Information Management and Business Review (ISSN 2220-3796)
Vol. 16, No. 1, pp. 204-215, SI(1) 2024

The Impact of Foreign Direct Investment, Green Technology Innovation and GDP on CO_2 Emissions in Western China: A Static Panel Data Analysis

Yunxiu Qiu[1], Soo-Cheng Chuah[1*] Ruhaini Muda[1], Theng-Huey Goh[2]
[1]Faculty of Business and Management, Universiti Teknologi MARA, Selangor, Malaysia
[2]Tunku Puteri Intan Safinaz School of Accountancy, Univerisiti Utara Malaysia, Kedah, , Malaysia
6548738@qq.com, *chuahsc@uitm.edu.my, ruhaini@uitm.edu.my, goh_theng_huey2@tissa.uum.edu.my

Abstract: This study investigates the impact of FDI, green technology innovation and GDP on CO_2 emissions in the western region of China. This study applies the extended STIRPAT model, selects the relevant data of nine provinces in western China from 2000 to 2019, applies the static panel data analysis method, compares and analyses the estimation methods of Pooled OLS, fixed effect and random effect, and finally adopts the robust standard error estimation method of fixed effect. The results of the robust standard error estimation indicate that, in addition to the negative impact of green technology innovation on CO_2 emissions, CO_2 emissions are positively impacted by FDI, GDP, population, and the proportion of the secondary and tertiary industries. Therefore, reasonable introduction of FDI and improving green technology innovation levels are crucial in reducing CO_2 emissions in the western region of China.

Keywords: *Foreign Direct Investment, Greem Technology Innovation, GDP, CO_2 Emissions, Western China*

1. Introduction and Background

Globalization has facilitated the world economy's growth, but it has also caused negative environmental impacts, such as ecological damage, the greenhouse effect, and increased CO_2 emissions. The latter has been identified as a significant contributor to climate change and global warming (Ahmed et al.， 2019). This issue has attracted widespread attention from scholars and policymakers around the world. There are many factors contributing to the increase in CO_2 emissions. Human activity, mainly fossil fuel burning, was identified as the main cause of global warming and greenhouse gases, particularly CO_2, have increased due to human activity (the IPCC Sixth Assessment Report, AR6, 2021). International treaty agreements have been reached by countries worldwide to reduce global CO_2 emissions. These include the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol, and the Paris Agreement. Since 2005, China, as a developing country, has surpassed the United States as the largest emitter of CO_2 (World Bank database, 2022). China's CO_2 emissions have increased every year over the past two decades accounting for approximately one-third of the global total annual CO_2 emissions.

Foreign Direct Investment (FDI) is a crucial component of globalization activities worldwide (Doytch, 2020). FDI facilitates the global movement of factors of production and contributes to economic development, technology transfer, and the mobility of people (Gan & Yin, 2016; Qi & Vilaiphorn, 2019; Doytch, 2020; Hu et al., 2021). At the same time, it also brings many negative impacts on the environment of the host country particularly developing countries, such as the increase in CO_2 emissions. There are two contradictory arguments on the nexus of FDI and environment quality – pollution haven and pollution halo hypotheses. The pollution halo hypothesis claims that foreign direct investments result in a decrease in emissions, while the pollution haven hypothesis holds that foreign direct investments cause emissions to rise.

To improve the increasing environmental degradation problems, governments worldwide are taking various measures to reduce CO_2 emissions, including improving recyclable and green technology innovation and promoting green consumption. Green technology innovation refers to technologies, processes and products that reduce environmental pollution and lessen energy use (Braun & Wield, 1994). Green technology innovation is essential for achieving a low-carbon economy (Xu et al., 2022). Current research on green technology innovation concentrates on energy conservation, environmental optimization, and low-carbon development, with a focus on technological advancements that contribute to energy conservation and emission reduction (Long et al. 2017; Sellitto et al. 2020; M. Wang et al. 2021).

China has 34 provincial administrative regions (which are referred to as provinces) that can be divided into the Eastern Region (12), the Central Region (9), the Western Region (10), and Hong Kong, Macao and Taiwan

(3). The National Development and Reform Commission (NDRC) of China reports that the coastal opening policy was first implemented in the eastern region, which is more economically developed. In contrast, the central region is less developed, and the western region is economically underdeveloped. There are clear disparities between China's regions in terms of FDI, economic growth, and CO_2 emissions. FDI is distributed unevenly across regions (B. Zhou & Shao, 2020), in which most of the FDI inflows mainly focus on the eastern coastal region, comparatively FDI inflows to central and western regions are relatively low. Since 2000, China has implemented several policies to stimulate economic growth in the central and western regions.

The "Western Development" strategy implemented in 2000 has resulted in significant economic growth, increased FDI, and green technology innovation in the Western region. This has increased significant FDI inflows to western regions and increased CO2 emissions. Western China's CO2 emissions climbed from 2158 million tonnes in 2010 to 3140 million tonnes in 2019, accounting for a rise in the country's overall CO2 emissions from 25.8% in 2010 to 28.6% in 2019 (Yang et al, 2023). However, variations in the utilization of foreign investment, capacity for green technology innovation, and economic growth among the western provinces of China are due to variations in regional investment promotion policies and environmental regulations. There is limited study on the nexus of FDI and CO2 emissions in the western region of China. Thus, this study aims to examine the impact of FDI, green technology innovation, and economic growth on CO_2 emissions in the western provinces of China.

2. Literature Review

Theoretical Framework

There are two theories about the relationship between FDI and environmental pollution. The first theory is the Pollution Haven Hypothesis (Walter & Ugelow, 1979; Baumol & Oates, 1988). FDI can increase CO_2 emissions in developing countries when their economic development is in the early stages. Increased CO_2 emissions mean more environmental pollution. Many scholars agree with this view, such as S. Wang et al. (2017), K. Zhang (2019), Do & Dinh (2020), Nadeem et al. (2020), Abdo et al. (2020), etc. The second theory is the Pollution Halo Hypothesis. It is believed that FDI can lead to a reduction in CO_2 emissions in host countries and contribute to environmental improvement. This view is also supported and endorsed by many scholars, such as Sapkota & Bastola (2017), Pazienza (2019), Zubair et al. (2020), Long et al., (2020), etc.

Furthermore, the STIRPAT model (Grossman & Krueger, 1995; York et al., 2003; Dietz & Rosa, 1994) is an extension of the IPAT model (Ehrlich & Holdren, 1971) and examines the factors that influence CO_2 emissions. It considers the effects of population, affluence, technology, and other factors on CO_2 emissions. Many scholars (Ghazali & Ali, 2019; Kong et al., 2022; etc.) use the STIRPAT model to examine the impact of population, affluence, technology, and other factors on CO_2 emissions. They arrive at different research conclusions due to differences in research subjects, time, etc. (Oladunni et al., 2022; Wen et al., 2022; Udeagha & Ngepah, 2022; etc.). Many scholars have also used the model to study China's CO_2 emissions from different perspectives, such as from the perspective of a single province in China (Du, 2020; Song & Xu, 2021), from the perspective of several provinces in China (Liu & Han, 2021; Guo & Zhao, 2022), from the perspective of a city or province in China (Xu & Ren, 2018), from the perspective of many cities in China (Huangfu et al., 2020; Tang & Hu, 2021; Zhao & Xi, 2022), from the perspective of transportation industry (Zhu et al., 2022).

FDI and CO_2 Emissions

There are contradictory arguments on the impact of FDI on CO_2 emissions as there are significant differences in the scale effect, the structural effect and the technology effect of FDI on CO_2 emissions. Some scholars found FDI can reduce CO_2 emissions in China from a different perspective. Dang (2018) and Wen (2021) studied FDI in various provinces. Dang (2018) selected panel data from 29 provinces in China from 1990 to 2016 and built an Autoregressive Distributed Lag (ARDL) panel model to investigate the impact of trade and FDI on CO_2 emissions in China. Wen (2021) used a threshold model and a fixed effect model to investigate the impact of FDI and industrial structure on CO_2 emissions in 30 provinces in China from 2004 to 2018. They all found that FDI inhibited the growth of CO_2 emissions. Elliott et al. (2013) studied FDI in various cities. He used the panel data of 206 of the largest prefecture-level cities in China from 2005 to 2008 and suggested that FDI could help reduce CO_2 emissions in inflowing countries. Xu (2016) and Cao et al. (2020) focused on FDI in a specific province. Xu (2016) studied the impact of FDI on CO_2 emissions in Shandong Province from 1995 to 2012. Cao et al. (2020) chose the data of Zhejiang province from 2005 to 2016 for the study. Both of them found that FDI could significantly reduce CO_2 emissions.

On the other hand, Su et al. (2021) studied FDI in 31 provinces in China from 2000 to 2019 and found FDI was associated with increasing CO_2 emissions. Yang & Wang (2022) used panel data from 30 provinces in China from 2003 to 2019 to construct the spatial Durbin model and found FDI contributed to increase CO_2 emissions in the eastern and western regions of China but had little impact after that according to the study. FDI intensity in 283 Chinese cities from 1992 to 2013 was the primary factor contributing to the increase in CO_2 emissions (Wang et al., 2019). Wu & Liu (2021) also found that FDI in 281 cities in China from 2008 to 2017 was associated with an increase in CO_2 emissions. However, FDI had different impacts on CO_2 emissions based on the region. While FDI contributed to the increase in CO_2 emissions in the Bohai Rim Economic Circle, the opposite was true in the Yangtze River Delta and Pearl River Delta regions (Zhu & Wei, 2018).

Moreover, some scholars have even found that there is a threshold effect in the impact of FDI on CO_2 emissions in China, such as Huang (2017), Wang (2019), etc. For instance, Wang (2019) selected panel data from 2003 to 2016 in 29 provinces in China and applied the panel threshold model to analyze the impact of financial development and two-way foreign direct investment (FDI) on China's CO_2 emissions. According to the study, there was a financial development threshold identified for the carbon emission effect of two-way FDI. CO_2 emissions were significantly reduced when financial development reached a high level, and outward DFI and inward FDI were significant contributors to this carbon emission reduction.

Green Technology Innovation and CO_2 Emissions

There is limited literature on the impact of green technology innovation on CO_2 emissions, and most of it focuses on the impact of technology innovation on CO_2 emissions. Similarly, there are fewer studies on the impact of green technology innovation on CO_2 emissions in China. The conclusions of China's CO_2 emissions differ slightly due to differences in the research objects. There is less empirical evidence on the role of green technology innovation in economic growth and CO_2 emission reduction in China (Hu & Shi, 2022). However, green technology innovation can effectively reduce CO_2 emissions in China (Qian & Li, 2017; Wu & Zhao, 2021). Qian & Li (2017) combined green technology innovation with carbon emission intensity at the industrial level to develop a model and found green technology innovation had become an increasingly significant factor in reducing CO_2 emissions. Furthermore, Wu & Zhao (2021) selected panel data from 2004 to 2018 in 30 provinces in China, decomposed green technology innovation into green product innovation and green process innovation, and used the generalized spatial panel model to study the impact of green technology innovation on the reduction of CO_2 emissions and energy conservation. According to the study, green technology innovations could reduce CO_2 emissions and contribute to energy conservation and carbon emission reduction.

Economic Growth and CO2 Emissions

The Environmental Kuznets Curve (EKC) provides a good representation of the "inverted U-shaped" relationship between economic growth and CO_2 emissions. However, there is no consensus on the relationship between economic growth and CO_2 emissions. In China, their relationships exhibit "inverted U-shaped" (J. Wang & Zhen, 2018; B. Jiang & Ma, 2020; etc.), "U-shaped" (Zhou et al., 2015), "inverted N-shaped" (Liu et al., 2018) or linear characteristics (Yuan & Sun, 2020), even maybe unrelated (Zhao et al., 2021), due to differences in research objects, areas and time. For instance, Wang & Zhen (2018) chose data from nine provinces and two cities in China's Yangtze River Economic Belt from 2000 to 2015, and Jiang & Ma (2020) used China's three northeastern provinces (Liaoning, Jilin, and Heilongjiang) from 1998 to 2018 to examine the relationship between economic growth and CO_2 emissions are "inverted U-shaped". Zhou et al. (2015) found the relationship between the two is "U-shaped" in China from 1978 to 2012. However, in nine provinces in China with GDP per capita over US $10,000 from 1995 to 2015, the relationship between the two is "inverted N-shaped" (Liu et al., 2018). Dividing 30 provincial-level data from 2002 to 2016 into four levels according to their economic development, those provinces with higher income levels had already experienced significant reductions in CO_2 emissions, whereas economically underdeveloped areas were still in the process of urbanization which would accelerate CO_2 emissions (Yuan & Sun, 2020). However, several provinces in China had obvious deviations from the Environmental Kuznets Curve (EKC) theory. Despite this, China's economic growth has been driven largely by energy consumption over the past 50 years (Zhao et al., 2021).

The main reason for the linear relationship between economic growth and CO_2 emissions is that most scholars directly assume a linear relationship in their studies. Some scholars have found that economic growth increases China's CO_2 emissions (Hao & Cao, 2021), while no scholars have found that economic growth reduces China's CO_2 emissions. Economic growth has a greater impact on CO_2 emissions in low-income areas than in high-income areas (Cai & Ye, 2017).

3. Research Methodology

The STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) model (Dietz & Rosa, 1994) is an extension of the IPAT model (Ehrlich & Holdren, 1971). The model is used to analyze the stochastic effects of population, affluence technology and other drivers on the environment. The STIRPAT model is therefore the basis for the construction of the research model in this study. The STIRPAT model is as follows: $\mathrm{I}_i = a\mathrm{P}_i^b \mathrm{A}_i^c \quad {}_i^d e_i$

where, the expression meanings of I, P, A and T are consistent with the IPAT model. a is the model parameter, b, c and d are the driving force index of population, affluence and technology factors respectively, also known as exponents, and e is the random error term. i indicates that these quantities (I, P, A, T, and e) vary with the units of observation.

This study examines the impact of FDI, green technology innovation, and economic growth on CO_2 emissions. FDI, green technology innovation, and economic growth are the core explanatory variables, while population, and the proportion of the secondary industry, as the control variables. The basic static panel data model in this study is shown in equation (1).

$$CO_{2it} = \alpha + \beta_1 FDI_{it} + \beta_2 GTI_{it} + \beta_3 GDP_{it} + \beta_4 POP_{it} + \beta_5 PSI_{it} + \beta_6 PTI_{it} + \varepsilon_{it} \quad (1)$$

where, CO_{2it} equals CO_2 emissions for the province i at time t, a proxy for the environment, FDI_{it} equals the amount of foreign capital actually utilized for the province i at time t, a proxy for foreign direct investment, GTI_{it} equals the number of green patent filings for the province i at time t, a proxy for green technology innovation, GDP_{it} equals GDP per capita for the province i at time t, a proxy for affluence, POP_{it} equals the number of permanent residents at the end of the year for the province i at time t, a proxy for population, PSI_{it} equals the proportion of the added value of the secondary industry in GDP for the province i at time t, a proxy for the proportion of secondary industry, PTI_{it} equals the proportion of the added value of the tertiary industry in GDP for the province i at time t, a proxy for the proportion of tertiary industry. The parameters β_1, β_2, β_3, β_4 and β_5 represent the coefficients for the independent variables, and ε indicates the error term. Furthermore, t stands for the period from 2000 to 2019, and iintendsrovince index in western CChna i = 1,2, … ,9.

This study uses the data from 9 provinces in the western region of China (as shown in Table 1), excluding Tibet due to the unavailability of the data. The description of the data is presented in Table 2.

Table 1: List of Provinces in the western region of China (except Tibet)

Xinjiang	Qinghai	Ningxia
Gansu	Shaanxi	Sichuan
Chongqing	Guizhou	Yunnan

Source: Standards Issued by China's National Bureau of Statistics in 2003

The specific variables and data sources are shown in Table 1.

Table 2: Summary of Variables

VARIABLES		SYMBOL	MEASUREMENT	UNIT	DATA SOURCES	EXPECTED SIGN
Dependent variable	CO_2 emissions	CO_2	CO_2 emissions	million tons	China Emission Accounts and Datasets (CEADs)	-
Explanatory Variables	Foreign Direct Investment	FDI	Actual utilization of foreign capital	million US$	China Statistical Yearbook	Positive
	Green Technology Innovation	GTI	Green patent filing	piece	OECD & the Patent Search and Analysis System of the State Intellectual Property Office of China	Negative
	Economic Growth	GDP	GDP per capita	US$	China Statistical Yearbook & the People's Bank of China	Positive
Control Variables	Population	P	permanent resident population at the end of the year	people	China Statistical Yearbook	Positive
	The Proportion of Secondary Industry	PSI	The proportion of the added value of the secondary industry in GDP	%	China Statistical Yearbook & the People's Bank of China	Positive
	The Proportion of Tertiary Industry	PTI	The proportion of the added value of the tertiary industry in GDP	%	China Statistical Yearbook & the People's Bank of China	Positive

This study employs the method of static panel approaches. The model can be tested simply using a pooled ordinary least square (POLS) test in equation (1). This model is assumed to have a similar intercept and slope across provinces and time. However, the result of regressing may lead to heterogeneity bias.
The model assumes a similar intercept and slope across provinces and time by the regressing equation (1). However, this assumption may lead to heterogeneity bias. Heterogeneity refers to individual-specific effects, which means that all provinces are heterogeneous. Therefore, the slope and intercept should be different for each province. To accommodate this individual-specific effect, the model is used as shown in equation (2).

$$CO_{2it} = \alpha + \beta_1 FDI_{it} + \beta_2 GTI_{it} + \beta_3 GDP_{it} + \beta_4 POP_{it} + \beta_5 PSI_{it} + \beta_6 PTI_{it} + \lambda_i + \mu_{it} \quad (2)$$

where, ε_{it} is decomposed into an individual-specific effect λ_i, indicating the specific unobservable factors of each province, and a random error term μ_{it}. This study could use two aotherstaticpanel approaches to regress equation (2), namely the random effects (RE) and fixed effects (FE) approaches, considering different sslopeandintercept. The iindividual-specificeffectlambdatlambdatlambdatλ_i doesn't change across time. The RE approach considers individual-specific effects as part of the error term and is independently derived from a probability distribution. The FE approach can control unobserved individual-specific fixed effects that are time-invariant and treat individual-specific effects as constant or fixed. Thus, the individual-specific effect is included in the error term in the RE model and the constant term in the FE model, as shown in equations (3) and (4).

$$CO_{2it} = \alpha + \beta_1 FDI_{it} + \beta_2 GTI_{it} + \beta_3 GDP_{it} + \beta_4 POP_{it} + \beta_5 PSI_{it} + \beta_6 PTI_{it} + \lambda_i + \mu_{it} \quad (3)$$
$$CO_{2it} = \alpha + \beta_1 FDI_{it} + \beta_2 GTI_{it} + \beta_3 GDP_{it} + \beta_4 POP_{it} + \beta_5 PSI_{it} + \beta_6 PTI_{it} + \mu_{it} \quad (4)$$

This study uses Breusch Pagan LMs (BPLMs) developed by Breusch and Pagan (1980) and Hausman tests developed by Hausman (1978) to select the research model. If the null hypothesis is rejected, the BP-LM test indicates a preference for the RE model over the POLS model, while the Hausman test indicates a preference for the FE model over the RE model.

4. Results

Descriptive statistics for the dependent and independent variables, using untransformed data, are shown in Table 3. The statistics show a significant imbalance in CO_2 emissions in the western region of China, with a maximum of 455.2746 and a minimum of only 0.8144065. There are also significant differences in FDI, green technology innovation and GDP per capita.

Table 3: Descriptive Statistics

VARIABLES	UNIT	OBS	MEAN	STANDARD DEVIATION	MIN	MAX
CO_2 emissions (CO_2)	million tons	180	151.991	94.501	0.814	455.275
FDI	million US$	180	1334.697	2337.818	4.460	10287.640
Green Technology Innovation (GTI)	piece	180	930.6167	1543.762	3.000	9220.000
GDP per Capita (GDP)	US$	180	3536.271	2685.833	321.506	10994.820
Population (POP)	thousand people	180	32263.740	21754.960	5165.000	83510.000
PSI	%	180	0.446	0.0526	0.328	0.584
PTI	%	180	0.416	0.052	0.323	0.551

The correlation matrix is presented in Table 4 for both dependent and independent variables. All variables are positively correlated with CO_2 emissions, except for the proportion of the secondary industry. The correlation coefficients among all independent variables are not greater than 0.7. Several of the correlation coefficients in the table are statistically significant at 0.01.

Table 4: Correlation Matrix

	CO2	FDI	GTI	GDP	POP	PSI	PTI
CO2	1.000						
FDI	0.585***	1.000					
GTI	0.568***	0.787***	1.000				
GDP	0.578***	0.450***	0.612***	1.000			
POP	0.537***	0.600***	0.469***	-0.023	1.000		
PSI	-0.117	0.202***	-0.102	0.124*	-0.212***	1.000	
PTI	0.212***	0.038	0.386***	0.424***	-0.076	-0.659***	1.000

Notes: * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Next, this study will conduct various regression analyses. The full regression results are shown in Table 5. Table 5 shows the positive impact of FDI and GDP on CO_2 emissions, as well as the negative impact of green technology innovation on CO_2 emissions.

Table 5: Results of FDI, Green Technology Innovation and Economic Growth on CO_2 Emissions Using Static Approaches, 2000-2019

	POLS	*FIXED EFFECT*	*RANDOM EFFECT*	*FE ROBUST STANDARD ERROR*
FDI	0.0111*** (0.0040)	0.0140** (0.0026)	0.0115*** (0.0029)	0.0140*** (0.0035)
GTI	-0.0095*** (0.0034)	-0.0122*** (0.0022)	-0.0106*** (0.0025)	-0.0122** (0.0050)
GDP	0.0266887*** (0.0024637)	0.0088*** (0.0021)	0.0173*** (0.0020)	0.0088* (0.0046)
POP	0.0018*** (0.0003)	0.0209*** (0.0031)	0.0030*** (0.0006)	0.0209* (0.0128)
PSI	-619.1162*** (168.5338)	854.0271*** (159.5066)	494.5532*** (172.9059)	854.0271*** (194.7089)
PTI	-386.1408*** (166.2390)	1040.4830*** (150.1000)	639.7635*** (163.2289)	1040.4830*** (233.7663)
cons	433.4994*** (137.8742)	-1368.8740*** (173.3938)	-513.6415*** (141.8579)	*-1368.8740** *(443.9727)*
$\bar{R}^2$	0.6610			
RMSE	55.024			
Poolability test		*37.91* *(0.0000)*		
BPLM test	*215.10* *(0.0000)*			
Hausman test		*37.62* *(0.0000)*		
Heteroscedasticity test		*586.41* *(0.0000)*		
CSD test			*-0.730* *(1.5344)*	
Wooldridge test		*19.789* *(0.0021)*		
VIF test	4.12			
Number of groups		9	9	9
Number of observations	*180*	*180*	*180*	*180*

*Notes: Figures in the parentheses are standard errors. $\bar{R}^2$ indicates adjusted R-squared, RMSE indicates root mean square error, Poolability test indicates the mixed effects of panel data, BPLM indicates Breusch–Pagan LM test, CSD test indicates cross-sectional dependence, Wooldridge test indicates serial correlation, and VIF test indicates multi-collinearity test. Figures in the parentheses for the F-test, BPLM test, Hausman test, Heteroscedasticity test, CSD test,and Wooldridge test are p-values. *, **, and *** indicate the respective 10%, 5%, and 1% significance levels.*

As shown in Table 5, all independent variables of the POLS model have a significant impact on CO_2 emissions at the 1% level of significance. Ir indicates that FDI, GDP and POP are significantly increasing the emissions of CO_2, while GTI, PSI and PTI can reduce CO_2 emissions. However, the impact of PSI and PTI on CO_2 emissions is inconsistent with the expected results. The results of the RE model are comparable to those of the FE model. All independent variables examined in the study have a significant impact on CO_2 emissions at the 1% or 5% significance levels. Moreover, the study revealed that apart from the negative impact of green technology innovation on CO_2 emissions, other factors such as an increase in FDI, GDP, population, the proportion of the secondary industry, and the proportion of the tertiary industry also contribute to an increase in CO_2 emissions. These findings align with the expected results, indicating that changes in all independent variables have a consistent impact on CO_2 emissions.

BPLM testing is required to select the best estimation model between the POLS model and the RE model. As the p-value is less than 0.05, the null hypothesis is rejected, therefore the RE model is superior to the POLS model. Additionally, the Poolability F-test was conducted with a p-value less than 0.05, rejecting the null hypothesis that the FE model is superior to the POLS model. These support the validity of panel data analysis. To select between the RE and FE models, a Hausman test is necessary. Based on the Hausman test results, it is evident that the FE model outperforms the RE model. Furthermore, a series of diagnostic tests are conducted, including the CSD test, serial correlation test, heteroscedasticity test, and multicollinearity test. The result of the CSD test indicates acceptance of the null hypothesis and no correlation with cross-sectional data. The VIF test yields a value of 4.12, indicating no multicollinearity. The results of the Wooldridge and Heteroscedasticity tests both indicate the presence of serial correlation and heteroscedasticity, as their p-values are less than 0.05.

To address issues of serial correlation and heteroscedasticity, this study employs robust standard error estimation for the FE model as shown in column 5, Table 5. The results of the robust standard error estimation indicate that FDI positively significantly increases CO_2 emissions at a 5% significance level. An increase of 1 million US$ in FDI leads to a rise of 0.014 million tons of CO_2 emissions. Green technology was found to hurt CO_2 emissions at a 5% significance level. This indicates greener technology innovation is effective in reducing CO_2 emissions. An increase of 1 unit in green technology innovation results in a decrease of 0.0122 units in CO_2 emissions. Results indicate a significant positive impact of GDP on CO_2 emissions at a 10% significance level implying higher economic growth leading to greater CO_2 emissions. An increase of 1 US$ in GDP per capita results in a rise of 0.00877 million CO_2 emissions. Population, secondary industry, and tertiary industry were found to have significantly impacted CO_2 emissions at 10% and 5% significance levels, respectively. An increase of 1000 people in the population leads to a rise in CO_2 emissions of 0.0209 million tons; a 1% increase in the secondary industry will increase CO_2 emissions by 854.027 million tons; a 1% increase in the tertiary industry will increase CO_2 emissions by 1040.483million tons. overall.

The estimation results show that FDI, GDP, and green technology innovation have a significant positive impact on CO_2 emissions. This suggests that FDI in the western region of China is mainly directed towards industries with high energy consumption and pollution, which in turn increases the pressure to reduce CO_2 emissions. Additionally, GDP growth in the western region contributes to the deterioration of environmental quality by increasing CO_2 emissions. The green technology innovation has reduced CO_2 emissions to some extent, thereby improving the environmental quality of the western region. The western region of China has experienced slower GDP growth and attracts less FDI compared to the central and eastern regions. As a result, regional governments have limited support for green technology innovation, leading to a smaller impact on CO_2 emissions, which is closely linked to regional development.

5. Discussion

This study examines the influence of FDI, green technology innovation, and GDP on CO_2 emissions in nine provinces in the western region of China. This study employs static panel data analysis methods. To begin with, the fixed effects (FE) model was chosen after conducting the Poolability test. Additionally, the random effects (RE) model was selected based on the BPLM test. To determine the most appropriate model, this study employs the Hausman test, which leads to the selection of the fixed effects model. To address potential issues related to serial correlation and heteroscedasticity, a fixed effects model with robust standard error estimation is utilized. This approach helps to ensure the reliability and accuracy of the estimation results. Overall, the estimation results obtained from this study are statistically significant, indicating that the variables under investigation (FDI, green technology innovation, and GDP) have a significant impact on CO_2 emissions in the nine provinces of western China.

The results of the estimation show that introducing FDI and improving green technology innovation levels are crucial in reducing CO_2 emissions in the western region of China. Local governments in the relatively underdeveloped western region of China have neglected the CO_2 emissions caused by GDP growth during the development process. The rise in population and the increase in output value of the secondary and tertiary industries about GDP will inevitably result in a rise in CO_2 emissions in the western region, leading to environmental degradation.

Therefore, the western region of China should focus on attracting high-quality investments, introducing low-energy and low-pollution industries, promoting green technology innovation, improving production processes, reducing CO_2 emissions, and prioritizing intensive economic growth. This will lead to high-quality and low-carbon economic development, ultimately improving environmental quality.

References

Abdo, A.-B., Li, B., Zhang, X., Lu, J., & Rasheed, A. (2020). Influence of FDI on environmental pollution in selected Arab countries: a spatial econometric analysis perspective. Environmental Science and Pollution Research, 27(22), 28222–28246. https://doi.org/10.1007/s11356-020-08810-4

Agrawal, G., & Khan, M. A. (2011). Impact of FDI on GDP: A comparative study of China and India. International Journal of Business and Management, 6(10), 71.

Agya, A. A., & Wunuji, E. A. (2014). Effect of foreign direct investment on China economic growth: a Granger Causality approach. IOSR Journal of Economics and Finance, 2(4), 56-63.

Ahmed, Z., Wang, Z., & Ali, S. (2019). Investigating the non-linear relationship between urbanization and CO_2 emissions: An empirical analysis. Air Quality, Atmosphere and Health, 12(8), 945–953. https://doi.org/10.1007/s11869-019-00711-x

Baumol, W. J., & Oates, W. E. (1988). The Theory of Environmental Policy. In Cambridge University Press. https://doi.org/10.2307/3145303

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. Journal of Econometrics, 87(1), 115-143.

Braun, E., and Wield, D. (1994). Regulation as a Means for the Social Control of Technology. Technology Analysis & Strategic Management, 6 (3), 259–272. doi:10.1080/09537329408524171

Cai, W. H., & Ye, A. Z. (2017). Interactive Relationship among Transportation, Economic Growth and Carbon Emissions Based on PVAR Model. *Journal of Transportation Systems Engineering and Information Technology*, 17(03), 26–31. https://doi.org/10.16097/j.cnki.1009-6744.2017.03.005

Cao, C., Wu, Q., Li, R., & Xu, B. (2020). The Impact of FDI and Trade Opening on Carbon Dioxide Emissions--A Case Study of Zhejiang Province. Northern Economy and Trade, 05, 16–20. https://kns.cnki.net/kcms/detail/detail.aspx?FileName=GFJM202005005&DbName=CJFQ2020

Dang, Y. (2018). The Impact of FDI and International Trade on CO_2 Emissions in China——Panel ARDL Approach. *China Business And Market*, 32(6), 113–121. https://doi.org/10.14089/j.cnki.cn11-3664/f.2018.06.012

Dietz, T., & Rosa, E. A. (1994). Rethinking the environmental impacts of population, affluence and technology. *Human Ecology Review*, 1(2), 277–300. https://www.jstor.org/stable/24706840

Do, T. V. T., & Dinh, H. L. (2020). Short-and long-term effects of GDP, energy consumption, FDI, and trade openness on CO_2 emissions. *Accounting*, 6(3), 365–372. https://doi.org/10.5267/j.ac.2020.1.002

Doytch, N. (2020). The impact of foreign direct investment on the ecological footprints of nations. *Environmental and Sustainability Indicators*, 8, 100085. https://doi.org/10.1016/j.indic.2020.100085

Du, J. (2020). Forecast and analysis of the impact of urbanization evolution on cultivated land in Shaanxi province based on the Logistic Model. *Journal of Qingyuan Polytechnic*, 13(3), 27–32.

Ehrlich, P. R., & Holdren, J. P. (1971). Impact of population growth: Complacency concerning this component of man's predicament is unjustified and counterproductive. *Science*, 171, 1212–1217. https://doi.org/10.1126/science.171.3977.1212

Ek, A. (2007). The impact of FDI on economic growth: The case of China.

Elliott, R. J. R., Sun, P., & Chen, S. (2013). Energy intensity and foreign direct investment: A Chinese city-level study. *Energy Economics*, 40, 484–494. https://doi.org/10.1016/j.eneco.2013.08.004

Gan, X., & Yin, B. (2016). A Study on the Impact of Foreign Direct Investment on China's Economic Growth --Based on the Dynamic Distribution Lag Model. *Hubei Social Sciences*, 03, 83–88. https://doi.org/10.13660/j.cnki.42-1112/c.013533

Ghazali, A., & Ali, G. (2019). Investigation of key contributors of CO 2 emissions in extended STIRPAT model for newly industrialized countries: A dynamic common correlated estimator (DCCE) approach. *Energy Reports*, 5, 242–252. https://doi.org/10.1016/j.egyr.2019.02.006

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. In *The Quarterly Journal of Economics* (pp. 353–377). https://doi.org/10.2307/2118443

Gu, H., Yang, W., & Chen, W. (2022). Effect of Green Technology Innovation on Urban Carbon Emission. *Academic Exploration*, 03, 120–132.

Guo, J., & Yang, L. (2020). Impact of environmental regulations and government R&D funding on green technology innovation empirical analysis based on provincial level data in Mainland China. *Science & Technology Progress and Policy*, 37(10), 37–44. https://doi.org/10.6049/kjjbydc.Q201908707

Guo, L., & Zhao, Y. (2022). Research on factors of carbon emissions from urban residents' consumption under different levels of demand: Evidence from Northern China. *Urban Development Studies*, 29(4), 110–117.

Hao, Y., & Cao, H. (2021). Relationship between energy consumption， CO_2 emission and economic growth in Yangtze River Delta. *Science & Technology and Economy*, 34(01), 101–105. https://doi.org/10.14059/j.cnki.cn32-1276n.2021.01.021

Hausman, J. A. (1978). Specification tests in econometrics. *Econometrica: Journal of The Econometric Society*, 1251-1271.

Hu, D., You, K., & Esiyok, B. (2021). Foreign direct investment among developing markets and its technological impact on host: Evidence from spatial analysis of Chinese investment in Africa. *Technological Forecasting and Social Change*, 166, 120593. https://doi.org/10.1016/j.techfore.2021.120593

Hu, G., Li, C., & Hui, S. (2016). Based on the improved STIRPAT model application in carbon intensity forecasts. *Statistics and Decision*, 03, 87–89. https://doi.org/10.13546/j.cnki.tjyjc.2016.03.023

Hu, X., & Shi, X. (2022). Research on the influence of green technology innovation on carbon emission performance： Take Northeast China as an example. *Hubei Agricultural Sciences*, 61(17), 5–10. https://doi.org/10.14088/j.cnki.issn0439-8114.2022.17.001

Huan, M., Hou, Y., Cao, D., & Wei, K. (2018). FDI, technological progress and regional economic growth in China: Based on the Inter-provincial Panel Data from 1979 to 2013. *Modern Economic Science*, 40(02).

Huang, J. (2017). The Threshold Effect Test of FDI's Impact on China's Carbon Emission Intensity. *Statistics & Decision*, 21, 108–111. https://doi.org/10.13546/j.cnki.tjyjc.2017.21.026

Huang, M. (2015). Relation among economic growth， foreign direct investment and environmental pollution based on provincial panel 2003—2012. *Resources & Industries*, 17(01), 92–97. https://doi.org/10.13776/j.cnki.resourcesindustries.20141203.009

Huangfu, Z., Hu, H., Xie, N., Zhu, Y. Q., Chen, H., & Wang, Y. (2020). The heterogeneous influence of economic growth on environmental pollution: evidence from municipal data of China. *Petroleum Science*, 17(4), 1180–1193. https://doi.org/10.1007/s12182-020-00459-5

Jakada, A. H., Mahmood, S., Ahmad, A. U., Sani, A. I., & Yola, A. T. (2022). The effect of economic factors on the quality of the environment in African countries: An application of panel quantile regressions. *Environmental Health Engineering and Management*, 9(2), 85–95. https://doi.org/10.34172/EHEM.2022.10

Jiang, B., & Ma, S. (2020). A study on the influencing factors of regional economic growth and carbon emission -- A case study of three Northeast Provinces. *Enterprise Economy*, 39(11), 122–131. https://doi.org/10.13529/j.cnki.enterprise.economy.2020.11.015

Kong, Y., Feng, C., & Guo, L. (2022). Peaking Global and G20 Countries' CO_2 Emissions under the Shared Socio-Economic Pathways. *International Journal of Environmental Research and Public Health*, 19(17). https://doi.org/10.3390/ijerph191711076

Lian, L., & Ma, H. (2013). FDI and economic growth in the Western region of China and dynamic mechanism: based on time-series data from 1986 to 2010. *International Business Research*, 6(4), 180.

Liu, F., Huang, Q., & Liu, W. (2018). Regional Economic Growth and Regional Carbon Emissions ——Research Based on Environmental Kuznets Model. *Journal of Central South University of Forestry & Technology (Social Sciences)*, 12(04), 20-26+35. https://doi.org/10.14067/j.cnki.1673-9272.2018.04.004

Liu, Y., & Han, Y. (2021). Impacts of urbanization and technology on carbon dioxide emissions of Yangtze River economic belt at two stages: Based on an extended stirpat model. *Sustainability*, 13(13). https://doi.org/10.3390/su13137022

Long, R., Gan, X., Chen, H., Wang, J., & Li, Q. (2020). Spatial econometric analysis of foreign direct investment and carbon productivity in China: Two-tier moderating roles of industrialization development. Resources, Conservation & Recycling, 155, 104677. https://doi.org/10.1016/j.resconrec.2019.104677

Long, X., Chen, Y., Du, J., Oh, K., Han, I., and Yan, J. (2017). The Effect of Environmental Innovation Behavior on Economic and Environmental Performance of 182 Chinese Firms. *Journal of Cleaner Production*, 166, 1274–1282. doi:10.1016/j.jclepro.2017.08.070

Lucas, R. E., Wheeler, D., & Hettige, H. (1992). Economic development, environmental regulation, and the international migration of toxic industrial pollution, 1960-88 (Vol. 1062). World Bank Publications.

Nadeem, A. M., Ali, T., Khan, M. T. I., & Guo, Z. (2020). Relationship between inward FDI and environmental degradation for Pakistan: an exploration of Pollution Haven Hypothesis through ARDL approach. *Environmental Science and Pollution Research*, 27(13), 15407–15425. https://doi.org/10.1007/s11356-020-08083-x

Oladunni, O. J., Mpofu, K., & Olanrewaju, O. A. (2022). Greenhouse gas emissions and their driving forces in the transport sector of South Africa. *Energy Reports*, 8, 2052–2061. https://doi.org/10.1016/j.egyr.2022.01.123

Pazienza, P. (2019). The impact of FDI in the OECD manufacturing sector on CO_2 emission: Evidence and policy issues. *Environmental Impact Assessment Review*, 77, 60–68. https://doi.org/10.1016/j.eiar.2019.04.002

Qi, P., & Vilaiphorn, C. (2019). The Impact of Foreign Direct Investment on Laos' Economic Development. Co-Operative Economy & Science, 24, 68–70. https://doi.org/10.13665/j.cnki.hzjjykj.2019.24.026

Qian, J., & Li, J. (2017). Performance of Energy Saving and Emission Reduction of Different Types of Technology Progress and Its Dynamic Change. *Journal of Technology Economics*, 36(04), 63-71+92.

Sapkota, P., & Bastola, U. (2017). Foreign direct investment, income, and environmental pollution in developing countries: Panel data analysis of Latin America. *Energy Economics*, 64, 206–212. https://doi.org/10.1016/j.eneco.2017.04.001

Sellitto, M. A., Camfield, C. G., and Buzuku, S. (2020). Green innovation and competitive advantages in a furniture industrial cluster: A survey and structural model. *Sustainable Production Consumption*, 23, 94–104. doi:10.1016/j.spc.2020.04.007

Song, L., & Xu, F. (2021). Research on carbon emission calculation and influencing factors of rural human settlement environment under the background of rural revitalization. *Journal of Human Settlements in West China*, 36(2), 36–45. https://doi.org/10.13791/j.cnki.hsfwest.20210205

Su, Y., Jiang, Q., Khattak, S. I., Ahmad, M., & Li, H. (2021). Do higher education research and development expenditures affect environmental sustainability? New evidence from Chinese provinces. *Environmental Science and Pollution Research*, 28(47), 66656–66676. https://doi.org/10.1007/s11356-021-14685-w

Tang, M., & Hu, F. (2021). How Does Land Urbanization Promote CO_2 Emissions Reduction? Evidence From Chinese Prefectural-Level Cities. *Frontiers in Environmental Science*, 9, 1–16. https://doi.org/10.3389/fenvs.2021.766839

Udeagha, M. C., & Ngepah, N. (2022). Dynamic ARDL Simulations Effects of fiscal decentralization, green technological innovation, trade openness, and institutional quality on environmental sustainability: Evidence from South Africa. *Sustainability*, 14(16), 10268. https://doi.org/10.3390/su141610268

Wang, J., & Zhen, Q. (2018). A study on the relationship between economic growth and CO2 emissions -- Taking the Yangtze River Economic Belt as an example. *Finance and Economy*, 04, 36–45. https://doi.org/10.19622/j.cnki.cn36-1005/f.2018.04.005

Wang, M. Y., Li, Y. M., Li, J., and Wang, Z. (2021). Green process innovation, green product innovation and its economic performance improvement paths: A survey and structural model. *Journal of Environmental Management*, 297, 113282. doi:10.1016/j.jenvman.2021.113282

Wang, S., Huang, Y., & Yuquan, Z. (2019). Spatial spillover effect and driving forces of carbon emission intensity at city level in China. Journal of Geographical Sciences, 29, 231–252. https://doi.org/10.1007/s11442-019-1594-1

Wang, S., Zhou, C., Wang, Z., Feng, K., & Hubacek, K. (2017). The characteristics and drivers of fine particulate matter (PM2.5) distribution in China. *Journal of Cleaner Production*, 142, 1800–1809. https://doi.org/10.1016/j.jclepro.2016.11.104

Wang, X. (2019). Financial development, two-way FDI and carbon emissions: Empirical analysis of Threshold Model based on China's Province-level panel data. *Value Engineering*, 38(26), 110–112. https://doi.org/10.14018/j.cnki.cn13-1085/n.2019.26.046

Walter, I. and Ugelow, J. (1979). Environmental Policies in Developing Countries. *AMBIO*, 8, 102-109.

Wei, H. (2003). The location change of foreign investment in China after China enters into WTO and the prospect of attracting foreign investment in Central and Western China. *Journal of Management World*, 07, 67–75. https://doi.org/10.19744/j.cnki.11-1235/f.2003.07.009

Wen, Y. (2021). Influence research on FDI and industrial structure optimization for carbon emission reduction. *Shanghai Energy Saving*, 03, 253–265. https://doi.org/10.13770/j.cnki.issn2095-705x.2021.03.005

Wen, Y., Shabbir, M. S., Haseeb, M., Kamal, M., Anwar, A., Khan, M. F., & Malik, S. (2022). The dynamic effect of information and communication technology and renewable energy on CO_2 emission: Fresh evidence from panel quantile regression. *Frontiers in Environmental Science*, 10(August), 1–12. https://doi.org/10.3389/fenvs.2022.953035

Wu, W., & Liu, P. (2021). Interaction between FDI and carbon emissions -- Empirical analysis based on panel data of 281 prefecture-level cities. *Business & Economy*, 02, 117-120+134. https://doi.org/10.19905/j.cnki.syjj1982.2021.02.042

Wu, Y., & Zhao, G. (2021). Does green technology innovation improve energy conservation and emission reduction? *Future and Development*, 45(06), 34–42.

Xu, G., & Ren, X. (2018). A Study on the correlation between urbanization and the water resource load of Bijie City using the STRIPAT Model. *China Rural Water and Hydropower*, 01, 40–45. https://kns.cnki.net/kcms/detail/detail.aspx?FileName=ZNSD201801010&DbName=CJFQ2018

Xu, J., Tong, B., & Wang, M. (2022). Research on the impact of green technology innovation on CO_2 emissions from a spatial perspective. *Studies in Science of Science*, 1–20. https://doi.org/10.16192/j.cnki.1003-2053.20220301.001

Yang L, Liang Z, Yao W, Zhu H, Zeng L, & Zhao Z. (2023). What are the impacts of urbanization on carbon emissions efficiency? Evidence from Western China. *Land,* 12(9), 1707. https://doi.org/10.3390/land12091707

Yang, X., & Wang, D. (2022). Heterogeneous environmental regulation, foreign direct investment, and regional carbon dioxide emissions: Evidence from China. *Sustainability*, 14(11). https://doi.org/10.3390/su14116386

York, R., Rosa, E. A., & Dietz, T. (2003). STIRPAT, IPAT and IMPACT: Analytic tools for unpacking the driving forces of environmental impacts*.* *Ecological Economics*, 46(3), 351–365. https://doi.org/10.1016/S0921-8009(03)00188-5

Yuan, B., Li, C., Yin, H., & Zeng, M. (2022). Green innovation and China's CO_2 emissions–the moderating effect of institutional quality. *Journal of Environmental Planning and Management*, 65(5), 877–906. https://doi.org/10.1080/09640568.2021.1915260

Yuan, Y., & Sun, X. (2020). Exploring the relationship between urbanization, industrial structure, energy consumption, economic growth and CO_2 emissions: an empirical study based on the heterogeneity of inter-provincial income levels in China. *Climate Change Research*, 16(6), 738–747. https://doi.org/10.12006/j.issn.1673-1719.2019.192

Zhang, K. (2019). Does FDI exacerbate CO_2 Emissions in China's manufacturing industry? *Journal of Finance and Economics Theory*, 06, 88–102. https://doi.org/10.13894/j.cnki.jfet.2019.06.009

Zhao, X., & Xi, Y. (2022). Threshold effects of urban population size and industrial structure on CO_2 emissions in China. *Frontiers in Environmental Science*, 10(April), 1–10.

Zhou, B., & Shao, H. (2020). FDI, financial development and regional economic growth--A study of Spatial Econometrics based on China's 31 provincial panel data. *Reform of Economic System*, 04, 150–157. https://kns.cnki.net/kcms/detail/detail.aspx?FileName=JJTG202004022&DbName=DKFX2020

Zhou, S., Zhao, M., & Su, L. (2015). An empirical study of the carbon emissions Kuznets Curve for China--Based on Gregory-Hansen Cointegration Test. *Resources and Environment in the Yangtze Basin*, 24(09), 1471–1476. https://doi.org/10.11870/cjlyzyyhj201509005

Zhu, C., Yang, S., Liu, P., & Wang, M. (2022). Study on carbon dioxide peak of transportation industry in China. *Journal of Transportation Systems Engineering and Information Technology*. https://kns.cnki.net/kcms/detail/detail.aspx?FileName=YSXT20220704002&DbName=CAPJ2022

Zhu, M., & Wei, J. (2018). Research on the impact of intra-industry trade and FDI on CO_2 emission of three economic circles in China. *Technology and Innovation Management*, 39(05), 606-610+628.

Zhu, Y., Gao, H., & Xu, Y. (2022). How does coordinated development of two-way FDI Reduce Regional CO_2 Emission Intensity? ——Based on the Mediating Effect of Enterprise Green Technology Innovation and the Moderating Effect of Government Quality. *Soft Science*, 02, 86–94.

Zubair, A. O., Abdul Samad, A. R., & Dankumo, A. M. (2020). Does gross domestic income, trade integration, FDI inflows, GDP, and capital reduce CO_2 emissions? Empirical evidence from Nigeria. *Current Research in Environmental Sustainability*, 2, 100009. https://doi.org/10.1016/j.crsust.2020.100009