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Infrastructure development, human development index, and CO_2 emissions in China: A quantile regression approach

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This study investigates the relationships between infrastructure development, human development index (HDI), and CO_2 emissions in China. Infrastructure has played an essential role in achieving social and economic developmental goals in China, but environmental pollution has significantly increased in the country in the last two decades. Our analysis uses time series data from 1990 to 2021 and quantile regressions, and we find that infrastructure has positive and statistically significant relationships with HDI, CO_2 emissions, and GDP in all quantiles. Recent infrastructure upgrades improve living standards and increase HDI but damage the environment, and infrastructure is the main source of CO_2 emissions in the country. Therefore, the government should invest in sustainable infrastructure to mitigate CO_2 emissions. The government may consider infrastructure options such as low carbon transportation, including railway infrastructure, urban metros, and light rail.

KEYWORDS

infrastructure, human development index, CO2 emissions, China, quantile regression

1 Introduction

China has implemented various economic reforms in recent decades that have significantly increased GDP, whereas CO_2 emissions and global warming potentially increase during the transition period (Wang et al., 2022). Economic growth has improved living standards, literacy rates, and health quality, but environmental concerns are a key issue in the country's economy. The sustained economic growth from the last two decades has also helped to improve China's human development index (HDI) from 0.41 in 1978 to 0.75 in 2017 (UNDP, 2017). This is a tremendous improvement in HDI and made China the first country to move from low HDI in 1990 to high HDI. According to (UNDP, 2017), China's improvement in HDI can be attributed to the rural development and improving rural lives during the industrialization and transition period. The Chinese government has implemented various reforms to achieve balanced human development in rural and urban populations.

Theoretically infrastructure affect the CO_2 emissions from the following aspects; firstly upgradation of infrastructure makes easier the transportation of commodities; thus, it increases the CO_2 emissions due the large transportation activities. The improvement of infrastructure raises industrial production due to easy access to market, the raise in industrial production leads to increase in CO_2 emissions. Thirdly the infrastructure increase facilitates the social and economic development and increase the income of the people, the raise in income leads to increase the energy consumption. Infrastructure development in China has proceeded rapidly, especially transport infrastructure, rising at an annual rate of 7.3% over the last three decades (Wang et al., 2022). Infrastructure are basic business channels, including school systems, sewage, water, communication systems, and transportation, but infrastructure development and expansion cause ecological damage (Shan et al., 2021). For instance, during infrastructure construction, smoke, wastewater, industrial emissions, and CO_2 are released, which harm the environment (Akbar et al., 2021). Transport infrastructure leads to CO_2 emissions in China and facilitate the social development (Xu et al., 2022; Zhou et al., 2022). Furthermore, natural resources tend to be consumed in large quantities during infrastructure construction and operation. Despite these challenges, improvements in infrastructure are associated with HDI improvements. For instance, according Meng et al. (2019), China has extensively reformed its health care system over the past 10 years. These reforms have focused on improving primary care, expanding and improving social health insurance coverage, ensuring everyone has access to basic public health services, and reforming public hospitals. In addition, China has made remarkable reforms in the internationalization of education and huge numbers of international students travel to China to study (Economy, 2018), these international students contribute to the scientific and research activities in the country. The expansion of international students in China expected to positively affect the scientific productivity (Yin & Zong, 2022).

Investment in infrastructure development promotes HDI by creating growth channels and improving productivity and incomes (Razmi et al., 2012; Horvat et al., 2021). Electricity and transport infrastructure are the main channels that facilitate production processes. The improvement in HDI includes increases in *per capita* income, and infrastructure development is the main source of these increases. However, infrastructure development and industrialization also result in higher rates of CO_2 emissions. Therefore, HDI and infrastructure improve in parallel with CO_2 emissions in the country. Furthermore, the literature suggests that the long-term impact of infrastructure development is greater than its short-term impact. For instance, Kusharjanto and Kim (2011) suggested that in the short-term, a 1% increase in the share of households with access to electricity will lead to a 0.052% increase in adult literacy, but in the long-term will cause a 0.12% increase in adult literacy.

Although the positive impact of infrastructure on HDI may be achieved over the long term, its impact on carbon emissions is instant. This is particularly important for transport infrastructure, which produces large amounts of CO_2 emissions. China's low-carbon emission goals are yielding some success, but effort is needed to accomplish desired welfare levels (Shan et al., 2021). Currently, China is the world's largest energy consumer and makes significant contributions to CO_2 emissions, but environmental protection law and reforms helps to mitigate its CO_2 emissions (Zhang, 2000; Abbas et al., 2021). Despite these laws and reforms, the growth rate of CO_2 emissions remains a major challenge for the Chinese government. In the 10 years from 2009 to 2019, Chinese CO_2 emissions increased by 1.5 times (Zhao et al., 2022). With development at a transitional stage, high energy consumption and infrastructure lead to high CO_2 emissions (Zeeshan et al., 2022a; Zeeshan et al., 2022b), but improvements in infrastructure also stimulate improvements in HDI (Acheampong et al., 2022). Therefore, this study investigates the relationships between infrastructure development, HDI, and CO_2 emissions in China.

Infrastructure has been investigated either with HDI or CO_2 emissions, to best of our knowledge infrastructure, CO_2 emissions and HDI has not been analyzed in single study. Besides, infrastructure has dual impact on the economy; on one had it facilitate the social development and improve HDI, which on other hand it contributes to the CO_2 emissions. Thus, this study covers both negative and positive aspects using the case of China. Infrastructure development has given keen attention from last few decades in China economy, which expected to improve the HDI and effect the CO_2 emissions in country. Therefore, this study main objective to analyze Infrastructure, HDI and CO_2 emissions in China. The contributions of this study are threefold. First, previous literature such as Wang et al. (2022) has linked infrastructure, economic development, and industrial pollution. However, the relationship between infrastructure and HDI has not been examined. This study examines the relationships between HDI, CO_2 emissions, and infrastructure. Second, we use the context of China's transitioning economy to provide insights into how infrastructure development can affect HDI and carbon emissions in transitional economies. Third, we use quantile regressions to provide more robust findings to support policy recommendations. The remainder of this paper is structured as follows. Section 2 reviews literature related to this study. Section 3 presents information about China's infrastructure development, HDI, and emissions. Section 4 explains our research methodology. Section 5 provides the results and discusses the findings. Section 6 summarizes the research findings and provides recommendations and directions for future research.

2 Literature review

This section comprehensively analyses previous research related to HDI, CO_2 emissions, and infrastructure. Sapkota (2014) performed cross-country research investigating how infrastructure access affects human development. His research used three basic infrastructure types—roads, clean water sources, and access to electricity—general moment methods, and panel data for the period 1995–2010. The findings revealed a significant positive relationship between infrastructure development and HDI. Furthermore, water and electricity had significant positive relationships with health and education indexes. Mohanty et al. (2016) explored the relationship between infrastructure development and HDI in India using 30 districts of the Odisha region. Infrastructure was represented by access to water, schools, banking, village electricity, postal services, and telecommunications. Their study reported that access to these types of infrastructure positively affected human development, and recommended that local governments should improve rural infrastructure. Nchofoung et al. (2022) investigated infrastructure development using linear and non-linear impacts on general human development in African countries. Their findings suggest that all infrastructure development indexes except ICT positively affect HDI, whereas ICT development negatively affects HDI. Furthermore, there is a positive relationship between HDI and the sanitation, water, and electricity index.

Chawla et al. (2022) investigated the impact of infrastructure development on HDI. Living standards, knowledge, and healthy living were used to measure HDI and social opportunities were conceptualized as social infrastructure. Panel data were used to explore the relationships between variables. The findings indicate that in most countries' social infrastructure, disparity is a major issue. Inequity in education and health was found a positive effect in the regions, whereas regions with less social infrastructure had greater social disparities. They recommended implementing equity policies in infrastructure development. Djokoto (2022) investigated the nexus between investment and HDI in 137 countries for the period 1990–2019. His findings suggest that infrastructure development is one of the main factors that promotes HDI. Specifically, there was a 60% correlation between infrastructure investment and HDI.

Dzator et al. (2021) investigated the implications of infrastructure development for carbon emissions in OECD countries, examining the period 1960–2018 and using variables including energy consumption, urbanization, and trade openness. They reported that rail transport increases CO_2 emissions, whereas air transport does not influence CO_2 emissions. Higher energy consumption and population size greatly increased CO_2 emissions. Thus, regions with larger populations may set up railway transport and adapt to consumption of renewable energy, which may reduce CO_2 emissions in the region. Additionally, foreign trade and financial development also increase regional CO_2 emissions. Cantos Sanchez and Gumbau Albert (2015) also examine OECD countries. Specifically, their research concentrated on the environmental impacts of transport infrastructure, and used general translogarithmic methods of moments to analyze data. They found that the output-elasticity of aggregate transport infrastructure is negative, whereas elasticity is positive. Therefore, the region is experiencing both an increase in HDI and a rise in environmental pollution.

Sharif and Tauqir (2021) investigated the relationship between infrastructure development and carbon emissions in Pakistan for the period 1972–2017. They used ordinary least squares (OLS) and fully modified OLS methods for analysis. Their findings suggest positive relationships between infrastructure development and HDI and carbon emissions in Pakistan. Furthermore, their findings indicate that infrastructure development increased human development at the cost of environmental pollution, and the authors recommended investing in green vehicles to reduce emissions in the country. Lyu et al. (2022) explored the relationship infrastructure and pollution in Chinese cities. They used panel data for the period 2011–2017 and employed robustness tests to validate their baseline findings, and found that infrastructure greatly reduced CO_2 emissions. Muller et al. (2013) explored the nexus between human development and climate change by using infrastructure development and CO_2 emissions. Their research compared the carbon footprints of developed and developing countries, and found that developed countries had carbon footprints five times higher than developing countries. Their research suggests that reductions in emissions can be attributed to three factors: innovation in green technologies, agglomeration of producer service industries, and adoption of industrial structure. Furthermore, the research suggests that Chinese cities with higher technological development have greatly reduced CO_2 emissions. The authors recommended promoting low-carbon and green development to mitigate global warming. Yin and Jin (2021) investigated the relationship between economic development and carbon emissions by comparing China and the US. They found that countries with high HDI and energy consumption have higher CO_2 emissions. They also acknowledged that countries like China and the US had made remarkable developments in trying to mitigate CO_2 emissions. Rahman et al. (2021) uses a cross-sectionally dependent panel to analyze effects of human capital, exports, economic growth, and energy consumption on CO_2 emissions. Their findings suggest a long run association between human capital, exports, economic growth, energy consumption and CO_2 emissions. Hussain et al. (2022) reinvestigate natural resources, economic policies, urbanization, and environmental Kuznets curve, they reported EKC hypothesis do no exists in G7 countries. Tan et al. (2022) found that negative association between CO_2 emissions and disclosures. Mohmmed et al. (2019) reported that among the other factors GDP is one main reasonable factor for the CO_2 emissions in the top 10 countries. Bashir et al. (2022a) found institutional quality and economic growth and financial developed reduces the CO_2 emissions. Bashir et al. (2022b) found that natural resources consumption leads to environmental degradation. Sadiq et al. (2022) reported that nuclear energy can contribute to HDI. Bashir (2022) found the existence of pollution haven hypothesis in most of the countries. Xia et al. (2022) that globalization and economic development increase the CO_2 emissions.

The past studies analyze the infrastructure with CO_2 emissions such as Dzator et al. (2021); Akbar et al. (2021); Xu et al. (2022); Emodi et al. (2022) and Churchill et al. (2021) investigated the relationship and they found a positive relationship between CO_2 emissions and infrastructure upgradation. Other studies such Nchofoung et al. (2022); Chawla et al. (2022); Mohanty et al. (2016) and Sapkota (2014) analyzed the infrastructure and infrastructure and HDI and found a positive relationship between HDI and infrastructure. However, both HDI and CO_2 emissions with infrastructure using the case of China has not been examined. The research provides value addition to the existing literature by adding both HDI, Co2 emission with infrastructure in single study. And quantile regression will also provide robust estimation and better statistical inferences and policy recommendations.

3 HDI, CO_2 emissions, and infrastructure trends in China

Figure 1 shows HDI and CO_2 emissions trends from 1990 to 2021. The percentage of total greenhouse gas emissions was relatively low in 1991, but gradually increased until 1996, then levelled off from 1997 to 2000. The trends in greenhouse gas emissions between 1991 and 2000 can be explained by reduced industrial and infrastructure developments in that period. Most sources of greenhouse gases are upgrading of infrastructure, operation of industrial machinery, and energy consumption. There is a sharp increase in the percentage change in greenhouse gases between 2002 and 2012, which shows that China underwent tremendous changes in industrialisation, exploitation of natural resources, and development of infrastructure during this period. Furthermore, China joined the WTO in 2002, opening its economy for trade with the rest of the world (Ullah et al., 2019).

Overall, there is a sharp rising trend in greenhouse gases emissions in China in the previous two decades. However, China has committed to reducing its greenhouse gas emissions by the year 2060. Currently, China operates over 1,058 coal plants, more than half of the world's total. China's heavy reliance on coal power is a challenge but the country is gradually implementing production of clean energy. According to world development indicators (WDI), from 1991 to 1995 there was a slight rise in CO_2 emissions in China. This suggests

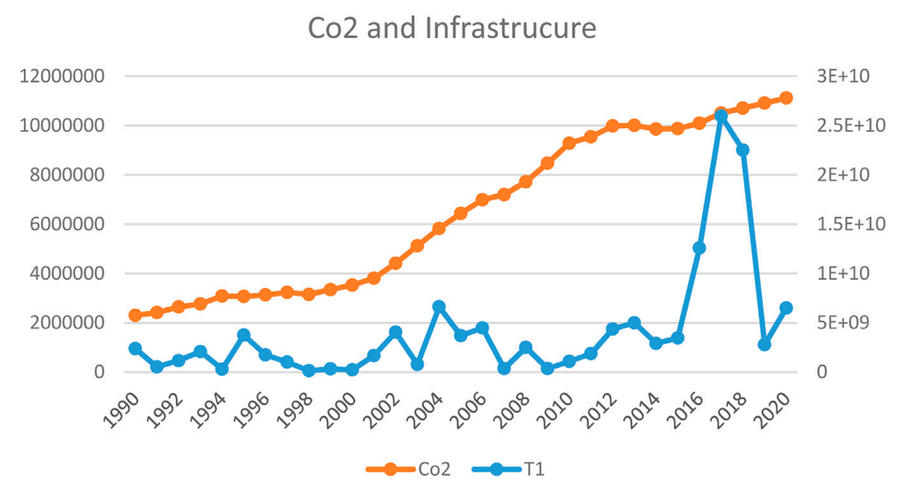

FIGURE 1
CO_2 emissions and Infrastructure.

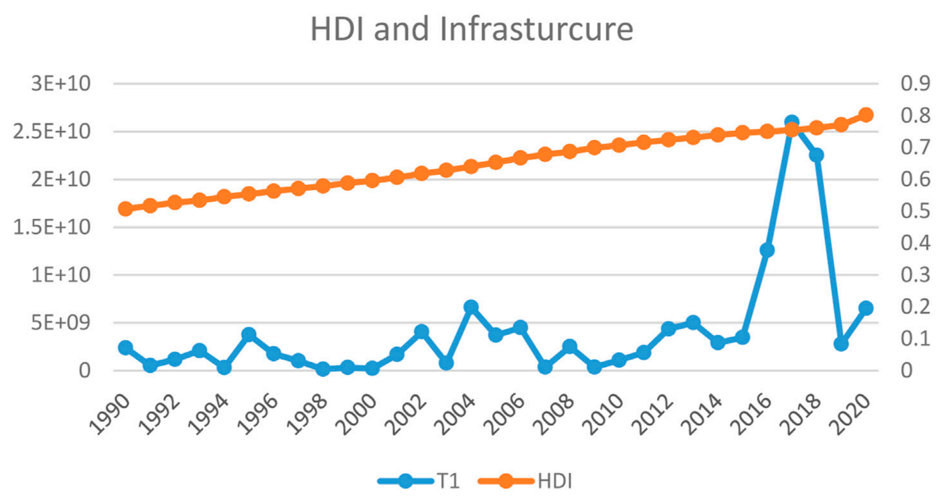

FIGURE 2
Hdi and infrastructure.

that in this period China was at an early stage of industrialization and CO_2 emissions are slightly lower in this period. From 1997 to 2000, CO_2 emissions *per capita* remained stable. From 2001 to 2014, CO_2 emissions *per capita* increased significantly. China's *per capita* GDP and trade increased significantly after joining the WTO in 2002, and in this period both income levels and per-capita emissions increased. Thus, the affordability of products and *per capita* emissions from the burning of fossil fuels are the main sources of CO_2 emissions in this period.

The increase in emissions can also be explained by population size. In 2022, China's population was 1.4 billion, which explains the country's high CO_2 emissions. Countries with larger population size are expected to have larger CO_2 emissions. For example, India has the second largest population and is the third largest CO_2 emitter in the world. Chinese energy mainly comes from fossil fuels, and industrial development in the last two decades has increased consumption of fossil fuels in industrial production, increasing CO_2 emissions in the country. CO_2 emissions from electricity and heat generation increased slightly from 1970 to 1980, indicating that the country was gradually making reforms and opening up to foreign investment. This investment increased demand for electricity, which explains the spike between 1977 and 1980. There was also a considerable increase in CO_2 emissions between 1984 and 2003 due to increased demand for electricity from the industrial and domestic sectors. Energy demand has also been increasing since 2002 due to expansion of trade and industrial production. According to Ling et al. (2021) China's electricity supply mostly comes from thermal generation, which provides more than 70% of all the electricity generated in the country. Over 60% of electricity from thermal generation comes from coal. However, the country is

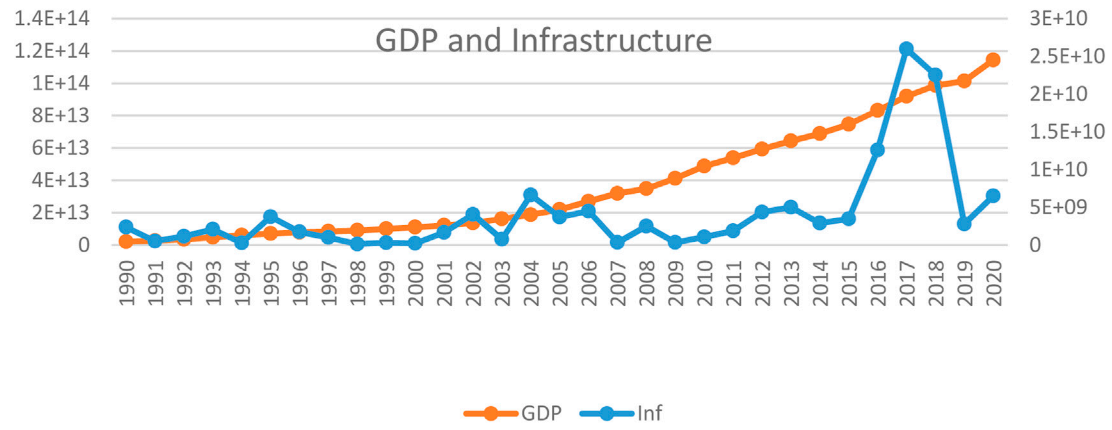

FIGURE 3
Gdp and infrastructure.

introducing laws and reforms to promote adoption of non-fossil-fuel energy sources (Yang & Lin, 2016).

Figure 2 presents trends in HDI and infrastructure. HDI has a deviation trend from 1990 to 2016. However, between 2016 and 2019 HDI is higher, which may reflect improvements in education, *per capita* GDP, and public health (Ullah et al., 2020). Furthermore, other measures such as clean drinking water and access to the electricity are also responsible for improvements in HDI in the region. According to WDI statistics, the proportion of people in urban populations who had access to at least basic drinking water services reached 100% in 2014. This can be attributed to the increasing urban population and government infrastructure improvements that made drinking water widely available. Access to at least basic drinking water services in the rural population has also been increasing gradually. This rising trend reflects the government's effort to balance infrastructure development in both urban and rural areas. Overall, there is a rising trend in both urban and rural populations' access to drinking water. In the year 2000, 80% of the Chinese population had access to drinking water; by 2020 this figure had increased to 94%. Access to electricity has also improved in recent decades; according to WDI statistics, the percentage of China's rural population with access to the electricity increased from 95% to 99% between 2000 and 2009, and reached 100% in 2012, and has since remained at this level. This indicates that the country has invested extensively in making urban areas fully operational by providing access to energy.

Improvements in sanitation are another important factor in the country's increasing HDI. WDI statistics suggest an overall rising trend in the percentage of people using either basic or safely managed sanitation services. It is suggested that the percentage of the rural population using safely managed sanitation services rose from 4% to 47% between 2000 and 2020. In the same period, the percentage of the urban population using safely managed sanitation services rose from 27% to 87%, and the percentage of the total population using safely managed sanitation services rose from 13% to 69%. This indicates that at least 45% of people in the early 2000's had access to at least basic sanitation services. By 2020, 85% of people both in rural and urban areas were using at least basic sanitation services.

Figure 3 depicts the association between GDP and HDI in China from 1990 to 2021. GDP increases steadily, indicating that infrastructure upgrades increase income, and hence GDP. WDI statistics report that net adjusted national income also increased steadily from 1970 to 1980. As mentioned earlier, these years were characterised by poor economic performance and policies that caused income levels to be low. However, after 2002, income levels increase substantially, reflecting industrialization and increasing trade activities. This can be considered a boom period in the Chinese economy.

4 Model and methodology

4.1 Model

This paper uses the following model for analysis

$$HDI, CO_2, GDP, G = f(Inf) \tag{1}$$

where *HDI* is the human development index, CO_2 is carbon dioxide emissions, *GDP* is gross domestic product, and *G* is government spending and *Inf* represents the infrastructure. In our model use infrastructure (Inf) as independent variable while, HDI, CO_2 emissions are the independent variables. G and GDP is used as control variable in the model the main targeted variables are Co2 emissions and HDI. According to the theory the model suggest that infrastructure determines the explanatory variables such as HDI, CO_2 emissions GDP and G. Theoretically the expected coefficient sign of HDI with other variables such as HDI, CO_2 emissions and GDP is positive.

4.2 Methodology

This study uses quantile regression for empirical analysis. Quantile regression is applied for this study because infrastructure developed in China has been carried out in different period. This method will differentiate the impact of infrastructure on CO_2 emission and HDI in different quantile. Besides the significance of coefficient in each quantile provide better statistical inferences and policy recommendation. Quantile regression helps to determine relationships between independent variables and dependent variables based on median values of residuals (Hoang et al., 2019). This method is preferred over OLS regression because it has high resistance to influence by outlying observations and is not based on assumptions about the target variable's distribution. Also, quantile regression is preferred over the OLS method because it uses different estimation weights such as symmetric weights for the median, whereas OLS estimates the conditional mean function (Furno and Vistocco, 2008). Quantile regression also helps in meeting conditions that linear regression cannot meet, such as normality, independence, homoscedasticity, and linearity. Quantile regression is used in a broad range of research, including financial economics, healthcare, and ecology (Huang et al., 2017). In our setting, quantile regression can be used to empirically examine the extent to which various factors such as HDI, CO_2 emissions, GDP, and government spending. In quantile regressions, a conditioned quantile is used to generalize unconditional quantiles. The OLS framework minimizes the sum of squared residuals as follows:

$$\min_{\{\beta_j\}_{j=0}^{k}} \sum_i \left(v_i - \sum_{j=0}^{k} \beta_j x_{j,i} \right)^2 \quad (2)$$

where v_i represents the largest variables for data set i and predictor variable j, and β_j represents parameters of estimation for the regression model. Because the aim of the quantile regression is to minimize the weighted sum of absolute deviations (Zietz et al., 2008), we can achieve the function:

$$\min_{\{b_j\}_{j=0}^{k}} \sum_i \left| v_i - \sum_{j=0}^{k} b_j x_{j,i} \right| h_i \quad (3)$$

In the above equation, p_i is defined as $p_i = 2q$ and shows the weights. For the case where the residual is strictly positive for observation i, p_i is defined as:

$$p_i = 2 - 2q$$

In the situation where observation i is zero or negative, the quantile variable q has a value between 0 and 1, which provides the predicted value in the equation. Following Gould (1998), bootstrapping is the method used to estimate standard errors in the quantile regression coefficients. The standard error estimation method is comparatively more volatile to heteroscedasticity, which is more stable in quantile regressions (Rogers, 1994). This paper uses quantile regression for two main reasons. First, this technique can provide more accurate estimations, which may help in determining the relationships between HDI, CO_2 emissions, GDP, and G. Second, this technique provides estimations of stability and relationships between regression coefficients on the target variable at different points; in our case, for HDI and CO_2 emissions. This study uses data extracted from World Bank Development indicators, which are available online, and HDI data from https://countryeconomy.com/.

TABLE 1 Descriptive statistics.

	CO_2	G	GDP	HDI	INF
Mean	7053457	15.49763	6.2239	0.6694	2190569
Median	7189817	15.74849	4.6130	0.6780	2374270
Maximum	11192409	17.63135	1.9540	0.8182	2968946
Minimum	3021242	13.13564	6.7703	0.5411	1250450
Std. Dev	2989032	1.130671	5.2703	0.0754	618207.5
Skewness	−0.125982	−0.297579	0.6108	−0.0931	−0.333549
Kurtosis	1.393126	2.301046	2.0448	1.7426	1.534380
Jarque-Bera	11.90489	3.792371	10.8211	7.2706	11.66878
Probability	0.002599	0.150140	0.0044	0.0263	0.002925
Sum	7.623939	1673.744	6.72021	72.2960	2.37012
Sum Sq. Dev	9.560376	136.7906	2.97021	0.609145	4.09021

5 Results and discussion

This section provides our results and discussion. We use the effect of infrastructure (INF) on the factors such as CO_2 emissions and HDI, and control for GDP and government spending (G). Table 1 presents descriptive statistics for the variables included in the model. GDP has high mean value, whereas CO_2 and infrastructure have subsequent high value. GDP has the highest variation among model variables, followed by CO_2 emissions and infrastructure.

Table 2 presents the results of our quantile regressions. We use infrastructure as the independent variable and take HDI and CO_2 emissions as dependent variables. GDP and G are control variables. The quantile regressions suggest that HDI is positively and statistically significantly associated with infrastructure in all quantiles, which indicates that infrastructure increases HDI in all quantiles. This implies that HDI can be enhanced by developing infrastructure. These findings are consistent with those of Sapkota (2014), Mohanty et al. (2016), and Nchofoung et al. (2022), who found a positive and statistically significant relationship between infrastructure and HDI. Infrastructure types such as access to hospitals and health help to improve public health and standards of living. In addition, access to water, schools, banking, village electricity, postal services, and telecommunications are essential in promoting and facilitating businesses and employment opportunities. Therefore, infrastructure acts as channel through which individuals can earn an income, improve their livelihoods, set up income generating activities, improve their health, and gain skills and education. Investments should therefore be made to develop new infrastructure and improve existing infrastructure.

The second model shows the relationship between CO_2 emissions and infrastructure; our results suggest that infrastructure level is statistically significantly associated with CO_2 emission levels for all quantiles. This implies that infrastructure upgrading leads to higher levels of energy consumption, which increases CO_2 emissions. This result is supported by previous researchers who have also found a positive relationship between infrastructure and CO_2 emissions (Dzator et al., 2021). Construction and operation of infrastructure such as transport systems, buildings, and plants increase CO_2

TABLE 2 Quantile regression results.

Dependent variable					
		HDI	CO2	GDP	G
Independent Variable	Quantile	Coefficient	Coefficient	Coefficient	Coefficient
Inf	0.100	1.0001 (0.0000)	3.8950 (0.0000)	3874447. (0.0000)	1.09021 (0.0000)
	0.200	1.0002 (0.0000)	3.90953 (0.0000)	4219649. (0.0000)	1.1135 (0.0000)
	0.300	9.43201 (0.0000)	3.923139 (0.0000)	3837541. (0.0000)	1.13532 (0.0000)
	0.400	9.47029 (0.0000)	3.956296 (0.0000)	4398242. (0.0000)	1.18929 (0.0000)
	0.500	9.63029 (0.0000)	4.268306 (0.0000)	5332674. (0.0000)	6.60292 (0.0866)
	0.600	1.12029 (0.0000)	4.685580 (0.0000)	7418318. (0.0000)	5.98039 (0.0732)
	0.700	1.20029 (0.0000)	4.913026 (0.0000)	8328711. (0.0000)	2.28029 (0.3494)
	0.800	1.30029 (0.0000)	5.202157 (0.0000)	9019529. (0.0000)	1.85938 (0.3809)
	0.900	1.46029 (0.0000)	5.597264 (0.0000)	9378368. (0.0000)	2.50793 (0.1997)

TABLE 3 Diagnostic test.

Quantile slope equality test				
Dependent variable				
Independent Variable	HDI	Co2	GDP	G
	Coefficient	Coefficient	Coefficient	Coefficient
	25.49642 (0.0000)	32.72275 (0.0000)	57.01067 (0.0000)	15.73248 (0.0000)
Symmetric Quantiles Test				
	13.77296 (0.0000)	3.054296 (0.2172)	4.222157 (0.1211)	0.194210 (0.9075)
Coefficient Stability Test—Wald Test				
	272.5212 (0.0000)	540.8883 (0.0000)	72.51726 (0.0000)	2.991122 (0.0837)

emissions, and development of infrastructure and transitional phases increase consumption of energy. China has invested heavily in infrastructure, and a large percentage of this infrastructure is run using non-renewable sources of energy, so the impact on CO_2 emissions is immense. Furthermore, with increasing population and access, infrastructure drives CO_2 emissions *per capita* in the country.

Our third model tests the relationship between GDP and infrastructure; for all quantiles, infrastructure is positively and statistically significantly associated with GDP, suggesting that infrastructure development improves GDP. Infrastructure is crucial in fostering economic development and prosperity. Infrastructure upgrades for transitional economies such as China help to increase economic growth and production and enable the country to utilize both its human and capital resources. These findings are supported by previous studies such as Chawla et al. (2022), and because the calculation of HDI incorporates a GDP measure, the findings suggest one mechanism by which infrastructure development promotes HDI.

The relationship between government spending (G) and infrastructure is presented in final model. Quantiles 1 to 4 show a positive relationship between these variables. However, quantiles 5 to 9 have no significant association. This means that increase in infrastructure stimulate the government spending only for lower quantiles of infrastructure. Infrastructure projects usually take a long time to complete, which means they create relatively long-term job opportunities. The association between government spending and infrastructure may also be bidirectional, whereby government spending may drive upgrading of infrastructure (Tam, 1999). Furthermore, infrastructure increase employment levels, raises people's income levels, and stimulates economic activity in the country.

Table 3 reports diagnostic tests for the quantile regression, including slope equality tests for median regressions for the different models. The findings are tested using Chi-square statistics and restrictions are imposed on the lower and upper quantiles. The Chi-square values are significant at the 5% level across the different models; we conclude from these statistics that

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TABLE 4 Pairwise granger causality tests.

Null hypothesis	F-Statistic	Prob
G does not Granger Cause CO2	2.76088	0.0991
CO_2 does not Granger Cause G	1.66004	0.2000
GDP does not Granger Cause CO2	39.4241	5.0122
CO_2 does not Granger Cause GDP	0.27159	0.6032
HDI does not Granger Cause CO2	8.31263	0.0046
CO_2 does not Granger Cause HDI	8.01617	0.0054
INF does not Granger Cause CO2	54.1884	4.9291
CO_2 does not Granger Cause INF	6.12960	0.0149
GDP does not Granger Cause G	4.44871	0.0369
G does not Granger Cause GDP	0.27090	0.6037
HDI does not Granger Cause G	0.90907	0.3422
G does not Granger Cause HDI	1.65379	0.2008
INF does not Granger Cause G	0.06411	0.8006
G does not Granger Cause INF	1.11449	0.2936
HDI does not Granger Cause GDP	6.9044	0.0161
GDP does not Granger Cause HDI	1.96616	0.1634
INF does not Granger Cause GDP	2.85134	0.0943
GDP does not Granger Cause INF	11.4008	0.0010
INF does not Granger Cause HDI	4.29712	0.0406
HDI does not Granger Cause INF	1.99238	0.1611

the coefficients differ across quantiles and conditional quantiles are not identical. The coefficient stability test is based on the Wald test and suggests that in almost all models, probability values are statistically significant, implying that variable coefficients are stable. Granger Causality tests is applied for robustness estimation, which main validates or support the bassline findings. Table 4 represents Granger Causality tests which indicate the casual relationships between variables. GDP drives CO_2 emissions, which implies that increases in economic activity cause increased CO_2 emissions in China. There is bidirectional causality between HDI and CO_2 emissions, indicating that HDI increase CO_2 emissions and CO_2 emissions increase HDI. This means infrastructure improvements boost economic activity and lead to higher CO_2 emissions. There is unidirectional causality between HDI and GDP, and the results suggest that infrastructure upgrading increases GDP.

Overall, the results suggest that infrastructure upgrading increases HDI and CO_2 emissions in China. With population growth in both developed and developing countries, the demand for high-quality infrastructure is increasing, and such infrastructure narrows income disparities, creates new employment, increases business opportunities, and sustains economic growth. In addition to developing infrastructure, countries with sustainable economic growth goal may seek to transition from fossil fuel energy to renewable energy, to achieve economic growth and a clean environment. Therefore, future infrastructure developments should address financial, climate, and inclusive challenges. Governments should also consider technological upgrades to existing infrastructure to enable more efficient use. This can help increase economic productivity, thus increasing HDI and GDP, and reducing emissions. The results of this study are in line with other studies such as Xu et al. (2022), Zhou et al. (2022), Emodi et al. (2022), Chawla et al. (2022), Yin and Jin (2021) and reported a positive relationship between HDI, CO_2 emissions and infrastructure.

6 Conclusion

The modernization and development of China's economy is based on upgrading the country's infrastructure. China's economic growth is rapid, but environmental challenges are one of the main concerns to both academia and government. Therefore, this study explores the relationships between infrastructure, HDI, and CO_2 emissions in China. We use time series data from 1990 to 2021 and a quantile regression method. Our findings reveal that infrastructure positively influences CO_2 emissions, but also improves HDI in China. Infrastructure also has positive implications for GDP and government spending.

Based on these findings, we suggest the following policy recommendations. First, the government should plan to establish low carbon infrastructure to reduce environmental pollution in the country. Therefore, infrastructure is needed to transition from consumption of fossil fuels to renewable energy. This could help to both provide the energy needed for infrastructure processes and achieve environmental sustainability. Indeed, these efforts will eventually lead China to become a zero-emissions country by 2050. Second, the government should invest in research and development (R&D) and in particular should direct reasonable expenditure towards infrastructure R&D, innovation, and new technologies that could help achieve low carbon emissions. Third, the government may choose other options in infrastructure development and establish low carbon transportation systems, such as railway infrastructure and urban transport projects including metros and light rail, and renewable energy projects such as hydro-power, wind, and solar generation. This sustainable infrastructure could help China to achieve both higher HDI and environmental sustainability goals.

This study has some limitations. First, the study only considers China, so our findings may not be generalisable to other countries. Future studies should examine other countries to test the relationships between infrastructure and HDI and CO_2. The second limitation is the nature of the data used. Whereas we use annual time-series data, future research may use household data. The third limitation is that we include transportation investment by government and public investment in infrastructure; future research may use another proxy for infrastructure to analyse the relationship between HDI and CO_2 emissions. Fourthly we applied quantile regression, the future studies may use some additional sophisticated techniques if short run and long run effect is desirable; some advance techniques such as quantile ARDL can applied which will provide both short run and long estimation. Fifthly future studies may use the regional or provisional effect in China and CO_2 emission and HDI effect in China. Sixthly the future research may add technological innovation in model which may provide most clear implications infrastructure for HDI and CO_2 emissions.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://databank.worldbank.org/country/CHN/556d8fa6/Popular_countries.

Author contributions

YL: Conceptualization, writing of main draft PeP: Funding and review the main draft PaP: Data collection, review of the main draft FU: Data analysis SN: Review the final draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Abbas, A., Chengang, Y., Zhuo, S., Manzoor, S., Ullah, I., Mughal, Y. H., et al. (2021). Role of responsible leadership for organizational citizenship behavior for the environment in light of psychological ownership and employee environmental commitment: A moderated mediation model. *Front. Psychol.* 12, 756570. doi:10.3389/fpsyg.2021.756570

Acheampong, A. O., Opoku, E. E. O., Dzator, J., and Kufuor, N. K. (2022). Enhancing human development in developing regions: Do ICT and transport infrastructure matter? *Technol. Forecast. Soc. Change* 180, 121725. doi:10.1016/j.techfore.2022.121725

Akbar, M., Hussain, A., Akbar, A., and Ullah, I. (2021). The dynamic association between healthcare spending, CO2 emissions, and human development index in OECD countries: Evidence from panel VAR model. *Environ. Dev. Sustain.* 23 (7), 10470–10489. doi:10.1007/s10668-020-01066-5

Bashir, M. A., Dengfeng, Z., Bashir, M. F., Rahim, S., and Xi, Z. (2022a). Exploring the role of economic and institutional indicators for carbon and GHG emissions: Policy-based analysis for OECD countries. *Environ. Sci. Pollut. Res.* 2022, 1–15. doi:10.1007/s11356-022-24332-7

Bashir, M. A., Dengfeng, Z., Shahzadi, I., and Bashir, M. F. (2022b). Does geothermal energy and natural resources affect environmental sustainability? Evidence in the lens of sustainable development. *Environ. Sci. Pollut. Res.* 2022, 1–12. doi:10.1007/s11356-022-23656-8

Bashir, M. F. (2022). Discovering the evolution of pollution haven hypothesis: A literature review and future research agenda. *Environ. Sci. Pollut. Res.* 29, 48210–48232. doi:10.1007/s11356-022-20782-1

Cantos Sanchez, P., and Gumbau Albert, M. (2015). Transport infrastructures, CO2 emissions and economic growth: New evidence from OECD countries. *Int. J. Transp. Econ.* 42, 251–270.

Chawla, S., Rahman, A., and Sharma, S. (2022). "Human development index among states of India: An empirical study," in 7th North American International Conference on Industrial Engineering and Operations Management, Florida, 12-14 June,2022.

Churchill, S. A., Inekwe, J., Ivanovski, K., and Smyth, R. (2021). Transport infrastructure and CO2 emissions in the OECD over the long run. *Transp. Res. Part D Transp. Environ.* 95, 102857. doi:10.1016/j.trd.2021.102857

Djokoto, J. G. (2022). The investment development path and human development: Is there a nexus? *Res. Glob.* 4, 100079. doi:10.1016/j.resglo.2021.100079

Dzator, J., Acheampong, A. O., and Dzator, M. (2021). The impact of transport infrastructure development on carbon emissions in OECD countries. *Environ. Sustain. Econ.* 2021, 3–17. Elsevier. doi:10.1016/B978-0-12-822188-4.00006-3

Economy, E. C. (2018). China's new revolution: The reign of Xi Jinping. *Foreign Aff.* 97 (3), 60–74.

Emodi, N. V., Inekwe, J. N., and Zakari, A. (2022). Transport infrastructure, CO2 emissions, mortality, and life expectancy in the Global South. *Transp. Policy* 128, 243–253. doi:10.1016/j.tranpol.2022.09.025

Furno, M., and Vistocco, D. (2008). *Quantile regression: Estimation and simulation, volume 2.* New York, United States: Wiley. Vol. 216.

Gould, W. (1998). "Interquartile and simultaneous-quantile regression," in *Stata Technical Bulletin 7*, 38.

Hoang, T. V. H., Dang, N. H., Tran, M. D., Van Vu, T. T., and Pham, Q. T. (2019). Determinants influencing financial performance of listed firms: Quantile regression approach. *Asian Econ. Financial Rev.* 9 (1), 78–90. doi:10.18488/journal.aefr.2019.91.78.90

Horvat, T., Bendix, H., Bobek, V., and Skoko, H. (2021). Impacts of investments in infrastructure projects on emerging markets' growth: The case of east african countries. *Econ. Research-Ekonomska Istraživanja* 34 (1), 2135–2161. doi:10.1080/1331677x.2020.1860799

Huang, Q., Zhang, H., Chen, J., and He, M. (2017). Quantile regression models and their applications: A review. *J. Biometrics Biostat.* 8 (3), 1–6. doi:10.4172/2155-6180.1000354

Hussain, M., Abbas, A., Manzoor, S., and Chengang, Y. (2022). Linkage of natural resources, economic policies, urbanization, and the environmental Kuznets curve. *Environ. Sci. Pollut. Res.* 30, 1451–1459. doi:10.1007/s11356-022-22339-8

Kusharjanto, H., and Kim, D. (2011). Infrastructure and human development: The case of java, Indonesia. *J. Asia Pac. Econ.* 16 (1), 111–124. doi:10.1080/13547860.2011.539407

Ling, Y., Xia, S., Cao, M., He, K., Lim, M. K., Sukumar, A., et al. (2021). Carbon emissions in China's thermal electricity and heating industry: An input-output structural decomposition analysis. *J. Clean. Prod.* 329, 129608. doi:10.1016/j.jclepro.2021.129608

Lyu, Y., Ji, Z., Liang, H., Wang, T., and Zheng, Y. (2022). Has information infrastructure reduced carbon emissions?—evidence from panel data analysis of Chinese cities. *Buildings* 12 (5), 619. doi:10.3390/buildings12050619

Meng, Q., Mills, A., Wang, L., and Han, Q. (2019). What can we learn from China's health system reform? *bmj* 365, l2349. doi:10.1136/bmj.l2349

Mohanty, A. K., Nayak, N. C., and Chatterjee, B. (2016). Does infrastructure affect human development? Evidences from Odisha, India. *J. Infrastructure Dev.* 8 (1), 1–26. doi:10.1177/0974930616640086

Mohmmed, A., Li, Z., Arowolo, A. O., Su, H., Deng, X., Najmuddin, O., et al. (2019). Driving factors of CO2 emissions and nexus with economic growth, development and human health in the Top Ten emitting countries. *Resour. Conservation Recycl.* 148, 157–169. doi:10.1016/j.resconrec.2019.03.048

Müller, D. B., Liu, G., Løvik, A. N., Modaresi, R., Pauliuk, S., Steinhoff, F. S., et al. (2013). Carbon emissions of infrastructure development. *Environ. Sci. Technol.* 47 (20), 11739–11746. doi:10.1021/es402618m

Nchofoung, T. N., Asongu, S. A., Njamen Kengdo, A. A., and Achuo, E. D. (2022). Linear and non-linear effects of infrastructures on inclusive human development in Africa. *Afr. Dev. Rev.* 34 (1), 81–96. doi:10.1111/1467-8268.12619

Rahman, M. M., Nepal, R., and Alam, K. (2021). Impacts of human capital, exports, economic growth and energy consumption on CO2 emissions of a cross-sectionally dependent panel: Evidence from the newly industrialized countries (NICs). *Environ. Sci. Policy* 121, 24–36. doi:10.1016/j.envsci.2021.03.017

Razmi, M. J., Abbasian, E., and Mohammadi, S. (2012). Investigating the effect of government health expenditure on HDI in Iran. *J. Knowl. Manag. Econ. Inf. Technol.* 2 (5).

Rogers, W. (1994). "Regression standard errors in clustered samples," in *Stata technical bulletin 3*, 13.

Sadiq, M., Wen, F., Bashir, M. F., and Amin, A. (2022). Does nuclear energy consumption contribute to human development? Modeling the effects of public debt and trade globalization in an OECD heterogeneous panel. *J. Clean. Prod.* 375, 133965. doi:10.1016/j.jclepro.2022.133965

Sapkota, J. B. (2014). "Access to infrastructure and human development: Cross-Country evidence," in *Working Papers 70* (JICA Research Institute).

Shan, Y., Fang, S., Cai, B., Zhou, Y., Li, D., Feng, K., et al. (2021). Chinese cities exhibit varying degrees of decoupling of economic growth and CO2 emissions between 2005 and 2015. *One Earth* 4 (1), 124–134. doi:10.1016/j.oneear.2020.12.004

Sharif, F., and Tauqir, A. (2021). The effects of infrastructure development and carbon emissions on economic growth. *Environ. Sci. Pollut. Res.* 28 (27), 36259–36273. doi:10.1007/s11356-021-12936-4

Tam, C. M. (1999). Build-operate-transfer model for infrastructure developments in Asia: Reasons for successes and failures. *Int. J. Proj. Manag.* 17 (6), 377–382. doi:10.1016/s0263-7863(98)00061-1

Tan, D., Komal, B., Ezeani, E., Usman, M., and Salem, R. (2022). Carbon emission disclosures and financial reporting quality: Does ownership structure and economic development matter? *Environ. Sci. Policy* 137, 109–119. doi:10.1016/j.envsci.2022.08.004

Ullah, I., Ali, S., Shah, M. H., Yasim, F., Rehman, A., and Al-Ghazali, B. M. (2019). Linkages between trade, CO2 emissions and healthcare spending in China. *Int. J. Environ. Res. Public Health* 16 (21), 4298. doi:10.3390/ijerph16214298

Ullah, I., Rehman, A., Khan, F. U., Shah, M. H., and Khan, F. (2020). Nexus between trade, CO2 emissions, renewable energy, and health expenditure in Pakistan. *Int. J. Health Plan. Manag.* 35 (4), 818–831. doi:10.1002/hpm.2912

UNDP (2017). *China national human development report special edition*. New York, United States: UNDP.

Wang, X., Dong, F., Pan, Y., and Liu, Y. (2022). Transport infrastructure, high-quality development and industrial pollution: Fresh evidence from China. *Int. J. Environ. Res. Public Health* 19 (15), 9494. doi:10.3390/ijerph19159494

Xia, W., Apergis, N., Bashir, M. F., Ghosh, S., Doğan, B., and Shahzad, U. (2022). Investigating the role of globalization, and energy consumption for environmental externalities: Empirical evidence from developed and developing economies. *Renew. energy* 183, 219–228. doi:10.1016/j.renene.2021.10.084

Xu, H., Cao, S., and Xu, X. (2022). The development of highway infrastructure and CO2 emissions: The mediating role of agglomeration. *J. Clean. Prod.* 337, 130501. doi:10.1016/j.jclepro.2022.130501

Yang, L., and Lin, B. (2016). Carbon dioxide-emission in China′ s power industry: Evidence and policy implications. *Renew. Sustain. Energy Rev.* 60, 258–267. doi:10.1016/j.rser.2016.01.058

Yin, X., and Zong, X. (2022). International student mobility spurs scientific research on foreign countries: Evidence from international students studying in China. *J. Inf.* 16 (1), 101227. doi:10.1016/j.joi.2021.101227

Yin, Z., and Jin, X. (2021). Recent advances in the relationship between economic development and carbon emissions. *Manag. Environ. Qual. Int. J.* 33, 141–165. doi:10.1108/meq-07-2021-0175

Zeeshan, M., Han, J., Rehman, A., Ullah, I., Afridi, F. E. A., and Fareed, Z. (2022a). Comparative analysis of trade liberalization, CO2 emissions, energy consumption and economic growth in southeast asian and Latin American regions: A structural equation modeling approach. *Front. Environ. Sci.* 79. doi:10.3389/fenvs.2022.854590

Zeeshan, M., Ullah, I., Rehman, A., and Afridi, F. E. A. (2022b). Trade openness and urbanization impact on renewable and non-renewable energy consumption in China. *Environ. Sci. Pollut. Res.* 29 (27), 41653–41668. doi:10.1007/s11356-021-18353-x

Zhang, Z. (2000). Decoupling China's carbon emissions increase from economic growth: An economic analysis and policy implications. *World Dev.* 28 (4), 739–752. doi:10.1016/s0305-750x(99)00154-0

Zhao, X., Jiang, M., and Zhang, W. (2022). Decoupling between economic development and carbon emissions and its driving factors: Evidence from China. *Int. J. Environ. Res. Public Health* 19 (5), 2893. doi:10.3390/ijerph19052893

Zhou, Q., Liu, Y., and Qu, S. (2022). Emission effects of China's rural revitalization: The nexus of infrastructure investment, household income, and direct residential CO2 emissions. *Renew. Sustain. Energy Rev.* 167, 112829. doi:10.1016/j.rser.2022.112829

Zietz, J., Zietz, E. N., and Sirmans, G. S. (2008). Determinants of house prices: A quantile regression approach. *J. Real Estate Finance Econ.* 37 (4), 317–333.