number of unit root tests as ADF, Ng-Perron, KPSS, PP, DF-GLS, ERSPO and also some other special unit root tests like Zivot–Andrews unit root tests are available to test the stationarity characteristics of time series data. Following the discussion of our unit root methodology section, we conducted structural break points test using Bai and Perron (2003) multiple break point tests, and the results are displayed in Appendix. The results revealed that there are several structural breaks of the variables Trade openness, Technological innovation, Economic growth, and CO₂ emission in different years. Then we have utilized structural break unit root tests in the modified ADF test, and the findings are displayed in Table – 2:

Table-2. Unit Root tests with structural break.

Variable	SC (Level)		SC (First Difference)		AC (Level)		AC((First Difference)	
	Intercept	Intercept & Trend	Intercept	Intercept & Trend	Intercept	Intercept & Trend	Intercept	Intercept & Trend
lnCO ₂	-2.0088 (0.98)	-3.8848 (0.44)	-4.3579* (0.06)	-5.9554*** (0.01)	-1.9250 (0.98)	-3.8848 (0.44)	-4.5421** (0.03)	-5.9554*** (0.01)
TO	-2.4061 (0.92)	-3.6765 (0.57)	-5.65722*** (0.01)	-5.5223*** (0.01)	-2.4061 (0.92)	-4.8574** (0.05)	-5.4036*** (0.01)	-5.5223*** (0.01)
lnTI	-0.5503 (0.99)	-3.5825 (0.64)	-6.9039 (0.01)	-6.7782*** (0.01)	-0.5503 (0.99)	-3.5771 (0.64)	-6.3803*** (0.01)	-6.7782*** (0.01)
lnGDP	-0.5287 (0.99)	-5.6461*** (0.01)	-6.0542*** (0.01)	-5.7205*** (0.01)	0.2971 (0.99)	-5.5504*** (0.01)	-5.7463*** (0.01)	-4.8624** (0.04)
India								
lnCO ₂	-3.4432 (0.41)	-4.6724* (0.08)	-7.0715*** (0.01)	-7.4085*** (0.01)	-3.4432 (0.41)	-4.6724* (0.08)	-6.7626*** (0.01)	-7.4085*** (0.01)
TO	-2.2044 (0.96)	-6.6102*** (0.01)	-6.8767*** (0.01)	-7.9851*** (0.01)	- (0.01)	6.8767*** (0.01)	-6.6102*** (0.01)	-6.8767*** (0.01)
lnTI	-2.7224 (0.82)	-4.8652** (0.04)	-5.5067*** (0.01)	-7.6513*** (0.01)	-2.7224 (0.82)	-4.8652** (0.04)	-5.5067*** (0.01)	-5.8875*** 0.01
lnGDP	0.3490 (0.99)	-2.1379 (0.99)	-7.2807*** (0.01)	-7.8010*** (0.01)	0.3490 (0.99)	-3.1503 (0.86)	-7.2807*** (0.01)	-7.7697*** (0.01)

Source: Author's own calculation in EViews.

The outcomes of the structural break unit root tests in the modified ADF refer accomplished the conditions to apply the ARDL method in this study.

4.2. ARDL Model Estimation

In accordance with the ARDL approach Lag selection order of the variables is essential for the condition of the model. Akaike information criterion (AIC) is applied in our research to determine the appropriate lag-length for the model. In the study of Lütkepohl (2006) indicates that AIC has the supremacy for small data in comparison to any lag-length criterion such as Schwarz information criterion (SC) and Hannan–Quinn information criterion (HQ). AIC presents consistent and efficient results as compared to final prediction error. The selected model for China and India are ARDL (1, 5, 5, 5). According to the result of AIC, the optimum lag-lengths of the variables lnCO₂, TO, lnTI, and lnGDP are: $\rho = 1, \rho_1 = 5, \rho_2 = 5, \rho_3 = 5$ respectively for both the countries.

4.3. Diagnostic Test of the Model.

In order to validate the robustness and stability of our designated model, we have conducted Normality (Jarque-Bera test), serial correlation (Q-Statistics and Breusch-Godfrey Serial Correlation LM tests), and Heteroscedasticity test ('Breusch-Pagan-Godfrey' test). The outcomes are presented in Table: 3.

Table-3. Diagnostic Test.

Test Statistics Name of Test	China		India	
	F test (Probability)	Observed R ²	F test (Probability)	Observed R ²
Breusch-Godfrey Serial Correlation LM test	0.6567	0.2438	0.1976	0.0212
Breusch-Pagan-Godfrey Heteroskedasticity test	0.4431	0.3589	0.9141	0.7574
Jarque-Bera test	0.0507	0.9749 (Prob.)	1.1102	0.5739 (Prob.)
R ²	0.9562		0.9432	
Adjusted R ²	0.7898		0.8353	

Source: Author's own calculation in Eviews.

According to our findings, the R² is 0.9562 and adjusted R² is 0.7898 of the model for China and the R² is 0.9432 and adjusted R² is 0.8353 of the model used for India. The findings of the investigation demonstrated that more than 95% and 83% variations in the dependent variables are elucidated by the model designed for China and India correspondingly and the rest by the error terms. The probability of F- statistics and observed R² tests illustrate that our model passed almost all the tests regarding Heteroscedasticity, Normality, and serial correlation tests. Only observed R² is significant of the model used for India whereas, F- statistics of this model is not significant. So we can disregard it and run our model. Under this circumstance, it is documented that this model is of good fit and passes almost all the diagnostic tests.

4.4. Bound Test.

With a view to determining the cointegration among our variables, we have operated the bounds test, and the findings are displayed below (Table 4):

Table-4. Bound test for cointegration.

Test Statistics	China		India	
F Statistic	12.6018		10.4013	
Number of Independent Variables – k	3		3	
Critical Values	Lower Bound	Upper Bound	Lower Bound	Upper Bound
1%	3.65	4.66	3.65	4.66
5%	2.79	3.67	2.79	3.67
10%	2.37	3.2	2.37	3.2

Source: Author's own calculation in Eviews.

The results of the ARDL bounds test documented that F-test is 12.6018 of the model used for China and F-test is 10.4013 of the model used for India. The value of the calculated F-statistic of our models has crossed the upper bound at the 1% level of significance. These findings reveal that there are long-run relationships exist among Trade openness, Technological innovation, Economic growth, and CO₂ emission.

4.5. Long-run Dynamics.

We have estimated the long-run relationships among the variables utilizing the ARDL (1, 5, 5, 5) for China and the ARDL (1, 5, 5, 5) for India. The result of the long-run dynamics is given in the table (5) below:

Table-5. Long-run coefficients in ARDL.

Dependent variable: lnCO₂

China			India		
Variable	Coefficient	t-statistic	Variable	Coefficient	t-statistic
TO	-0.0002	-0.1569	TO	0.0162***	3.1898
LNTI	1.0872***	6.0389	LNTI	-0.4465***	-5.0052
LNGDP	-2.6204***	-6.6124	LNGDP	0.6563***	5.0805
C	3.4070***	8.4633	C	1.7374***	2.8568

Source: Author's own calculation in Eviews.

The results are shown in the table (5) reveal that Technological innovation and Economic growth has a significant impact on CO₂ emission of China at a 1% level of significance in the long-run. Surprisingly, Technological innovation has a positive impact, and Economic growth has a negative impact on CO₂ emission. The reason may be that China has achieved tremendous development in the innovation sector, but the number of eco-friendly innovation is small. The inventions in the environmentally friendly technology and renewable energy sector are still lying behind the total number of innovations of other sectors. So China should emphasis to operate its R&D programs towards eco-friendly innovation for the greater sake of the country. In the last few years, though China has achieved significant development in the renewable energy sectors such as solar energy and wind power, this is not enough. Presently 30% of electricity is coming from the renewable energy sector. So China is achieving Economic development but trying to avoid environmental deterioration. That's why, from our study, it was empirically proved that Economic growth has a negative impact on CO₂ emissions in China. On the contrary, Trade openness is not significant on the CO₂ emissions in China. So China can go for the more openness of Trade. Trade will increase the Economic Growth and reduce the CO₂ emissions.

In the case of India, in the long-run, our obtained results illustrate that Trade openness and Economic growth have a significant positive impact and Technological innovation has a strong negative impact on CO₂ emission at 1% level of significance. So Economic growth is taking place in India but at the cost of destroying the environment. One of the reasons is India's export goods are made by using the fossil fuel and coals which refers by using the non-renewable energy as well as among the import items - a large portion is the fossil fuel and coals, so Trade openness is increasing the CO₂ emissions in India. On the other hand, Technological innovation has a significant adverse

effect on CO₂ emissions in India. So India should keep up the present innovation trend which will enhance the quality of the environment in the long-run.

On the basis of our investigation, we found that Trade openness is not significant in the environmental deterioration of China, but it is significant for India. Technological innovation has a strong positive impact on the environment of China; on the other hand, it is negative for India. On the contrary, Economic growth has a negative impact on environment of China, which is positive for India. The result of our study documented that the use of energy is still playing a significant and crucial role in the economic development of both countries. So the use of energy is very much important for China and India to keep up the present economic development preserving the environment.

Our results are similar to the findings of Hossain (2012); Acheampong (2018) and it is against the findings of Ang (2009); Massa (2015); Shahbaz *et al.* (2017); Solarin *et al.* (2017) for China in the long-run. In respect of India, our results are similar to the findings of Ang (2009); Massa (2015); Ertugrul *et al.* (2016); Shahbaz *et al.* (2017); Solarin *et al.* (2017); Shahbaz *et al.* (2018) and it is against the findings of Hasson and Masih (2017); Acheampong (2018); Mohammed (2018) in the long-run.

4.6. Short-run Analysis

Explaining the long-run relationships, we are moving to illustrate the short-run relationships in ARDL (1, 5, 5, 5) for China and India. The results are reported in the table (6) below:

Table-6. Short-run estimations from ECM.

Dependent variable: lnCO₂.

China			India		
Variable	Coefficient	t-statistic	Variable	Coefficient	t-statistic
D(TO)	0.0016	1.9279	D(TO)	0.0006	0.8204
D(TO(-1))	0.0013	1.3469	D(TO(-1))	0.0015*	1.7750
D(TO(-2))	0.0012	1.2011	D(TO(-2))	-0.0037***	-4.0421
D(TO(-3))	0.0009	1.0276	D(TO(-3))	-0.0028***	-2.8369
D(TO(-4))	-0.0016*	-2.3644	D(TO(-4))	0.0023***	2.9259
D(LNTI)	0.0043	0.0495	D(LNTI)	-0.0214*	-1.9627
D(LNTI(-1))	-0.0492	-1.0769	D(LNTI(-1))	0.0259*	1.9612
D(LNTI(-2))	-0.0929*	-1.9936	D(LNTI(-2))	0.0214*	1.8719
D(LNTI(-3))	-0.1607**	-2.7247	D(LNTI(-3))	0.0234*	2.0512
D(LNTI(-4))	-0.1078	-1.6194	D(LNTI(-4))	0.0386***	3.2103
D(LNGDP)	-0.1624	-0.3151	D(LNGDP)	-0.5785***	-3.1655
D(LNGDP(-1))	0.8725	0.7402	D(LNGDP(-1))	-0.0171	-0.0868
D(LNGDP(-2))	-1.0513	-0.9710	D(LNGDP(-2))	-0.3266*	-1.8027
D(LNGDP(-3))	0.3510	0.3905	D(LNGDP(-3))	0.3435	1.3302
D(LNGDP(-4))	1.3230*	1.9640	D(LNGDP(-4))	0.3512	1.2952
CointEq(-1)	-0.5266***	-4.1927	CointEq(-1)	-0.4007***	-4.7690

Source: Author's own calculation in Eviews.

The findings of the short-run estimation documented that short-run relationships among the variables also exist so as the long-run dynamics in China and India. The sign of lagged error correction term (ECT) 'CointEq(-1)' is negative and significant at 1% level of significance for both the countries. It has been revealed by the figures and signs of 'CointEq(-1)' that long-run relationships exist between the dependent variable and the explanatory variables.

For China, the estimated figure of ECT coefficient is -0.5266, and it is at 1% level of significance which illustrates a faster and stronger speed of adjustment to the equilibrium. It means more than 52% of the imbalance congregates back to the long-term equilibrium within one year. The short-run impact of Technological innovation and Economic growth on Environmental deterioration are not so strong in China such as India. The effect of different lag periods of explanatory variables on Environmental Deterioration is mixed of positive and negative or

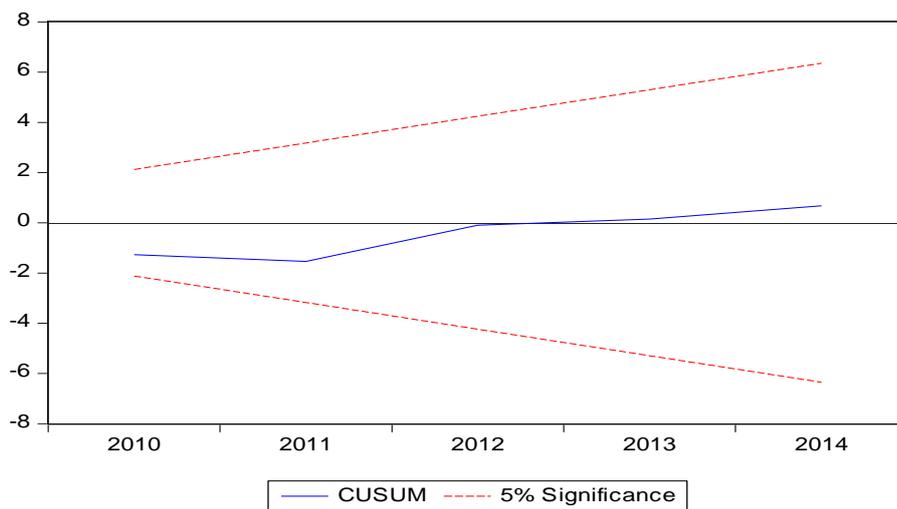
neutral. It is revealed from our empirical findings that Trade openness and Economic growth has a weak and Technological innovation has a little bit stronger impact on Environmental deterioration in the short-run for China.

In the case of India, the calculated value of ECT coefficient is -0.4007 , and it is at 1% level of significance which refers to the speed of adjustment to the equilibrium. It indicates that 40% of the disequilibrium returns to the long-term balance within one year in India. Different lag values of Trade openness, Technological innovation, and Economic growth are significant on the Environmental deterioration in the short-run. It is also mixed of the positive and negative impact like China, but this impact is stronger in India than that of China.

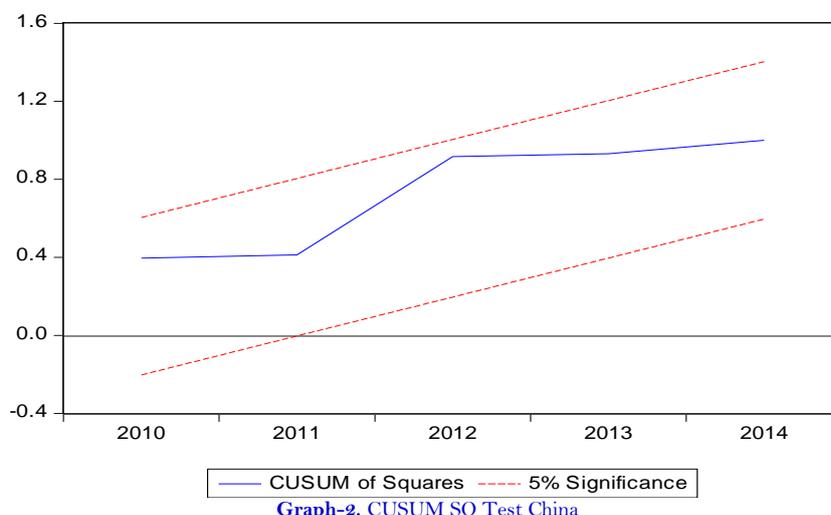
Since the short-run results for China and India are mixed of negative and positive or not significant, our findings are partially supported by the investigation of [Jebli and Youssef \(2015\)](#); [Ohlan \(2015\)](#); [Salahuddin et al. \(2016\)](#); [Rasoulinezhad and Saboori \(2018\)](#).

4.7. Stability of the Model

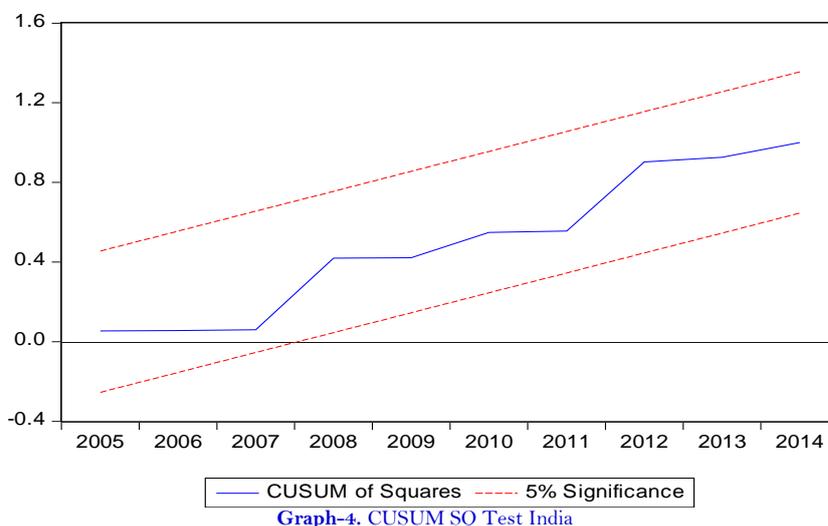
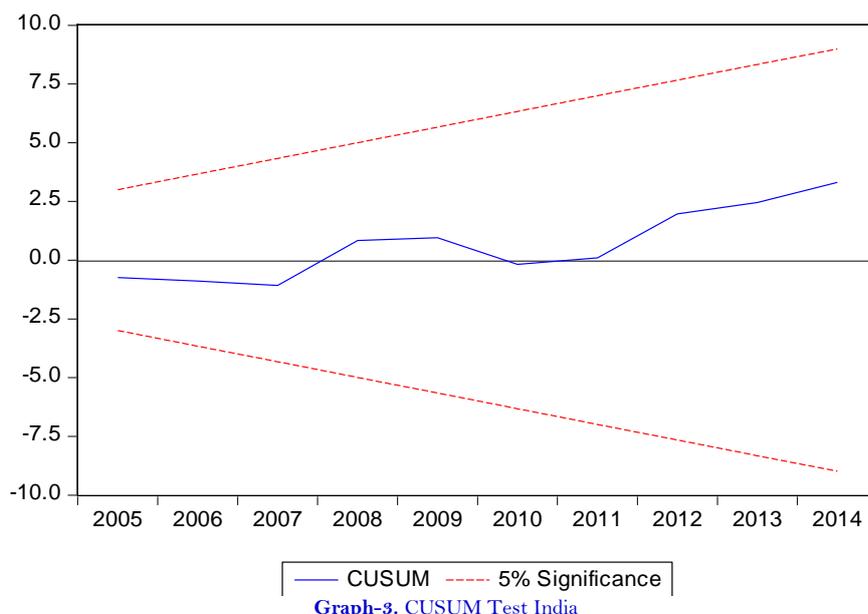
With a view to authenticating the robustness of the short-run and long-run outcomes of our investigation for China and India, we have utilized the structural stability tests on the parameters. It is on the basis of the cumulative sum of recursive residuals (CUSUM) and cumulative sum of recursive residuals of squares (CUSUMSQ) tests suggested by [Pesaran and Pesaran \(1997\)](#). Graphs 1 to 4 are displayed below:



Graph-1. CUSUM Test China



Graph-2. CUSUM SQ Test China



The graphical demonstration of CUSUM and CUSUMSQ tests has been displayed in Graph1 and 2 for China and graph 3 and 4 for India. It is ascertained from the previous study that if the plots of the CUSUM and CUSUMSQ remain within the 5 percent critical bound, it would validate the steadiness of the parameter and stability of the model. The graphical representation of both the models exposed that none of the straight lines (drawn at the 5% level) are exceeded by CUSUM and CUSUMSQ. It indicates that the plots of both the CUSUM and CUSUMSQ are inside the boundaries.

4.8. Toda-Yamamoto Granger Non-Causality Test.

We have utilized the bound tests in the ARDL approach to determine the long-run and short-run relationships among our respective variables and have examined our models till now. We have found our models are stable and passed almost all tests. Now we are going to use Toda-Yamamoto Granger non-causality (TYGC) test to verify the directions and causality between the variables for the cross-check of our results. By this test, we want to determine unidirectional, bi-directional/feedback or no-directional causality exist among our variables for China and India. The obtained result from the TYGC test has been given in Table: 7.

Table-7. Toda-Yamamoto Granger Non-Causality test.

Direction of Causality									
China					India				
	lnCO2	TO	lnTI	lnGDP		lnCO2	TO	lnTI	lnGDP
lnCO2	---	4.6807	5.5470	3.9046	lnCO2	---	2.8495	0.5956	6.8233
TO	0.9339	---	1.3531	2.8518	TO	15.753***	---	1.1676	4.0207
lnTI	19.369***	10.046**	---	0.5889	lnTI	23.170***	8.7642*	---	2.4222
lnGDP	8.3815*	35.087***	1.6988	---	lnGDP	24.805***	1.3882	1.2548	---

Source: Author's own calculation in Eviews.

The results of the TYGC test indicates that unidirectional causality is running from Technological innovation and Economic growth to CO₂ emissions (Environmental deterioration) and Trade openness for China. There has been no causality running from Trade openness to CO₂ emissions which is consistent with the findings of our ARDL approach. The causality of Economic growth to CO₂ emissions is at 10% level of significance whereas; it is at 1% level of significance from Economic growth to Trade openness.

In the case of India, our results illustrate that there is a unidirectional causality running from Trade openness, Technological innovation and Economic growth to CO₂ emissions at 1% level of significance. Similarly, there is another unidirectional causality running from Technological innovation to Trade openness which is not so strong. It can be mentioned here that Economic growth has a significant impact on the deterioration of Environment for India, but it is not so strong for China. There has been a strong unidirectional causality running from Technological innovation to CO₂ emissions for both the countries. The findings of this test support the results of the ARDL method in our research.

Both for China and India, in accordance with the result of TYGC Test, our findings resemble to the result of Hossain (2011); Al-Mulali *et al.* (2015) and it is against the findings of Omri *et al.* (2015); Ayeche *et al.* (2016); Jamel and Maktouf (2017).

5. CONCLUSION AND POLICY IMPLICATION

China and India are the two biggest transitional and developing economies of Asia. They remain in two distinct and diverse level of technological innovation, energy use, structural change, trade, and economic growth as well as different in culture and religious believes. In this study, we have investigated empirically the impact of Trade openness, Technological Innovation, and Economic growth on the Environmental deterioration of China and India. The period was covered from 1974–2016. These two largest transitional and emerging countries of Asia have gained miraculous development in many sectors but at the cost of Environmental deterioration. We have applied the ARDL Bounds Test methodology and TYGC test in an augmented VAR framework with Zivot-Andrews structural break unit root test to determine the short-run and long-run relationships of the variables. The results of the study illustrate that Technological innovation has a significant positive impact and Economic growth has a strong negative impact on the Environmental deterioration of China in the long-run. But it is not so strong in the short-run. In the case of India, Trade openness and Economic growth have a significant positive impact; and Technological innovation has a strong negative impact on Environmental deterioration in the long-run. The selected macro-economic explanatory variables have a significant impact on the Environmental deterioration of India in the short-run as well.

The results of the TYGC test indicate that unidirectional causality is running from Technological innovation and Economic growth to CO₂ emissions and Trade openness for China. There is no causality running from Trade openness to CO₂ emissions which is consistent with the findings of our ARDL approach. In the case of India, our results illustrate that there is a unidirectional causality running from Trade openness, Technological innovation and Economic growth to CO₂ emissions. Similarly, there is another unidirectional causality running from Technological innovation to Trade openness which is not so strong. There has been a strong unidirectional

causality running from Technological innovation to CO₂ emissions for both the countries. In comparison to China and India, Trade openness has a significant impact on the Environmental deterioration of India, but it is not factual for China. In addition, Technological innovation and Economic growth have an inverse relation on the Environmental deterioration of two Countries. The obtained results from our study have important policy implication for China and India, and they are illustrated as follows:

In accordance with the discussion in the introduction section, the faster economic growth of China and India is taking place by the higher use of non-renewable energy which creates the CFC gases. But the volume of energy use depends on the rapid transition of these two countries based on the personal expenditure and a greater service-centric economy. According to the report of International Energy Outlook 2018, China is predicted to generate 35% of the world's energy-concentrated manufacturing goods in 2040 which is more than double than that of India. It was commented in the report that energy- concentrated commodities are highly tradable and connect China to a greater global supply chain. The position of China in International Trade and the impact of elevated Chinese economic growth on predicted global use of energy bring to light the significance of exact projection of Chinese economic growth (Report, 2018).

In another report (Report, 2018) it was commented that China is getting the benefit from longer-term structural forces. In addition, some of the extraordinary performances have been seen in current years improved by momentary, cyclical developments. These longer-term forces are determining the transition in the energy sector. Renewable energy is growing strongly with the significant gains in solar energy and generation. The principal source of energy growth was Natural gas, making better by an extensive program of coal-to-gas transformation in residential and industrial sectors.

In case of India, the Report of International Energy Outlook 2018 showed that the export-led growth of India would result in the largest increase in energy use, and it will be 33% more than the developed countries in 2040. In addition, the nominal gross output would be 50% larger which is coming from the energy-intensive manufacturing sector, and the industrial sector also will be the largest sector of energy-consuming throughout 2040. It was also commented in the report that India has to evaluate the relationship between changes in Economic growth and the relative sizes of the services and manufacturing sectors. Key changes in the industrial structure of India will use higher levels of energy. It was also projected that India's GDP or energy use per capita would not be able to catch up to China's by 2040 (Report2, 2018).

Despite strong development has been accomplished in the energy sector by China and India, much more progress is needed (Report, 2018). The power sector still matters for both countries. It sucks up more primary energy than any other sector which contributes to over a third of CO₂ emissions from energy consumption. Though a large number of policy action by both the countries encouraging a switch away from coal to renewable energy, there is no development in the mix of the fuel feeding in power sector. The percentage of non-fossil fuels is still very low (Report, 2018). Since these two countries can't decrease the use of fossil-fuel overnight to decrease CO₂ emissions, both the countries should go for the use of more renewable energy such as solar energy, wind power, hydroelectricity, nuclear energy, etc. The use of renewable energy will lessen the CO₂ emissions as well as maintain the present economic growth without hampering the environment. China has gained significant progress in the renewable energy sector, but India is far behind of it. So both China and India should take proper policy actions as well as make a roadmap about the use of energy in the power sector to lessen the CO₂ emissions which will protect Environmental deterioration.

Secondly, the empirical results obtained from our investigation indicate that Technological Innovation has a significant positive impact in the Environmental deterioration of China; on the other hand, it has a strong negative impact in the Environmental deterioration of India which is noticeably remarkable. In line with it, TYGC test also confirmed that unidirectional causality is running from Technological innovation to CO₂ emission for both the countries. Since technology is increasing the CO₂ emission for China, China should go for more green and clean

technology to save the environment. On the contrary, India should maintain the present pace of Technological Innovation to improve environmental quality. It could be mentioned here that still many industries are destroying the atmosphere, but the inclusion of clean and green technology in the detrimental industries would develop the environmental excellence of these two countries as a whole. So, Government of China and India should prepare the Technological Innovation policy which will boost economic development but saving the Environment. More Government investment in R&D in the industrial sector and university-based research could improve this situation. China has improved in this sector recently but still has to go a long way, and India is far away from it.

Thirdly, from our investigation, we found that Trade Openness is not significant in the Environmental deterioration of China, but it has a strong positive impact on the Environmental deterioration of India in the long-run and short-run. We know that Trade openness is creating new prospects for realizing profits, setting up new industries, the creation of jobs, and overruling the negative effects of foreign competition. So China should keep up the present momentum of Trade openness. It will increase Economic growth by saving the Environment of the country as well. On the contrary, India should be more cautious in formulating trade policy. Since international trade is intensifying the Environmental deterioration of India, she should formulate pro-environmental trade policy to continue the present economic growth. So Both India and China should go for more trade openness by encouraging enhanced institutional quality and efficient government interferences in the trade policy to preserve the present economic growth without destroying the Environment.

In conclusion, to realize the balanced and sustainable growth of China and India pro-environmental Trade, Technology, and energy use policy is necessary to maintain the quality of Environment. It would intensify the inward FDI, enhance the international and local trade, as well as expand the stock market which will ensure the economic growth of the two countries. In line with it, an absorption of green and clean trade, Technology and energy use policy will play a strong role in harmful gas and element producers industries which will develop the environmental characteristics of the countries. In respect of policy, any single and isolated policy measure in any macroeconomic variable like trade, Technology, and use of energy will not bring any fruitful outcome. Therefore, integrated macroeconomic policy will ensure the Environmental quality of China and India.

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APPENDIX

Bai-perron multiple Break date and number of break.

China				India			
lnCO ₂	TO	lnTI	lnGDP	lnGDP	lnTI	TO	lnCO ₂
1993	1993	2002	1985,	1999	2003	2004	2004
1984	1982	1998	1995,	1988	1995	1995	1985 (2)
1999	2003	1992	2006 (3)	2007	1985 (3)	1980 (3)	
2009 (4)	2009 (4)	2010		1982 (4)			
		2006 (5)					

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