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# Influence of green technology, tourism, and inclusive financial development on ecological sustainability: exploring the path toward green revolution

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**ABSTRACT**

This study demonstrates the linkages between green technological innovations, sustainable tourism, financial development, economic growth, and ecological sustainability using China's regional data from 2000 to 2019. The study applies the novel estimation technique, Quantile Autoregressive Distributive Lag (QARDL) approach to examine long-run and short-run relationships between the stated variables. The initial findings confirm non-linearity in the data verified through J-B test statistics. It approves the implication of QARDL estimation for exploring ecological sustainability trends over the study period. The study outcomes confirm that tourism and green technology innovation assists in reducing ecological footprints in China in the long run. Moreover, financial development and economic growth reflect a direct role towards more ecological footprints; therefore, the sustainability dimension has been missing both in financial development and growth. Furthermore, the results in the short run cover the same phenomenon and confirm that ecological innovations and tourism would help in sustaining the natural environment. The study outcomes demonstrate that government officials in China should specifically implement long-term policies to support the natural environment from adverse shocks of more financial development and economic growth.

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## 1. Introduction

Tourism is one of the most profitable, money-making, and progressive sectors. It has emerged with many socio-economic opportunities and extensive scope in advanced and emerging economies. Over the past few decades, international tourism has risen by 4% annually and is expected to grow further, reaching 1.80 billion people by 2030. In addition, the yield or output of tourism has also risen by 5.5% exceeding $5.5 trillion, which makes up nearly 7% of China's GDP (Glaesser et al., 2017). Developed

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Information and Communication Technology (ICT), emerging economies worldwide, and improved business models have increased tourism. In 2018, the number of global tourists crossed the UNWTO forecasts with a growth of 5% annually and reached 1.4 billion through cheap and eased outlay. Exports in the tourism sector have grown more than the merchandise sector and crossed the $1.7 trillion mark, making the tourism sector a considerable force of foreign remittances, social-economic development, employment opportunities, and improved, innovative technologies (Eyuboglu & Uzar, 2020). Financial products have seen a rise in people's lifestyles, ultimately enhancing tourism expenditure. The income level also plays a vital role in tourism responsiveness and economic development.

Despite the tremendous economic growth, the tourism sector is regularly blamed for its negative impacts on the environment, considering the increased carbon emissions (Razzaq et al., 2021a; Robaina-Alves et al., 2016). Caron emissions due to global tourism from 2009 to 2013 have been critically re-estimated, resulting from that $CO_2$ emissions due to the tourism sector have risen from 3.90 to 4.55. This ratio accounts for 8.1% of overall carbon emissions, which has increased four times compared to previous estimates (Lenzen et al., 2018). According to the report provided by UNWTO, 2008, the core contributors to carbon emissions include accommodation and transportation sectors towards global emissions with 21% and 75%, respectively. In recent years, unparalleled growth was seen in China's tourism industry based on sustainable economic development, improved landscape, outstanding infrastructure, and opening-up policies. China, the fourth largest market in terms of global tourism spots, has now gained tourist arrivals that is three-fold as compared to previous research reports (Luo et al., 2018; Razzaq et al., 2021b). Despite many developments in the tourism sector, there are severe consequences based on detrimental impacts on the environment. Higher demand for fuel, energy consumption, carbon emissions, and fossil fuel utilization are significant effects of tourism that place China at the top spot in global carbon emissions, responsible for more than 30% of overall carbon pollution (Y. Shan et al., 2018). Tourism can negatively impact the environmental quality through an increased flow of visitors that ultimately raises the utilization of resources and energy causing Green House Gas emissions, increased carbon content, and ever-increasing global temperatures.

Interlinkage between the environment and ICTs has been complicated following digital innovation and development. The atmosphere gets impacted by ICTs development by generating, operating, and dismantling network devices and information technology (IT) equipment. Nevertheless, it also provides processes to reduce carbon emissions and increase energy consumption through several channels (Williams, 2011). ICTs impact environmental quality in three different ways. The first mode is the price effect. The ICTs increase the demand for linked items and assistance due to a drop in prices that cause higher carbon emissions (Chien et al., 2021; Shabani & Shahnazi, 2019). The second mode includes the environmental impacts of ICTs in a substitution effect that provides for the restructuring of the development process for IT devices, including demobilization, de-carbonization, surface mail with email, dematerialization through the substitution of physical books with electronic ones, traffic monitoring, and management through AI and GPS based technologies (Shabani & Shahnazi, 2019).

Similarly, web-based dissemination, dematerialization, administrative and control systems, stewardship and recycling of products, transport, and travel replacement enhance energy saving and reduce carbon emissions (Mohsin et al., 2021; Nawaz et al., 2021; Jianwu Zhang et al., 2019). The third mode of ICT impacts the environment is the usage effect which indicates the development of ICT devices, installation, processing, and scrap distribution, leading to enhanced carbon emissions and energy consumption (Dinda, 2018). Technology innovation is developing the latest intelligent devices using more natural resources, but these innovations can reduce carbon emissions by generating clean and green energy in the long run. Cleaner production and utilization of efficient technologies can ultimately develop a sustainable environment. This way, carbon emissions will be reduced, and the tourism sector will be able to regain its lost position in this dynamic world.

One of the effective strategies for reducing carbon emissions globally, saving natural resources, improving economic development, and implementing sustainable business methodologies is through the development of technology and innovative tools (Ahmed, 2017; S. Shan et al., 2021; Tiep et al., 2021). In addition, technology innovation has also played a significant role in tourism development in many countries, specifically in digital tourism, by collecting online and factual content to enhance visitors' experience (Adeola & Evans, 2019). Technology innovation has become vital for the tourism industry by providing information about accommodations, pre-planned destinations, climate, landscape, geopolitical and economic conditions, procurement, travel reservations, payment methods, and capturing visitors' memories (Law et al., 2018). Moreover, a dynamic environment is provided by ICT-developed tourists spot to meet visitors' expectations in the modern tourism industry (Petrovic). Technological developments have changed the ways of travel that provide an even more exciting and interactive experience for people. According to the Google travel study, 74% of people plan to visit tourist locations via the internet and digital applications. Ben Jebli and Hadhri (2018) investigated the interrelation between GDP, carbon emissions, economic development, and tourism. Their study utilized VECM and the dynamic casual method while taking the data from 1995 to 2013 of the top ten tourist locations. The proxy under consideration was the number of tourists arriving. The study revealed that with an increased rate of GDP, carbon emissions were also improved along with significant growth in the tourism sector. Moreover, tourism generated carbon content rises with economic development, as more income will bring more people to tourists' locations, enhancing the utilization of resources and fuel consumption. Figure 1 provides an outlook on the trends in ecological footprints and green technology innovation in China during the last two decades.

Several studies have determined the interconnection between financial developments, technology, tourism, and the environment, including innovation-environment connection, tourism-environment connection, and tourism-economic growth connection. Some of these studies include the research study of Vickers (2017), who estimated the interconnection between tourism development and carbon emissions between 1995 and 2014 in top tourist destinations around the globe using a Continuous-updated fully modified (CUP-FM) estimator and Continuously updated bias-corrected (CUP-BC) estimator. The study measured that with increased tourist

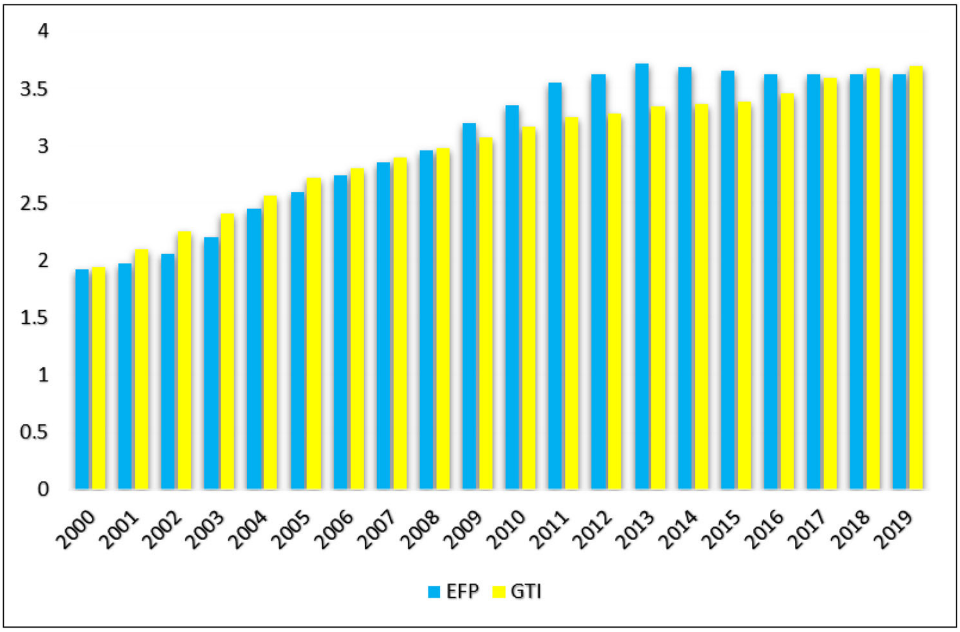


**Figure 1.** Trends in ecological footprints and green technology innovations in China. Source: Data from GFN and OECD.stats, developed by authors.

arrivals, carbon emissions also increase, and there is a direct connection between carbon emissions and tourist arrival at a particular tourist destination. Another research report by Z. Khan et al. (2020) provided the tourism-environment nexus between 1990 and 2016 for 51 Belt and Road countries, including China. The study estimated the increase in carbon emissions with an increase in tourism and an increase in carbon emissions with an increase in GDP using a generalized method of moments (GMM) system. In addition, the research study by Aziz et al. (2020) determined the interrelation between tourism, environment, economy, and technology for BRICS countries from 1995 to 2018. Their research study implemented the method of moment quantile regression (MMQR) on account of tourist arrival and found that carbon emissions decreased through tourism development and increased with the developed GDP. In the case of China, Zha et al. (2020) studied the interrelation between technology, tourism, and the environment for the period of 2005–2016 using Data development analysis (DDA). This research resulted that carbon emissions also raised and improved the economy with increased tourism development. Another research report by L. Zhang and Gao (2016) proposed that within Chinese provinces, carbon emissions have increased with tourism development between the years 1995 and 2011. They employed the Granger casualty method to analyze tourist arrival receipts and stated that economic growth and carbon emissions are directly linked.

However, there are no empirical shreds of evidence to determine the clear interrelation between these aspects in a varying structural framework. The after-effects of ICT and tourism ventures rely on linear practical methods such as BARDL and OLS and single dimension technological and tourism industry measures. Tourism growth and technology innovation (TI) is found to be affecting the environment in terms of a higher rate of carbon emissions through different sources such as opening up policy after the COVID-19, going-out strategy, economic reforms, structural development, foreign direct investment, technological development, and significant industrialization (Zheng et al., 2020). These factors directly or indirectly affect the environment by increasing carbon emissions at different stages. To tackle the highlighted gaps in the interrelation between given aspects of tourism and ecology, this study will contribute to the existing literature by providing insights into the relationship between tourism, technology, environment, and economy in China. The temporal and spatial interrelationship of the given variables of tourism and environment will also be studied in the given research for China.

Over the past decade, environmental challenges have become widespread and affect the global economy, attracting policymakers, environmental developers, and worldwide environmental organizations. Increased energy resources caused climate change and global warming, impacting human health (Vickers, 2017). United Nations Framework Convention on Climate Change occurred in 1992 due to a massive rise in global temperatures deteriorating environmental conditions. Other similar conventions include the Paris Agreement on carbon control, 2015, and the Kyoto Protocol in 1997 to eliminate the impacts of global warming by limiting carbon and GHG emissions. Over the years, Green House Gas emissions have become an essential issue in worldwide environmental debates (Seetanah et al., 2019). Carbon emissions are the source of more than 75% of ecological degradation through GHGs (Abbasi & Riaz, 2016). From 2016–2017, carbon emissions contributed only 1.2% to global emissions, which raised to 1.9% during 2018, a massive rise in $CO_2$ content in the environment (Thio et al., 2021).

According to the 'United Nations Inter-governmental Panel on Climate Change', global temperatures are raised to 1.5 °C, which is extremely high. As a result, immediate action is required to reduce $CO_2$ emissions from major polluting countries. These top emitter countries include Canada, Brazil, China, Iran, India, Korea, Japan, the United States, Saudi Arabia, and South Africa, which account for almost two-thirds of the carbon emissions (Westerlund, 2005). According to the review of BP Statistics of World Energy 2019, these top emitters contribute toward carbon emissions with USA 15.2%, China 27.8%, India 7.3%, South Korea 2.1%, Iran 1.9%, Japan 3.4%, Saudi Arabia 1.7%, Brazil 1.3%, Canada 1.6%, and South Africa 1.2%, which makes it clear that these countries can contribute to reducing global emissions in the world. In addition, the top ten countries account for 51% of the total global population, 65% of the global GDP, 80% of the fossil fuel utilization, and 67.5% of the worldwide carbon emissions (Olarreaga et al., 2020). The spread of the Coronavirus pandemic has also negatively impacted China's tourism industry. The research was conducted using the Bootstrap regression model that provided the nonlinear relationship between governmental policies and tourism growth. The Chinese government made people quarantine themselves during the rise of a pandemic that cost the nation up to 97% of the inbound tourism revenue, gross domestic product by 11%. It decreased employment related to tourism in China by 15%. COVID-19 has posed negative impacts on all sectors in China that have ultimately ruined the tourism sector, which needs to be revamped to its previous state for improved the economy, environment, and financial conditions of this sector.

Some research studies (Bekhet et al., 2017) introduced financial development as an essential variable determining that economic growth can directly determine environmental degradation. Different research writers have provided definitions to interlink carbon emissions and financial development. One of the studies stated that environmental deterioration increases with economic growth (Brännlund et al., 2007). According to Tamazian and Rao (2010), a developed financial system of a country contributes to improving the economy and leads to the country's development. Development of economic and stock markets lowers financial expenditures, reducing liquidity restrictions for organizations, investing in new ventures for enhanced production,improved energy production, and thus overall environmental pollution (Dasgupta et al., 2001). In addition, financial development also raises the economic growth rate and hence $CO_2$ emissions through investments in industries and production units. It also motivates people to take loans for heavy vehicles resulting in to rise in carbon emissions. On the other hand, some research studies have denied these arguments and stated that financial development could eliminate environmental degradation while utilizing clean and green technologies (King & Levine, 1993). Economic growth is investigated to be boosting eco-friendly innovations through energy-efficient intelligent devices and technologies. This leads to a decrease in energy utilization and greenhouse gas emissions.

The International Monetary Fund (IMF) has provided nine financial development factors to understand economic development impacts on carbon emissions better. Some research studies combined financialization with domestic credit and stated that positive results were seen in the environment (Al-Mulali et al., 2015) for Europe and (Ahmed, 2017) for China. The markets in the financial sector and other institutions aid in monitoring finance activities and corporate management effectiveness. The financial sector's primary function is to bring debtors and lenders together to allocate capital to the most efficient use. Financial institutions and financial markets play an essential role in developing a country's economic stability and development. This study will contribute to developing and utilizing factors affecting tourism development and innovation that combine various constructs into a single composite factor. The ongoing research study will also employ the 'Quantile Autoregressive Distributed Lag (BARDL)' model (Kayani et al., 2020). Some meaningful results while exploring the relationship between the variables of interest. This model is a novel addition to the literature on the environment-technology-tourism nexus. QARDL model contains an advantage over the traditional ARDL. This model will provide relationships between different variables that can also investigate the results from previous studies.

## 2. Literature review

The literature research is based on two well-merged branches of environmental aspects called economic growth, tourism development, and environmental quality on one side and economic development, technology innovation, and environmental quality. Both components have been discussed to interlink the economy, environment, tourism, and technology development for a better understanding. Several research studies have made valuable insights into the interrelationship between environment, technology, and climate in China using different methodologies. These methodological models, their outcomes, and ultimate trends for the future will be discussed in this study from the available literature.

Many researchers have discussed environmental research and tourism in recent years; however, it has raised contradictions and indefinite shreds of evidence. One side of the available literature declared an enhanced relationship between tourism development and carbon emissions due to enhanced fuel and energy utilization in tourism-related activities such as hoteling and transport (S. A. R. Khan et al., 2020). Another side of the literature claimed a decrease in carbon emissions through tourism development based on increased investment in clean energy, reliable infrastructure, and biodiversity conservation for tourist spots (Dogan & Aslan, 2017). Research results generally claim that the Chinese tourism business contributes a smaller percentage of total carbon dioxide emissions, but their rapid growth cannot be ignored. In China, tourism activities contributed 2.48, 2.42, 2.43, and 2.44 percent of total carbon emissions in 2002, 2005, 2007, and 2010. According to Zheng et al. (2020), energy-related $CO_2$ emissions have increased six-fold since the opening-up plan began in 1978, owing primarily to 176% GDP and 16% population expansion. These trends were hindered due to the spread of the Coronavirus pandemic initiated in China, which caused massive damage to many sectors in Chinese provinces.

Considering the developmental impacts of tourism and technology innovation, estimating the capital generated Environment Kuznets Curve (EKC) hypothesis in China is essential. This manual stated that pollution increases with the per capita income at the start but eventually decreases with more income. EKC was studied under three different mediums, namely the composition effect, scale effect, and technical effect. The scale effect refers to increased energy consumption in terms of increased economic activity, which results in environmental degradation (Sarkodie, 2018). On the other hand, the composition effect refers to the diminished use of energy due to economic structural changes, particularly in developed nations. The technology effect refers to the widespread adoption of sophisticated innovations and technical expertise, improving fuel economy, reducing carbon emissions, and promoting financial growth. China's clean and green energy growth has improved the country's air quality. In 2020, China's government planned to generate green electricity by producing 35–39% of its overall energy needs. Economic Growth, Technology, and $CO_2$ Emissions.

Over the past few decades, research on the impacts of innovation and ICTs, economic development, and carbon emissions gained enormous consideration in environmental studies. The first group of research studies considered that ICTs positively impact the environment by reducing carbon emissions through energy-efficient technologies (Batool et al., 2019). The second group suggested that development in ICTs poses negative impacts on the environment in China by vast rates of carbon emissions through enhanced consumption of resources and energy (Park et al., 2018). In the view of Higón, Gholami, & Shirazi (2017), ICT was termed a double-edged sword. It negatively impacts the environment by enhanced development, utilization, and disposal of digital devices positively impacts the environment by producing effective transport systems, smart cities, and energy-saving techniques. Energy-efficient technologies can also improve air quality as China is aimed to shift the use of fossil fuels toward green energy utilization at the organizational level.

The environmental damage to tourism growth and technology innovation is complex and confusing, as evidenced by the recent discussion that classic linear techniques and one-dimensional alternatives fail to account for these variables. In addition, the uneven impacts of technology and tourism development on environmental degradation are missing in the available literature. The structural transformations, composite nature of the socio-economic system, and supporting technology can be provided by the structural transformations that can lead to diversified variables in China. Thus, 'technology-tourism-climate' needs to be re-evaluated by comprehensive measures, consistent estimates, and improved estimation systems. The research report by Agbanike et al. (2019) investigated that given variables are cointegrated, and unidirectional causalities were found in the research. In addition, it was highlighted that renewable energy, tourism development, and foreign direct investment (FDI) contribute to reduced greenhouse gas emissions. On the other hand, economic development and trade growth can lead to higher emissions and deteriorate the environment in the short term.

Financial development has been rising in China and has become multidimensional in the past two decades. For example, financial organizations and financial securities markets use household savings to invest in business opportunities such as tourism development. The International Monetary Fund's proposed economic development factors can state the financial markets regarding access, liquidity, and efficacy with sustainable returns. Financial institutions such as the banking sector and non-banking firms play a vital role in establishing a sustainable economy. A research study (Anser et al., 2020) examined the impacts of tourism growth on environmental quality in China by employing the EKC framework. Three proxies were implemented to measure tourism development and environmental pollution in response, including atmospheric particulate matter, carbon emissions, and Greenhouse gas discharge. This study also investigated the opening trade effects after COVID-19 using the data between 1995 and 2018. Due to the inconsistent behavior of tourism growth on the overall environmental conditions in China, a study proposed the BARDL model to integrate nonlinear and dynamic trends in the nexus of the tourism environment. Their study determined that carbon emissions were reduced with the arrival of more tourists in the long run. In addition, trade openings have also seen a reduction in carbon emissions and GHGs. The government of China must impose specific regulations to sustain trade and tourism.

Another group of studies provided by Lai et al. (2020) stated that much emphasis has previously been paid to how to establish a sustainable and integrated growth of the ecological environment, the economy, and tourism. The coupling degrees and coordination degrees of the three subsystems of 31 Chinese provinces from 2003 to 2017 are calculated using a complete assessment index system of the natural ecosystem, the economy, and tourism. According to the findings, the average coupling and coordination degrees showed rising patterns between 2003 and 2017. As indicated in research studies, tourism development has great significance in the overall economic development of any country. COVID-19 has impacted China's travel and tourism sector, as quarantine policies, home isolation, and travel restriction have damaged the tourism industry. Outcomes of this study revealed that the spread of pandemics have negatively affected China's tourism sector in the long run. Based on 2001 to 2018, an advanced economic methodology named 'Augmented Mean Group' (AMG) was implemented by Chenghu et al. (2021) to investigate the interconnection of tourism development, technology innovation, and environmental degradation. A significant interrelation was found between the three aspects in the wake of the Coronavirus epidemic that has negatively impacted China's economic condition. Bootstrap regression has also become of the important models to be extensively employed in environmental research studies compared to conventional regression analysis. This model provides the conditional distribution of all related variables and showcases their dependence. In the light of the literature, as mentioned earlier, this research aims to provide an investigative model determining the impacts of financial growth, tourism, energy utilization, and $CO_2$ emissions.

Two novel indicators provided in the research study include the dataset related to China's technology innovation and tourism development index, which was at the fourth spot in the work ranking for visitors for tourism purposes (Usman et al., 2021). Based on the research studies of Shahzad et al. (2017), the current study employs quarterly data regarding tourism and technology development from 1995 to 2017. World Development indicators were used to get the datasets on tourism constructs, technology innovation measures, carbon emissions, and GDP for China. A study done by Rasool et al. (2021) proposed using the ARDL model to determine the interrelation between economic growth and tourism development between 1195 and 2013. It resulted that tourism development positively impacting economic growth in China. The emergence of the tourism industry has recently been seen as an alternative for long-term ecological and economic development. Even though China is expanding tourism in various places as part of 'The New Normal', it must confront the challenges of dismantling in the interests of the environment. The study's primary goal (Rauf et al., 2021) was to investigate the long-term relationship between tourism development, economic progress, transportation, energy consumption, significant hotel catering services, and $CO_2$ emissions for a panel of thirty Chinese provinces from 1995 to 2017. This study increased investment in Green Energy that can enhance economic growth and tourism development without deteriorating the environment. Investigation (Usman et al., 2021) explored dynamic coordination between tourism, economic development, renewable energy production, carob emission, and environmental impacts. The study employed the PMG model to reveal that economic development effectively upgrades the environmental quality in developed nations such as China.

In addition, Jiekuan Zhang and Zhang (2021) examined China's economic growth, tourism, and carbon emissions interconnection using the vector error correction model (VECM) in the long run and short time impact scenarios. The results provided in the study stated that all the given factors were found to be stationary at their initial differences. Long-term effects were found to be positive in the interrelationship of the shared variables. In comparison, there were short-term causalities determined from the Ganger Causality Test between tourism and the GDP of China. In the case of developed and emerging nations, Mishra et al. (2019) investigated the relationship between tourism, economic growth, and $CO_2$ emissions. Despite the tourism-driven expansion, the authors discovered that the effects of tourism on carbon emissions in prosperous economies are declining significantly quicker than in emerging economies. In addition, Bella (2018) validated the increased carbon emissions and economic growth concerning tourism development. A long-term equilibrium relationship was found in the given literature between carbon emissions, tourism, and economic growth.

Similarly, the causal relationships between different variables change dramatically among jurisdictions. The empirical analysis was made regarding China's economic techniques for improved financial development and tourism growth. Even the study of Churchill and Ivanovski (2020) proposed the determination of heterogeneity and cross-sectional dependence in environmental expansion and financialization. These studies utilized the conventional estimation methodologies such as Vector Autoregressive Approach and Vector Error Correction method.

One of the fastest developing industries in China is the tourism sector, including rural tourism, to raise the standards of rural areas in different provinces of China. After the massive wave of COVID-19 restrictions and quarantine periods, China is opening up to all sectors, including tourism, to raise the inbound and outbound tourists at allowed tourist spots. According to the statistics of the Tourism Ministry in China, there were 47.95 million tourists back in 2018 before the pandemic (Huang et al., 2021). The interconnection between economy and ecology has been a hotspot for research studies by many researchers. A study by Pang et al. stated that implementing the coupling model and EKC determined the scope of tourism development in Eastern China and its positive impacts on regional economic development. Environmental quality and financial aspects were also evaluated using quantitative methods (Fan et al., 2019). The degree of interaction between two or more subsystems can be described using the coupling coordination theory. The strength of the contact can be characterized by the degree of coupling, while the intensity of cooperative development can be reflected by the degree of coordination. The coupling coordination theory has been widely employed in empirical applications because of its capacity to provide a comprehensive evaluation system and its intuitiveness and ease of comprehension. Two different nexuses were undertaken in the given literature from the existing research studies to provide an overview of various researchers related to the impacts of tourism development on economic growth, environment, and technology innovation.

COVID-19 has brought several detrimental changes in almost all sectors of life, including tourism. The pandemic spread has changed the tourism patterns around the world, including in China which is reconsidering the opening-up strategy under certain limitations to bring the tourism industry back (Wen et al., 2021). Saidi and Mbarek (2017) stated that tourism and urbanization coexist, having common infrastructures and public services in China. A coupling coordination evaluation model evaluated vast development levels in three variables: tourism, environment, and economy. Results of the study showed that the development of tourism and the economy are highly correlated, with an increasing trend in both factors. In addition, it was estimated that there would be a rise in coupling coordination degree for the given variables within Chinese cities in the next few years. However, the existing literature still lags accurately depicting interlinkages between the shared variables (R. Li et al., 2022). Both heterogeneity and dependency aspects were seen in research studies for China's tourism-technology innovation nexus and environment-tourism nexus. The Chinese government must integrate the policies for tourism development based on the emotional impacts of emissions reduction in the tourism industry through innovative technologies in the long run. Most of the studies have employed quarterly data related to financial development and its impacts on China's ecology, tourism, and technology innovation. Such research studies should be encouraged to define the asymmetric trend between the given variables.

## 3. Research methods

The current research study has revealed mixed findings related to the relationship between ecological footprints, tourism, green technology innovation, financial development, and gross domestic product using QARDL approach. The unit root problem typically occurs in the time series analysis per the macroeconomic variables. The levels at which distinct variables are stationary are frequently used in such studies because associations between nonstationary series are typically misleading, resulting in a large information loss in long-run approximations. These issues can cause some additional cointegration tests for further development. Engle and Granger (1991) developed a cointegration test with two stages, suggesting that a series with unit roots at its initial levels can be reverted at its levels after becoming stationary at the initial difference. This way, the loss of data can be prevented effectively. According to Engle and Granger's cointervention, there should be at least one correlated vector for its implication in any system. In addition, a VAR model-based test was proposed by Johansen (1992) to identify the chance of determining more than one interrelated factor between the given variables.

Since this study applies QARDL model, which has various advantages, such as predicting equilibrium effects of essential variables impacting the environment, economic development, and growth for short-term and long-term outcomes. In addition, applying the QARDL approach is helpful in determining the diversified impact of independent variables on ecological footprints in China across the grid of low, medium, and higher quantiles. It also assists in determining the impacts of independent variables such as tourism, green technology innovation, and financial development on ecological footprint while examining the increasing or decreasing effect for all quantile levels (Razzaq et al., 2021b). The following equations provide the relationship between given variables under the context of ARDL.

$$Y_t = \alpha + \sum_i^p \beta_1 Y_{t-i} + \sum_i^q \beta_2 X1_{t-i} + \sum_i^m \beta_3 X2_{t-i} + \sum_i^n \beta_4 X3_{t-i} + \sum_i^r \beta_5 X4_{t-i} + \epsilon_t \quad (1)$$

Here in this equation, the term related to white noise error ($\epsilon_t$) is provided by the shortest field developed by the given irregularities. The suggested research study provides lag orders by the symbols p, q, n, and r by the Schwarz information criterion (SIC) (Jiang et al., 2021; Sun et al., 2021). The main independent variable (Y) is the ecological footprints in the given study. The term $X_s$ means the explanatory variable employed in the research model named as tourism, green technology innovation, and financial development while controlling the effect of GDP. The following equation provides the quantile factors suggested in the current research through the application of the QARDL model.

$$Q_{Y_t} = \alpha(\tau) + \sum_i^p \beta_1(\tau)Y_{t-i} + \sum_i^q \beta_2(\tau)X1_{t-i} + \sum_i^m \beta_3(\tau)X2_{t-i} + \sum_i^n \beta_4(\tau)X3_{t-i} + \sum_i^r \beta_5(\tau)X4_{t-i} + \epsilon_t(\tau) \quad (2)$$

The quantiles of the study are provided by the titles as $\epsilon_t(\tau) = Y_t - Q_{Y_t}(\tau/\epsilon_{t-1})$ and $0 < \tau < 1$. In addition, the given research study has implemented varying quantiles with subsequent pairs ranging from 0.05th to 0.95th. The following equation (3) can redefine the QARDL structure shown under Eq. (2) due to the prospects of the consecutive association present in white noise error.

$$Q_{\Delta Y_t} = \alpha(\tau) + \rho Y_{t-i} + \varphi_1 X1_{t-i} + \varphi_2 X2_{t-i} + \varphi_3 X3_{t-i} + \varphi_4 X4_{t-i} + \sum_i^p \beta_1(\tau)Y_{t-i} + \sum_i^q \beta_2(\tau)X1_{t-i} + \sum_i^m \beta_3(\tau)X2_{t-i} + \sum_i^n \beta_4(\tau)X3_{t-i} + \sum_i^r \beta_5(\tau)X4_{t-i} + \epsilon_t(\tau) \quad (3)$$

After modification of the QARDL methodology for the error correlation model in Eq. (3), the following equation is obtained:

$$Q_{\Delta Y_t} = \alpha(\tau) + \rho(\tau)(Y_{t-i} - \omega_1(\tau)X1_{t-i} - \omega_2(\tau)X2_{t-i} - \omega_3(\tau)X3_{t-i} - \omega_4(\tau)X4_{t-i}) + \sum_{i=1}^{p-1} \beta_1(\tau)\Delta Y_{t-i} + \sum_{i=0}^{q-1} \beta_2(\tau)\Delta X1_{t-i} + \sum_{i=0}^{m-1} \beta_3(\tau)\Delta X2_{t-1} + \sum_{i=0}^{n-1} \beta_4(\tau)\Delta X3_{t-i} + \sum_{i=0}^{r-1} \beta_5(\tau)\Delta X4_{t-i} + \epsilon_t(\tau) \quad (4)$$

The study investigated the combined impact in the short term of past values of factor (Y) on the current values of (Y) with the help of $\beta_* = \sum_{i=1}^{p-1} \beta_1$. However, the combined result of the latest and earlier values of X based on the latest values of Y has been calculated through $\beta_* = \sum_{i=1}^{q-1} \beta_2$. In addition, the same approach is used to estimate the cumulative short-term effects of previous and current values of (Xs) on current values of YI. From Eq. (4), the term P provides the adjustment speed coefficient that is significantly negative for the given research quantiles in the study. However, our research uses the Wald test to examine the short-term and long-term regular effect of Xs on the value of Y while also exploring the null hypotheses for both factors.

**Table 1.** Description of the variables.

| Variable name | Abbreviation | Measurement | Source |
|---|---|---|---|
| Tourism | TOR | It is measured through the number of tourists arrival during a year | WDI |
| Green technology innovation | GTI | It is measured through environmental technologies as a percentage of total technologies | OECD.stat |
| Financial development | FD | It is measured through FD index based on nine set of indices that summarize how developed financial markets and financial institutions are. | IMF.org |
| Gross domestic product | GDP | It is measured through the gross domestic product in USD during a year | WDI |
| Ecological footprints | EFP | It is measured as ecological footprints constant per capita (total). | GFN |

Source: Authors compilation.

There is expected to be a dynamic and significant nonlinear correlation between the given research factors based on the given QARDL model. The role of tourism, green technology, financial development, and economic growth will be observed for an ecological footprint in both short and long-term aspects. The QARDL methodology provided in the study was very beneficial for addressing the research questions and examining the nonlinear relation between study variables. Table 1 describes the variables and data sources.

## 4. Results and discussion

Descriptive results for the study variables entitled ecological footprints, tourism, green technology innovations, financial development, and GDP were presented in Table 2 through central tendency (Mean) and dispersions. The result confirms that GDP (measured by taking the natural log) reflects the highest mean score, followed by tourism (log of international arrivals). It shows that economic growth reflects higher scores than green technology innovations. Meanwhile, financial development reflects the lowest mean score and standard deviation of 0.096. The rest of the study variables have been measured while taking the natural log except financial development. More specifically, Table 2 shows that the latter reflects a higher trend between EFP and GDP. The highest deviation in the mean is associated with EFP, followed by green technology innovations and GDP, respectively. The J-B test was applied to examine the normal distribution of the data, and the results show significant results for ecological footprints, tourism, green technology innovation, financial development, and economic growth, rejecting the data's normal distribution hypothesis. Based on these findings, the implication of QARDL estimation is quite evident.

To examine the unit root properties of the study variables, this research considers Zivot and Andrews (2002) with the augmented Dicky-Fuller or ADF test, which covers the findings in Table 3. The existing body of literature highlights various benefits of applying the ZA as it helps count the data's structural breaks. The results in Table 3 show that both ADF and ZA tests have validated the stationarity property of the data at a 5% level of significance. The study variables like EFP, TOR, GTI, FD, and GDP demonstrate a unique order of integration like $I(1)$.

After analyzing the stationarity properties and descriptive outcomes, the current study explores the long-run and short-run association between the study variables

**Table 2.** Results of descriptive statistics.

| Variables | Mean | SD | Min | Max | J-B Stats |
|---|---|---|---|---|---|
| EFP | 3.051 | 0.653 | 1.920 | 3.720 | 60.352*** |
| TOR | 8.092 | 0.081 | 7.921 | 8.211 | 36.200*** |
| GTI | 2.998 | 0.527 | 1.940 | 3.7 | 31.205*** |
| FD | 0.511 | 0.096 | 0.344 | 0.637 | 62.058*** |
| GDP | 12.684 | 0.374 | 12.083 | 13.155 | 26.505*** |

Source: Authors estimation.
The asterisk ***, ** and * represent level of significance at 1%, 5% and 10% respectively.

**Table 3.** Results of unit root test.

| Variables | ADF (Level) | ADF (Δ) | ZA (Level) | Break year | ZA (Δ) | Break year |
|---|---|---|---|---|---|---|
| EFP | −2.368 | −3.369*** | −2.368 | 20/05/2013 | −8.010*** | 10/05/2014 |
| TOR | −0.272 | −4.159*** | −1.105 | 23/08/2012 | −7.159*** | 05/08/2015 |
| GTI | −1.159 | −3.357*** | −2.375 | 03/08/2010 | −6.159*** | 11/06/2018 |
| FD | −0.015 | −6.519*** | −1.159 | 03/05/2017 | −8.269*** | 19/01/2018 |
| GDP | −1.152 | −5.205*** | −2.753 | 09/10/2018 | −6.057*** | 10/05/2016 |

Note: The values in the table specify statistical values of the ADF and ZA test.
Source: Author estimation.
The asterisk ***, ** and * represent level of significance at 1%, 5% and 10%, respectively.

through QARDL estimation. The findings are reported in Table 4, which confirms that for the ECM, the stated values of $P^*$ are found to be negatively significant, ranging from middle-order quantile to higher-order quantiles. Moreover, the findings under long-run estimation show that TOR is negatively ad significantly associated with the ecological footprints in the region of China over the study period. More specifically, this negative association is significant at 10% for the lower order quantiles (0.05–0.30); however, it becomes a highly substantial output from 0.40th quantile to 0.95th quantiles. It means that more arrival of international tourists in the region of China is beneficial in controlling the environmental pollution, hence reducing the EFP over the study period. Various reasons can be identified for the product role of tourism in dealing with ecological footprints. For example, Katircioglu et al. (2018) explain that factors like tourists' arrival are negatively linked with the environmental footprint because increasing environmental awareness would help achieve environmental objectives, hence reducing environmental degradation. In this regard, the role of green tourism is quite important through which environmental awareness would be created to sustain the natural environment. Ali et al. (2021) aim to explore the impact of tourism, economic growth, and renewable energy in determining the ecological footprints of the 128 economies. It is observed that natural resource depletion has been found because of an increase in tourism for the higher-upper-middle and lower-middle-income economies. For sustainable output, it is recommended that tourism-related activities should be expanded. However, contrary to our findings, some other studies explore the positive nexus between tourism and environmental degradation in the form of $CO_2$ (Godil et al., 2020; Peeters & Schouten, 2006).

The results in Table 4 reflect that green technology innovation's significant and negative impact on EFP exists. More specifically, it shows that for the lower order quantiles like 0.05th to 0.10, the effect of GTI on EFP is 0–0.365 and −0.135. In contrast, this relationship turns highly significant and negative from medium to higher-order quantiles. More specifically, it shows that over the long run estimations, GTIs

**Table 4.** Results of quantile autoregressive distributed lag (QARDL) for EFP.

| Quantiles | Constant | ECM | Long-run estimation | | | | Short-run estimation | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (τ) | $\alpha_*(\tau)$ | $\rho_*(\tau)$ | βTOR(τ) | βGTI(τ) | βFD(τ) | βGDP(τ) | $\varphi_1(\tau)$EFP | $\omega_0(\tau)$TOR | $\lambda_0(\tau)$GTI | $\theta_0(\tau)$FD | $\acute{\varepsilon}_0(\tau)$GDP |
| 0.05 | −0.018 | −0.264 | −0.210* | −0.365** | 0.150 | 0.628*** | 0.128*** | −0.062*** | −0.023 | 0.005 | 0.052* |
| | (−0.005) | (−0.793) | (−1.715) | (−2.205) | (1.10) | (4.367) | (3.201) | (−3.521) | (−0.413) | (0.604) | (1.735) |
| 0.10 | −0.016 | −0.210 | −0.201* | −0.139** | 0.257 | 0.352*** | 0.432*** | −0.020*** | −0.028 | 0.050 | 0.057* |
| | (−0.010) | (−0.713) | (−1.812) | (−2.307) | (1.607) | (3.520) | (4.028) | (−4.204) | (−0.624) | (1.267) | (1.851) |
| 0.20 | −0.027 | −0.201 | −0.198* | −0.157* | 0.369 | 0.208*** | 0.632** | −0.057*** | −0.037 | 0.033* | 0.024** |
| | (−0.003) | (−0.739) | (−1.819) | (−1.807) | (0.263) | (3.628) | (3.268) | (−3.820) | (−0.368) | (1.670) | (2.207) |
| 0.30 | −0.023 | −0.210 | −0.428** | −0.109* | 0.178*** | 0.207*** | 0.159** | −0.030*** | −0.063 | 0.010* | 0.034** |
| | (−0.007) | (−0.813) | (−2.068) | (−1.737) | (2.985) | (4.027) | (2.250) | (−4.638) | (−0.105) | (1.871) | (2.108) |
| 0.40 | −0.024 | −0.180 | −0.159** | −0.063 | 0.157** | 0.206*** | 0.257** | −0.052 | −0.019*** | 0.037* | 0.027*** |
| | (−0.004) | (−0.898) | (−2.962) | (−1.07) | (2.401) | (3.270) | (2.715) | (−1.357) | (−2.985) | (1.747) | (3.087) |
| 0.50 | −0.007 | −0.226* | −0.041*** | −0.037 | 0.125** | 0.358* | 0.325*** | −0.017 | −0.075*** | 0.065* | 0.037** |
| | (−0.003) | (−1.782) | (−3.659) | (−1.030) | (2.05) | (1.83) | (3.637) | (−0.752) | (−4.230) | (1.678) | (2.538) |
| 0.60 | −0.016 | −0.237** | −0.237*** | −0.216** | 0.287** | 0.507 | 0.405*** | −0.058 | −0.266*** | 0.028** | 0.037** |
| | (−0.004) | (−2.055) | (−3.62) | (−2.13) | (1.997) | (1.128) | (3.753) | (−1.105) | (−3.205) | (2.052) | (1.990) |
| 0.70 | −0.010 | −0.212** | −0.152*** | −0.150*** | 0.347*** | 0.038 | 0.539*** | −0.015 | −0.057*** | 0.017** | 0.037 |
| | (−0.002) | (−2.676) | (−3.652) | (−3.375) | (3.204) | (0.357) | (4.563) | (−1.108) | (−4.432) | (1.995) | (0.811) |
| 0.80 | −0.012 | −0.215*** | −0.207*** | −0.385*** | 0.052*** | 0.652*** | 0.852*** | −0.035*** | −0.027*** | 0.048** | 0.015** |
| | (−0.003) | (−4.357) | (−3.635) | (−3.670) | (3.635) | (4.201) | (5.027) | (−3.332) | (−4.528) | (1.991) | (2.018) |
| 0.90 | −0.012 | −0.207*** | −0.251*** | −0.013*** | 0.228*** | 0.163*** | 0.357*** | −0.015 | −0.034*** | 0.027*** | 0.016* |
| | (−0.013) | (−3.758) | (−2.996) | (−4.407) | (4.280) | (2.952) | (4.201) | (−1.205) | (−3.239) | (2.981) | (1.893) |
| 0.95 | −0.022 | −0.208*** | −0.262*** | −0.096*** | 0.108*** | 0.528*** | 0.357*** | −0.057* | −0.083*** | 0.035*** | 0.09* |
| | (−0.007) | (−4.723) | (−3.004) | (−4.816) | (3.698) | (2.937) | (4.159) | (−1.87) | (−4.057) | (2.938) | (1.917) |

Note: The table reports the quantile estimation results. The t-statistics are between brackets.
Source: Author estimations.
***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

are playing their role as a panacea towards environmental issues, hence reducing EFP. During the past two decades, the trends in ecological technologies, specifically in China's region, reflect some remarkable achievements. For example, during the last two decades, environmental technologies in China have made great progress, specifically in water and wastewater treatment, solar, energy, lightning, electric vehicles, and other technologies (Wang et al., 2019).

Meanwhile, the Chinese government also works to promote green technologies in different industries (L. Li, 2018). At the same time, various theoretical and empirical studies support the association between green technologies and ecological footprints. For instance, Ke et al. (2022) focus on 283 cities in China to explore the effect of green innovation efficiency on ecological footprints. Their findings state that EFP receives the influence from green innovation efficiency. Chu (2022) explores the OECD economies to investigate EFP determinants. The study findings confirm the existence of long-term association between green technology innovation and EFP. More specifically, environmental technologies are negatively and significantly linked with environmental management and climate change mitigation both in long run and short run, respectively.

The nexus between financial development and ecological footprints under long-run estimation show positively significant outcomes. More specifically, from the 0.30th to higher-order quantile, the significant and positive impact of financial development on ecological footprints has been observed. For multiple reasons, various authors have confirmed FD's direct role in ecological footprints. Baloch et al. (2019) examine the trends in environmental footprints for 59 Belt and Road countries from 1990–2016. The study findings confirm that financial development pollutes the natural environment while increasing the EFP. More financial development in any region provides more credit facilities to different industries, which utilize the stated facilities towards investing in various energy-related projects to fulfill their production-related and other requirements. Such investment increases environmental pollution with more carbon emissions, creating environmental issues. Amin et al. (2020) focus on the nexus between financial development and environmental degradation through quantile regression estimation under the shadow of EKC. Their study provides empirical evidence for the significant impact of different proxies of financial development on carbon emission, specifically under lower-order quantiles. On the other side, financial development negatively impacts pollution over higher order quantiles. Finally under long run estimation, significant and direct role of GDP in creating more EFP for Chinese economy was found. More specifically, the results confirm that from lower to 0.40th quantile, a higher change in EFP was found due to increasing level of economic growth over the study period. Meanwhile, 0.80th quantile shows the highest coefficient value with a score of 0.652, significant at 1%.

Under short-run estimation, findings confirm that past levels significantly and positively influence present values of EFP in the region of China under all three levels of quantiles: low, medium, and higher, respectively. Meanwhile, the current and past changes in tourism are significantly and negatively linked but only for lower and higher-order quantiles. Meanwhile, the changes in green technology innovations are observed as considerably and negatively correlated with the EFP in the region of China.

**Table 5.** Results of the Wald test for the constancy of parameters.

| Variables | Wald-statistics [F-statistics] |
|---|---|
| ρ | 36.020*** [0.000] |
| βTOR | 50.871*** [0.000] |
| βGTI | 19.202*** [0.000] |
| βFD | 22.540** [0.000] |
| βGDP | 16.052*** [0.000] |
| φ1 | 8.516*** [0.000] |
| ω0 | 0.837 [0.561] |
| λ0 | 8.672*** [0.000] |
| θ0 | 0.319 [0.910] |
| έ0 | 7.201*** [0.000] |

Source: Author estimations.
The *p*-values are between square brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Similarly, the past and current changes in FD are directly and significantly linked with the current level of EFP. Meanwhile, GDP also reflects significant outcomes in short-run estimation.

In the last step, Table 5 reports the Wald test output, which helps examine the constancy of the study parameters under all the stated quantiles. Meanwhile, it also helps analyze the nonlinear association both in the long and short run, respectively. The null hypothesis reflects no asymmetries and nonlinear association, whereas the alternative rejects it. The findings in Table 5 report that for the study, variables like tourism, green technology innovation, financial development, and economic growth (GDP) have shown significant output in the long run. Similarly, the short-run estimation findings also offer some considerable output. It implies a significant nonlinear association between the variables.

## 5. Conclusion and policy suggestions

This study explores the role of ecological innovations, tourism, financial development, and economic growth toward EFP in the Chinese economy over the past two decades. It applies the novel approach of QARDL while estimating the non-linearity between the stated variables in short-run and long-run durations. Initially, the J-B test confirms the non-linearity in the data during the study period. Also, the stationarity properties of the data were examined through ZA and ADF tests. The outcomes through QARDL estimation reflect that estimated values under ECM were significantly negative, and the same was expected. Moreover, another significant contribution associated with this research confirms the existence of a nonlinear relationship that rejects the earlier findings between the stated variables through traditional econometric estimations like OLS/ARDL. In this regard, unlike conventional data estimation techniques, QARDL helps get cointegrated coefficients across different ranges of quantiles. More specifically, ECM findings confirm the existence of long-term equilibrium among these variables for the Chinese economy. More specifically, the results through long-run estimation confirm that tourism and green technology innovations reflect a substantial role in reducing the EFP. It also reports that the Chinese economy would focus on green tourism and those technologies through which sustainable environmental results can be generated. The findings for tourism reflect that medium to higher order quantiles (0.40th to 0.95th) cover that tourists' arrival in China is a good sign of sustainable environmental practices. Similarly, technological innovations show that green technologies are more efficient in reducing ecological footprints but in the higher-order quantiles for long-term outcomes. Meanwhile, financial development and economic growth cause environmental degradation as most of their coefficients are positively significant in different quantiles.

The findings show that tourism development and eco-innovations are good instruments to reduce the EFP in the long run. These factors may work through different channels like green energy consumption in terms of technological innovation, efficient utilization of transportation in green tourism development, and focusing more on research and development for green technologies. Policymakers at the government level should consider these channels through which environmentally sustainable outcomes would be generated for the economy of China. Moreover, these instruments will generate some fruitful environmental outcomes but also helps in getting more technological movement, green tourism growth, sustainable economic output, and employment creation over the long run. On the other side, the negative role of financial development and economic growth in creating more EFP reflects that these macroeconomic dynamics are not sustainable. Therefore, governmental officials responsible for economic and financial policies should control the adverse effect on financial development in line with environmental guidelines.

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