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RESEARCH ARTICLE

# Which is more important, foreign direct investment inflow or outflow, on the pollution of European Union countries? Evidence from Panel Fourier symmetric and asymmetric causality

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**Abstract**
Uncertainty remains regarding the impact of foreign direct investments on countries' environmental policies and pollution levels. Therefore, this study examines the relationship between foreign direct investment inflows, outflows, and carbon dioxide emissions for EU (European Union) member states. Accordingly, the data for the period 1993–2019 were subjected to the Panel Fourier symmetric and asymmetric causality tests for 21 EU countries. According to the Panel Fourier symmetric causality test results, the effect of foreign investment outflows on carbon dioxide emissions is more dominant in general. While there is a bidirectional relationship between these variables in the Austrian and Slovak Republics, there is a unidirectional relationship between foreign investment outflows to carbon dioxide emissions in Belgium, Bulgaria, Cyprus, Ireland, and Portugal. On the other hand, one-way causality was found from foreign investment inflows to carbon dioxide emissions in Belgium, Cyprus, France, Ireland, and Romania and from carbon dioxide emissions to foreign investment inflows in Finland, Greece, and Sweden. According to the Panel Fourier asymmetric causality test results, causality between variables is statistically significant in many countries. This shows that the asymmetric relationship is essential for the variables.

**Keywords** Carbon dioxide emission · Foreign direct investment · EU countries · Panel Fourier casualty

## Introduction

With the growth in globalization, liberalization, and free movement of capital in the international arena in the 1990s, environmental pollution also began to increase. According to the World Bank (2023), the total greenhouse gas emissions (% change from 1990) ratio corresponded to 0.92 in 1991, while there was a change of 40.003 in 2012. Moreover, carbon dioxide emissions today are about 67% higher than in 1990 (World Bank 2023). Especially countries that industrialized at an early stage endure pollution until per capita income reaches a particular milestone and then need a clean environment once the nation becomes wealthy. In the literature, this situation is explained by the environmental Kuznet curve theory (Murthy and Gambhir 2018; Cansino et al. 2019; Rana and Sharma 2020; Polloni-Silva et al. 2021). Therefore, governments strengthen environmental regulations, and companies use clean technologies in the production process to avoid high environmental taxes. However, this increases the production costs of companies. This raises the question of where developed societies would realize their dirty industries and the search for host countries for foreign direct investments (Destek and Okumus 2019; Liu et al. 2019; Shao et al. 2019; Benzerrouk et al. 2021).

Foreign direct investment (FDI) impacts the host country positively and negatively. This leads to the fact that the effect of FDI on the environment remains to be determined, and there needs to be a clear consensus on this issue (Polloni-Silva et al. 2021; Akram et al. 2022; Khan et al. 2023). In this direction, the impact of FDI, which has become one of the vital channels of economic growth, on the environment (more specifically,

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pollution) is analyzed under two different hypotheses in the literature. The first of these, the pollution haven hypothesis, is based on the preference of companies operating under strict environmental regulations to reposition to countries with soft environmental policies and regulations. This hypothesis suggests that multinational corporations shift their polluting activities to less-regulated countries to avoid costly environmental regulations in their countries of origin. Regarding the FDI, the pollution haven hypothesis emphasizes the possibility for investors to seek out economies where they can settle with fewer regulatory requirements and cheaper industry operating costs (Kathuria 2018). Strict environmental regulations require companies to use new equipment, new alternative methods, and processes and impose restrictions on inputs and outputs. These requirements result in more pollution due to FDI in countries with weaker environmental regulations (Kisswani and Zaitouni 2021). Countries with weak environmental regulations and no interest in improving them are often developing and underdeveloped countries where dirty industries are transferred. These host countries are willing to put up with this pollution to achieve a certain level of development (Neves et al. 2020).

The other is the pollution halo hypothesis, the opposite of the pollution haven hypothesis. Accordingly, multinational companies engaged in FDI export greener environmental standards and best management practices to host countries. Proponents of this hypothesis argue that multinational corporations are more likely to use friendly technology and less polluting production practices to operate in compliance with environmental regulations, thereby reducing pollution in host countries compared to countries of origin (Kisswani and Zaitouni 2021; Balsalobre-Lorente et al. 2022; Apergis et al. 2023).

Foreign investment inflows and outflows generally increased towards the end of the 1990s. Developed nations made the majority of foreign investments during this period. According to World Bank (2023) data, EU countries have the highest share of foreign investment inflows and outflows in gross domestic product (GDP) worldwide. When this situation is analyzed in Fig. 1, foreign investment inflows have been around 17% on average over the years, while this rate is approximately 24% in EU countries. Moreover, the share of EU countries' foreign investment inflows in the world averaged 30% over the period shown in the graph. This rate is 37% for foreign investment outflows. This indicates that foreign investments, especially outflows, have an essential role in the economies of EU countries.

Figure 1 shows that foreign investment inflows in the world and EU member states reached their highest levels in 2000 and 2007, respectively, and outflows in the following periods. However, when this is evaluated in terms of carbon emissions, as seen in Fig. 2, while there has been a decrease in EU member states since 2008, there has been an increase worldwide. During this period, the EU community signed the Kyoto protocol and put stronger and legally binding measures in place to reduce global greenhouse gas emissions (Cirman et al. 2009). Nevertheless, according to World Bank (2023), the average carbon dioxide $\left(CO_2\right)$ emission level per capita is 4.27 globally and 7.52 in EU countries. Furthermore, EU countries' $CO_2$ emissions account for an average of 12% of the world's total. An analysis of foreign investment inflows and outflows as two separate groups, taking into account the data of 2008, when carbon emissions tended to decrease in EU member states, reveals that foreign investment outflows increased at a higher rate than inflows.

Cave and Blomquist (2008) found that less developed European countries, especially non-EU countries, have a comparative advantage in energy-intensive industries and import energy-intensive goods from these countries. The strict environmental standards of EU countries and the strict uniform application of environmental regulations in these countries cause them to be seen as a pollution haven. This is among the reasons for the outflow of foreign investment into these countries.

Studying the relationship between the pollution level and foreign investment in EU countries is particularly critical, not only because the EU is a leader in promoting policies and technologies

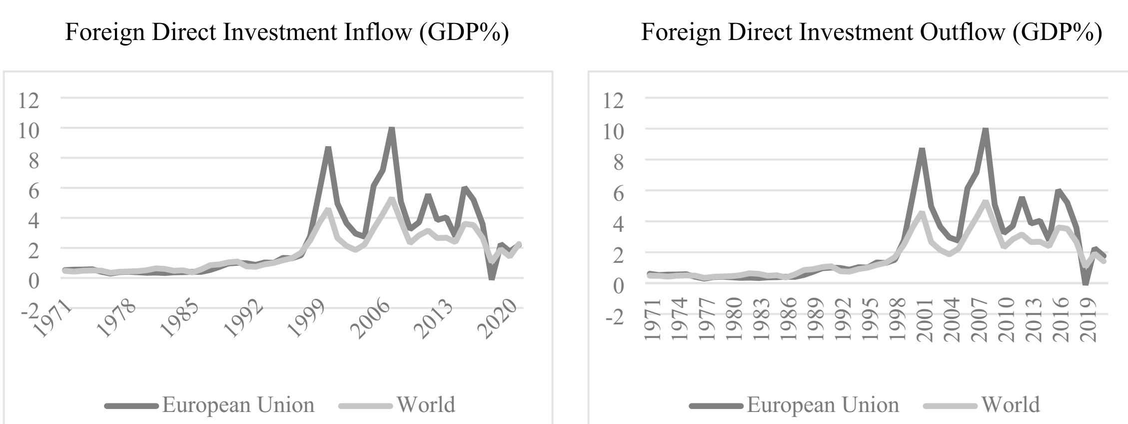
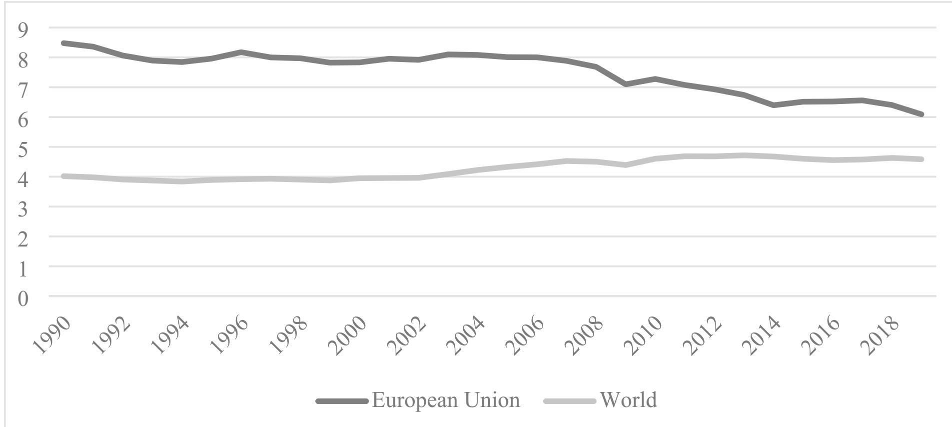



**Fig. 1** Foreign direct investment inflow and outflow

**Fig. 2** $CO_2$ emissions (metric tons per capita)




to reduce emissions but also because strict regulations on polluting activities are already well established (Neves et al. 2020). This study aims to analyze the relationship between foreign investment inflows and outflows and carbon dioxide emissions for EU countries. This study has more than one contribution to the literature. First, the empirical literature on pollution levels and foreign investment inflows focuses more on less developed countries and country groups. However, EU countries are one of the country groups with the highest outflow of foreign investment (World Bank 2023; Eurostat 2023). Moreover, although there are countries with different levels of development within the EU, it is predominantly constituted of developed countries. This has led to the need for more examining the relationship between foreign investment and pollution levels in EU countries. In this sense, this study aims to fill the gap in the literature by reviewing EU countries. Another contribution of the study is that it considers foreign investment outflows. As the pollution haven hypothesis states, if developed countries transfer their dirty industries to other countries, it is expected to affect their carbon dioxide emissions. In this framework, the most critical gap in the literature is addressed by determining the impact of foreign investment outflows on the carbon dioxide emissions of the EU countries, which have the highest foreign investment inflows.

Environmental policies have changed over the years as EU countries have adopted various agreements (Paris agreement) to prevent environmental degradation. Therefore, examining the relationship between variables is crucial in considering structural change. Hence, this study examines the relationship between variables using Fourier approaches that assume smooth structural transition. It is also observed that the hidden relationship between the variables needs to be considered in analyzing the relationship between foreign investments and pollution. Nonetheless, while no relationship between the variables considered cumulatively can be identified, it is essential to identify hidden relationships when the variables are decomposed into positive and negative shocks. Hidden relationships are also addressed in this study.

This study consists of seven sections. The current literature will be discussed in the next section of the study. Subsequently, the methodology, the utilized data, the empirical findings, and the discussion will be presented. The final section will provide conclusions and policy recommendations.

## Literature review

A comprehensive review of the literature reveals that environmental degradation not only affects foreign investment but is also affected by foreign investment. In these studies, many pollution variables, such as $CO_2$, sulfur oxide $(SO_2)$, nitrous oxide $(NO_x)$, and ecological footprint (EF), are used as environmental degradation factors. However, as a result of the empirical analysis, it was concluded that although there are many studies on the relationship between pollution and FDI, there has yet to be a common consensus. While some studies find a positive relationship between the variables, others argue that this relationship is negative. The mixed results may be due to the choice of country, research period, data length, econometric methods, and environmental degradation indicators. The issue is still topical in this sense.

Since carbon dioxide emissions contribute the most to environmental degradation among greenhouse gas emissions (EuroStat 2023), studies generally use $CO_2$ (Huynh and Hoang 2019; Rahman and Ahmad 2019; Rana and Sharma 2020; Bulut et al. 2021; Gong et al. 2023; Firoj et al. 2023) as the environmental degradation variable. Furthermore, the majority of the studies examining the link between FDI and $CO_2$ have analyzed developing country groups with panel data methods (MENA, BRICS, MINT, PIIGS) (Shao et al. 2019; Salehnia et al. 2020; Balsalobre-Lorente et al. 2022; Tasdemir and Ozcelik 2023), in some studies, developing and underdeveloped countries are discussed with time series analysis (China, Italy, Pakistan, India, Turkey, Korea) (Murthy and Gambhir 2018; Liu et al. 2019; Nadeem et al. 2020; Bulus and Koc 2021; Cil 2023; Javed et al. 2023). It has been determined that very few studies have addressed developed country groups (The Organisation for Economic Cooperation and Development (OECD), EU), especially EU countries are covered less in the studies conducted in the literature (Caetano et al. 2022; Singh and Dhiman 2023).

EU countries promote various environmental policies and technologies to reduce emissions and also have strict regulations on polluting activities (Cave and Blomquist 2008). However, despite the measures taken, there has not been a steady decrease in $CO_2$ levels in the EU over the years (World Bank 2023). This can be addressed from two perspectives (Cave and Blomquist 2008). The first is the import of toxic goods from less developed OECD countries, and the other is the increase in primary energy consumption in the short and long run despite increases in national income. Among the studies conducted for EU countries in the literature, Li et al. (2022) could not find a strong relationship between FDI and $CO_2$, while Singh and Dhiman (2023) found that FDI generally has an increasing effect on the pollution level of countries. In a study conducted on G-20 countries, including EU countries, Musah et al. (2022) found that foreign investments increase $CO_2$ in the long run and that there is bidirectional causality between the variables in the short run. Similarly, in an analysis of the impact of investments made by OECD countries (including the EU countries) in BRICS countries regarding pollution, Apergis et al. (2023) found that OECD countries generally transfer their dirty industries to BRICS countries and contribute positively to the pollution of the host country.

In this study, we have divided the literature into two sections. The first section includes studies on country groups, followed by studies on single country groups in the second section. Table 1 provides an overview of the existing literature. It also includes studies addressing the country dimension and $CO_2$ as an environmental degradation variable. Since studies on the subject have attracted more attention recently, the literature mainly covers the last 5 years.

In this study, we have divided the literature into two sections. The first section includes studies on country groups, followed by studies on single country groups in the second section. Table 1 provides an overview of the existing literature. It also includes studies addressing the country dimension and $CO_2$ as an environmental degradation variable. Since studies on the subject have attracted more attention recently, the literature mainly covers the last 5 years.

In the literature, studies generally focus on foreign investment inflows or investment outflows from a specific source country (from X country to Y country). Relatively few studies have addressed the impact of environmental regulations on foreign investment outflows and their effects on the pollution level of the source country. Among these studies, Cave and Blomquist (2008) found that EU member states utilize less developed countries as pollution havens for energy-intensive trade. In addition, among the studies examining the relationship at the country and firm size, Cole and Fredrikson (2009) found that 13 OECD countries; Kellenberg (2009) found that the United States (US); Chung (2014) found that South Korea; Zugravu-Soilita (2017) found that France, Germany, Sweden, and the UK; Wagner and Timmins (2009) found that six industries of German; Ben Kheder and Zugravu (2012) found that French firms; and Rezza (2013) found that firm-level investment in Norway shifted their investments to other countries due to strict environmental regulations, causing an increase in the pollution level of the host country. In contrast to these studies, Jeppesen et al. (2002) claim that the US, Mulatu et al. (2010) claim that 13 European countries, Manderson and Kneller (2012) argue that the United Kingdom (UK) does not move its dirty industry to the host country at FDI outflows.

The literature on the issue suggests that foreign investment flows from developed countries with strict environmental policies to developing and underdeveloped countries with more lax environmental policies. In this regard, studies examining the relationship between foreign investment and pollution focus on foreign investment inflows. Nevertheless, considering that countries transfer their dirty industries to less developed countries due to strict environmental policies, the relationship between foreign investment outflows and pollution needs to be addressed. This study fills the gap in the literature by examining the relationship between foreign investment inflows, as well as foreign investment outflows and pollution.

## Methodology

### Panel unit root tests

Pesaran (2007), the cross-sectionally augmented Dickey–Fuller (CADF) unit root test, is one of the most popular unit root tests in the literature and takes cross-sectionally dependent into account. This test is based on the Im et al. (2003) (IPS) modified *t*-test and the ADF unit root test applied to each unit. In addition, the unit root process of the panel can be examined using the cross-sectionally augmented panel unit root (CIPS) statistic, which is the average of the *t*-tests of the units. However, this test needs to take structural change into account.

Many tests are employed to investigate the unit root process of a series under structural change. The described tests figure out changes in the structure under a shift break using dummy variables (Im et al. 2005; Bai and Carrion-i-Silvestre 2009). In contrast to these studies, Lee et al. (2016) added a new unit root test to the body of literature by capturing structural change using the Enders and Lee (2012) Fourier approach. Fourier functions offer a convenient approximation for breaks of unknown form. The most important reason for this is identifying the appropriate component in the model. Therefore, it eliminates complex procedures such as determining break dates, the number of breaks, and the shape of the breaks (Lee et al. 2016).

**Table 1** Literature summary

| Author(s) | Period and country(ies) | Methodology | Result(s) |
|---|---|---|---|
| Results for single countries using time series analysis | | | |
| Murthy and Gambhir (2018) | 1991–2014 India | Regression nalysis | FDIN $\rightarrow CO_2^+$ |
| Liu et al. (2019) | 1996–2015 China | Panel data partially linear additive model | Inverted N-shaped |
| Rahman and Ahmad (2019) | 1975–2016 Pakistan | NARDL model | FDIN $\rightarrow CO_2^+$ |
| Assamoi et al. (2020) | 1980–2014 Cote d'Ivoire | ARDL bounds test | FDIN $\rightarrow CO_2^+$ |
| Mert and Caglar (2020) | 1974–2018 Turkey | Asymmetric causality, GY hidden cointegration | FDIN $\rightarrow CO_2^{SR}$<br>FDIN $\rightarrow CO_2^{LR,-}$ |
| Nadeem et al. (2020) | 1971–2014 Pakistan | ARDL bounds test | FDI $\neq CO_2$ |
| Rana and Sharma (2020) | 1982–2013 India | TY causality | $CO_2 \rightarrow$ FDI |
| Bulus and Koc (2021) | 1970–2018 Korea | ARDL bounds test | FDIN $\rightarrow CO_2^+$ |
| Bulut et al. (2021) | 1970–2016 Turkey | ESTR cointegration | FDIN $\rightarrow CO_2^+$ |
| Danish and Ahmad (2021) | 1994–2018 China | ARDL bounds test | FDIN $\rightarrow CO_2^-$ |
| Kisswani and Zaitouni (2021) | 1971–2014 Asian countries | ARDL bounds test | Mixed Results |
| Akram et al. (2022) | 1982–2018 China | Quantile ARDL and quantile Granger causality | FDIN $\rightarrow CO_2^{LR,+}$<br>FDIN $\leftrightarrow CO_2^{SR}$ |
| Chen et al. (2022) | 2001–2015 China | Spatial FE, SGMM | FDIN $\rightarrow CO_2^-$ |
| Cil (2023) | 1970–2020 Turkey | Fourier Shin and Fourier ADL cointegration, Fourier TY causality | FDIN $\rightarrow CO_2^{LR,+}$<br>FDIN $\leftrightarrow CO_2^{SR}$ |
| Chi and Meng (2023) | 2003–2017 China companies | POLS, FE, SGMM | FDIN $\rightarrow CO_2^+$ |
| Firoj et al. (2023) | 1986–2018 Bangladesh | ARDL bounds test | FDIN $\rightarrow CO_2^{LR,-}$<br>FDI $\neq CO_2^{SR}$ |
| Javed et al. (2023) | 1970–2018 Italy | ARDL bounds test, NARDL | FDIN $\rightarrow CO_2^{LR,+}$<br>FDIN $\rightarrow CO_2^{SR,-}$ |
| Wang and He (2023) | 2000–2021 China | ARDL bounds test | FDIN $\rightarrow CO_2^+$ |
| Results for country groups using panel data analysis | | | |
| Huynh and Hoang (2019) | 2002–2015<br>19 developing Asian countries | FGLS, SGMM | FDIN $\rightarrow CO_2^+$ |
| Shao et al. (2019) | 1982–2014<br>BRICS and MINT | Panel cointegration, FMOLS, Granger causality | FDIN $\rightarrow CO_2^{LR,+}$<br>FDIN $\rightarrow CO_2^{SR}$ |
| Guzel and Okumus (2020) | 1981–2014<br>ASEAN-5 | Panel cointegration, CCEMG, AMG | FDIN $\rightarrow CO_2^+$ |
| Nathaniel et al. (2020) | Mediterranean countries | OLS and quantile regression, Westerlund (2007) cointegration | FDI $\neq CO_2$ |
| Salehnia et al. (2020) | 2004–2006 MENA | Panel quantile regression | FDIN $\rightarrow CO_2^-$ |
| Ahmad et al. (2021) | 1998–2016 Chinese provinces | CCEMG, Westerlund (2007) cointegration | Mixed Results |
| Benzerrouk et al. (2021) | 1980–2016<br>31 developed, 100 developing countries | GMM | FDIN $\rightarrow CO_2^{developing,+-}$<br>FDIN $\rightarrow CO_2^{developed,-}$ |
| Gyamfi et al. (2021) | 1990–2016 sub-Saharan African countries | Panel quantile regression, OLS | FDIN $\rightarrow CO_2^+$ |
| Khan et al. (2023) | 2000–2016 108 developing countries | Pedroni Panel Cointegration, P-VECM, OLS | FDIN $\rightarrow CO_2^{LR,+}$<br>FDI $\neq CO_2^{SR}$ |
| Nawaz et al. (2021) | South Asian economies | FMOLS, panel cointegration | Interved U-shaped |
| Singhania and Saini (2021) | 1990–2016 21 countries | GMM, SGMM | Mixed Results |
| Wang et al. (2021) | 2005–2014 64 middle and low-income countries | PSTR model | N-shaped |
| Bulut et al. (2022) | 1993–2018 developing countries | Westerlund (2007) cointegration, CCEMG | FDI $\neq CO_2$ |
| Caetano et al. (2022) | 2005–2018 OECD | Panel ARDL | FDIN $\rightarrow CO_2^+$ |
| Balsalobre-Lorente et al. (2022) | 1990–2019 PIIGS countries | DOLS, Westerlund (2007) cointegration, panel Granger causality | FDIN $\rightarrow CO_2^{LR,+}$<br>FDI $\neq CO_2^{SR}$ |

**Table 1** (continued)

| Author(s) | Period and country(ies) | Methodology | Result(s) |
|---|---|---|---|
| Li et al. (2022) | 1995–2017 89 belt and road initiative countries | PCSE, GLS, Pedroni panel cointegration | Mixed Results |
| Musah et al. (2022) | 1992–2018 G-20 countries | Westerlund-Edgerton Cointegration, DCCEMG, S-ARDL, Panel Granger Causality | $FDIN \rightarrow CO_2^{LR,+}$ $FDIN \leftrightarrow CO_2^{SR}$ |
| Apergis et al. (2023) | 1993–2912 BRICS countries | GMM, panel Granger causality | Mixed Results |
| Abbas et al. (2023) | 2006–2020 sub-Saharan African | FE, RE, SAR SGMM | $FDIN \rightarrow CO_2^{+}$ |
| Balli et al. (2023) | 1981–2021 Asia–Pacific economic cooperation countries | Westerlund (2008) cointegration, MG, PMG estimator, panel TY Granger causality | $FDI \neq CO_2^{LR}$ Mixed Results$^{SR}$ |
| Chien et al. (2023) | 1970–2019 G-7 countries | Johansen Fisher panel cointegration, OLS | $FDIN \rightarrow CO_2^{-}$ |
| Dutta and Hazarika (2023) | 2000–2019 SA-EAP, MENA-SSA, and LAC countries | Pedroni panel cointegration, FMOLS | $FDIN \rightarrow CO_2^{MENA-SSA,+}$ $FDI \neq CO_2^{SA-EAP,LAC}$ |
| Gong et al. (2023) | 1985–2014 46 African countries | Kao and Johansen Fisher Cointegration, FMOLS | $FDIN \rightarrow CO_2^{LR,-}$ $FDIN \leftrightarrow CO_2^{SR}$ |
| Mahmood et al. (2023) | 1995–2020 MENA countries | SAR | $FDIN \rightarrow CO_2^{+}$ |
| Mahmood (2023) | 1970–2019 18 Latin American countries | Non-spatial and spatial models | $FDIN \rightarrow CO_2^{+}$ |
| Singh and Dhiman (2023) | 2000–2018 Eastern, Southern, Northern, and Western Europe | 3SLS | Mixed Results |
| Tasdemir and Ozcelik (2023) | 1996–2019 MENA countries | FE, FE threshold, and dynamic panel threshold estimations | $FDIN \rightarrow CO_2^{+}$ |
| Wencong et al. (2023) | 1998–2019 twelve transition countries | Westerlund, Pedroni, and Kao Cointegration, CS-ARDL, PQR | $FDIN \rightarrow CO_2^{+}$ |

CIPS test created by Pesaran et al. (2013) is enhanced by adding a Fourier function to the Lee et al. (2016) unit root test to analyze the unit root process. The break and cross-sectionally dependent augmented ADF statistic (BCADF) is an extension of the CADF statistic proposed in Eq. 1 by Lee et al. (2016).

$$\begin{aligned}\Delta y_{it} &= c_{i,0} + c_{i,1}\text{sinsin}\left(\frac{2\pi kt}{T}\right) + c_{i,2}\text{coscos}\left(\frac{2\pi kt}{T}\right) + c_{1,3}{}'z_{t-1} \\ &+ c_{1,4}{}'\Delta z_t + \sum_{j=1}^{p} c_{1,5}{}'\Delta z_{t-1} \\ &+ \sum_{j=1}^{p} c_{i,6}\Delta y_{i,t-1} + b_{,}y_{i,t-1} + e_{it}\end{aligned} \quad (1)$$

In this equation, $p$ is the optimal lag length, $t$ is the trend value, $\pi = 3.1416$, $T$ is the sample size, $k$ is the optimal number of frequencies of the Fourier functions, and $z_{it} = \left(y_{it}, x_{it}{}'\right)'$ is the vector of the common factor $x_{it}{}'$. The break augmented CIPS (BCIPS) test statistic developed by Lee et al. (2016) by taking into account the breaks and cross-sectionally dependent augmented version of the unit root test under Pesaran (2007) and Pesaran et al. (2013) studies are calculated as follows:

$$\text{BCIPS}(N,T) = \frac{1}{N}\sum_{i=1}^{N} t_i(N,T) \quad (2)$$

where $t_i$ denotes the test statistic calculated for each unit. In addition, the test's null hypothesis expresses the unit root process.

## Panel Fourier Toda-Yamamoto causality

The Granger causality test is one of the pioneering tests among causality tests. This test was developed by Granger (1969) and is based on the vector autoregressive model (VAR), but has some limitations. The standard Granger causality analysis requires testing for unit roots and cointegration. This is because if the variables in the VAR model are integrated or cointegrated, the Wald test has a non-standard distribution and depends on nuisance parameters (Yilanci and Gorus 2020; Durusu-Ciftci et al. 2020). Toda and Yamamoto (1995) overcame this problem with the approach developed. This approach is based on the VAR $\left(p + d_{max}\right)$ model. In this case, the only thing that has to be calculated is the maximum stationarity level of the variables ($d_{max}$). Using the Fisher test statistic, Emirmahmutoglu and Kose (2011) produced it to apply this causality test to panel data. Emirmahmutoglu and Kose (2011) suggest the bootstrap simulations to obtain the critical values of Fisher test statistics in cross-sectionally dependent.

When structural change is not considered, the results obtained may be misleading. Enders and Jones (2016) demonstrate that the traditional dummy variable approach to modeling structural changes in the VAR framework is inappropriate and propose a new approach based on formulating a Fourier function for structural changes. Therefore, the number, dates, and structure of breaks can be determined using Fourier functions without doing it in advance. Nazlioglu et al. (2016) modified the Toda-Yamamoto model using the Fourier technique and created a new test considering structural changes. Yilanci and Gorus (2020) have extended the Fourier Toda-Yamamoto causality test proposed by Nazlioglu et al. (2016) for panel analysis. In this context, the Panel Fourier Toda-Yamamoto causality test for the two variables is expressed as follows:

$$y_{i,t} = \mu_i + A_{11}\sin\left(\frac{2\pi tf_i}{T}\right) + A_{12}\cos\left(\frac{2\pi tf_i}{T}\right) + \sum_{j=1}^{p_i+d_{\max_i}} A_{13}y_{i,t-j} + \sum_{j=1}^{p_i+d_{\max_i}} A_{14}x_{i,t-j} + u_{1i,t} \quad (3)$$

$$x_{i,t} = \mu_i + A_{21}\sin\left(\frac{2\pi tf_i}{T}\right) + A_{22}\cos\left(\frac{2\pi tf_i}{T}\right) + \sum_{j=1}^{p_i+d_{\max_i}} A_{23}x_{i,t-j} + \sum_{j=1}^{p_i+d_{\max_i}} A_{24}y_{i,t-j} + u_{2i,t} \quad (4)$$

where $\pi = 3.1416$; $t$, trend; $T$, sample size; $f_i$, the integer value of the minimum sum of the residual squares of the equations for each unit in the range of 1–5. At the same time, the Fisher test statistic for the Panel Fourier Toda-Yamamoto causality test is calculated as $\mathrm{FTYP} = -2ln(p^*)$. Here, $p^*$ indicates the Wald statistic calculated by bootstrap technique for each unit.

In the Toda-Yamamoto model, the Wald statistic for the null hypothesis of Granger non-causality follows an asymptotic $\chi^2$ distribution with p degrees of freedom (Durusu-Ciftci et al. 2020). This test has some advantages. The first one is that it deals with cross-sectionally dependent with the bootstrap technique and takes heterogeneity into account. Second, it uses Fourier functions to account for structural changes in the VAR model. Lastly, it employs the Toda-Yamamoto method to prevent the loss of information about the variables.

The Panel Fourier Toda-Yamamoto causality test analyzes variables without dividing them into positive and negative shocks. However, the variables' impact on one another may vary when they are divided into hidden shocks and examined. For the first time in the literature, Granger and Yoon (2002) analyzed the relationship between variables by using their cumulative positive and negative shocks. For the panel causality test, the cumulative positive and negative shocks for each of the variables are calculated as follows:

$$y_{i,t} = y_{i,t-1} + \varepsilon_{1,i,t} = y_{i,t,0} + \sum_{i=1}^{t} \varepsilon_{1,ij} \quad (5)$$

$$x_{i,t} = x_{i,t-1} + \varepsilon_{2,i,t} = x_{i,t,0} + \sum_{i=1}^{t} \varepsilon_{2,i,j} \quad (6)$$

In Eqs. (5) and (6), $t = 1, 2, ..., T$; $\varepsilon$ is the error term with white noise. Positive and negative shocks are represented as follows.

$$\varepsilon^{+}_{1,i,t} = \max(\varepsilon_{1,i,t}, 0)\mathrm{ve}\varepsilon^{-}_{1,i,t} = \min\left(\varepsilon_{1,i,t}, 0\right) \quad (7)$$

$$\varepsilon^{+}_{2,i,t} = \max(\varepsilon_{2,i,t}, 0)\mathrm{ve}\varepsilon^{-}_{2,i,t} = \min\left(\varepsilon_{2,i,t}, 0\right) \quad (8)$$

Error terms are defined as $\varepsilon_{1,i,t} = \varepsilon^{+}_{1,i,t} + \varepsilon^{-}_{1,i,t}\mathrm{ve}\varepsilon_{2,i,t} = \varepsilon^{+}_{2,i,t} + \varepsilon^{-}_{2,i,t}$. Hence, the cumulative positive and negative shocks (9) and (10) calculated for each of the variables can be written as follows by adding Eqs. (7) and (8).

$$y_{i,t} = y_{i,t-1} + \varepsilon_{1,i,t} = y_{i,t,0} + \sum_{i=1}^{t} \varepsilon^{+}_{1,i,t} + \sum_{i=1}^{t} \varepsilon^{-}_{1,i,t} \quad (9)$$

$$x_{i,t} = x_{i,t-1} + \varepsilon_{2,i,t} = x_{i,t,0} + \sum_{i=1}^{t} \varepsilon^{+}_{2,i,t} + \sum_{i=1}^{t} \varepsilon^{-}_{2,i,t} \quad (10)$$

where $\sum_{i=1}^{t} \varepsilon^{+}_{1,i,t}$ and $\sum_{i=1}^{t} \varepsilon^{-}_{1,i,t}$ are respectively positive and negative shocks of $y_{i,t}$; $\sum_{i=1}^{t} \varepsilon^{+}_{2,i,t}$ and $\sum_{i=1}^{t} \varepsilon^{-}_{2,i,t}$ are respectively positive and negative shocks of $x_{i,t}$. Therefore, the Panel Asymmetric Fourier Toda-Yamamoto causality relationship between variables can be tested as follows by Eqs. (11, 12, 13, 14):

$$y^{+}_{i,t} = \mu_i + A_{11}\sin\left(\frac{2\pi tf_i}{T}\right) + A_{12}\cos\left(\frac{2\pi tf_i}{T}\right) + \sum_{j=1}^{p_i+d_{\max_i}} A_{13}y^{+}_{i,t-j} + \sum_{j=1}^{p_i+d_{\max_i}} A_{14}x^{+}_{i,t-j} + u_{1i,t} \quad (11)$$

$$x^{+}_{i,t} = \mu_i + A_{21}\sin\left(\frac{2\pi tf_i}{T}\right) + A_{22}\cos\left(\frac{2\pi tf_i}{T}\right) + \sum_{j=1}^{p_i+d_{\max_i}} A_{23}x^{+}_{i,t-j} + \sum_{j=1}^{p_i+d_{\max_i}} A_{24}y^{+}_{i,t-j} + u_{2i,t} \quad (12)$$

$$y^{-}_{i,t} = \mu_i + A_{11}\sin\left(\frac{2\pi tf_i}{T}\right) + A_{12}\cos\left(\frac{2\pi tf_i}{T}\right) + \sum_{j=1}^{p_i+d_{\max_i}} A_{13}y^{-}_{i,t-j} + \sum_{j=1}^{p_i+d_{\max_i}} A_{14}x^{-}_{i,t-j} + u_{1i,t} \quad (13)$$

$$x^{-}_{i,t} = \mu_i + A_{21}\sin\left(\frac{2\pi tf_i}{T}\right) + A_{22}\cos\left(\frac{2\pi tf_i}{T}\right) + \sum_{j=1}^{p_i+d_{\max_i}} A_{23}x^{-}_{i,t-j} + \sum_{j=1}^{p_i+d_{\max_i}} A_{24}y^{-}_{i,t-j} + u_{2i,t} \quad (14)$$

## The data

This study aims to examine the relationship between foreign direct investment inflows and outflows and pollution levels in European Union countries (Austria, Belgium, Bulgaria, Cyprus, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Malta, the Netherlands, Poland, Portugal, Romania, the Slovak Republic, Spain, and Sweden). For this objective, the share of foreign direct investment inflows (FDIN) and outflows (FDOUT) in national income (GDP%) is taken into account. Furthermore, $CO_2$ emission (kt) has been considered since, according to the European Commission (2020) report, carbon dioxide emissions are identified as the gas that causes the most pollution among greenhouse gases. All data is obtained from the World Bank (2023). The study covers between 1993 and 2019, in which the countries' data is jointly available. Additionally, since the relevant data for 27 European Union countries could not be obtained, 21 countries were included in the study. Descriptive statistics for the variables are given in Table 2.

This study examines the relationship between foreign investments and carbon dioxide emissions for each country by employing Panel Fourier Toda-Yamamoto tests for both symmetric and asymmetric causality in bidirectional models ($CO_2$=f(FDIN), FDIN = $f(CO_2)$, $CO_2$=$f$(FDOUT), FDOUT = $f(CO_2)$). Developed countries typically conduct foreign investments (United Nations Conference on Trade and Development 2021). Since the European Union consists mainly of developed countries, similar countries engage in foreign investment in these countries. Since these countries have strict environmental policies, FDOUTs are anticipated to impact pollution more than FDINs substantially. This is because countries generally relocate their dirty industries to less developed countries.

## Empirical results

The findings of the econometric analysis performed to determine the causal relationship between foreign investment inflows and outflows and carbon dioxide emissions are presented in this section. In this study, the causality relationship between the variables is analyzed by the Panel Toda-Yamamoto Fourier causality test (PFTY). The PFTY causality test is based on the VAR ($k + d_{max}$) model. The initial step is to examine the cross-sectionally dependent (CD) variables to determine the appropriate unit root test. For this purpose, the CD tests developed by Breusch and Pagan (1980) and Pesaran (2004) are considered.

Based on the findings presented in Table 3, the null hypothesis positing the absence of cross-sectionally dependent is rejected, indicating that the variables have cross-sectionally dependent. The CIPS and BCIPS unit root tests were employed to determine the variables' maximum stationarity level. Both tests take into account cross-sectionally dependent. The results of the CIPS unit root test are reported in Table 4. As a result of the test, $CO_2$ is stationary at the first difference, and other variables are stationary at the level.

The variables were also examined using the BCIPS unit root test, as the CIPS unit root test does not account for structural change, and the results are shown in Table 5. While $m = 1$ indicates no common factor, $m = 2$ indicates that the GDP collected from the World Bank was employed as a common factor in Table The results of the BCIPS unit root analysis and the CIPS unit root analysis are in line. $CO_2$ is stationary at the first difference, while other variables are stationary at the level. Thus, the maximum stationarity level is $I(1)$.

Panel Toda-Yamamoto Fourier causality test allows the calculation of results for units and cross-sectionally dependent. Therefore, the null hypothesis that the models are homogeneous was also tested. The fact that the variables have cross-sectionally dependent does not mean that the models do. Hence, the cross-sectionally dependent models to be investigated were also tested. Table 6 shows the results of the cross-sectionally dependent and homogeneity tests, which were regarded for the bidirectional causality directions investigated in the study.

**Table 2** Descriptive statistic

| | $CO_2$ | FDIN | FDOUT |
|---|---|---|---|
| Mean | 150,371.6 | 11.286 | 7.795 |
| Median | 65,750 | 2.968 | 1.735 |
| Maximum | 904,340 | 449.081 | 300.406 |
| Minimum | 1350 | −40.087 | −87.226 |
| Std. dev | 185,480.3 | 38.216 | 32.867 |

**Table 3** Cross-section dependence test results

| CD tests | $CO_2$ | FDIN | FDOUT |
|---|---|---|---|
| Breusch and Pegan (1980)—LM | 446.598*** | 364.464*** | 353.313*** |
| Pesaran (2004)—scaled LM | 11.545*** | 7.537*** | 6.993*** |
| Pesaran (2004)—CD | −1.831** | 1.967** | 4.232*** |

**, *** indicate 5% and 1% statistical significance levels, respectively

**Table 4** CIPS unit root test results

| Variables | $I(0)$ | $I(1)$ |
|---|---|---|
| $CO_2$ | −2.09 | −3.428*** |
| FDIN | −2.299** | |
| FDOUT | −2.633*** | |

**, *** indicate 5% and 1% statistical significance levels, respectively. The maximum lag length was chosen as 4, and the Schwartz information criterion (SIC) was employed

The test findings show that the models are both heterogeneous and cross-sectionally dependent, and the maximum stationarity level of the variables is $I(1)$. The Panel Fourier Toda-Yamamoto causality test's precondition is therefore fulfilled. Firstly, we analyzed the relationship between the variables using symmetric causality (without shocks), and the findings are presented in Table 7. The empirical results show that there are more countries where the effect of foreign investments on $CO_2$ is statistically significant than there are where the impact of $CO_2$ on foreign investments. A unidirectional statistically significant causality relationship was found from $CO_2$ to FDIN in Finland, Greece, and Sweden; from FDIN to $CO_2$ in Belgium, Cyprus, and France; from $CO_2$ to FDOUT in Germany; and from FDOUT to $CO_2$ in Belgium, Bulgaria, Cyprus, Ireland, and Portugal. In addition, bidirectional statistically significant causality was found between $CO_2$ and FDOUT in Austria and Slovak Republic.

The upper indices represent the optimal lag length, frequency, and statistical significance level. The maximum lag length was chosen as 4, and SIC was employed. Five thousand bootstrap simulations obtained the critical values.

There are differences in the relationship between the variables when shocks are ignored. Therefore, this study considers the effects of positive and negative shocks, as proposed by Granger and Yoon (2002). In this context, positive and negative shocks of $CO_2$, FDIN, and FDOUT variables are expressed as $CO_2^+$, $FDIN^+$, $FDOUT^+$, $CO_2^-$, $FDI^-$, and $FDOUT^-$, respectively. The results are given in Table 8 in the appendices. When Table 8 is examined, it can be observed that results vary depending on variables divided up into shocks. Moreover, it is found that causality, whose validity cannot be determined in most countries in the symmetric causality test, exists when analyzed under shocks. When the effect of positive shocks is included, unidirectional causality from $CO_2$ to FDOUT is found to be valid in more EU countries. In contrast, unidirectional causality from $CO_2$ to FDIN is found to be more dominant across countries when adverse shocks are considered.

This study also examines the relationship between variables regarding cross-shocks (Mert and Caglar 2020). The results are given in Table 9 in the appendix. These findings show that $FDOUT^-$ to $CO_2^+$ causation holds valid in more EU countries than other causality results. While the cross-shock results in some countries were similar, significant relationships in other countries that had not before been recognized were found. These results highlight the crucial role of variable shocks in identifying previously hidden relationships.

Suppose a statistically significant relationship is found in any of the integrated components. In that case, it can be said that the variables involved affect one another when the cumulative values of the variables are taken into account (Granger and Yoon 2002). In this situation, if a statistically significant relationship is found in any of the Panel Fourier integrated components determined by considering this situation, it can be said that the variables affect each other. Panel Asymmetric Toda-Yamamoto causality test results are in Table 10 in the appendix. Table 10 in the appendix shows that in the majority of the countries, bidirectional causality is found to be valid when the relationship between the variables is examined using shocks. No statistically significant

**Table 5** BCIPS unit root test results

| Variable | $m=1$ | | | $m=2$ | | |
|---|---|---|---|---|---|---|
| | Optimal lag | Frequency | Test stat | Optimal lag | Frequency | Test stat |
| $CO_2$ | 4 | 2 | −2.095 | 4 | 1 | −2.5973 |
| $\Delta(CO_2)$ | 4 | 1 | $-3.2989^{***}$ | 4 | 5 | $-5.3459^{***}$ |
| FDIN | 1 | 3 | $-2.4395^{**}$ | 4 | 2 | $-2.7274^{**}$ |
| FDOUT | 1 | 3 | $-2.7597^{***}$ | 4 | 4 | $-2.0823^{**}$ |

$^{**}$, $^{***}$ indicate 5% and 1% statistical significance levels, respectively. The maximum lag length was chosen as 4, and SIC was employed

**Table 6** Cross-section dependence and homogeneity tests for model results

| CD tests | $CO_2 \rightarrow$ FDIN | F FDIN $\rightarrow CO_2$ | $CO_2 \rightarrow$ FDOUT | FDOUT $\rightarrow CO_2$ |
|---|---|---|---|---|
| Breuscha and Pagan (1980) | $580.049^{***}$ | $1977.693^{***}$ | $518.012^{***}$ | $1682.469^{***}$ |
| Pesaran (2004) | $18.057^{***}$ | $86.255^{***}$ | $15.029^{***}$ | $71.849^{***}$ |
| Pesaran (2004) | $14.637^{***}$ | $35.161^{***}$ | $13.083^{***}$ | $32.962^{***}$ |
| $\tilde{\Delta}$ | $2.527^{***}$ | $2.477^{***}$ | $7.363^{***}$ | $7.082^{***}$ |
| $\tilde{\Delta}_{adj}$ | $2.675^{***}$ | $2.622^{***}$ | $7.792^{***}$ | $7.495^{***}$ |

$^{***}$ indicates 1% statistical significance levels

**Table 7** Panel Fourier Toda-Yamamoto causality test results

| Countries | $CO_2 \rightarrow$ FDIN | FDIN $\rightarrow CO_2$ | $CO_2 \rightarrow$ FDOUT | FDOUT $\rightarrow CO_2$ |
|---|---|---|---|---|
| Austria | $1.924^{1,1}$ | $2.307^{1,1}$ | $2.4^{1,1,10\%}$ | $3.168^{1,1,10\%}$ |
| Belgium | $1.83^{2,3}$ | $5.336^{2,3,10\%}$ | $1.103^{2,3}$ | $4.825^{2,3,\%10}$ |
| Bulgaria | $0.551^{1,3}$ | $1.009^{1,3}$ | $0.171^{1,2}$ | $2.436^{1,2,\%10}$ |
| Cyprus | $1.202^{1,1}$ | $6.368^{1,1,5\%}$ | $2.211^{1,1}$ | $5.141^{1,1,5\%}$ |
| Czechia | $0.863^{1,1}$ | $0.356^{1,1}$ | $0.403^{1,1}$ | $1.102^{1,1}$ |
| Denmark | $0.01^{1,3}$ | $0.866^{1,3}$ | $0.069^{1,3}$ | $0.908^{1,3}$ |
| Finland | $7.891^{3,3,10\%}$ | $5.777^{3,3}$ | $0.22^{1,1}$ | $1.469^{1,1}$ |
| France | $1.508^{1,1}$ | $4.449^{1,1,5\%}$ | $0.58^{1,1}$ | $1.242^{1,1}$ |
| Germany | $0.268^{1,3}$ | $2.048^{1,3}$ | $4.477^{2,3,10\%}$ | $0.989^{2,3}$ |
| Greece | $5.291^{2,2,10\%}$ | $1.518^{2,2}$ | $0.117^{1,1}$ | $1.368^{1,1}$ |
| Hungary | $1.019^{1,1}$ | $0.375^{1,1}$ | $1.005^{1,1}$ | $0.332^{1,1}$ |
| Ireland | $0.121^{1,1}$ | $6.612^{1,1,5\%}$ | $1.329^{3,1}$ | $9.809^{3,1,10\%}$ |
| Italy | $0.112^{1,1}$ | $1.381^{1,1}$ | $0.099^{1,1}$ | $0.08^{1,1}$ |
| Malta | $0.358^{1,1}$ | $0.032^{1,1}$ | $0.36^{1,1}$ | $0.2^{1,1}$ |
| Netherlands | $0.271^{1,1}$ | $0.126^{1,1}$ | $0.156^{1,1}$ | $0.014^{1,1}$ |
| Poland | $0.068^{1,2}$ | $0.049^{1,2}$ | $1.849^{1,2}$ | $0.609^{1,2}$ |
| Portugal | $1.787^{1,1}$ | $1.223^{1,1}$ | $0.018^{1,1}$ | $3.958^{1,1,5\%}$ |
| Romania | $0.778^{1,2}$ | $4.188^{1,2,5\%}$ | $1.141^{1,2}$ | $0.053^{1,2}$ |
| Slovak Republic | $6.367^{3,1}$ | $1.797^{3,1}$ | $13.233^{3,2,5\%}$ | $6.745^{1,3,10\%}$ |
| Spain | $2.351^{1,1}$ | $0.072^{1,1}$ | $1.691^{1,1}$ | $2.451^{1,1}$ |
| Sweden | $9.772^{3,3,5\%}$ | $6.696^{3,3}$ | $0.992^{1,1}$ | $0.732^{1,1}$ |

bidirectional relationship was found between $CO_2$ and FDIN in Ireland and Italy, a unidirectional relationship between FDIN and $CO_2$ in France, Poland, and Spain, and a statistically significant bidirectional relationship between FDIN and $CO_2$ in Malta. Furthermore, no statistically substantial bidirectional relationship was found from $CO_2$ to FDOUT in Belgium, Denmark, Romania, and Spain, a unidirectional relationship from FDOUT to $CO_2$ in Czechia and Germany, and a statistically significant bidirectional relationship from FDOUT to $CO_2$ in Hungary and Romania.

Since EU countries have strict environmental rules, foreign investment inflows are not anticipated to increase pollution. However, it can be stated that the statistically significant effect of foreign investment outflows on pollution is in the direction of reducing the level of pollution.

## Discussion

This study presents the summary results of the relationship between carbon dioxide emissions and foreign investments obtained from the Panel Fourier bootstrap asymmetric and symmetric Toda-Yamamoto causality tests in Tables 8, 9, and 10 in the appendix. As the table shows, contrary to the symmetric test, at least one unidirectional causal relationship exists between most countries' variables. Moreover, the empirical findings vary across countries. This indicates that although EU member states have a common environmental policy in many areas with certain agreements, their policies may differ in line with their interests.

Studies in the literature examine the relationship between foreign investment outflows and carbon dioxide emissions from two different perspectives. First, since developed countries transfer their dirty industries to another country due to their strict environmental policies (Cai et al. 2018; Liu et al. 2019; Guzel and Okumus 2020; Akram et al. 2022), foreign investment outflows from the source country are expected to affect the pollution level. In this case, we can say that source countries see host countries as pollution havens. Similarly, the effect of pollution on foreign investment outflows is also interpreted in this way. In this context, it can be said that this is the case in countries with unidirectional (Belgium, Czechia, Germany, Greece, Poland, and Spain) and bidirectional (Austria, Bulgaria, Cyprus, Denmark, France, Ireland, Italy, Malta, the Netherlands, Portugal, Slovak Republic, and Sweden) relationships between variables. These results support those of Cave and Blomquist (2008), Cole and Fredriksson (2009), Kellenberg (2009), Ben Kheder and Zugravu (2012), Rezza (2013), Wagner and Timmins (2009), Chung (2014), and Benzerrouk et al. (2021). In their firm- or country-sized study of FDI outflows from the EU or developed countries, the authors argue that source countries often use less developed countries as pollution havens due to their energy-intensive trade, lower environmental standards, and lower costs of exporting polluted industrial waste.

The other relationship between foreign investment outflows and carbon dioxide emissions is that if the source country's foreign investment outflows do not affect the pollution level, it can be stated that it transfers a similar production process to the host country. Panel Fourier bootstraps Toda-Yamamoto causality results show that Finland and Romania support this case. These findings are consistent with Eskeland and Harrison (2003) and Manderson and Kneller (2012). Thus, it can be stated that these countries do not see host countries as pollution havens in their foreign investment outflows.

Since EU members have generally developed countries with strict environmental policies, foreign investment inflows are not expected to increase environmental degradation, and similarly, environmental degradation is not likely to contribute to foreign investment inflows (Cole and Fredriksson 2009; Wagner and Timmins 2009; Zugravu-Soilita 2017; Tasdemir and Ozcelik 2023). However, the ongoing fossil energy consumption in EU member states does not correspond to this expectation, as primary energy consumption is the main factor that positively affects pollution in foreign investment inflows (Mert et al. 2019). Considering the causality test results used in this study, positive (negative) shocks of foreign investment inflows in Austria, Bulgaria, Cyprus, Czechia, Germany, Greece, Hungary, Italy, the Netherlands, Portugal, and the Slovak Republic affect the positive (negative) shock of $CO_2$. In this case, it can be argued that FDIN changes from source countries to these countries similarly affect $CO_2$, supporting the pollution haven hypothesis (PHH). This result supports the findings, especially for developing countries (Murthy and Gambhir 2018; Huynh and Hoang 2019; Benzerrouk et al. 2021; Bulus and Koc 2021; Bulut et al. 2021; Danish and Ahmad 2021; Cil 2023; Dutta and Hazarika 2023; Tasdemir and Ozcelik 2023; Wencong et al. 2023), while it is in line with the results of Mert et al. (2019), Caetano et al. (2022), Javed et al. (2023), Singh and Dhiman (2023), and Wang and He (2023) among the studies conducted for the developed country/country group.

When the effect of foreign investment inflows on $CO_2$ is analyzed with cross-shocks, it is determined that there is a statistically significant causality for Belgium, Denmark, Finland, Romania, and Sweden in this case, similar to the pollution halo hypothesis, it can be stated that the relationship has a negative direction in these countries, as in Kim and Adilov (2012), Omri et al. (2014), Shahbaz et al. (2015), Benzerrouk et al. (2021), Li et al. (2022), Chien et al. (2023), which address the developed country/country group in the literature.

The absence of a statistically significant relationship between the variables indicates that the source country invests within the scope of the host country's environmental regulations. Therefore, investment from the source country does not change the emissions of the host country. In the literature, Smarzynska and Wei (2004), Kearsley and Riddel (2010), Mulatu et al. (2010), Nathaniel et al. (2020), Singhania and Saini (2021), and Dutta and Hazarika (2023) have confirmed the validity of this situation in their empirical analysis by considering the developed country/country group. In this regard, the empirical results obtained in this study show that investments in Ireland and Malta are moving in this direction.

## Conclusion and policy recommendations

This study examines the relationship between foreign investment inflows and outflows and carbon dioxide emissions in EU countries. However, due to the need for more data for all EU countries, only 21 member states could be included in the study. In addition, considering the most extended possible period range, the period between 1995 and 2019 is covered. The relationship between the variables is analyzed using Fourier panel causality methods, which account for structural breaks under cross-sectionally dependent and heterogeneity. Unlike the literature, causality has been examined asymmetrically as well as symmetrically. Thus, the hidden causality relationship between the variables was also attempted to be determined. In this context, the study fills the gap in the literature regarding the methodology. In addition, it is determined that EU countries are only considered in the literature for Singh and Dhiman (2023). On the other hand, Singh and Dhiman (2023) use a regional classification of countries. The most significant contribution of this study to the literature is the analysis of the impact of foreign investment inflows and outflows on pollution.

The CIPS and BCIPS unit root tests, first conducted to determine the tests to analyze the relationship between the variables, show that the variables have different unit root levels. Therefore, the Panel Fourier Toda-Yamamoto test is applied symmetrically and asymmetrically without using cointegration tests. The symmetric Panel Fourier Toda-Yamamoto test results indicate that the causality relationship is realized more from FDOUT to $CO_2$ in countries. The causality from FDIN to $CO_2$ follows this. However, causality from $CO_2$ to FDI and FDOUT is acknowledged in very few countries. Nonetheless, the asymmetric causality test results show that the causality between the variables is statistically significant in many countries. This indicates that there is an asymmetric relationship between these variables. In particular, in many countries, an asymmetric causal link between negative shocks in carbon dioxide emissions and negative movements in FDI has been found. While the negative shocks of foreign investments are generally more effective on carbon dioxide emissions, the negative shocks of carbon dioxide emission in foreign investment inflows and the negative shocks of carbon dioxide emission in foreign investment outflows vary across countries.

As a result, any shock (positive or negative) in FDI and emissions affect each other in the short run. Given the asymmetric link between these two variables in the short and long run, policymakers need to understand the dynamic relationship between foreign investment and pollution to conduct an effective environmental policy. While transferring pollution from the source country may reduce pollution levels in the short run, it would inevitably increase environmental degradation worldwide in the long run. Thus, governments can provide tax incentives and subsidies for foreign investors to use environmentally friendly technology instead of taking strict measures on environmental regulations. Besides, as the EU countries' pollution levels are generally driven by increasing energy consumption, policymakers can accelerate the transition to renewable energy sources by reducing fossil energy consumption. Accordingly, they should promote renewable energy projects such as solar and windmills and provide subsidy funds for ease of implementation and installation.

This study has certain limitations. The most important of these limitations is that the long-run relationship cannot be analyzed under the unit root test results. The other is that six countries are excluded from the analysis due to the need for more homogeneous data for all EU member states. $CO_2$, which causes the most pollution among environmental variables, is evaluated in this study. In future studies, a comparison can be performed by using a different variable, such as ecological footprint, as an alternative environmental variable in addition to $CO_2$. Moreover, the empirical findings can be discussed by considering the country groups with different levels of foreign investment and/or receiving foreign investment together, in addition to the country groups with the highest level of foreign investment.

## Appendix

**Table 8** Panel Fourier bootstrap asymmetric Toda-Yamamoto causality test results

| Countries | $CO_2^+ \rightarrow FDIN^+$ | $FDIN^+ \rightarrow CO_2^+$ | $CO_2^+ \rightarrow FDOUT^+$ | $FDOUT^+ \rightarrow CO_2^+$ | $CO_2^- \rightarrow FDIN^-$ | $FDIN^- \rightarrow CO_2^-$ | $CO_2^- \rightarrow FDOUT^-$ | $FDOUT^- \rightarrow CO_2^-$ |
|---|---|---|---|---|---|---|---|---|
| Austria | $5.852^{3,3}$ | $6.084^{3,3}$ | $1.009^{1,3}$ | $0.845^{1,3}$ | $0.591^{3,3}$ | $30.137^{3,3,1\%}$ | $0.031^{1,2}$ | $19.686^{1,2,1\%}$ |
| Belgium | $3.399^{1,3,10\%}$ | $0.078^{1,3}$ | $1.827^{1,1}$ | $0.204^{1,1}$ | $13.930^{3,1,5\%}$ | $2.749^{3,1}$ | $1.314^{1,2}$ | $6.285^{2,2,10\%}$ |
| Bulgaria | $0.986^{1,2}$ | $0.465^{1,2}$ | $5.496^{1,3,5\%}$ | $0.617^{1,3}$ | $1.674^{3,1}$ | $9.831^{3,1,5\%}$ | $0.198^{1,1}$ | $0.459^{1,1}$ |
| Cyprus | $0.003^{1,1}$ | $0.277^{1,1}$ | $0.001^{1,1}$ | $0.218^{1,1}$ | $8.984^{3,1,10\%}$ | $27.235^{3,1,1\%}$ | $13.069^{3,1,5\%}$ | $11.676^{3,1,5\%}$ |
| Czechia | $0.042^{1,1}$ | $4.036^{1,1,5\%}$ | $4.455^{1,1,5\%}$ | $0.143^{1,1}$ | $3.697^{1,2,10\%}$ | $1.688^{1,2}$ | $0.406^{1,1}$ | $1.132^{1,1}$ |
| Denmark | $2.834^{2,2}$ | $2.548^{2,2}$ | $19.862^{3,2,5\%}$ | $3.920^{3,2}$ | $1.252^{3,1}$ | $3.512^{3,1}$ | $0.131^{3,3}$ | $11.011^{3,3,5\%}$ |
| Finland | $1.481^{1,1}$ | $0.686^{1,1}$ | $0.037^{1,1}$ | $0.315^{1,1}$ | $24.115^{1,1,1\%}$ | $1.048^{2,3}$ | $5.269^{3,1}$ | $0.997^{3,1}$ |
| France | $1.598^{2,1}$ | $0.239^{2,1}$ | $37.406^{3,1,1\%}$ | $3.276^{3,1}$ | $0.704^{1,1}$ | $0.055^{1,1}$ | $1.092^{1,1}$ | $0.789^{1,1}$ |
| Germany | $0.672^{2,1}$ | $8.836^{1,1,5\%}$ | $6.402^{2,1,10\%}$ | $0.003^{2,1}$ | $0.093^{1,1}$ | $0.014^{1,1}$ | $0.002^{1,1}$ | $0.009^{1,1}$ |
| Greece | $0.818^{1,1}$ | $0.883^{1,1}$ | $1.461^{1,1}$ | $2.367^{1,1,10\%}$ | $10.682^{3,2,10\%}$ | $23.641^{3,2,1\%}$ | $0.000^{1,2}$ | $1.086^{1,2}$ |
| Hungary | $0.118^{1,2}$ | $6.243^{1,2,5,\%}$ | $2.286^{3,2}$ | $2.114^{3,2}$ | $0.035^{1,1}$ | $0.144^{1,1}$ | $0.027^{1,1}$ | $0.154^{1,1}$ |
| Ireland | $1.773^{1,1}$ | $0.989^{1,1}$ | $0.009^{1,3}$ | $1.183^{1,3}$ | $1.074^{3,3}$ | $3.339^{3,3}$ | $0.752^{3,1}$ | $27.870^{3,1,1\%}$ |
| Italy | $4.185^{2,1}$ | $0.556^{2,1}$ | $6.675^{2,1,5\%}$ | $1.462^{2,1}$ | $0.176^{1,3}$ | $40.204^{1,3,1\%}$ | $0.637^{1,1}$ | $7.117^{1,1,1\%}$ |
| Malta | $3.844^{2,1}$ | $1.289^{2,1}$ | $10.140^{3,3,5\%}$ | $2.014^{3,3}$ | $0.000^{1,1}$ | $0.360^{1,1}$ | $0.059^{1,2}$ | $0.115^{1,2}$ |
| Netherlands | $0.864^{1,2}$ | $0.321^{1,2}$ | $0.461^{1,3}$ | $1.158^{1,3}$ | $13.997^{3,2,5\%}$ | $14.848^{3,2,5\%}$ | $0.001^{1,2}$ | $0.021^{1,2}$ |
| Poland | $0.014^{1,3}$ | $0.165^{1,3}$ | $1.107^{2,3}$ | $8.795^{2,3,5\%}$ | $8.418^{3,1}$ | $5.916^{3,1}$ | $0.295^{1,2}$ | $0.822^{1,2}$ |
| Portugal | $11.907^{1,1,1\%}$ | $3.189^{1,1,10\%}$ | $5.862^{2,3,5\%}$ | $2.112^{1,1}$ | $3.021^{1,2,10\%}$ | $0.497^{1,2}$ | $2.322^{3,2}$ | $5.731^{3,2}$ |
| Romania | $1.007^{1,3}$ | $0.342^{1,3}$ | $0.406^{1,1}$ | $1.657^{1,1}$ | $9.942^{3,2,10\%}$ | $3.329^{3,2}$ | $0.009^{1,2}$ | $1.552^{1,2}$ |
| Slovak Republic | $0.062^{1,1}$ | $13.054^{1,1,1\%}$ | $10.310^{2,3,\%5}$ | $6.921^{2,3,10\%}$ | $23.999^{3,1,1\%}$ | $3.378^{3,1}$ | $0.994^{1,1}$ | $4.560^{1,1,5\%}$ |
| Spain | $3.340^{1,1,10\%}$ | $0.627^{1,1}$ | $0.014^{1,3}$ | $0.004^{1,3}$ | $10.905^{1,1,1\%}$ | $0.019^{1,1}$ | $0.004^{1,1}$ | $10.046^{1,1,1\%}$ |
| Sweden | $0.284^{2,1}$ | $0.197^{2,1}$ | $0.516^{3,1}$ | $23.618^{3,1,1\%}$ | $18.320^{3,1,1\%}$ | $0.318^{3,1}$ | $4.014^{1,2,10\%}$ | $0.023^{1,2}$ |

**Table 9** Panel Fourier bootstrap asymmetric Toda-Yamamoto causality test results (mixed shocks)

| Countries | $CO_2^- \rightarrow FDIN^+$ | $FDIN^+ \rightarrow CO_2^-$ | $CO_2^- \rightarrow FDOUT^+$ | $FDOUT^+ \rightarrow CO_2^-$ | $CO_2^+ \rightarrow FDIN^-$ | $FDIN^- \rightarrow CO_2^+$ | $CO_2^+ \rightarrow FDOUT^-$ | $FDOUT^- \rightarrow CO_2^+$ |
|---|---|---|---|---|---|---|---|---|
| Austria | $0.463^{2,2}$ | $29.894^{2,2,1\%}$ | $0.754^{2,2}$ | $37.326^{2,2,1\%}$ | $9.176^{3,3,10\%}$ | $2.299^{3,3}$ | $9.836^{3,3,5\%}$ | $1.986^{3,3}$ |
| Belgium | $1.649^{3,1}$ | $20.096^{3,1,1\%}$ | $0.999^{3,1}$ | $30.079^{3,1,1\%}$ | $5.597^{2,3,10\%}$ | $12.004^{2,3,5\%}$ | $0.189^{2,3}$ | $40.286^{2,3,1\%}$ |
| Bulgaria | $0.014^{1,1}$ | $0.066^{1,1}$ | $1.465^{3,2}$ | $15.032^{3,2,5\%}$ | $25.285^{2,2,1\%}$ | $4.889^{2,2,10\%}$ | $0.147^{1,1}$ | $0.416^{1,1}$ |
| Cyprus | $2.269^{1,2}$ | $14.960^{1,2,1\%}$ | $3.535^{2,2}$ | $16.825^{2,2,1\%}$ | $0.254^{1,1}$ | $8.288^{1,1,1\%}$ | $1.457^{1,1}$ | $4.621^{1,1,5\%}$ |
| Czechia | $0.243^{1,2}$ | $0.503^{1,2}$ | $0.024^{1,2}$ | $2.001^{1,2}$ | $33.102^{3,3,1\%}$ | $4.376^{3,3}$ | $0.312^{1,1}$ | $2.638^{1,1}$ |
| Denmark | $13.994^{3,1,5\%}$ | $1.473^{3,1}$ | $2.423^{1,1}$ | $0.191^{1,1}$ | $0.337^{2,2}$ | $9.871^{2,2,5\%}$ | $0.464^{2,1}$ | $6.114^{2,1,10\%}$ |
| Finland | $8.328^{2,1,5\%}$ | $0.548^{2,1}$ | $0.692^{1,1}$ | $0.360^{1,1}$ | $0.008^{1,1}$ | $2.639^{1,1,10\%}$ | $0.147^{1,1}$ | $2.324^{1,1}$ |
| France | $4.139^{1,1,10\%}$ | $1.078^{1,1}$ | $0.944^{1,1}$ | $1.464^{1,1}$ | $0.005^{1,1}$ | $1.749^{1,1}$ | $37.517^{3,1,1\%}$ | $23.241^{3,1,5\%}$ |
| Germany | $8.084^{3,1,1\%}$ | $1.459^{1,1}$ | $8.554^{1,1,1\%}$ | $1.540^{1,1}$ | $2.231^{2,1}$ | $0.018^{2,1}$ | $8.802^{2,1,5\%}$ | $1.113^{2,1}$ |
| Greece | $0.214^{1,2}$ | $0.021^{1,2}$ | $2.111^{2,2}$ | $5.401^{2,2,10\%}$ | $0.703^{1,1}$ | $0.085^{1,1}$ | $24.735^{1,1,1\%}$ | $3.400^{1,1,10\%}$ |
| Hungary | $10.257^{3,1,5\%}$ | $0.753^{3,1}$ | $15.465^{3,1,1\%}$ | $1.096^{3,1}$ | $0.685^{1,2}$ | $0.059^{1,2}$ | $0.934^{1,2}$ | $0.024^{1,2}$ |
| Ireland | $0.113^{1,2}$ | $0.034^{1,2}$ | $2.243^{1,2}$ | $0.012^{1,2}$ | $2.377^{1,1}$ | $1.681^{1,1}$ | $2.630^{1,1,10\%}$ | $2.423^{1,1}$ |
| Italy | $0.486^{1,1}$ | $0.122^{1,1}$ | $0.065^{2,1}$ | $10.143^{2,1,5\%}$ | $0.040^{2,1}$ | $2.346^{2,1}$ | $0.091^{1,2}$ | $1.206^{1,2}$ |
| Malta | $0.057^{1,1}$ | $0.308^{1,1}$ | $0.744^{1,1}$ | $0.204^{1,1}$ | $0.979^{2,1}$ | $1.565^{2,1}$ | $0.008^{1,1}$ | $3.377^{1,1,10\%}$ |
| Netherlands | $9.232^{1,2,1\%}$ | $0.388^{1,2}$ | $9.156^{1,2,1\%}$ | $0.020^{1,2}$ | $0.113^{1,1}$ | $0.833^{1,1}$ | $0.339^{2,1}$ | $13.139^{2,1,5\%}$ |
| Poland | $0.368^{1,2}$ | $0.072^{1,2}$ | $3.860^{3,3}$ | $27.413^{3,3,1\%}$ | $2.287^{2,2}$ | $4.389^{2,2}$ | $11.674^{1,1,1\%}$ | $0.159^{1,1}$ |
| Portugal | $0.095^{1,2}$ | $0.000^{1,2}$ | $2.364^{1,2}$ | $0.008^{1,2}$ | $0.106^{1,1}$ | $0.207^{1,1}$ | $4.312^{3,2}$ | $26.915^{3,2,1\%}$ |
| Romania | $0.209^{2,1}$ | $3.386^{1,2,10\%}$ | $2.100^{3,2}$ | $1.008^{3,2}$ | $4.412^{3,2}$ | $29.304^{3,2,1\%}$ | $0.401^{1,1}$ | $0.240^{1,1}$ |
| Slovak Republic | $27.317^{2,1,1\%}$ | $4.286^{2,1}$ | $1.259^{1,2}$ | $0.005^{1,2}$ | $0.362^{1,1}$ | $1.228^{1,1}$ | $3.164^{1,2,10\%}$ | $0.617^{1,2}$ |
| Spain | $0.083^{1,2}$ | $0.311^{1,2}$ | $0.012^{1,2}$ | $1.958^{1,2}$ | $0.119^{1,1}$ | $1.274^{1,1}$ | $1.704^{1,1}$ | $0.585^{1,1}$ |
| Sweden | $17.693^{3,1,1\%}$ | $11.019^{3,1,5\%}$ | $2.708^{1,1,10\%}$ | $0.060^{1,1}$ | $0.057^{2,1}$ | $6.859^{2,1,10\%}$ | $0.464^{2,2}$ | $10.269^{1,2,5\%}$ |

**Table 10** Summary of asymmetric causality results

| Countries | $CO_2 \rightarrow FDIN$ | $FDIN \rightarrow CO_2$ | $CO_2 \rightarrow FDIN$ | $FDOUT \rightarrow CO_2$ |
|---|---|---|---|---|
| Austria | + | + | + | + |
| Belgium | + | + | | + |
| Bulgaria | + | + | + | + |
| Cyprus | + | + | + | + |
| Czechia | + | + | + | |
| Denmark | + | + | + | + |
| Finland | + | + | | |
| France | + | | + | + |
| Germany | + | + | + | |
| Greece | + | + | + | + |
| Hungary | + | + | + | |
| Ireland | | | + | + |
| Italy | | + | + | + |
| Malta | | | + | + |
| Netherlands | + | + | + | + |
| Poland | + | | + | + |
| Portugal | + | + | + | |
| Romania | + | + | | |
| Slovak Republic | + | + | + | + |
| Spain | + | | | + |
| Sweden | + | + | + | + |

The upper indices represent the optimal lag length, frequency, and statistical significance level, respectively. The maximum lag length was chosen as 4, and SIC was employed. Five thousand bootstrap simulations obtained the critical values.

The upper indices represent the optimal lag length, frequency, and statistical significance level, respectively. The maximum lag length was chosen as 4, and SIC was employed. Five thousand bootstrap simulations obtained the critical values.

**Author contribution** Asiye Tutuncu: material preparation, data collection, and analysis. Sukran Sirkintioglu Yildirim and Omca Altin: writing the first manuscript draft. Asiye Tutuncu, Sukran Sirkintioglu Yildirim, and Omca Altin: review and editing. All authors read and approved the final manuscript.

**Data availability** The data that support the findings of this study are openly available on the World Development Indicator page published by (World Bank 2023) at https://databank.worldbank.org/source/world-development-indicators

## Declarations

**Ethical approval** Not applicable.

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