https://doi.org/10.52131/joe.2023.0504.0177

*i*RASD Journal of Economics

Volume 5, Number 4, 2023, Pages 1032 – 1043

Journal Home Page:
https://journals.internationalrasd.org/index.php/joe

The Role of Technological Innovation and Foreign Direct Investment in Influencing Energy Intensity in China

Fahim Ullah[1], Asad Mahmood[2], Sumera Khalid[3], Dilawar Hussain[4]

[1] Faculty of Arts & Social Sciences, Bahauddin Zakariya University, Multan, Punjab, Pakistan. Email: fahimullah7861@hotmail.com
[2] Faculty of Commerce, Law, & Business Administration, Bahauddin Zakariya University, Multan, Punjab, Pakistan. Email: asadmahmood2199@gmail.com
[3] Faculty of Commerce, Law, & Business Administration, Bahauddin Zakariya University, Multan, Punjab, Pakistan. Email: sumerakhalid6298@gmail.com
[4] Faculty of Commerce, Law, & Business Administration, Bahauddin Zakariya University, Multan, Punjab, Pakistan. Email: dilawar.lyh@gmail.com

ARTICLE INFO

Article History:
Received: October 07, 2023
Revised: December 19, 2023
Accepted: December 20, 2023
Available Online: December 21, 2023

Keywords:
Technological Innovation
Foreign Direct Investment
Energy Intensity
ARDL Model
China

JEL Classification Codes:
F21, Q41, Q55

Funding:
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

This article examines the role of technological innovation and foreign direct investment on energy intensity in China by employing yearly data from 1990 to 2020. For this purpose, ADF test and ARDL model are utilized for data estimation. The results exhibit that technological innovation and foreign direct investment are negative and significant factors of energy intensity in China. Likewise, the interaction term of FDI and technological innovation also significantly reduces China's intensity of energy. In contrast, the variables urbanization and gross fixed capital formation are encouraging factors of energy intensity. Considering the study outcomes, it is concluded that technological innovation and FDI play an imperative role in declining intensity of energy in China. Therefore, technological innovation and FDI inflows that encourage energy-saving technology to decline the intensity of energy in China should be encouraged.

Corresponding Author's Email: asadmahmood2199@gmail.com

Citation: Ullah, F., Mahmood, A., Khalid, S., & Hussain, D. (2023). The Role of Technological Innovation and Foreign Direct Investment in Influencing Energy Intensity in China. *IRASD Journal of Economics*, *5*(4), 1032 – 1043.https://doi.org/10.52131/joe.2023.0504.0177

1. Introduction

To decline carbon emissions while maintaining economic growth levels, reducing energy intensity (EI) is considered as an effective method. In the current era, countries are urged to decline EI to combat climate change (Hille & Lambernd, 2020; Wurlod & Noailly, 2018). The economy's structural composition changes significantly impact energy intensity, leaning toward less energy-intensive sectors (Sadorsky, 2013). Reduced energy intensity suggests that the country produces goods and services more efficiently with its energy resources. This indicates that little energy is utilized to produce a single unit of income (Pan, Uddin, Han, & Pan, 2019). Energy-saving technology is a potential means of reducing energy intensity (Huang, Du, & Tao, 2017).

According to Brookes and Grubb (1992) and Khazzoom (1987), technology's impact on the efficiency of energy may lower the use of energy in the short-run; however, the development of advanced and green technologies is likely to improve energy efficiency over time and eventually lead to the lowest possible energy consumption. On the contrary, technological innovation fosters economic expansion, which raises long-term energy demand and carbon emissions is clarified as a rebound effect (Freire-González, 2011). Thus, in many countries, especially industrialized ones, technological innovation that promotes economic growth has emerged as a viable means of reducing energy intensity and mitigating CO_2 emissions (Osabuohien-Irabor & Drapkin, 2022).

Liu, Zhang, Adebayo, and Awosusi (2022) proposed that a country can advance technologically through its independent innovation and the technology transferred through international investment and trade. Thus, the mobility of skilled labor, technology transfer to domestic firms, better managerial expertise, and global investment in the form of foreign capital inflows play an imperative role in higher productivity and economic growth (Cole, Elliott, & Strobl, 2008; Wang, 2017). Similarly, FDI is vital for modernizing the economy and fostering the growth of the economy of developing countries by improving productivity, technological innovation and better managerial capabilities (Abdouli & Hammami, 2018; Keller, 2004; Lai, Peng, & Bao, 2006; Liang, 2017; Zheng, Qi, & Chen, 2011). International aid, imports, and foreign investments also promote the transmission of energy-saving technologies that reduce EI. Therefore, countries using advanced energy-saving technologies with better management practices are typically able to transmit knowledge and improve their energy efficiency (Mimouni & Temimi, 2018). As a result, it is thought to be the primary cause of emerging market countries' decreasing energy intensity (Cao, Chen, & Huang, 2020). China has seen a notable increase in FDI inflows, which has improved the nation's economic growth (Qi & Wang, 2013; Sadorsky, 2013).

China has been the world's most significant energy user and CO_2 emitter, with its energy consumption maintaining a consistently high growth rate in tandem with its rapid economic expansion (Du & Lin, 2015; Guan et al., 2018; Zheng et al., 2011). A discernible environmental degradation has occurred due to rising energy use (Haug, 2002). In China, at this stage of development, limiting the overall energy consumption will have a disastrous influence on the growth of the economy. Consequently, energy intensity is given a lot of weight (Haug, 2002). China's overall energy consumption has expanded quickly, but sectoral and aggregate energy intensities have generally decreased over the past few years (as shown in Figure 1). China's energy intensity level, however, continues to trail behind developed countries like US, EU, and Japan, as well as the global average (Shi, Chu, & Zhao, 2021).

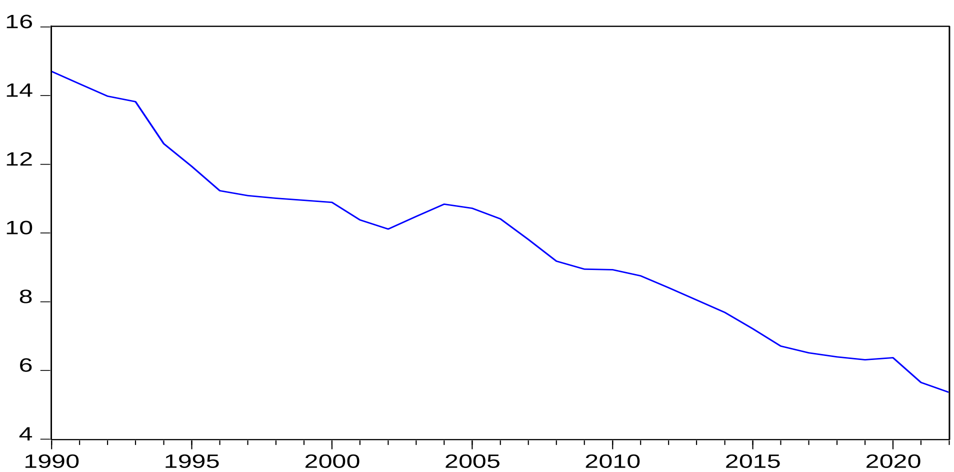


Figure 1: Energy Intensity in China from 1990 to 2020
Source: World Development Indicators

One of the main factors boosting China's economy is inward foreign direct investment, which steadily grows the country's economy. Figure 2 illustrates that FDI inflows into China increased between 1990 and 2018 while they began to decline in 2019 due to COVID-19 shocks. However, FDI may also bring issues related to China's energy and environmental consumption while fostering economic growth. Some academics have proposed that China's declining energy usage and environmental conditions may be inextricably linked to FDI inflows (Zhang & Fu, 2008).

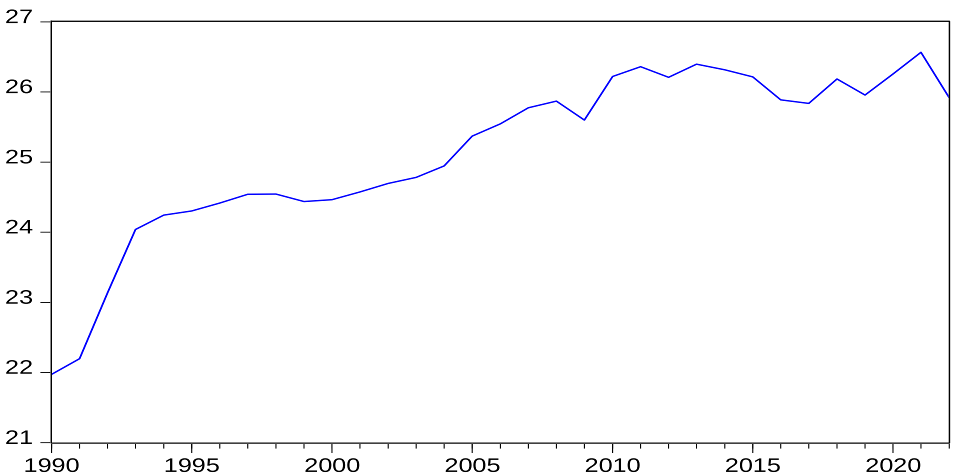


Figure 2: Inflows of Foreign Direct Investment in China (Current US$)
Source: World Development Indicators

Similarly, Technological innovation is critical to comprehend China's persistent decline in EI. Figure 3 shows that the number of patent applications in China has consistently increased from 1990 to 2020. It suggests that technological innovation in China is significantly growing.

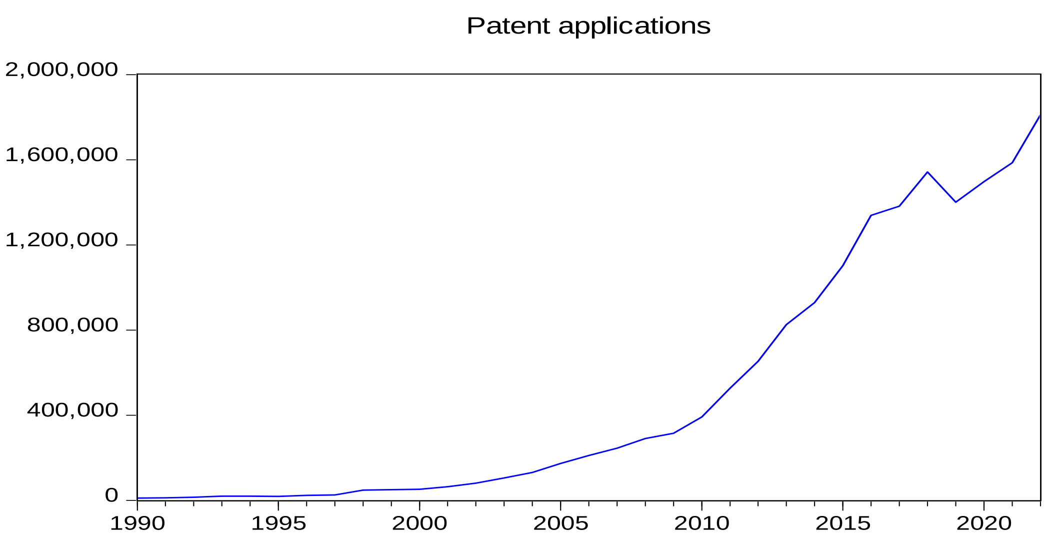


Figure 3: Number of Patent Applications in China
Source: World Development Indicators

Considering the above theoretical discussion, TI and FDI transmitted from developed economies are crucial ways to decline China's EI. Therefore, it is important to empirically analyze the association between technological innovation, FDI and EI in China. In addition to technological innovation and FDI, the study also considers urbanization and GFCF as a factor of EI. To observe the combined impact of TI and FDI, the analysis adds an interaction term of FDI and TI as a factor of energy intensity. In sum, this article will contribute significantly to the literature by providing the macroeconomic impacts of technological innovation and EI in China as previous studies, especially in China, consider provincial and city-level datasets to analyze these channels. The study's outcomes will also provide important insights to policymakers in reducing energy intensity by encouraging technology-driven FDI inflows in a country.

2. Literature Review

Different studies analyzed the influence of FDI on energy intensity (EI); therefore, this section discussed the review of literature of these studies.

2.1. Relationship between Foreign Direct Investment and Energy Intensity

Different studies analyzed the influence of FDI on EI, such as from 2008 to 2015; Saraswati, Hartono, and Indriyani (2022) analyzed how FDI affected the EI of 33 Indonesian provinces and confirmed that the FDI inflows positively associated with the energy intensity. Petrović and Lobanov (2022) used data from 43 countries from 1990 to 2014 to estimate the influence of FDI on EI. The findings showed that FDI had an energy-saving impact both directly and indirectly. Energy intensity decreases with each net new FDI input. The degree of a country's inventiveness and technological progress determine how strong of an impact this has. The author concluded that FDI has a greater energy-saving impact at higher technological development levels. Another study conducted by Cao et al. (2020) employed panel data from 1990 to 2014 in both BRICS and non-BRICS nations to examine the influence of FDI on EI and found that FDI had little influence on the EI. They also showed that the influence of FDI on EI varied between countries. The study in case of Russia using data from 1992 to 2015 was accompanied by Rudenko and Raschetova (2018) to observe the variables influencing energy intensity. The findings demonstrated a substantial negative correlation between EI, energy prices, and non-carbohydrate energy percentage. In China, Elliott, Sun, and Chen (2013) employed data from 206 Chinese cities between 2005 and 2008 to investigate the link between per capita income, FDI and EI. The findings supported the hypothesis that the influence of income varies with the degree of regional development by confirming an inverted U association between increasing income and EI. Keeping in view the review of the literature, the following hypothesis is developed:

H_1: *Foreign Direct Investment Can Negatively Influence the Energy Intensity*

2.2. Relationship between Technological Innovation and Energy Intensity

Different studies analyzed the effect of technological innovation (TI) on EI, such as the study by Guo et al. (2023), which investigated the digital economy's regional influence on EI using Chinese province panel data from 2012 to 2019. The findings demonstrated that the digital economy negatively impacted EI. The outcome demonstrated considerable regional spillover outcomes of the digital economy on EI, with the central region's EI decreasing as the digital industry grows in surrounding areas. Furthermore, other factors influence energy intensity differently, including industrial structure, urbanization, energy price, and FDI. In the context of OECD countries, Osabuohien-Irabor and Drapkin (2022) explored the link between TI and energy demand in OECD economies from 1996 to 2015, focusing on the roles of FDI and international trade. The findings also demonstrated that the OECD nations were strengthened in their efforts to achieve environmental sustainability and energy efficiency by effect of TI on energy usage through the reverse technology spillover effects from FDI. Another study by Liu et al. (2022) investigated the influence of trade, TI, industrialization and growth of the economy on EI in the BRICS countries by employing data from 1990 to 2019. This article showed that openness of trade and TI lowers EI while economic expansion and industrialization raise it. The BRICS economies' energy intensity declined due to industrialization and technological advancement working together.

Similarly, to estimate the relationships between financial development, technological innovation, trade and EI in Bangladesh, Pan et al. (2019) analyzed data from 1976 to 2014. Their study showed that EI was influenced by trade, economic expansion, financial advancement, and TI. The variables trade openness, TI and financial development significantly impact the EI in Bangladesh. The study by Saudi, Sinaga, Roespinoedji, and Ghani (2019) scrutinized the relationship between EI and TI in Indonesia utilizing data from 1981 to 2017. The outcomes verified that Indonesia's primary drivers of decreasing energy inefficiency were high-tech exports, TI, and R&D expenditures. Similarly, Jin, Duan, and Tang (2018) used data of China from 1995 to 2012 to inspect the link between TI and energy usage. The findings demonstrated that TI drives an upsurge in usage of energy. The study also concluded a positive link between use of energy and TI. Wurlod and Noailly (2018) examined how energy intensity changed in 17 OECD nations between 1975 and 2005 due to green innovation. According to the study, most sectors have seen a decrease in energy intensity, which can be attributed to green innovation. Another study in China was conducted by Huang et al. (2017) to investigate how technological factors affected energy intensity using data from 30 provinces between 2000 and 2013. The findings demonstrated that research and development were major factors in reducing energy intensity. Furthermore, technology spillovers from openness to imports and FDI reduce energy intensity overall, except for exports. Keeping in view the review of the literature, the following hypothesis is developed:

H_2: *Technological Innovation Can Negatively Influence the Energy Intensity*

After thoroughly discussing the literature review, it has been clear that technological innovation and foreign direct investment are significant sources of energy intensity. Different studies have been carried out in different regions to analyze this nexus; however, few studies were available in the context of China. Therefore, this study revisits the nexus between technological innovation, foreign direct investment and energy intensity in China and will provide important implications to the policymakers to reduce the energy intensity in China.

3. Data and Methodology

This study used China's yearly data from 1990 to 2022 to analyze the role of technological innovation and FDI on EI. The main source of data collection was World Development Indicators. The analysis utilizes energy intensity as a dependent variable, while the core explanatory variables are technological innovation (number of patent applications of both residents and non-residents of the country) and FDI inflows (percentage of GDP). The core explanatory variables added in a model are urbanization (Percentage of urban population to the total population) and gross fixed capital formation (Percentage of GDP). The following model is constructed in a study:

$$EI_t = \beta_o + \beta_1 TI_t + \beta_2 FDI_t + \beta_3 TI * FDI_t + \beta_4 URB_t + \beta_5 GFCF_t + u_t \quad (1)$$

Where EI indicates energy intensity, TI demonstrates technological innovation, FDI indicates foreign direct investment, TI*FDI indicates the interaction term of FDI and TI, URB represents urbanization, GFCF specifies gross fixed capital formation, u_t represents error term, and β_i represents the parameters of the variables.

For data estimation, first, we applied the Augmented Dickey-Fuller (ADF) test to check the stationary level of variables. The ADF test uses the lagged difference to capture serial correlation (Dickey & Fuller, 1979). Second, we have used the ARDL bound test to examine the long-run cointegration. Then, the ARDL model is used to analyze the parameters long-run estimation as developed by (Pesaran & Shin, 1995). This model is suitable when data series have mixed integration order, such as I(0) and I(1). Furthermore, the ARDL model still provides consistent results in small datasets (Huang et al., 2017). This model also provides an error correction form, which is important to evaluate the adjustment speed towards long-run equilibrium in case of disturbances. The short-run error correction (ECM) form is given in the following equation:

$$\Delta EI = \beta_0 + \sum_{l=1}^{n} \alpha_1 \Delta TI_{t-j} + \sum_{l=0}^{n} \alpha_2 \Delta FDI_{t-j} + \sum_{l=0}^{n} \alpha_3 \Delta TI * FDI_{t-j} + \sum_{l=0}^{n} \alpha_4 \Delta URB_{t-j} + \sum_{l=0}^{n} \alpha_5 \Delta GFCF_{t-j} + \nu_1 ECM_{t-1} + u_{1t} \quad (2)$$

Where ɑ's are short-run parameters, ECM indicates error correction term that measures the adjustment speed from short- to long-run equilibrium after disturbances. The ECM term ranges from -1 to 0, where zero indicates no convergence toward equilibrium and -1 suggests perfect convergence to the long-run equilibrium.

Lastly, we have applied various model diagnostic tests to evaluate the issues of autocorrelation, heteroskedasticity, residual normality, and model misspecification. For this purpose, Breusch-Godfrey, Breusch-Pagan-Godfrey, Jarque-Bera and Ramsey Reset tests are utilized, respectively. We have used OLS recursive residuals of CUSUM and CUSUM of a square to check the model's dynamic stability.

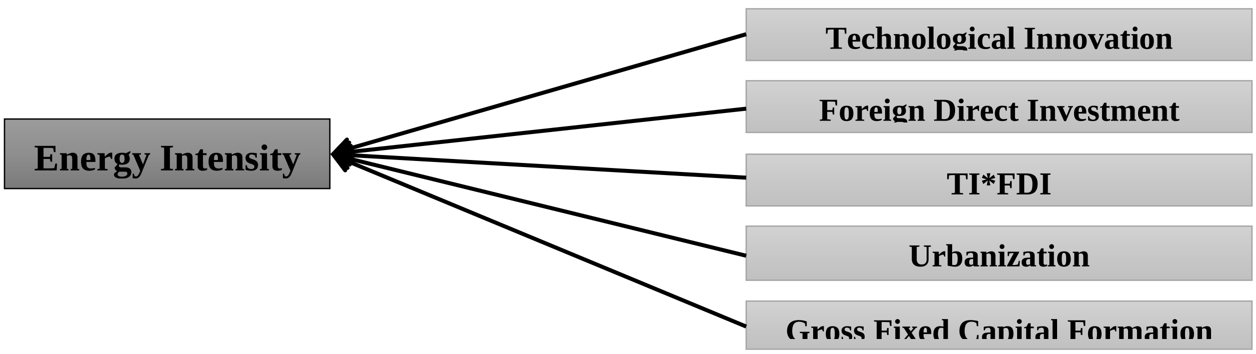


Figure 4: Conceptual Framework

4. Data Analysis

Table 1 exhibits the descriptive analysis of variables. The mean value of energy intensity is 9690, maximum value is 14.700, minimum value is 5.360, standard deviation is 2.581, skewness value (0.147) exhibits positively skewed distribution, kurtosis value (2.240) indicates platykurtic distribution and Jarque-Bera test indicates the distribution is normally distributed. The descriptive statistics of other variables can be observed similarly.

Table 1
Descriptive Analysis

Variable	Mean	Maximum	Minimum	S.D.	Skew.	Kurt.	J.B.	Prob.
EI	9.690	14.700	5.360	2.581	0.147	2.237	0.919	0.632
TI	511681	1811326.0	10137	597274.2	0.903	2.240	5.279	0.071
FDI	3.199	6.187	0.966	1.421	0.120	2.223	0.909	0.635
URB	3.450	4.602	1.649	0.786	-0.647	2.500	2.649	0.266
GFCF	37.867	44.519	23.989	5.704	-0.678	2.509	2.858	0.240

Source: Author's Compilations

Table 2:
Correlation Matrix

Correlation	EI	TIN	FDI	URB	GFCF
EI	1.000	-0.894			
TI	-0.894	1.000			
FDI	0.483	-0.673	1.000		
URB	0.841	-0.950	0.570	1.000	
GFCF	0.836	0.692	-0.199	-0.765	1.000

Source: Author's Compilations

Correlation analysis is imperative to examine the extent of link between a pair of variables. Table 2 shows that energy intensity is negatively correlated to technological innovation while it is positively correlated to FDI, urbanization, and GFCF. This analysis also confirms that there is no issue of multicollinearity as none of the pair have coefficient value above 0.90.

In the time series analysis, checking the stationary level of variables is vital. Therefore, we have utilized Augmented Dickey-Fuller test. Table 3 exhibits that EI, urbanization, and GFCF are stationary at a level while technological innovation and foreign direct investment are integrated at 1st order. Therefore, the diverse integration order suggests that ARDL model is right for the long-run parameters' estimation.

Table 3
ADF Test Estimates

Variable	t-test	Prob.	t-test	Prob.	Outcomes
EI	-2.719	0.008	--	--	I(0)
TI	--	--	-5.249	0.000	I(1)
FDI	--	--	-4.404	0.002	I(1)
URB	-2.827	0.006	--	--	I(0)
GFCF	-3.856	0.027	--	--	I(0)

Source: Author's Compilations

It is essential to examine the long-run cointegration of the variables before delving into the model's long-run parameters. Therefore, we have utilized the ARDL bound test of cointegration. Table 4 illustrates that the value of Wald tests is higher than all upper and lower bound values; therefore, the null hypothesis is rejected, and it is established that among variables, there is an existence of long-run cointegration.

Table 4
Bound Test Analysis

Null Hypothesis: No Cointegration				
Test Statistic	**Value**	**Sig.**	**I(0)**	**I(1)**
F	16.0581	10%	2.08	3
K	5	5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.15

Source: Author's Compilations

The long-run estimation of the ARDL model is exhibited in Table 5. Considering first the role of technological innovation as a factor of energy intensity, it is found that technological innovation is adversely and considerably linked to the EI in China. The TI's coefficient illustrates that as TI augments by a single unit, the EI declines by -1.3941 units. It implies that technological advancements can enhance energy efficiency by raising production's marginal productivity directly while indirectly advancing energy allocation efficiency (Sun, Edziah, Kporsu, Sarkodie, & Taghizadeh-Hesary, 2021; Zhu, Zhang, Li, Feng, & Li, 2019). Technological innovation promotes energy-saving technologies in enterprises and can lead to decline the energy usage and EI (Wang, Wang, Li, Cai, & Gao, 2019). These findings were also confirmed by Liu et al. (2022) and Osabuohien-Irabor and Drapkin (2022). Similarly, foreign direct investment promotes technological innovation and brings energy-saving technologies to a country. The study found that FDI is inversely and significantly associated with China's energy intensity. The FDI's coefficient demonstrates that as it boosts by a single unit, the EI declines by -0.9846 units. It advocates that the EI of China may be decreased by the transmission of energy-saving technologies from developed countries and the inflow of finance from abroad (HÜBler & Keller, 2010). When moderation of TI and FDI is considered, it also supports the phenomenon that technological innovation and FDI reduce China's EI. It implies that technology transfer through FDI can lower energy consumption in two ways: directly through effective foreign companies working in the host countries, and indirectly via technology spillovers from the foreign companies to local companies (HÜBler & Keller, 2010; Saggi, 2002). Therefore, it is concluded that FDI and technological innovation should be encouraged in China.

Urbanization is also crucial to analyze as a factor of energy intensity. The outcomes confirm a positive and substantial relation between urbanization and EI in China. The URB's coefficient exhibits that as URB augments by a single unit, the EI is augmented by 1.2345 units. It implies that as more people move into cities, the economic structure and public infrastructure built there will alter as well, which will encourage the growth of energy-intensive companies and lead to increase EI (Huang et al., 2017). These outcomes were also confirmed by Song and Zheng (2012) and Yan (2015). The results demonstrate a positive and substantial link between GFCF and EI in China. The GFCF's coefficient demonstrates that as GFCF augments by a single unit, the EI is augmented by 0.3274 units. It implies that increasing the level of GFCF in a country promotes economic development and thus enhances the energy demand and intensity in a country (Osabuohien-Irabor & Drapkin, 2022).

Table 5
ARDL Long Run Estimates

DV: Energy Intensity Selected Model: ARDL(1, 2, 2, 1, 2, 2)				
Variable	**Coefficient**	**S.E.**	**t-Statistic**	**Prob.**
TI	-1.3941	0.3736	-3.7313	0.0020
FDI	-0.9846	0.3181	-3.0950	0.0074
TI*FDI	-0.1659	0.0722	-2.2957	0.0365
URB	1.2345	0.5589	2.2086	0.0432
GFCF	0.3274	0.1144	2.8598	0.0119
C	13.2960	3.5871	3.7066	0.0021

Source: Author's Compilations

The ECM term is essential to analyze the ECM model. Table 6 unveils that the results of ARDL short-run ECM model. It is found that the ECM term originated to be negative and significant at percent level. It suggests that at 36.56 percent the short-run errors become adjusted towards long-run equilibrium in case of disturbances.

Table 6
Estimates of ARDL ECM Model

DV: Energy Intensity Selected Model: ARDL(1, 2, 2, 1, 2, 2)				
Variable	**Coefficient**	**S.E.**	**t-Statistic**	**Prob.**
D(TI)	0.1615	0.1971	0.8193	0.4254
D(FDI)	-0.0998	0.0430	-2.3207	0.0348
D(TI_FDI)	-0.0179	0.0083	-2.1577	0.0476
D(URBG)	-0.6149	0.2115	-2.9073	0.0108
D(GFCF)	0.0614	0.0184	3.3394	0.0045
ECM(-1)	-0.3656	0.0291	-12.54472	0.0000

Source: Author's Compilations

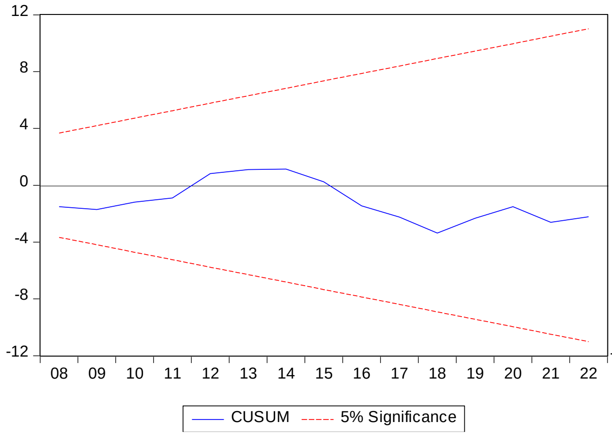
We have also applied different model diagnostic tests to evaluate the issues of autocorrelation, heteroskedasticity, residual normality, and model misspecification. For this purpose, Breusch-Godfrey (BG), Breusch-Pagan-Godfrey (BPG), Jarque-Bera (JB) and Ramsey Reset (RR) tests are applied, respectively. The results confirm no issue of autocorrelation and heteroskedasticity in a model. The Jarque-Bera (JB) and Ramsey Reset (RR) tests ensure that the residuals are distributed normally and the model is correctly specified.

Table 7
Model Diagnostic Tests

Problem	Test	Statistic	Prob.	Outcomes
Autocorrelation	BG	0.0237	0.9765	Not Present
Heteroskedasticity	BPG	0.3892	0.9613	Not Present
Residuals Normality	JB	2.1287	0.3449	Normally Distributed
Model Misspecification	RR	1.8764	0.1816	Correctly Specified

Source: Author's Compilations

Lastly, the dynamic stability of the model under investigation is implied by Figure 4, which shows that the recursive residuals of CUSUM and CUSUM of square lie within the critical region lines at the 5-significance level.



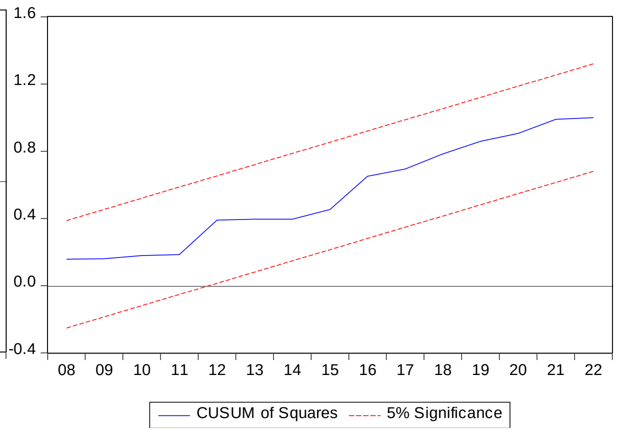


Figure 4: Model Stability Analysis
Source: Author's Compilations

5. Conclusions and Policy Suggestions

In this study, we analyzed the role of technological innovation and foreign direct investment on energy intensity in China. This article also adds the interaction terms of FDI and TI, and the control variables incorporated in a study are urbanization and GFCF. Firstly, the study conducted unit root analysis and found energy intensity, urbanization, and GFCF are integrated at a level I(0) while technological innovation and FDI are integrated at 1st order. Secondly, the bound test ensures the long-run cointegration among variables. The ARDL long-run estimation confirms that technological innovation and foreign direct investment reducing China's EI. Similarly, the interaction term of both FDI and TI supports the phenomenon that TI and FDI reduce China's EI. In contrast, other variables such as urbanization and gross fixed capital formation, enhance China's energy intensity. Lastly, we have found no problem of autocorrelation and heteroskedasticity in a model, whereas the residuals are distributed normally, and the model is specified correctly, respectively. Lastly, this article applied OLS recursive residuals to observe the model's dynamic stability and confirms that the model is dynamically stable. In the light of analysis, it is established that TI and FDI play a vital role in dropping EI in China. Therefore, it is suggested that for China, it is critical to promote TI to decline EI. The industrial structure of China needs to be transformed by energy-saving technology to improve efficiency of energy. Similarly, it is suggested that the Chinese government must boost FDI inflows that promote technology-intensive and energy-saving technology to promote innovation and reduce the EI in China.

The study has some limitations. First, this article utilizes China's macroeconomic data from 1990 to 2022 to determine the role TI and FDI inflows on EI. However, future investigations can analyze this association using panel datasets, especially in developing countries, to get comprehensive results. Secondly, an analysis can be conducted that compares China's energy structure with developed economies such as the United States to identify the strengths and weaknesses of the energy structure. Lastly, other variables, such as digitalization, economic growth, and green energy utilization, can also be observed as a factor of energy intensity in China.

Author's Contribution:
Fahim Ullah: Writing Original Draft, Review of Literature, Data Analysis.
Asad Mahmood: Data and Methodology and Interpretation.
Sumera Khalid: Introduction, Review of Literature and Editing.
Dilawar Hussain: Review the Final Draft and Proofreading.

Conflict of Interests/Disclosures
The authors declared no potential conflicts of interest w.r.t the research, authorship and/or publication of this article.

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