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Unveiling the Connection Between Outward Foreign Direct Investment and Environmental Quality in Turkey: A Frequency Domain Causality Analysis

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Abstract

Debates relating to the sustainability of the environment have emerged as a major goal of the global agenda in recent years. As a result, this research examines the impact of outward foreign direct investment (OFDI) on carbon dioxide emissions (CO_2) in Turkey from 1985 to 2022, using the autoregressive distributed lag model (ARDL) and frequency domain causality analysis (FDCA). In addition, economic growth (GDP) and trade in services (TROP) were used as control variables because they capture two big ways the economy interacts with environment. The empirical results are as follows: (i) The bounds test confirms a long-run association among the variables. (ii) The ARDL result confirms that in the long and short run, OFDI and GDP increase CO_2 in Turkey, while TROP contributes to the quality of the environment. (iii) The FDCA demonstrates that OFDI Granger causes CO_2 in the short and medium term, while TROP Granger causes CO_2 in the short, medium, and long-term. Based on these results, policies are recommended for implementation.

Keywords: outward foreign direct investment; carbon dioxide emissions; economic growth; trade openness; Turkey

1. Introduction

The concept of Sustainable Development Goals (SDGs) has continued to increase in momentum and importance. This is because of the concrete idea of achieving present developmental goals without jeopardizing the chances of future generations. One of the goals is geared towards tackling the issue of climate change, caused by rising greenhouse gases (GHGs). One of the GHGs that harms the environment the most is carbon dioxide emissions (CO_2). The burning of fossil fuels, industrial activities, and deforestation are the main sources of CO_2 [1]. If CO_2 can contribute to the degradation of the environment, the factors that drive or reduce it need to be investigated.

To achieve environmental quality (EQ), diverse factors come into play, such as environmental policies [2], the level of urbanization [3,4], population size [5], clean energy consumption [6,7], financial development [8,9], and technological innovation [10], among other factors. More specifically, it has been established that foreign direct investment (FDI) can improve the quality of the environment [11,12]. Ref. [13] stated that globally, FDI flows have significantly expanded, particularly in the past 20 years. FDI can come in the form of inflows or outflows. FDI inflows (IFDI) are investments coming into a country, while OFDI refers to investments going into other economies. This research focuses on OFDI because of the gap in existing studies regarding this topic.

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The combination of ownership, location, and internalization benefits offered by a nation's firms may vary across the country's path of economic progress, according to the most recent advances in economic theory clarifying the OFDI positions of nations [14,15]. If it is acknowledged that a nation's businesses' inclination to invest overseas depends on their capacity to obtain and use assets that generate money domestically, then the frequency of foreign engagement will increase with this capacity [15]. As a result, the inclination to invest overseas can be hypothesized as a function of such endowments [15]. Ref. [16] exclaimed that in the home country, OFDI could result in reverse technology transfer and advance domestic technology. Ref. [17] further opined that OFDI could promote green innovation. Ref. [18] suggested that, through spillover effects, supporting viable businesses to participate in ODFI initiatives could effectively encourage efforts to reduce pollution. However, in contrast, OFDI can contribute to the degradation of the environment through the scale effect.

OFDI in various developed economies has been investigated, but it has been neglected emerging economies, such as Turkey. According to [19], Turkey's location at the meeting point of three continents—Africa, Europe, and Asia—represents a very special circumstance that contributes to the development of several advantages for the home country. For example, Turkey's geographical, organizational, and political closeness to Europe enabled it to join the Customs Union (CU) while pursuing full EU membership status. In a similar vein, Turkey maintains cultural connections with the recently independent Central Asian nations. It has a sizable diaspora that resides in the EU and other countries. Turkish OFDI stock is expanding quickly in these areas. Turkey can serve as an excellent example of the current factors influencing OFDI, which can contribute to EQ or degrade the environment of the home country. In December 2024, Turkey's direct investment abroad increased by USD 834 million, and its foreign portfolio investment rose by USD 4.4 billion. In January 2025, Turkey's FDI grew by USD 1.4 billion, up from USD 2 billion the month before [20]. Turkey is also a trillion–dollar economy [21], which makes it a significant player in the global economy.

It is important to state that the service sector is a significant part of FDI. Ref. [22] opined that, in addition to being potential sources of exports, related jobs, and household income, services are important for achieving the SDGs because many of them depend on improving the performance of a number of particular service sectors in nations that are developing. Reaching the SDGs is mostly a service-oriented mission. Increasing the capability and efficiency of a variety of service activities, such as transportation, distribution, logistics, ICT, vocational training, medical services, and so on, will be necessary to eradicate poverty and hunger, improve health and educational outcomes, or lessen regional disparities.

Based on the aforementioned arguments, this study uses the autoregressive distributed lag (ARDL) model and frequency domain causality approach (FDCA) to examine the effects of OFDI, TROP, and economic growth (GDP) on CO_2 in Turkey from 1985 to 2022. Because Turkey has a high level of OFDI, which suggests that Turkish businesses are expanding internationally, it is crucial to examine the links between these variables. This inquiry aids in determining whether Turkey is importing greener technologies from overseas markets or exporting its carbon-intensive operations. Additionally, the Turkish economy is heavily reliant on trade services, particularly tourism and transportation, which continue to have a large carbon footprint because of the energy requirements of aviation and hospitality. By analyzing these factors alongside economic progress, stakeholders can determine whether Turkey has reached a tipping point where it can continue to grow without increasing CO_2 levels.

Based on the following discussions, the gaps and contributions of this study are as follows: *First*, the literature on OFDI and EQ is quite scanty, as existing studies have focused

on the dynamics of IFDI [23,24]. *Second*, prior research on FDI has mostly concentrated on how it affects the host country's environment, neglecting the impact on the home country's environment, with very few studies having used Turkey as a case study. *Third*, in addition to the ARDL method employed, because of its application to small-sample-size data [25], this research also used the FDCA of [26]. The FDCA assesses the degree of a particular variation in a time series [27]. Seasonal changes can be eliminated from the small-sample data using the FDCA [28]. Furthermore, the FDCA allows for the detection of causality between factors at short, medium, and long frequencies as well as the distinction of non-linearity and causality stages. *Lastly*, the outcome of this research has important practical ramifications for comprehending how OFDI affects the environment. The outcome confirms that OFDI and GDP increase CO_2, while TROP reduces CO_2.

The structure of this research is as follows: Section 2 is the reviewed literature; Section 3 captures the theoretical framework; Section 4 shows the data and methodology employed; Section 5 presents the findings; and Section 6 concludes the study.

2. Literature Review

Using a single and simultaneous equation model, ref. [29] established that China's OFDI has enhanced economic scale (scale impact), which has led to an increase in domestic ecological pollution. On the other hand, OFDI's reverse technology spillover effect has reduced domestic ecological degradation by optimizing the domestic industrial structure (composition impact) and raising the level of domestic technology (technical effect). The implication of this is that OFDI can both drive ecological degradation and contribute to EQ. Using the ARDL approach, ref. [30] confirmed the EKC hypothesis for the MENA region. Additionally, the empirical findings support the "pollution haven" hypothesis, which holds that wealthy countries' polluting industrial operations relocate to developing nations with laxer environmental laws. Ref. [31] explained that OFDI could spur CO_2 emissions.

In BRICS economies, using the FMOLS, DOLS, and PMG methodologies, ref. [32] established that the empirical findings support the EKC hypothesis, suggesting that energy use and OFDI contribute to the long–term expansion of greener technologies to improve the environmental conditions of host nations and validate the existence of an inverted U-shaped association. Ref. [33] opined that regulating the environment (ER) greatly increases OFDI, and these ER-driven OFDI flows are primarily directed toward nations with weaker environmental laws and that are closer geographically and culturally to the home country.

For developing economies, employing the SYS–GMM approach, ref. [34] revealed that domestic institutions support the reverse technology spillover effects of OFDI to increase its efficacy in reducing CO_2 through eco-friendly technologies. High levels of human capital, however, have been shown to boost the quality of domestic institutions, which in turn encourages more FDI spillover that enhances EQ. In line with the reverse transfer of knowledge approach, ref. [35] discovered that enterprises' ecological performance increases following the start of OFDI. Additionally, the study noted that firms experience an additional boost in ecological performance when the OFDI host nations are advanced, have more stringent laws pertaining to the environment, and exhibit higher standards for the future-oriented dimensions of national culture.

In Vietnam, ref. [36] ascertained that OFDI has no association with CO_2. Although GDP per capita has a negative long-term correlation, this is consistent with Vietnam's 2021–2030 National Climate Strategy, which places a strong emphasis on fostering the expansion of GDP through low-carbon industries. In Turkey, using the ARDL approach, ref. [13] found that economic expansion significantly impacts CO_2, while FDI has a positive but negligible influence. Furthermore, it is observed that the long- and short-run results are comparable. In newly industrialized economies, ref. [37] revealed that increasing OFDI

effectively lowers carbon footprints in Mexico and Turkey, while increased well-being of people lowers pollution in the Philippines. Additionally, trade openness lowers emissions in China and Malaysia. According to panel analysis, OFDI's moderating effect on human well-being promotes a sustainable ecosystem. Generally, ref. [38] also argued that FDI spurs CO_2 emissions in Turkey.

In existing studies, it has been confirmed that economic expansion can drive ecological degradation [39–42]. This assertion is also true for the Turkish economy [43,44]. Ref. [45], however, found that economic progress drives EQ.

In terms of the TROP and EQ nexus, ref. [46] stated that countries' trade limitations on services may have a negative impact on the execution of ecological initiatives through the formation of specialized businesses with commercial presences outside those countries. Ref. [47] opined that carbon efficiency is increased via trade in services. Exports saw a larger increase in carbon efficiency as a result of trade in services, whereas imports had the opposite effect. Ref. [22] established that a number of the SDGs rely on how well the services economy performs. In addition, the performance of the service industry can be improved by loosening trade restrictions. Ref. [48] argued that trading as a whole raises CO_2, while trading in commodities raises CO_2 more than trade in services.

According to the examined literature, there is a dearth of research on OFDI, particularly for a nation like Turkey, which necessitates further study. Additionally, the research reveals inconsistent results on the relationship between OFDI and CO_2. While some research contends that OFDI drives EQ, others contend that OFDI is the primary cause of environmental deterioration. These discrepancies also call for additional research. Finally, this study applied FDCA as an addition to the methods used in previous studies.

3. Theoretical Framework

This research employed the theory of [49,50] to examine the impact of OFDI on CO_2, and this can be broken down into the scale, composite, and technique effects. The *scale effect* of OFDI examines how the home country is affected due to continuous pollution activities [29]. This effect, as expressed by [51], is a pollution-causing factor that quantifies the degree of ecological degradation that results from merely scaling up the economy. Through the return on investment and the introduction of new technologies, OFDI has a reciprocal impact on the home country's economic expansion and CO_2 emissions. The *composition effect* shows how a nation's industrial mix at a certain scale of production relates to its performance regarding the environment [52]. Put another way, a nation's pollution levels will be high if its industrial structure is characterized by pollution-intensive industries, whereas it will be low if its industrial architecture is controlled by clean-intensive industries. The use of environmentally sound technologies leading to a beneficial spillover effect is known as the "*technique effect*" [51]. Via OFDI, businesses in the investing nation can have access to the resources and innovative technologies of the host nation, eventually facilitating the transfer of these innovations from the host nation to the home nation. Both direct and indirect effects are included in the technique effect. The transfer of cutting-edge ecological technology through cooperation and international exchange of technological advances is known as the "direct technique effect" [53]. In contrast, the "indirect technique effect" occurs when FDI boosts economic expansion, which in turn increases wealth and the demand for cleaner environments, which may lead to the deployment of greener technologies [51].

Other theories that are relevant to the discussions of this research are the "pollution haven hypothesis" and "pollution halo hypothesis." According to the "pollution haven hypothesis," wealthy nations frequently relocate their highly polluting businesses or industries to less-developed nations in the context of economic globalization, which has a

detrimental effect on the environment of those nations. These developing nations become oases of pollution because they significantly increase their pollutant emissions, despite the fact that the movement of pollution-intensive businesses raises their degree of specialization, growth in production, and income [54]. Nonetheless, ref. [55] proposed the "pollution halo hypothesis," which holds that the introduction of foreign capital produces more sophisticated management techniques, concepts, and effective technology, all of which have a positive effect on the environment. Up until now, there has not been much agreement on the opposing conclusions of the "pollution haven" and "pollution halo" hypotheses, both of which are supported by facts [29].

In summary, the Turkish economy's ecological trajectory is determined by the tension between the scale and technology effects. While the rapid expansion of the industrial sector has historically resulted in a pro-cyclical increase in emissions, Turkey's increasing trade openness acts as an amplifier for the pollution halo effect. By incorporating cleaner technical spillovers from partner countries, Turkey has the potential to overcome the structural emissions inherent in its manufacturing-intensive makeup.

4. Data and Methodology

4.1. Data

The data employed in this research are from 1985 to 2022. The variable used to capture the sustainability of the environment is carbon dioxide emissions (CO_2), while the independent variables employed include foreign direct investment, net outflows (percentage of GDP) (OFDI), trade in services (percentage of GDP) (TROP), and GDP (constant 2015 USD) (GDP). It is important to state that TROP and GDP are used as control variables because they play a very crucial role in determining the quality of the environment. All variables were sourced from [21]. The integration of OFDI, TROP, and GDP as CO_2 determinants is established in their capacity to shape Turkey's industrial and environmental landscape. Table 1 shows the overview of the variables.

Table 1. Overview of the variables.

Symbols	Variables	Description	Source
CO_2	Carbon Dioxide Emissions (Indicator for Environmental Quality)	Carbon Dioxide Emissions (Total) excluding LULUCF (Mt CO_2e)	[21]
OFDI	Outward Foreign Direct Investment	Foreign Direct Investment, Net Outflows (% of GDP)	[21]
TROP	Trade Openness	Trade in Services (% of GDP)	[21]
GDP	GDP (Indicator for Economic Growth)	Constant 2015 USD	[21]

Furthermore, the model of this study, adopted from the studies of [11,29,56], is presented in Equation (1) and transformed to log form in Equation (2).

$$CO2_t = f(OFDI_t, TROP_t, GDP_t) \quad (1)$$

$$LCO2_t = \rho_0 + \rho_1 OFDI_t + \rho_2 LTROP_t + \rho_3 LGDP_t + \omega_t \quad (2)$$

The intercept can be denoted as ρ_0; $\rho_1 \rightarrow \rho_3$ represents the independent variables' coefficients; t is time; and the error term is ω_t. Based on the reviewed literature and theoretical foundation, this study hypothesizes that OFDI will contribute to ecological degradation $(\rho_1 > 0)$, TROP will drive EQ $(\rho_2 < 0)$, and GDP will degrade the environment $(\rho_3 < 0)$.

4.2. Methodology

The technique employed is the autoregressive distributed lag (ARDL) model proposed by [57]. Ref. [27] stated that when the data set is either I(0), I(1), or a combination of I(0) and I(1), the ARDL technique has the advantage of allowing for the joint analysis of short- and long-term linkages; however, it is incompatible with I(2) variables. This method is more advantageous to studies requiring stringent stationarity conditions [58]. In addition, this approach is very suitable for small-sample-size data investigations. The ARDL long- and short-run equation can be seen in Equation (3).

$$\begin{aligned}\Delta LCO2_t = \sigma_0 \quad & +\sum_{i=1}^{p} \sigma_1 \Delta LCO2_{t-1} + \sum_{i=1}^{q} \sigma_2 \Delta LOFDI_{t-1} + \sum_{i=1}^{q} \sigma_3 \Delta LTROP_{t-1} + \sum_{i=1}^{q} \sigma_4 \Delta LGDP_{t-1} + \\ & \varpi_1 LCO2_{t-1} + \varpi_2 LOFDI_{t-1} + \varpi_3 LTROP_{t-1} + \varpi_4 LGDP_{t-1} + \varpi ECT + \mu_t\end{aligned} \quad (3)$$

The parameters for the short-run coefficients are represented by $\sigma_1 - \sigma_4$, while those of the long-run coefficients are shown as $\varpi_1 - \varpi_4$. ECT is the error correction term, which shows the rate at which the economy moves back to equilibrium. Furthermore, this research employed the FDCA proposed by [26]. The FDCA assesses the degree of a particular variation in a time series, whereas the "time-domain" approach tells us where a certain change occurs within a time series [27]. Seasonal changes can be eliminated from the small-sample data thanks to the FDCA [28]. Furthermore, the FDCA allows for the detection of causality between factors at short, medium, and long frequencies as well as the distinction of non-linearity and causality stages [59]. Lastly, using the FDCA will tell us when and how consistently OFDI drives CO_2.

5. Analysis and Discussions

5.1. Descriptive Statistics

From Table 2, it is evident that the highest mean and median values can be seen in the LGDP variable, with the values 26.93181 and 26.85473, respectively. The next, in terms of high values, is LCO_2. This pattern is also observed in the maximum and minimum values. For skewness, LCO_2 and LOFDI are skewed negatively at −0.149534 and −2.036834, respectively, while LTROP and LGDP are skewed positively at 0.317885 and 0.164348, respectively. LCO_2, LTROP, and LGDP are platykurtic because the kurtosis values are below 3, while LOFDI is leptokurtic because the value is above 3. Aside from LOFDI, which demonstrates a non-normal distribution nature, every other variable displays normal distribution. The trends and patterns of the variables are presented in Figure 1. LCO_2 and LGDP evidently moved in an upward trend, while fluctuations are observed in LOFDI and LTROP.

Table 2. Descriptive statistics.

	LCO_2	**LOFDI**	**LTROP**	**LGDP**
Mean	5.485935	−2.800015	2.195019	26.93182
Median	5.449980	−1.608315	2.124766	26.85473
Maximum	6.132650	−0.239890	2.692827	27.80867
Minimum	4.682274	−11.58177	1.766019	26.11594
Std. Dev.	0.422189	3.170645	0.232388	0.494133
Skewness	−0.149534	−2.036834	0.317885	0.164348
Kurtosis	1.877865	5.932235	2.443322	1.821635
Jarque–Bera	2.135329	39.88855	1.130651	2.369592
Probability	0.343811	0.000000	0.568175	0.305809
Observations	38	38	38	38

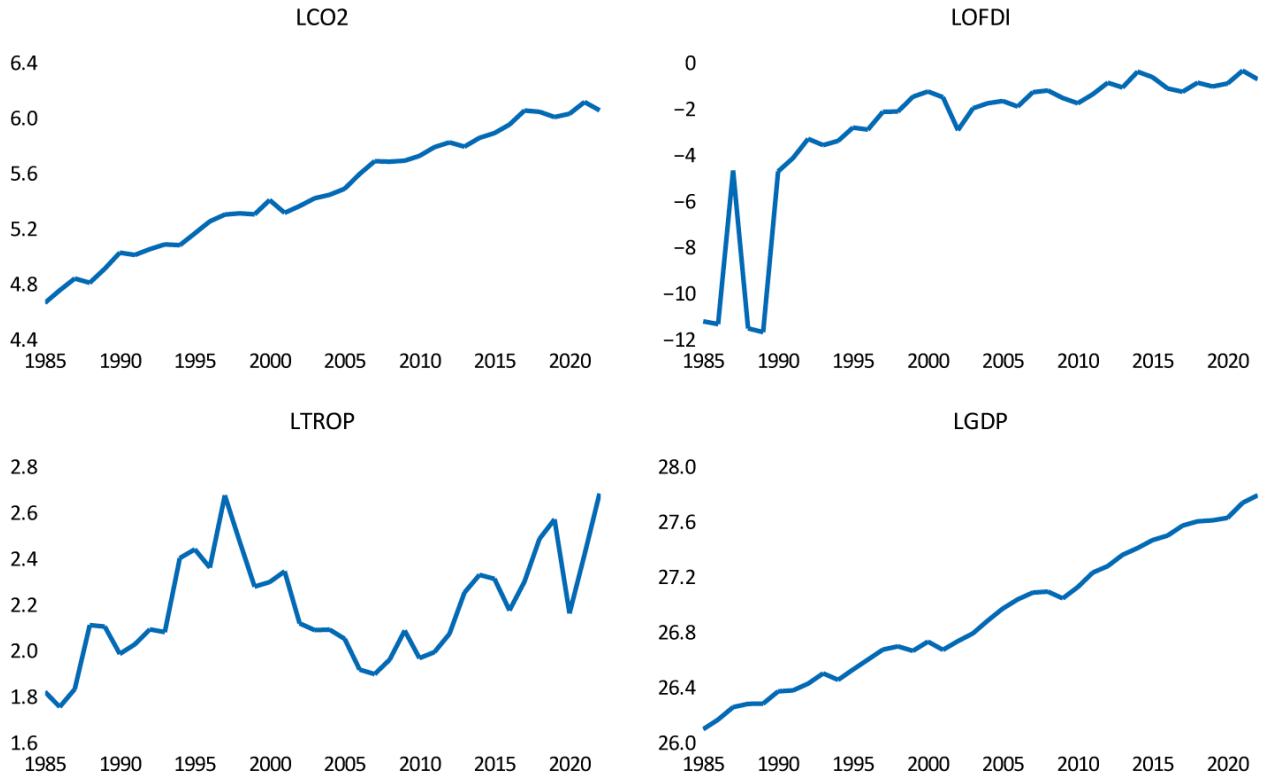


Figure 1. Trends and patterns of variables.

5.2. Correlation Matrix

In Table 3, the correlation matrix shows that LOFDI, LTROP, and LGDP are positively correlated with CO_2. It is essential to state that these correlations are statistically significant.

Table 3. Correlation matrix.

Probability	**LCO_2**	**LOFDI**	**LTROP**	**LGDP**
LCO2	1.000000			
LOFDI	0.782224 0.0000	1.000000 -		
LTROP	0.405 0.0117	0.435965 0.0062	1.000000 -	
LGDP	0.989485 0.0000	0.726404 0.0000	0.417912 0.0090	1.000000 -

5.3. Unit Root Analysis

The results presented in Table 4 are the unit root results of [60,61]. The outcome of both tests shows that LCO_2 and LOFDI are stationary at I(0), while LTROP and LGDP are stationary at I(1). This confirmation shows that the proposed methodology, which is ARDL, can be used.

Table 4. Unit root evaluation.

	ADF		PP		
Variables	**I(0)**	**I(1)**	**I(0)**	**I(1)**	**Decision**
LCO2	−3.595650 **	−6.929647 *	−3.590214 **	−8.219288 *	I(0)
LOFDI	−3.043574 **	−8.320178 *	−3.043574 **	−3.043574 *	I(0)
LTROP	−1.955654	−6.017651 *	−2.198031	−6.181128 *	I(1)
LGDP	−2.443282	−6.329250 *	−2.508011	−7.690346 *	I(1)

* denotes $p < 0.01$, and ** denotes $p < 0.05$.

5.4. Bounds Test

From the bounds test in Table 5, it is evident that there is a long-run association between the investigated variables. The F-stat value (3.966983) is more than the I(0) and I(1) bounds at the 5% and 10% significance levels.

Table 5. Bound test.

Test Statistic	Value	Significance	I(0)	I(1)
F–statistic	3.966983	10%	2.37	3.2
		5%	2.79	3.67
		2.50%	3.15	4.08
		1%	3.65	4.66

5.5. ARDL Long- and Short-Run Outcomes

In Table 6, the outcome confirms that LOFDI and LGDP increase LCO_2, while LTROP reduces LCO_2. Empirically, in the long run, as LOFDI and LGDP increase by 1%, LCO_2 rises by 0.02% and 0.69%, respectively. On the other hand, as LTROP increases by 1%, LCO_2 is depleted by 0.25%. In the short run, as LOFDI and LGDP increase by 1%, LCO_2 increases by 0.007% and 0.48%, respectively. On the contrary, LTROP reduces LCO_2 by 0.07%. It is important to note that these dynamics change when the lags are taken into consideration. This can be ascribed to structural change dynamics and the deployment of cleaner technologies, which cannot be sustained. That is why in the long run, these variables move back to their original positions. Furthermore, the ECM confirms a reversal to equilibrium at 0.35%. This is the cointegrating equation in Table 6. To ensure the viability of these results and to justify the rationale of including the variables in this study's model, the R-squared shows that 81% of LCO_2 can be explained by LOFDI, LGDP, and LTROP. Furthermore, the overall model shows normality, confirms the absence of serial correlation, is homoskedastic, and is confirmed stable by the Ramsey RESET test in Table 6 and the CUSUM and CUSUMQ tests in Figure 2.

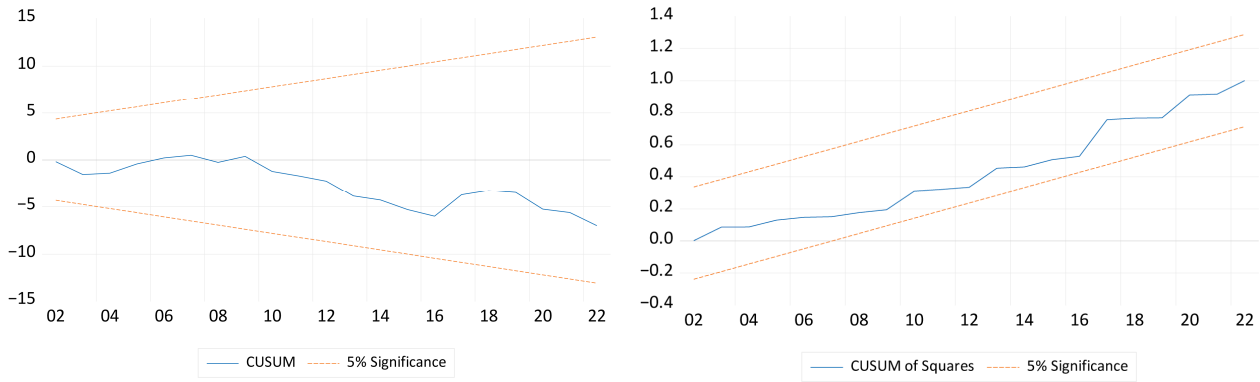


Figure 2. CUSUM and CUSUMQ.

Table 6. ARDL long- and short-run outcomes.

Long-Run Estimates				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LOFDI	0.028316	0.010553	2.683184	0.0139
LGDP	0.697810	0.045088	15.47672	0.0000
LTROP	−0.259298	0.093974	−2.759261	0.0118
C	−12.59644	1.334828	−9.436749	0.0000
Short-Run Estimates				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
D(LOFDI)	0.007025	0.003887	1.807093	0.0851
D(LOFDI(−1))	−0.013649	0.002753	−4.957111	0.0001
D(LGDP)	0.484864	0.092088	5.265252	0.0000
D(LGDP(−1))	−0.155154	0.094457	−1.642589	0.1154
D(LTROP)	−0.077006	0.032575	−2.363930	0.0278
D(LTROP(−1))	−0.006877	0.031043	−0.221533	0.8268
D(LTROP(−2))	0.057689	0.033939	1.699774	0.1039
D(LTROP(−3))	0.138317	0.038196	3.621197	0.0016
CointEq(−1) *	−0.359990	0.074082	−4.859321	0.0001
R-squared	0.811146			
Adjusted R-squared	0.750713			
Durbin–Watson (DW)	1.976329			
Residual Diagnostics	F–Stat	*p*–value		
Normality Test	1.023555	0.599429		
Serial Correlation LM Test	0.083634	0.9201		
Heteroskedasticity Test	0.250495	0.9916		
Ramsey Reset Test	2.621135	0.1211		

Note: * denotes the cointegrating equation.

5.6. Frequency Domain Causality Approach (FDCA)

In Figure 3, the FDCA shows that LOFDI Granger causes LCO_2 in the short and medium term. Furthermore, the causality between LTROP and LCO_2 is significant in the short, medium, and long term. Finally, LGDP is seen not to have a significant association with LCO_2.

5.7. Discussions

Contrary to other findings, this research asserts that OFDI can drive CO_2 in Turkey. There are various reasons for this assertion. One of the factors responsible for this is structural economic reallocation. This refers to a scenario where firms in Turkey move standardized and low-energy-intensive activities to host countries, while retaining high-energy-intensive activities, such as complex manufacturing processes. Ref. [31] opined that this positive OFDI–CO_2 nexus is driven by numerous legislative obstacles (stringent ecological policies) that the government has put in place to stop the flight of industrial capital. Consequently, high-polluting and high-emission businesses have not been moved out of the country by Turkey's OFDI. An example of such policies is the adoption of the climate law, which creates the legal framework for a national emissions trading system (ETS) to help Turkey achieve its net-zero emissions goal. Additionally, the legislation establishes institutional arrangements, financing methods, and a structure for governing the climate. It further emphasizes that firms should not feel forced to relocate to countries with lower ecological standards [62]. In addition, the size of the population, the level of overall economic progress, the level of technological advancement, and ecological policies are

factors that determine how OFDI impacts the environment. This relationship is supported by the studies of [13,29] and opposed by the studies of [30,36].

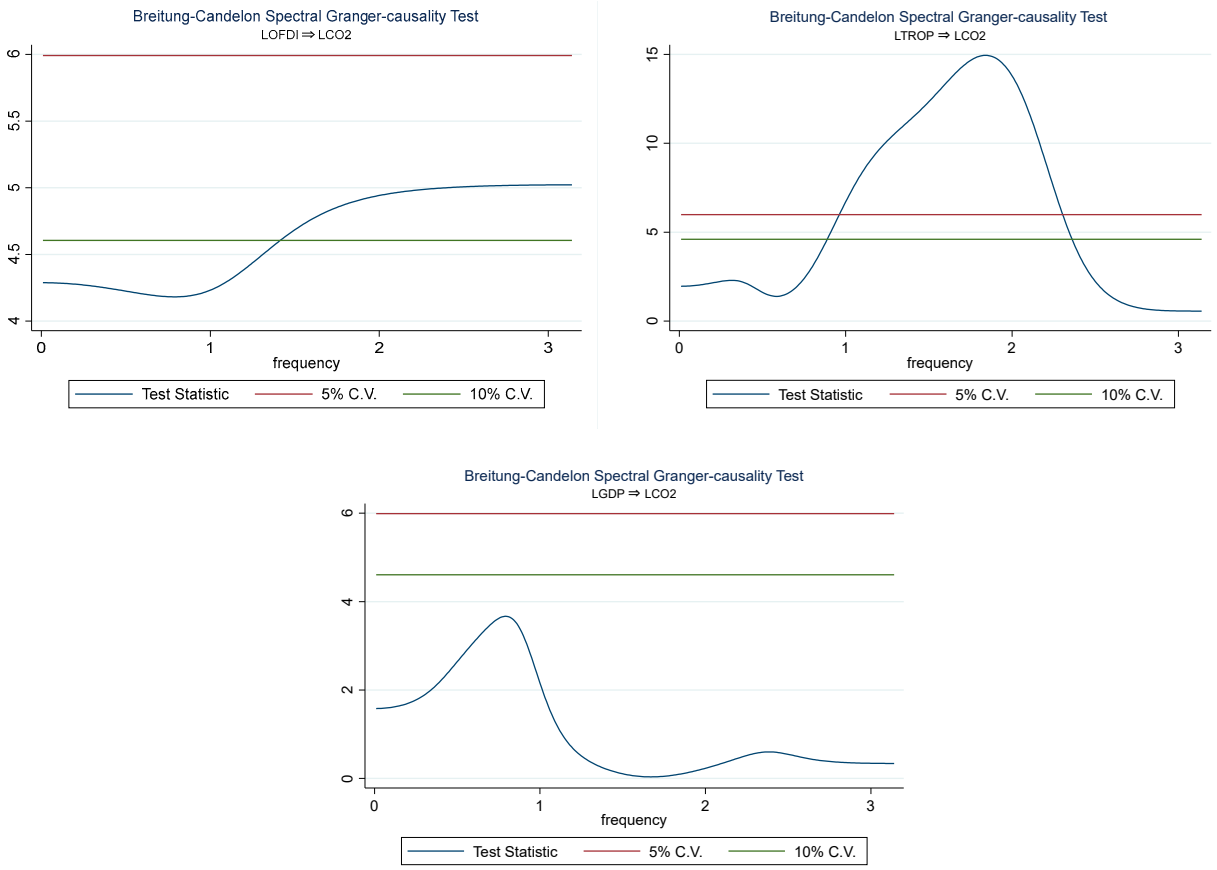


Figure 3. Frequency Domain Causality Approach.

The empirical outcome of GDP boosting CO_2 has been hypothesized. This is because Turkey still depends on fossil fuels for economic activities. According to [63], a positive GDP–CO_2 nexus is driven by the goal to increase output, which requires energy use; nevertheless, the demand for unclean energy greatly exceeds the need for clean energy. Therefore, in the long run, increased utilization of energy in the quest for higher output results in higher CO_2. This outcome aligns with the studies of [39–41] and contradicts the research of [45].

Lastly, the outcome of an inverse association between TROP and CO_2 is expected. This is because services require fewer physical resources, and as a result, their expansion effectively decouples economic progress from CO_2. Ref. [47] opined that the export of services could increase a country's carbon efficiency. In addition, trade in services also aids the flow of clean technologies and management practices. This result is confirmed by the research of [22] and stands in contrast to the research of [48].

In summary, based on the theoretical foundation used in this research, the scale effect and pollution haven hypothesis are confirmed due to the exhibited relationship between OFDI, GDP, and CO_2.

6. Conclusions and Policy Recommendation

6.1. Conclusions

Debates relating to the sustainability of the environment have emerged as a major goal of the global agenda in recent years. As a result, this research examines the impact of outward foreign direct investment (OFDI) on carbon dioxide emissions (CO_2) in Turkey

from 1985 to 2022, using the autoregressive distributed lag model (ARDL) and frequency domain causality analysis (FDCA). In addition, economic growth (GDP) and trade in services (TROP) were used as control variables because they capture two big ways the economy interacts with the environment. OFDI is considered for the Turkish economy because it turns the country's own firms into global players. The empirical results are as follows: (i) The bounds test confirms a long-run association among the variables. (ii) The ARDL result confirms that in the long and short run, OFDI and GDP increase CO_2 in Turkey, while TROP contributes to the quality of the environment. Empirically, in the long run, as OFDI and GDP increase by 1%, CO_2 increases by 0.02% and 0.69%, respectively, while TROP decreases CO_2 by 0.25%. In the short run, as OFDI and GDP increase by 1%, CO_2 increases by 0.007% and 0.48%, respectively, while TROP decreases CO_2 by 0.07%. (iii) The FDCA demonstrates that OFDI Granger causes CO_2 in the short and medium term, while TROP Granger causes CO_2 in the short, medium, and long term.

6.2. Policy Recommendations

First, because OFDI contributes to a country's long-term sustainable growth, strategic OFDI policies should be formulated. In the wake of the 2025 climate law, Turkey must move beyond broad regulations and adopt frequency-specific policies. Short-term policies include green capital screening, which states that a business must demonstrate that the domestic setup phase will not surpass a certain carbon limit if it wants to move capital abroad. If it does, the money the business pays out will be subject to a temporary environmental tax. In the medium term, the Turkish government may grant a carbon credit refund to businesses that use their international profits to purchase sophisticated green technology and install it in their Turkish facilities. In the long term, the Turkish government should fully classify businesses that can be regarded as green so that they can have access to funding thorough attractive interest rates, grants, or subsidies. Ref. [33] opined that environmental regulation greatly increases OFDI. Ref. [64] stated that businesses reroute their investment capital to green innovation R&D when ecological constraints limit OFDI in highly polluting industries. This boosts competitive advantage, increases profitability, and eventually encourages OFDI. On the other hand, when ecological policies permit OFDI in highly polluting industries, businesses not only immediately minimize the release of pollutants and ameliorate local production operations, but they also use OFDI to obtain advanced green technologies and best practices globally. A positive feedback loop can be created by these newly acquired technologies and experiences, stimulating additional OFDI. *Second*, although GDP increases CO_2 emissions, adopting eco-friendly technologies can help foster economic progress while at the same time contributing to the quality of the environment. This is called decoupling. Economic growth is achieved when Turkey reduces its reliance on expensive fossil fuel imports, allowing the country to save billions of dollars in energy costs. This further creates highly skilled green manufacturing jobs, ensuring that exports remain competitive in markets such as the EU, which now taxes carbon-intensive goods. Simultaneously, it promotes EQ by removing hazardous emissions at their source, which significantly improves human health and protects natural resources. *Lastly*, the trend of a positive association between TROP and EQ should be maximized by the government and all concerned stakeholders by ensuring that restrictions relating to trade service exports are reduced. In addition, significant investment should be made in digital infrastructure and skills to aid the private sector's competitiveness.

6.3. Limitations and Future Research Suggestions

This research used two control variables in analyzing the main research question. Thus, other studies can include additional control variables such as environmental policy

stringency, technological and green innovation, and energy use depending on the country being studied. This means that other countries can be investigated to allow for robust policy formulation. More specifically, non–parametric econometric methods can be used, such as wavelet quantile regression, wavelet quantile correlation, and quantile-on-quantile Granger causality, because of the reliable insights they can yield about the underlying research questions.

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Abbreviations

The following abbreviations are used in this manuscript:

CO_2	Carbon Dioxide Emissions
DOLS	Dynamic Ordinary Least Squares
EKC	Environmental Kuznets Curve
EQ	Environmental Quality
FMOLS	Fully Modified Ordinary Least Squares
GMM	Generalized Method of Moments
ICT	Information and Communication Technology
IFDI	Inward Foreign Direct Investment
OFDI	Outward Foreign Direct Investment
PMG	Pooled Mean Group
R&D	Research and Development

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