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Economic recovery and resilience in post-pandemic Europe: evidence from eleven European Union economies

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Abstract
This study examines the economic recovery and resilience of eleven European Union member states after the COVID-19 pandemic, using annual data from 1990 to 2022. It applies a multi-method approach, combining the Pooled Mean Group (PMG) estimator, Nonlinear Autoregressive Distributed Lag (NARDL) model, and Common Correlated Effects Estimator to analyze long- and short-run relationships. The findings show that, in the long run, inflation and mobile cellular subscriptions slow growth, while greenhouse gas emissions have a positive effect. Youth unemployment, labor force participation, trade openness, population growth, and foreign direct investment (FDI) do not show significant effects. In the short run, inflation and mobile subscriptions remain negative, while emissions continue to support growth. PMG results confirm that labor force participation, inflation, and mobile subscriptions reduce long-term growth, whereas population growth, trade openness, and emissions contribute positively. The NARDL model finds uneven effects of FDI, inflation, population growth, and trade openness, with short-run imbalances in inflation and trade openness. Causality analysis shows two-way links between inflation, trade openness, youth unemployment, and GDP growth, while one-way effects are observed for greenhouse gas emissions, population growth, and mobile subscriptions. These results help shape post-pandemic economic policies, emphasizing the importance of managing inflation and improving mobile connectivity to support long-term growth.

Keywords GDP growth · Recovery · Resilient · European Union · Trade openness

1 Introduction

The COVID-19 pandemic caused a severe global economic downturn, significantly disrupting economies worldwide. In Europe, the impact was particularly pronounced, leading to sharp declines in GDP, trade disruptions, rising unemployment, and increased government

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debt due to fiscal stimulus measures aimed at supporting businesses and households (Ciobanu et al. 2020; Baldwin and di Mauro 2020; Ashraf and Goodell 2022; Ikram et al. 2022; Vysochyna et al. 2023). These challenges prompted European Union (EU) member states to implement short-term recovery strategies while also focusing on long-term measures to enhance economic resilience. Initiatives such as NextGenerationEU and the European Green Deal reflect the EU's approach to balancing economic recovery with sustainability and innovation (European Commission 2021). However, the recovery process has varied across member states due to differences in economic structures, healthcare systems, and pre-existing vulnerabilities, highlighting the importance of assessing both the pace of recovery and the factors that contribute to resilience.

Economic recovery refers to an economy's return to pre-crisis levels, often measured by GDP, employment, and trade performance (Archibugi 2017; Dogru and Bulut 2018; Xiuzhen et al. 2022; Zhang and Dilanchiev 2022; Gopinath 2020; Jiang et al. 2022). However, short-term recovery alone does not guarantee long-term economic stability. Economic resilience, defined as an economy's ability to withstand, adapt to, and recover from future shocks, plays a crucial role in sustaining long-term growth (Simmie and Martin 2010; Modica and Reggiani 2015; Martin and Sunley 2015; Di Caro and Fratesi 2018). Given the heterogeneous effects of the pandemic across EU countries, understanding both economic recovery and resilience is critical for designing effective policy responses. While some countries, such as Germany, experienced a relatively swift recovery, others, including Italy and Spain, faced prolonged economic challenges and deeper economic setbacks (OECD 2021).

This study aims to assess economic recovery and resilience across eleven EU economies by analyzing both short-term and long-term determinants. Specifically, it investigates the key macroeconomic drivers of post-pandemic recovery, examines the asymmetric effects of economic variables such as inflation, foreign direct investment, and trade openness, and identifies causal relationships between these factors and GDP growth. In doing so, it contributes to the existing literature by adopting a broader perspective that extends beyond traditional short-term recovery measures such as GDP and inflation (Ciobanu et al. 2020; Dogru and Bulut 2018; Ashraf and Goodell 2022). Unlike previous studies, which often focus on isolated macroeconomic indicators, this research integrates digital infrastructure and environmental sustainability as key determinants of long-term resilience. The inclusion of mobile cellular subscriptions and greenhouse gas emissions provides a more comprehensive assessment, addressing gaps in post-pandemic economic research.

Methodologically, this study employs a multi-method econometric approach, combining the Pooled Mean Group (PMG) estimator, Nonlinear Autoregressive Distributed Lag (NARDL) model, and Common Correlated Effects Estimator (CCEE). This approach allows for a detailed assessment of both short-run and long-run relationships while capturing asymmetric effects, offering deeper insights into post-pandemic recovery patterns. Unlike studies such as Abidemi et al. (2024), Olumuyiwa et al. (2023), Mayowa et al. (2022), and Kayode et al. (2022), which primarily focus on models incorporating COVID-19 vaccination rates, this study takes a broader economic perspective by examining multiple macroeconomic and structural factors influencing post-pandemic recovery.

The analysis focuses on key drivers of economic performance, including GDP, foreign direct investment, inflation, mobile cellular subscriptions, labor force participation, youth unemployment, trade openness, total greenhouse gas emissions, and population growth. It hypothesizes that greater trade openness will accelerate economic recovery, as reflected in GDP growth and FDI inflows, while higher labor force participation and lower youth unemployment will contribute to greater resilience. Additionally, investments in digital infrastructure and reductions in greenhouse gas emissions are expected to support long-term economic stability. By integrating economic, social, and environmental factors, this study offers a comprehensive analysis of post-pandemic recovery and resilience. Its findings aim to provide evidence-based recommendations to policymakers, assisting in the formulation of strategies that reduce economic vulnerabilities and enhance preparedness for future global shocks.

2 Literature review

Numerous studies have examined the impact of COVID-19 on economies; this literature review focuses on those most relevant to the current research. Apergis and Apergis (2021) analyzed the pandemic's effect on industrial production in various economies, using a sample of OECD countries from March 2020 to January 2021. They utilized two proxies for pandemic effects: total confirmed COVID-19 cases and total deaths. Their findings, derived from the Bayesian panel vector autoregressive (BPVAR) method, indicated that COVID-19 significantly and negatively affected industrial production, highlighting the profound economic disruptions experienced by the OECD countries.

Goel et al. (2021) investigated how different aspects of supply chain logistics influence economic growth across 130 nations. They assessed the impact of overall logistics performance and both input and output dimensions. Results showed that improvements in logistics positively affected economic growth, with input and output dimensions contributing variably. Notably, the growth impact of logistics performance varied among countries with differing growth rates.

Nguyen et al. (2022) provided estimates of COVID-19's impact on the Vietnamese economy using a Bayesian method to estimate dynamic stochastic general equilibrium (DSGE) models. Their research found that a one standard deviation increases in the probability of a COVID-19 outbreak (approximately 1.49%) led to an immediate output gap reduction of 0.94%, although this effect was short-lived, lasting only one quarter before widening again. They also noted immediate declines in refinancing interest rates, inflation, and exchange rates due to the COVID-19 shock, though these reductions were relatively small. Alam et al. (2022) reviewed recent research, reports, and working papers to assess the pandemic's potential impact on Bangladesh's economy. Their findings indicated significant effects on various key economic indicators, particularly in sectors such as readymade garments, foreign remittances, banking and finance, food and agriculture, and local and foreign trade. The study highlights the widespread and multifaceted economic disruptions caused by the pandemic in Bangladesh.

Zhang (2021) proposed an economic model emphasizing the critical role of broadband in driving economic growth during the pandemic. Analyzing data from China, the study demonstrated that broadband significantly mitigated economic losses in early 2020, suggesting that its impact on growth during the pandemic surpassed that in normal periods, emphasizing important policy implications. Farzanegan et al. (2021) examined the relationship between globalization and the COVID-19 case fatality rate (CFR) across more than 150 countries as of July 28, 2020. Their regression analyses revealed that countries with higher levels of socio-economic globalization tended to experience higher CFRs. Zhou et al. (2022) investigated how government responses influence the transmission dynamics of COVID-19 and its CFR. Using a dynamic generalized moment method to analyze panel data from eight countries, the study found that government responses significantly affected

COVID-19 transmission. Additionally, the relationship between government responses and CFR exhibited cyclical behavior, highlighting the lag in government effectiveness and the need for timely interventions.

Zhang et al. (2022) developed a comprehensive evaluation index system and employed a panel data regression model to analyze the digital economy's impact on economic growth in Belt and Road countries prior to the pandemic. They also utilized a global trade analysis project (GTAP) model to assess the pandemic's effects on digital industries and trade patterns. Their findings revealed that, despite notable regional imbalances in digital economy development, the digital economy significantly boosted economic growth, emphasizing the importance of digital advancements amid the pandemic's influence on trade and industry dynamics.

Szeles and Saman (2020) explored the varying effects of globalization on economic growth across EU member states, focusing on international finance indicators. Their analysis of Eurostat panel data showed that foreign-controlled companies significantly impact foreign direct investment inflows and economic growth, with differing influences between New and Old Member States. This suggests a need for common EU initiatives to mitigate globalization's adverse effects, especially during global crises like COVID-19.

Soava et al. (2021) analyzed the impact of the COVID-19 pandemic on economic growth and electricity consumption in Romania, specifically examining how electricity consumption affects gross domestic product (GDP). Using monthly data on electricity consumption and quarterly GDP from 2007 to 2020, the study compared trends during the financial crisis and the COVID-19 crisis. The findings revealed a severe reduction in both electricity consumption and GDP in the first half of 2020, followed by a slight recovery. The analysis confirmed long-term relationships between GDP and both domestic and non-household electricity consumption, with non-household consumption exerting a more significant impact. Singh et al. (2021) evaluated various factors affecting COVID-19 transmission across 83 countries, including age, population density, total population, rural population, annual average temperature, basic sanitation facilities, and diabetes prevalence. They found that a higher proportion of elderly individuals (aged over 65) correlated with increased COVID-19 cases, while a lower median age was associated with fewer cases, likely due to higher comorbidities and lower immunity in older populations.

Vitenu-Sackey and Barfi (2021) examined the pandemic's impact on poverty alleviation and global GDP across 170 countries using econometric panel techniques, including ordinary least squares (OLS) and robust least squares regression. Analyzing data from OurWorldInData.com, their findings revealed that stricter pandemic measures and the spread of the virus negatively affected both poverty alleviation and economic growth. Conversely, the number of recorded deaths had a positive impact on these outcomes. Khan et al. (2021) investigated the economic costs of the pandemic, which has severely affected various sectors globally since its emergence in December 2019. The research focused on key economic variables such as economic growth, global trade, health, unemployment, underemployment, foreign direct investment, and the travel and tourism sector, highlighting the widespread economic disruption caused by the virus. Their descriptive analysis revealed significant negative impacts, including slowed global economic growth, reduced international trade, strained healthcare systems, increased unemployment and underemployment, decreased FDI, and devastation of the tourism industry, illustrating the extensive toll on both developed and developing nations.

Ghecham (2022) explored the relationship between income inequality and economic performance during the pandemic's first year. The research posited that income inequality is a key factor explaining variations in economic outcomes among nations.

Contrary to some previous studies, findings indicated that countries with lower income inequality experienced a more severe economic impact from health casualties due to COVID-19. Both economic growth decline and COVID-19-related casualties were generally proportional to income inequality levels in each country. The study also noted that countries heavily reliant on the service sector and those enforcing stricter lockdown measures saw a more significant decline in GDP growth during the pandemic's first year.

Varona and Gonzales (2021) analyzed the short-term behavior of economic activity and causal relationships amid the COVID-19 pandemic, focusing on the basic reproduction number of the virus. Using an Autoregressive Distributed Lags (ARDL) model, they found a negative and statistically significant impact of the COVID-19 shock on economic activity levels. Their analysis also identified a long-term cointegration relationship, supported by an error correction model that is statistically significant at the 1% level and shows the expected direction of influence. This highlights the strong link between the pandemic's spread and economic performance in both the short and long term. Habtamu (2020) conducted a review of findings related to the impacts of COVID-19 on key macroeconomic variables such as economic growth, unemployment, and poverty levels, laying the groundwork for future solutions. While numerous studies have examined the pandemic's impact on economies, a significant gap remains in understanding the specific pathways through which these impacts manifest in economic recovery and resilience within European Union member states.

Previous literature has primarily focused on the immediate effects of the pandemic on industrial production and supply chain logistics but often lacks a comprehensive analysis of how these factors contribute to long-term recovery and resilience in post-pandemic economies. Additionally, some studies provide valuable insights into the economic repercussions of COVID-19 in individual countries but do not fully address how these insights can be generalized across multiple EU economies, particularly regarding comparative recovery strategies and resilience-building measures. This highlights a critical need for research that explores not only the immediate economic impacts of the COVID-19 pandemic but also assesses the effectiveness of recovery strategies implemented across ten European Union economies. By examining how these economies have navigated the challenges posed by the pandemic and evaluating their resilience, the current research aims to fill the existing gap in the literature.

3 Research methodology

3.1 Data source

This study examines the post-pandemic recovery of eleven European Union economies using annual time series data from the World Bank for the period 1990 to 2022. The timeframe was selected based on data availability for the economies included in the analysis. The study aims to evaluate how different factors influence economic growth in both the short and long term, identifying both positive and negative effects. A detailed description of the variables used in the analysis is provided in Table 1.

Table 1 Variables description and data source. Source: World Bank

Variable	Acronyms in the equations	Detail	Source
Gross domestic product	GDP	Annual growth %	World Bank (2024); https://data.worldbank.org/
Foreign direct investment	FDI	Net inflows % of gross domestic product (GDP)	World Bank (2024); https://data.worldbank.org/
Inflation rate	INFLA	Consumer prices (annual %)	World Bank (2024); https://data.worldbank.org/
Mobile cellular subscriptions (per 100 people)	MCS	% of GDP	World Bank (2024); https://data.worldbank.org/
Labor force participation rate (age 15 +)	LFPR	% of the total labor force	World Bank (2024); https://data.worldbank.org/
Youth unemployment rate (15–24)	YUNE	% of the total labor force	World Bank (2024); https://data.worldbank.org/
Trade openness	Top	Exports plus imports % of GDP	World Bank (2024); https://data.worldbank.org/
Total greenhouse gas emissions	TGGE	Kt of CO2 equivalent	World Bank (2024); https://data.worldbank.org/
Population growth rate	Popg	Annual growth %	World Bank (2024); https://data.worldbank.org/

3.2 Trend analysis of the variables

Figure 1 illustrates the GDP growth rate in the selected countries, highlighting periods of expansion and contraction. A sharp and simultaneous decline is observed across all economies, signaling a significant downturn likely caused by a major crisis such as the COVID-19 pandemic. Following this drop, the trends show a slow and uneven recovery, with some countries rebounding faster than others. This pattern of decline and recovery suggests that these economies are closely connected and respond similarly to global shocks.

Figure 2 presents inflation trends in the selected economies. Initially, inflation rates drop sharply in most countries, likely due to reduced demand during the same crisis that affected GDP. After this decline, inflation remains relatively stable, with minor fluctuations over an extended period. However, a sharp rise in inflation is later observed across nearly all countries. This increase may be linked to post-crisis factors such as supply chain disruptions, rising energy prices, or increased government spending. The inflation surge is particularly notable, indicating that while economic growth resumes, new challenges emerge, especially due to rising inflation.

Figure 3 depicts population growth rates. While most countries maintain relatively stable growth with minor fluctuations, some experience sharp declines or spikes. These outliers may reflect migration patterns, birth and death rate changes, or broader economic influences. Notably, Germany and Portugal show significant negative spikes, which may indicate population losses due to aging populations, emigration, or other socioeconomic factors.

Figure 4 shows an increase in mobile cellular subscriptions during and after the pandemic, likely due to the rise of remote work and digital adoption**.** In contrast, Fig. 5 indicates that Sweden maintains a higher level of trade openness than the other selected economies. Lastly, Fig. 6 reveals that most economies experienced a decline in foreign direct investment growth during the pandemic. This trend suggests that global uncertainties and economic disruptions led to a reduction in investment flows.

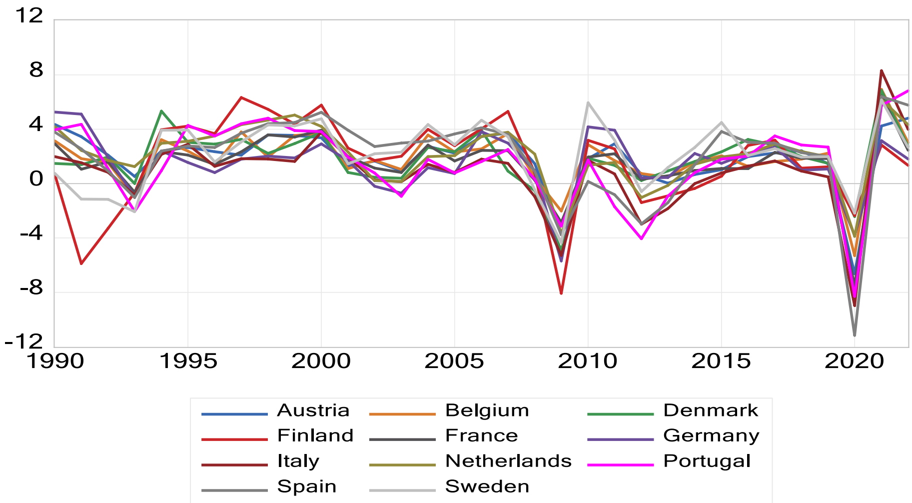

Fig. 1 GDP growth trend in the selected economies from 1990 to 2022

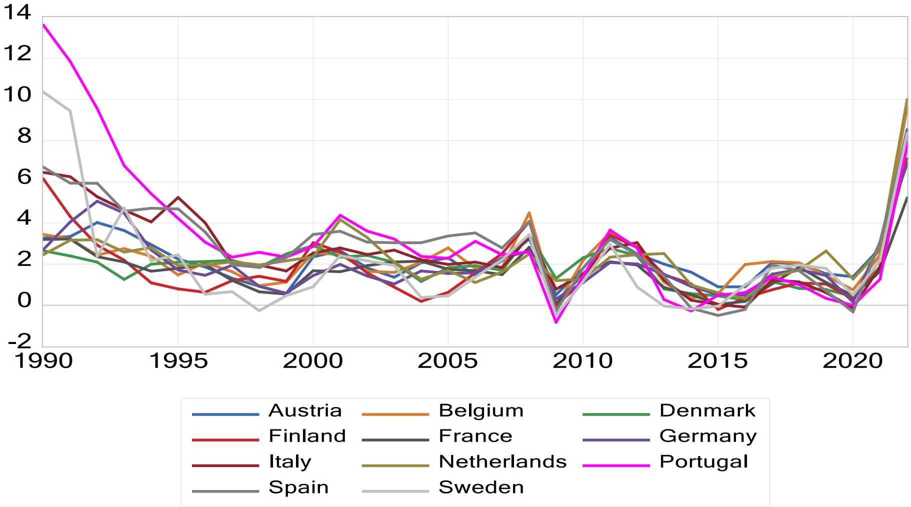

Fig. 2 Inflation rate trend in the selected economies from 1990 to 2022

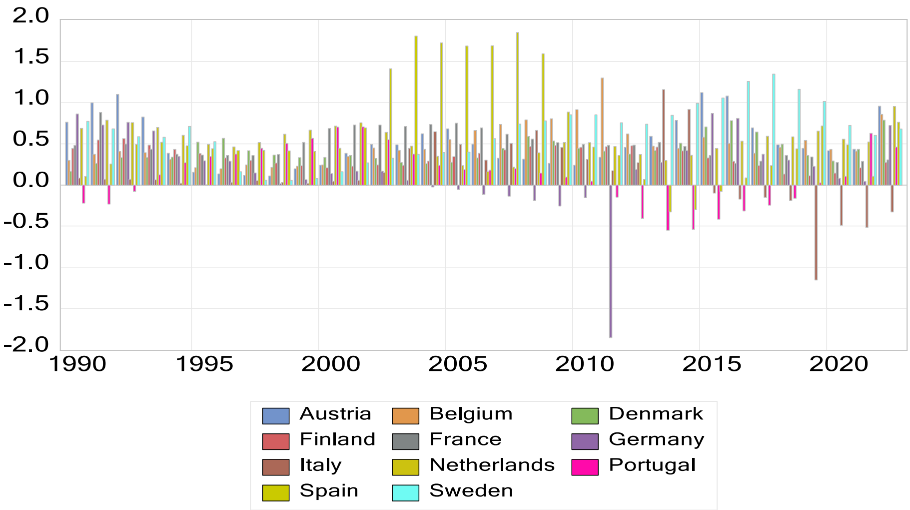

Fig. 3 Population growth rate trend in the selected economies from 1990 to 2022

3.3 Theoretical model framework

The selection of variables for analyzing economic recovery and resilience in post-pandemic Europe is based on established economic and development theories. Each variable helps explain both the short-term recovery process and the factors that contribute to long-term stability. Gross domestic product (GDP) is used as the dependent variable, grounded in Keynesian economic theory, which emphasizes the role of aggregate demand in shaping economic performance. Keynes (1936) argued that government intervention, particularly through fiscal policies and public spending, is essential for stimulating demand

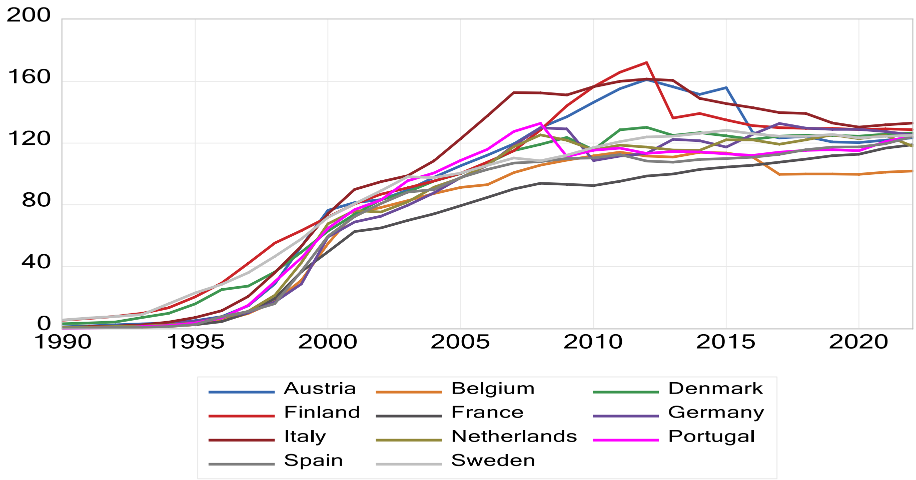

Fig. 4 Mobile cellular subscription in the selected economies from 1990 to 2022

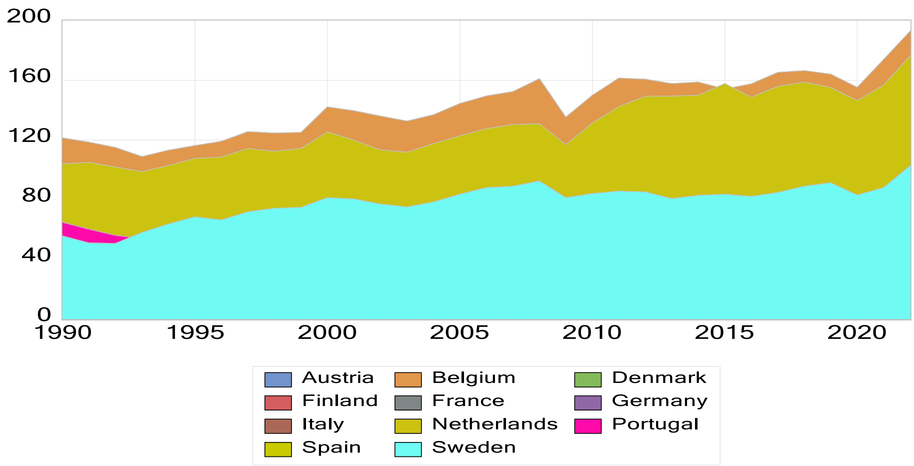

Fig. 5 Trade openness trend in the selected economies from 1990 to 2022

and restoring economic activity. GDP, as a measure of total economic output, reflects the overall health of an economy, and its growth signals a successful recovery. Additionally, neoclassical growth theory (Solow 1956) explains that long-term economic expansion is driven by capital accumulation, labor, and technological progress, making GDP a relevant indicator of both short- and long-term growth.

Foreign direct investment is included based on Dunning's Eclectic Paradigm (OLI Framework) (Dunning 1980), which highlights ownership, location, and internalization advantages as key factors influencing investment flows. FDI is an indicator of international confidence in a country's economic stability and growth prospects. In the post-pandemic context, rising FDI suggests that an economy is becoming more attractive to investors, stimulating job creation, innovation, and technology transfer, which support both recovery and long-term stability. Inflation is analyzed through the lens of Monetarist theory,

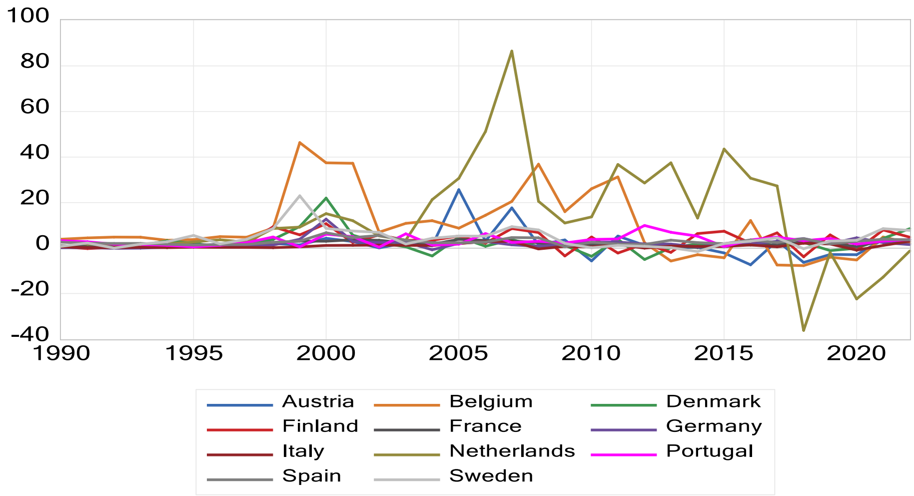

Fig. 6 FDI inflow growth trend in the selected economies from 1990 to 2022

particularly the work of Friedman (1968), who argued that inflation is primarily driven by changes in the money supply. High inflation can reduce purchasing power, lower consumer and business confidence, and create uncertainty. In contrast, low and stable inflation fosters economic recovery by allowing businesses and consumers to plan more effectively. In the post-pandemic period, maintaining price stability is essential for steady growth, making inflation a key variable in understanding both recovery and resilience.

Labor force participation rate is included as a measure of economic activity, supported by human capital theory (Becker 1964). This theory emphasizes that education and skills development contribute directly to economic productivity. A high labor force participation rate indicates a greater proportion of the population is engaged in productive activities, which is especially important in the post-pandemic context, where labor market disruptions have been widespread. A strong labor force participation rate reflects an economy's ability to draw on its full potential, supporting both recovery and long-term stability. Youth unemployment is closely linked to Keynesian unemployment theory (Keynes 1936), which explains that cyclical unemployment occurs when aggregate demand falls. This is particularly relevant in the post-pandemic setting, where youth unemployment surged due to economic disruptions. High youth unemployment indicates that a key segment of the labor market is underutilized, which can have lasting consequences if not addressed. Prolonged joblessness among young people can lead to skill erosion and lower long-term productivity. Reducing youth unemployment is important for ensuring that young workers contribute effectively to economic growth and development.

Trade openness is examined using Ricardian trade theory and the principle of comparative advantage (Ricardo 1817). Ricardo argued that economies benefit from specializing in goods where they have a comparative advantage and engaging in international trade. In the post-pandemic context, economies with higher trade openness are expected to recover more quickly, as access to international markets boosts exports, imports of essential goods, and capital inflows. Additionally, economies that are well-integrated into global trade networks tend to be more resilient, as they can diversify their sources of income and production. Technological infrastructure, measured by mobile cellular subscriptions, is supported by endogenous growth theory (Romer 1990), which emphasizes the role of innovation and technological advancement in driving long-term economic growth. The COVID-19 pandemic accelerated the shift toward digital economies, making mobile connectivity a critical factor in recovery. Economies with widespread mobile adoption are better positioned to integrate digital innovations, enhance productivity, and adapt to changing economic conditions, strengthening both recovery and long-term growth.

Environmental sustainability, represented by total greenhouse gas emissions, is analyzed through the Environmental Kuznets Curve (EKC) hypothesis (Grossman and Krueger 1991). The EKC suggests that as economies grow, environmental degradation initially increases but eventually declines as societies invest in cleaner technologies. In the post-pandemic period, efforts to reduce emissions while fostering economic recovery reflect an economy's ability to balance growth with environmental responsibility. This balance is a key aspect of long-term stability. Population growth rate is examined using demographic transition theory (Notestein 1945), which describes how economies transition from high birth and death rates to lower rates as they develop. Population growth affects labor supply, demand for goods and services, and overall economic productivity. In the post-pandemic recovery, a growing population can enhance labor availability in the short run and support economic expansion in the long term through innovation and sustained consumer demand. Based on these theoretical foundations, the estimated model is presented in Eq. 1.

$$GDPG_t = \mathfrak{f}\left(FDI_t, INFLA_t, MSC_t, POPG_t, TGGE_t, TOP_t, YUNE_t, LFPR_t\right) \tag{1}$$

where: $GDPG_t$ represents the annual growth rate of Gross Domestic Product (GDP) at time t, FDI_t refers to Foreign Direct Investment as a percentage of GDP, $INFLA_t$ denotes the annual inflation rate (consumer prices), MSC_t indicates mobile cellular subscriptions as a percentage of GDP, $POPG_t$ is the annual population growth rate, $TGGE_t$ stands for total greenhouse gas emissions in kilotons of CO2 equivalent, TOP_t represents trade openness, measured as exports plus imports as a percentage of GDP, $YUNE_t$ is the youth unemployment rate (ages 15–24) as a percentage of the total labor force, $LFPR_t$ is the labor force participation rate (ages 15 +) as a percentage of the total labor force.

3.4 Cross-section dependence test

The economies selected for this study are interconnected through the EU single market and the broader effects of globalization. These interdependencies can lead to cross-sectional dependence, meaning that economic shocks or policy changes in one country may influence others within the region. To identify such dependence, this study applies the bias-adjusted LM test, originally developed by Breusch and Pagan (1980) and later refined by Pesaran et al. (2004), Baltagi et al. (2012), and Chudik and Pesaran (2015). This test assesses whether residuals from different cross-sectional units are correlated, with the CD statistic following a standard normal distribution under the null hypothesis of no cross-sectional dependence, as shown in Eq. 2.

If the model is non-stationary, both homogeneous and heterogeneous dynamic processes produce a CD statistic with a mean of zero, provided that the time dimension (T) and the number of cross-sectional units (N) meet specific conditions. This distinguishes it from the traditional Lagrange Multiplier (LM) statistic. For unbalanced panel data, Pesaran et al. (2004) introduced an improved version of the LM test to correct for potential biases, as detailed in Eq. 3.

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}ij\right) \tag{2}$$

where CD is the cross-sectional dependence statistic, T is the time dimension, N is the number of cross-sections and $\hat{\rho}ij$ is the sample correlation coefficient between cross-sections i and j.

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\sqrt{\mathrm{T}_{ij}}\hat{\rho}ij\right) \tag{3}$$

where T_{ij} represents the number of common time periods between cross-sections i and j. Breusch and Pagan (1980) recommend using the cross-sectional dependence (CD) method within the Lagrange Multiplier (LM) framework to address issues related to cross-sectional dependency (CSD). The panel data model for conducting the Breusch-Pagan LM test is presented in Eq. 4.

However, the Breusch-Pagan LM test, commonly applied to detect cross-sectional dependence, may become unreliable when the number of cross-sections is large. Pesaran (2007) noted that, in such cases, the average pairwise correlation may converge to zero, reducing the statistical power of the test. To overcome this limitation, Pesaran et al. (2008) introduced a bias-corrected version, which adjusts the mean and variance estimates, enhancing the test's reliability in large panels, as shown in Eq. 5.

$$LM = \sum_{i=1}^{N-1}\sum_{J=i+1}^{N} T_{ij}\hat{p}^2 ij \sim \mathrm{X}^2\frac{N(N-1)}{2} \tag{4}$$

where LM follows a chi-square distribution with $\frac{N(N-1)}{2}$ degrees of freedom.

$$LM = \sqrt{(\frac{2}{N(N-1)})}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}ij\frac{(T-K)\hat{p}^2 ij-\mu}{\sqrt{v^2 T_{ij}}} \sim N(0{,}1) \tag{5}$$

where K represents the number of regressors, μ is the bias-corrected mean and v^2 is the variance of T_{ij}.

3.5 Panel unit root test

Traditional unit root tests may fail to account for cross-sectional dependence and heterogeneity, which can lead to incorrect conclusions about the stationarity of variables. To address these limitations, Pesaran (2007) introduced the cross-sectionally augmented IPS (CIPS) test, an extension of the Augmented Dickey-Fuller (ADF) test that incorporates cross-sectional averages of lagged terms. This adjustment allows the test to account for both common shocks and heterogeneous dynamics across countries.

The CIPS test works by averaging the results of cross-sectionally augmented individual ADF tests, making it a more reliable method for evaluating stationarity in the presence of cross-sectional dependence. By incorporating common factors into the unit root testing procedure, this approach improves the accuracy of the results and ensures that the findings are not distorted by omitted cross-sectional influences.

$$CIPS = \mathrm{N}^{-1} \sum_{i=1}^{N} CADF_i \tag{6}$$

3.6 Panel cointegration test

To examine the long-term equilibrium relationships between the dependent variable and its explanatory factors, this study applies the Kao (1999) and Johansen (1995) cointegration tests. The Kao test is based on a cointegrating regression framework that accounts for individual-specific intercepts and coefficients, allowing it to capture variations across different countries in the panel. This approach offers a comprehensive assessment of long-run relationships by testing whether the residuals from the estimated equation are stationary. The Kao cointegration test is presented in Eq. 7.

$$y_{it} = \beta_i t + \beta_{1it}x_{1it} + \beta_{2it}x_{2it} + \cdots + \beta_{kit}x_{kit} + \epsilon_{it} \tag{7}$$

This model allows the investigation of cointegration between the targeted y_{it} and the regressors x_{1it},x_{2it}…,x_{kit} The individual-specific coefficients $\beta_i t$, β_{1it},β_{2it},and β_{kit} accommodate potential variations in the linkage across entities within the panel. The Johansen cointegration test applies a vector autoregressive (VAR) approach to identify multiple cointegrating relationships. It uses a likelihood ratio framework to determine whether long-run relationships exist among the variables while accounting for both short-term adjustments and long-term equilibrium. The presence of cointegration indicates that the variables share a common stochastic trend, suggesting a stable long-term relationship despite short-term fluctuations, as shown in Eq. 8. Where γ_{it} is the vector of NT $\times 1$ variables integrated at first order difference. The cointegration and the short run terms can be written as follows in Eq. 9.

$$\gamma_{it} = \alpha_i + \mathrm{K}_1\gamma_{it-1} + \cdots + \mathrm{K_Z}\gamma_{it-\mathrm{Z}} + \vartheta_{it} \tag{8}$$

$$\Delta\gamma_{it} = \alpha_i + \prod \gamma_{it-1} + \sum_{j=1}^{z} \Gamma_i \Delta\gamma_{it-j} + \theta_{it} \tag{9}$$

where the null hypothesis of no cointegration indicates that z ($\prod$) $=0$ and the alternative hypothesis indicates cointegration existence when z ($\prod$) $\neq 0$.

3.7 Panel causality test

This study applies the panel causality test developed by Dumitrescu and Hurlin (2012) to examine causal relationships among the variables in the panel dataset. Unlike traditional Granger causality tests, this approach accounts for heterogeneity across cross-sections, allowing causality to differ between countries. The test assesses whether past values of one variable can predict changes in another while considering differences in the economic structures of the selected EU countries.

The test procedure involves computing individual Wald statistics for each cross-section, which are then averaged to obtain an overall measure of causality. As the time dimension (T) increases, these individual statistics converge, leading to more reliable inferences about causal linkages. The null hypothesis assumes no causality, while the alternative hypothesis suggests that causality exists in at least some of the cross-sections. The standardized Z-statistic further improves the robustness of the test, ensuring its applicability across different panel sizes. The causality test is presented in Eq. 10

$$y_{it} = \sum_{k=1}^{K} a_i^{(k)} y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} x_{i,t-k} + \varepsilon_{i,t} \tag{10}$$

K represents the lag length. The panel used for this test balanced. $a_i^{(k)}$ is the autoregressive parameter and $\beta_i^{(k)}$ is the regression coefficient, which can vary across entities (i). Dumitrescu and Hurlin (2012) suggest that as T (the time dimension) approaches infinity, the individual Wald statistics become independently and identically distributed.

$$W_{N,T}^{Hnc} = \frac{1}{N} + \sum\nolimits_{i=1}^{N} W_{it} \tag{11}$$

The $ZH_{nc}^{N,T}$ represents the z-statistic, where N is the number of cross-sections and K is the optimal lag length in Eq. 12.

$$Z_{N,T}^{Hnc} = \sqrt{\frac{N}{2K}} \left(W_{N,T}^{Hnc} - K \right) T, N \to \infty N(0,1) \tag{12}$$

The average of these Wald statistics converges to K, while their variance is equivalent to 2 K. A standardized Z-statistic for the mean Wald statistic, under the HNC null hypothesis, is then computed, as shown in Eq. 13.

$$Z_N^{Hnc} = \frac{\sqrt{N}\left[W_{N,T}^{Hnc} - N^{-1} \sum_{i=1}^{N} E\left(W_{i,T}\right) \right]}{\sqrt{N^{-1} \sum_{i=1}^{N} Var\left(W_{i,T}\right)}} T, N \to \infty N(0,1) \tag{13}$$

The null hypothesis and the alternative hypothesis for the calculated panel are as follows:

$$H_O : \beta_i = 0 \quad \forall i = 1,2, \ldots, N$$

$$H_1 : \beta_i = 0 \quad \forall i = 1,2, \ldots, N1$$

$$\beta_i \neq 0 \quad \forall i = N_1 + 1, N_1 + 2, \ldots, N$$

3.8 Estimation technique

This study employs the Pooled Mean Group (PMG) and Nonlinear Autoregressive Distributed Lag (NARDL) model, as proposed by Pesaran et al. (1999). It also applies the Common Correlated Effects Estimator (CCEE-ARDL) developed by Chudik and Pesaran (2015) to estimate both long-run and short-run coefficients of the variables. The PMG-ARDL and CCEE-ARDL models are presented in Eqs. 14 and 15, respectively. Additionally, the nonlinear ARDL model is used to capture asymmetric effects of the variables. The PMG-ARDL model is selected for its ability to estimate both long-run and short-run coefficients while allowing for heterogeneity in the short run across the selected EU countries.

It assumes that long-run relationships are homogeneous, whereas short-run dynamics can vary across cross-sections. The PMG-ARDL model is presented in Eq. 14.

$$y_{it} = \beta_i + \sum_{j=1}^{z} \beta_{ij} y_{it-j} + \sum_{j=1}^{z} \delta_{ij} M_{it-j} + \mu_{it} \tag{14}$$

where y_{it} is the target variable, β_i is the constant term, $\beta_{ij}y_{it-j}$ is the lag coefficient of the explained variable, $\delta_{ij}M_{it-j}$ indicates the regressors, μ_{it} indicates the error term in the estimated model in the PMG-ARDL. The CCEE-ARDL model, presented in Eq. 15, is used to account for cross-sectional dependence by incorporating cross-sectional averages of the variables. This approach helps control for unobserved common factors that may affect all cross-sections in a similar manner.

$$y_{it} = \alpha_i + \sum_{j=1}^{p} \varnothing_{ik} y_{it-k} + \sum_{j=1}^{p} \theta_{ik} Q_{it-k} + \sum_{j=1}^{p} \beta_{ik} \mathrm{G}_{it-k} + \epsilon_{it} \tag{15}$$

In the CCEE-ARDL G_{it-k} is the lagged cross-sectional averages, y_{it} indicates the explained variable, $\varnothing_{ik}y_{it-k}$ is the lagged of the target variable, $\theta_{ik}Q_{it-k}$ represents the regressors. To examine the potential asymmetric effects of key economic factors such as foreign direct investment, population growth, inflation, and trade openness, the nonlinear ARDL (NARDL) model is applied. This model differentiates between positive and negative changes in explanatory variables, allowing for a more precise assessment of asymmetries in their impact. The NARDL model is presented in Eq. 16.

$$y_{it} = a + \lambda\left(y_{it-1} - \theta^{+}X^{+}_{it-1} - \theta^{-}X^{-}_{it-1}\right) + \sum_{p=1}^{p} a_p \Delta y_{it-p} + \sum_{q=0}^{Q} \left(\beta^{+}_{q}\Delta X^{+}_{it-q} + \beta^{-}_{q}\Delta X^{-}_{it-q}\right) + \epsilon_{it} \tag{16}$$

where X^{+}_{it} and X^{-}_{it} represent the positive and negative changes in the explanatory variables, allowing to capture asymmetry. However, θ^{+} and θ^{-} are the long-run coefficient for positive and negative shocks respectivelyThe combination of these models provides a comprehensive framework for analyzing economic relationships by capturing homogeneity, heterogeneity, dependence, and asymmetry across the selected EU countries. The PMG-ARDL accounts for long-run homogeneity while allowing for short-run flexibility, the CCEE-ARDL addresses cross-sectional dependence, and the NARDL captures nonlinear effects in key economic indicators.

4 Results and discussions

Table 2 presents the descriptive statistics for the economic and social indicators. The average GDP growth rate is 1.71%, indicating moderate economic expansion. However, the high standard deviation and extreme values reveal significant fluctuations, ranging from severe contractions to strong growth periods. Foreign direct investment averages 4.25% of GDP, emphasizing the role of external capital, but its high volatility suggests an unstable investment environment. Mobile cellular subscriptions average 3.75%, reflecting expanding communication infrastructure. However, fluctuations and a wide range of values suggest unequal access to mobile technology across regions and over time. Total greenhouse gas

Table 2 Descriptive statistics. Source: Authors calculations

	GDP	FDI	Inflation	MCS	Popg	TGGE	Top	YUnem	LFPR
Mean	1.710	4.246	2.284	3.753	0.408	12.01	82.03	18.68	59.47
Median	1.983	2.147	1.973	4.607	0.411	11.74	74.64	17.89	59.35
Maximum	8.310	86.47	13.63	5.148	1.851	13.93	193.0	55.47	74.37
Minimum	− 11.16	− 36.1	− 0.835	− 2.734	1.851	10.62	33.87	3.720	48.21
Std.Dev	2.559	9.251	1.963	1.691	− 1.853	0.954	32.21	10.13	5.166
Skewness	− 1.408	3.505	2.199	− 1.645	0.383	0.417	1.018	0.886	0.334
Kurtosis	7.007	25.89	9.955	3.643	− 0.164	1.753	3.478	3.523	3.105
Jarque–Bera	362.9	8674	1024	204.5	410.7	34.05	66.17	51.67	6.930
Prob	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.031
Sum	620.7	1541	829.3	1362	148.4	4358	27,967	6780	21,588
Sum Sq.Dev	2364	30,982	1396	1035	53.3	329.6	37,564	37,137	9662
Observation	363	363	363	363	363	363	363	363	363

emissions average 12.01%, highlighting environmental pressures from industrial and economic activities. Although relatively stable, emissions levels show some variation.

Population growth remains steady at 0.41%, reflecting consistent demographic expansion. However, youth unemployment stands at 18.68%, signaling persistent labor market challenges for younger populations. Trade openness is relatively high at 82.03%, suggesting strong global integration, though significant variations indicate fluctuations in trade activity. The labor force participation rate averages 59.47%, meaning that around 60% of the working-age population is engaged in the labor market, with minor variations. The skewness, kurtosis, and Jarque–Bera test results suggest that many variables deviate from a normal distribution, indicating the presence of outliers and asymmetrical distributions, which may reflect economic instability over time.

Figure 7 presents the correlation matrix of the variables. A strong positive correlation is observed between trade openness and mobile cellular subscriptions, suggesting that greater trade openness is associated with higher levels of mobile phone usage. Trade openness is also positively correlated with labor force participation, indicating that economies with greater trade integration tend to have higher labor force participation rates. Additionally, trade openness shows a positive correlation with GDP growth and FDI, implying that more open economies generally grow faster and attract more foreign investment.

Conversely, trade openness is negatively correlated with inflation, TGGE, and youth unemployment, meaning that countries with greater trade openness tend to experience lower inflation, reduced greenhouse gas emissions, and lower youth unemployment rates. These correlations suggest that increased trade contributes to economic stability, environmental improvements, and labor market efficiency. Mobile cellular subscriptions show positive correlations with LFPR and GDP growth, implying that countries with greater access to mobile technology tend to have higher labor participation and faster economic growth. Additionally, MCS is negatively correlated with TGGE and youth unemployment, suggesting that technological advancements may contribute to environmental sustainability and employment opportunities.

LFPR is positively correlated with GDP growth and population growth, indicating that higher labor force participation is associated with economic and demographic expansion. However, LFPR is negatively correlated with inflation, TGGE, and youth unemployment,

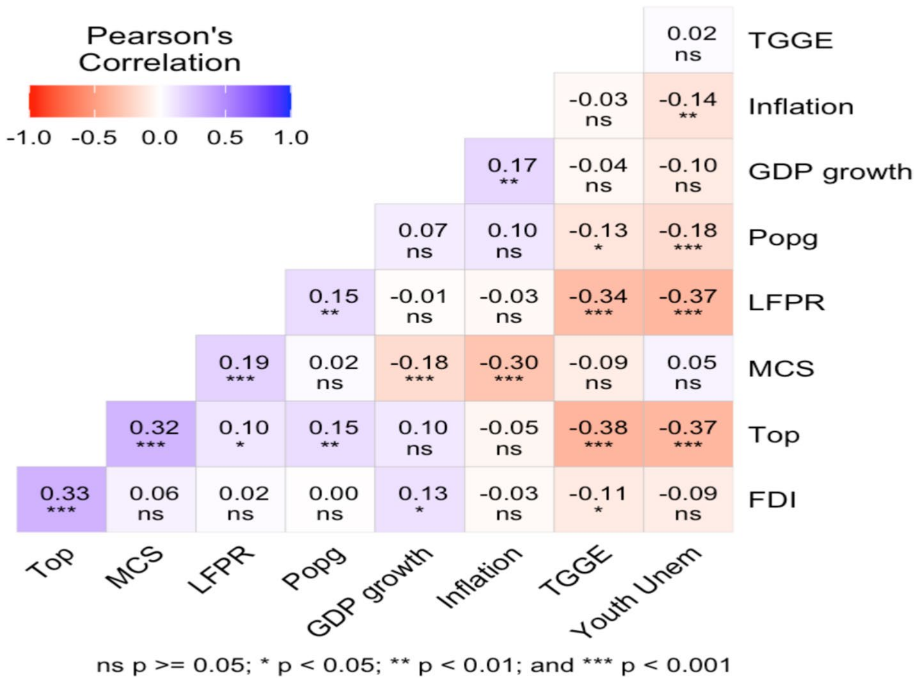

Fig. 7 Pearson correlation

suggesting that greater workforce participation coincides with lower inflation, reduced greenhouse gas emissions, and lower youth unemployment rates. This could imply that higher employment rates promote both economic and environmental stability. Population growth is positively correlated with GDP growth, meaning that countries with higher population growth tend to experience stronger economic expansion. However, it is negatively correlated with inflation, TGGE, and youth unemployment, indicating that higher population growth is associated with lower inflation, fewer greenhouse gas emissions, and reduced youth unemployment.

GDP growth shows weak but generally positive correlations with most variables, with the strongest correlation observed with FDI, suggesting that countries experiencing economic growth tend to attract more foreign investment. However, GDP growth exhibits weak or no significant correlations with TGGE and youth unemployment, indicating that economic expansion in this dataset is not strongly linked to changes in greenhouse gas emissions or youth unemployment rates. Inflation has negative correlations with several variables, particularly LFPR, Popg, and MCS, meaning that higher inflation is associated with lower labor participation, slower population growth, and fewer mobile cellular subscriptions. Inflation also shows a weak negative correlation with GDP growth and FDI, implying that rising inflation may slightly dampen economic growth and foreign investment.

TGGE is negatively correlated with trade openness, MCS, LFPR, and Popg, suggesting that countries with higher greenhouse gas emissions tend to have lower trade openness, fewer mobile subscriptions, lower labor force participation, and slower population growth. This could indicate that countries with higher emissions are generally less technologically advanced or have fewer dynamic economies. Additionally, TGGE exhibits a weak positive correlation with youth unemployment, suggesting that higher emissions may be

Table 3 Collinearity test results. Source: Authors calculations

Variable	Coefficient variance	Uncentered VIF
FDI	0.001	1.530
Inflation	0.089	1.774
LFPR	0.010	1.209
MCS	0.001	6.046
POP	0.846	1.799
TGGE	0.000	1.589
TOP	0.002	5.070
Youth unem	0.004	1.677

Table 4 Cross-section dependence test results. Source: Authors calculations

Test	Statistic	d.f	p-value
Breusch-Pagan LM	974.105***	55	0.000
Pesaran Scaled LM	87.633***		0.000
Pesaran CD	30.727***		0.000

***P < 0.001

linked to increased youth unemployment. Lastly, youth unemployment is negatively correlated with trade openness, MCS, LFPR, and Popg, meaning that greater trade integration, higher mobile penetration, increased labor participation, and faster population growth are associated with lower youth unemployment rates. However, the weak positive correlation between youth unemployment and TGGE suggests that higher youth unemployment is somewhat linked to increased greenhouse gas emissions.

4.1 Collinearity test

The collinearity test results in Table 3 indicate that multicollinearity is not a significant concern among the variables in the model. All variance inflation factor (VIF) values are below 10, with the highest value being 6.046 for mobile cellular subscriptions. While this suggests that MCS has a relatively higher correlation with other variables, it does not reach a level that would indicate severe multicollinearity. The other variables, including foreign direct investment, inflation, labor force participation rate, population growth, total greenhouse gas emissions, trade openness, and youth unemployment, all have VIF values well below 10, confirming low levels of collinearity.

4.2 Cross-section dependency test

The cross-section dependence test results, presented in Table 4, indicate a strong interdependence among the cross-sectional units in the dataset. The Breusch-Pagan LM test produces a statistically significant value of 974.105, suggesting that the selected countries exhibit correlations with one another. This implies that economic events in one country are likely to influence others. The Pesaran Scaled LM test further confirms this dependence, as does the Pesaran CD test, which yields a statistic of 30.727, reinforcing the presence of cross-sectional correlations.

The cross-section dependence tests, presented in Table 5, evaluate the degree of interdependence among the variables. The Breusch-Pagan LM test consistently indicates strong cross-sectional dependence for most variables, with high T-statistics observed for GDP, foreign direct investment, inflation, mobile cellular subscriptions, total greenhouse gas emissions, trade openness, youth unemployment, and the labor force participation rate. This suggests that these variables exhibit significant interconnections across countries. Population growth also shows some degree of dependence, but its T-statistic is lower compared to the other variables. The Pesaran Scaled LM and Bias-Corrected Scaled LM tests further confirm this pattern, with all variables displaying high T-statistics, except for population growth, which again demonstrates weaker dependence relative to the other indicators.

These results suggest that factors such as economic growth, foreign investment, price stability, communication infrastructure, trade openness, and unemployment are strongly correlated across countries, implying that changes in one region are likely to influence others. The Pesaran CD test reinforces these findings, particularly for GDP, inflation, mobile subscriptions, and trade openness. Interestingly, the population growth variable shows no significant dependence in the Pesaran CD test, as indicated by a near-zero statistic. This suggests that population dynamics are more independent across regions compared to economic and financial variables.

The results in Table 6 present the findings of the slope homogeneity test, following the approach of Pesaran and Yamagata (2008) and Swamy (1970). The delta statistic is 3.898, with an adjusted value of 4.670, both of which have highly significant p-values. This indicates that the null hypothesis of slope homogeneity is rejected, suggesting that the slope coefficients across the cross-sectional units are not homogeneous. These results imply that the effect of the independent variables on the dependent variable differs across units, reinforcing the presence of heterogeneous relationships among the selected countries.

4.3 Stationarity test

The CIPS test results, presented in Table 7, assess the stationarity of the variables at their levels and first differences. For GDP, foreign direct investment, inflation, and youth unemployment, both the constant test and the constant and trend test at level 0 indicate that these series are stationary. This implies that they do not have a unit root and remain stable over time, meaning their values tend to revert to a mean level rather than following a random walk. In contrast, mobile cellular subscriptions, population growth, total greenhouse gas emissions, trade openness, and the labor force participation rate are non-stationary at level 0 in both tests, indicating the presence of a unit root and a lack of mean reversion. However, at the first difference (level 1), these variables become stationary in both tests, suggesting that they are integrated of order 1.

4.4 Panel cointegration

The Kao cointegration test results, presented in Table 8, confirm the presence of a long-term equilibrium relationship among the variables. The Augmented Dickey–Fuller (ADF) T-statistic is − 7.876, which is highly significant, as indicated by the corresponding p-value. This result leads to the rejection of the null hypothesis of no cointegration, suggesting that the variables in the model move together in the long

Table 5 Cross-section dependence test results using the variables. Source: Authors calculations

Test	GDP	FDI	Infla	MCS	Popg	TGGE	Top	YUnem	LFPR
	T-Stat	T-Stat	T-Stat	T-Stat	T-Sat	T-Sat	T-Sat	T-Sat	T-Sat
Breusch-Pagan LM	1075***	227***	1090***	1787***	194.9***	951.1***	1484***	366.6***	464***
Pesaran Scaled LM	97.34***	16.42***	98.68***	165.2***	13.31***	85.44***	136.3***	29.71***	39.06***
Bias-corrected Scaled LM	97.16***	16.25***	98.51***	164.9***	13.14***	85.26***	136.2***	29.53***	38.88***
Pesaran CD	32.36***	12.06***	32.71***	42.28***	− 0.055	27.94***	38.41***	13.17***	2.587***

***$P < 0.001$

Table 6 Slope of homogenous results. Source: Authors calculations

	Delta	p-value
	3.898***	0.000
Adj	4.670***	0.000

***P < 0.001

Table 7 CIPS unit root test results. Source: Authors calculations

Variable	Level	Constant	Constant and trend
GDP	0	– 4.229***	– 3.989***
FDI	0	– 3.204***	– 3.458***
Inflation	0	– 2.445**	– 2.941**
MCS	0	– 2.111	– 2.650
MCS	1	– 4.350***	– 3.909***
Popg	0	– 1.801	– 1.825
Popg	1	– 3.914***	– 4.093***
TGGE	0	– 1.331	– 2.304
TGGE	1	– 4.169***	– 3.962***
Top	0	– 2.236	– 2.554
Top	1	– 2.786***	– 3.128***
LFPR	0	– 2.398**	– 2.171
LFPR	1	– 4.242***	– 4.682***
Youth unem	0	– 2.373**	– 3.135***

****P < 0.001, **P < 0.05*

Table 8 Kao cointegration results. Source: Authors calculations

Kao cointegration	Statistic	p-value
Augmented Dicky-Fuller T	– 7.876***	0.000
Residual variance	8.112	
HAC variance	3.187	

***P < 0.001

run despite short-term fluctuations. Additionally, the residual variance is 8.112, while the heteroscedasticity and autocorrelation consistent (HAC) variance is 3.187. These values provide further insights into the variability of the residuals and how they are adjusted for heteroscedasticity and autocorrelation.

The Johansen cointegration test results, presented in Table 9, indicate a strong presence of cointegration among the variables. Both the trace test and maximum eigenvalue test produce significantly high statistics with extremely low p-values. This leads to the rejection of the null hypothesis of no cointegration for all tested ranks, confirming the existence of long-run relationships among the variables.

Table 9 Johansen cointegration results. Source: Authors calculations

Hypothesized No. of CE(s)	Fisher Stat.* (from trace test)	p-value	Fisher Stat.* (from max-eigen test)	p-value
None	464.4***	0.000	566.0***	0.000
At most 1	692.1***	0.000	280.1***	0.000
At most 2	372.6***	0.000	166.2***	0.000
At most 3	236.2***	0.000	106.1***	0.000
At most 4	145.2***	0.000	64.82***	0.000
At most 5	93.65***	0.000	42.37***	0.006
At most 6	64.81***	0.000	35.80**	0.032
At most 7	48.43***	0.001	34.07**	0.048
At most 8	48.05***	0.001	48.05***	0.001

***P < 0.001

4.5 Panel estimated results

The results from Table 10, utilizing the common correlated effects estimator (CCEE-ARDL), reveal how independent variables influence GDP growth in both the long run and short run. In the long run, the coefficient for foreign direct investment is 0.005, indicating that FDI has a minimal effect on GDP growth, suggesting that it does not significantly

Table 10 Common correlated effects estimator (CCEE-ARDL) estimated results. Source: Authors calculations

	Coefficient	Std. Err	t-statistics	p-value
Long run				
FDI	0.005	0.033	0.14	0.892
Inflation	– 0.483***	0.177	– 2.72	0.007
MCS	– 0.034*	0.018	– 1.88	0.060
POPg	– 0.820	0.754	– 1.09	0.277
TGGE	0.007*	0.000	1.75	0.080
TOP	– 0.004	0.057	– 0.06	0.951
Youth unemp	0.063	0.063	0.98	0.325
LFPR	0.223	0.219	1.02	0.310
Short run				
ΔGDP	– 0.450***	0.047	– 9.64	0.000
ΔFDI	0.002	0.048	0.04	0.965
ΔInflation	– 0.685***	0.253	– 2.71	0.007
ΔMCS	– 0.049*	0.027	– 1.79	0.074
ΔPOPg	– 1.265	1.054	– 1.20	0.230
ΔTGGE	0.001*	0.005	1.79	0.074
ΔTOP	0.004	0.082	0.01	0.996
ΔYouth unemp	0.093	0.095	0.97	0.333
ΔLFPR	0.281	0.314	0.90	0.370
ECT (– 1)	– 1.454***	0.047	– 30.87	0.000

***P < 0.001; *P < 0.1

contribute to long-term economic expansion. This aligns with Tocar (2018), who argues that the impact of FDI on economic growth depends on factors such as economic freedom and the absorptive capacity of the host country. Similarly, a study on Gulf Cooperation Council countries found that while FDI can drive economic development, its effectiveness is influenced by macroeconomic and environmental factors (Alharthi et al. 2024). These findings suggest that the mere presence of FDI is insufficient; rather, the host country's economic environment plays a critical role in translating FDI into tangible growth.

Inflation has a coefficient of − 0.483, indicating a negative impact on GDP growth. This suggests that higher inflation reduces GDP growth by eroding purchasing power, creating economic uncertainty, and discouraging investment and consumption. This finding is consistent with research emphasizing the adverse effects of inflation on economic stability and growth (Adu-Gyamfi et al. 2020). The coefficient for mobile cellular subscriptions is − 0.034, suggesting a slight negative relationship with GDP growth, which may be linked to the costs or inefficiencies associated with expanding mobile infrastructure. Population growth has a coefficient of − 0.820, indicating that changes in population size do not significantly affect GDP growth in the long term.

Total greenhouse gas emissions have a coefficient of 0.007, suggesting a positive relationship with GDP growth. This may imply that higher emissions are associated with increased economic output, although the relationship is not strongly significant. This finding emphasizes the growth-environment trade-off, where economic expansion often leads to environmental degradation. Recent literature highlights the need for sustainable development practices to decouple economic growth from environmental harm (Alharthi et al. 2024). Trade openness has a coefficient of − 0.004, indicating no significant effect on GDP growth. This is notable, as traditional economic theories suggest that trade openness facilitates market access and efficiency. However, recent research indicates that the benefits of trade openness depend on complementary factors such as institutional quality and economic development levels (Saini and Singhania 2018). In some cases, without the necessary supporting structures, trade openness may not directly translate into economic growth. Youth unemployment and the labor force participation rate have coefficients of 0.063 and 0.223, respectively, indicating that these labor market factors do not significantly influence GDP growth in the long run. This finding aligns with research suggesting that labor market variables often have indirect effects on economic growth, potentially mediated through productivity and human capital development (Bajaj and Bhooshetty 2024).

In the short run, the coefficient for GDP growth is − 0.450, suggesting that past GDP growth negatively affects current GDP growth, indicating a tendency for growth to revert to its long-term mean. FDI has a coefficient of 0.002, showing no significant short-term impact on GDP growth. Inflation has a coefficient of − 0.685, reinforcing the long-run finding that higher inflation negatively affects GDP growth in the short run as well. The coefficient for MCS is − 0.049, suggesting a marginal negative short-term effect on GDP growth. The coefficient for population growth is − 1.265, indicating no significant short-term impact on GDP growth. Total greenhouse gas emissions have a coefficient of 0.001, suggesting a marginal positive short-term relationship with GDP growth. Trade openness has a coefficient of 0.004, indicating no significant short-term impact on GDP growth. Youth unemployment and LFPR have coefficients of 0.093 and 0.281, respectively, suggesting that these variables do not significantly influence GDP growth in the short term. The error correction term (ECT) has a coefficient of − 1.454, indicating a speed of adjustment of approximately 145.4%. This high speed of adjustment suggests that deviations from the long-run equilibrium are corrected rapidly, highlighting a strong tendency for the system to return to equilibrium after short-term shocks.

Figure 8a, b presents a summary of the long-run and short-run results from the CCEE-ARDL model estimates. In the long run, cyan pentagons represent positive effects, indicating that total greenhouse gas emissions contribute positively to GDP growth, while yellow-green squares denote negative effects, highlighting that inflation, mobile cellular subscriptions, and population growth negatively affect GDP growth. Pink hexagons indicate neutral or insignificant effects, showing that foreign direct investment, trade openness, youth unemployment, and labor force participation rate do

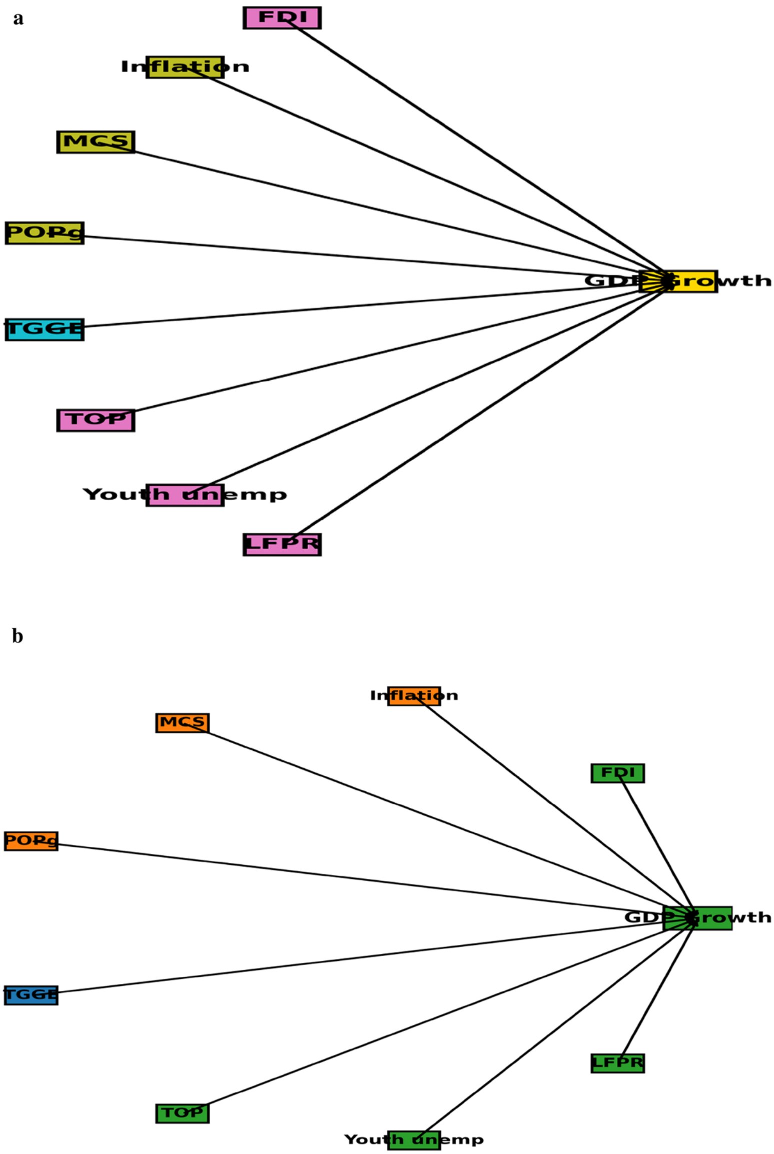

Fig. 8 **a** Long-run findings from the CCEE model. **b** Short run findings from the CCEE model

not significantly impact long-run GDP growth. In the short run, blue rectangles represent positive effects, again indicating that TGGE contributes positively to GDP growth, while orange rectangles denote negative effects, confirming that inflation, MCS, and Popg have adverse short-term impacts on GDP growth. Green rectangles indicate neutral or insignificant effects, showing that FDI, Top, youth unemployment, and LFPR do not significantly influence GDP growth in the short run.

The results in Table 11, which presents the PMG-ARDL estimated results, demonstrate how various variables influence GDP growth. In the long run, the coefficient for foreign direct investment is 0.008, suggesting a positive but statistically insignificant effect on GDP growth. This indicates that while FDI may have a slight positive relationship with economic growth, it is not strong enough to be considered impactful. This finding aligns with recent research suggesting that FDI alone does not guarantee economic growth; rather, complementary factors such as human capital and financial market development play a critical role in realizing its benefits (Vintila 2024; Ai-Jun et al. 2024; Vysochyna et al. 2024). Conversely, inflation has a coefficient of – 0.268, reflecting a significant negative effect on GDP growth. This suggests that higher inflation is associated with lower GDP growth, likely due to its adverse effects on economic stability and purchasing power. Recent studies highlight that rising inflation can depress GDP by causing banking sector losses, which in turn reduce lending and economic activity (Živkov et al. 2020; Lawton and Gallagher 2020; Özyılmaz 2022).

Table 11 PMG-ARDL estimated results. Source: Authors calculations

	Coefficient	Std. error	t-statistic	p-value
Long run				
FDI	0.008	0.006	1.260	0.208
Inflation	– 0.268***	0.066	– 4.018	0.000
MCS	– 0.016***	0.003	– 5.498	0.000
POPg	0.751***	0.266	2.824	0.005
TGGE	0.005***	0.001	2.838	0.005
TOP	0.027***	0.009	2.803	0.006
Youth unemp	– 0.026	0.020	– 1.320	0.188
LFPR	– 0.067**	0.031	– 2.128	0.034
Short run				
ECT (– 1)	– 1.081***	0.075	– 14.330	0.000
DFDI	0.042	0.084	0.496	0.620
Dinflation	0.128	0.126	1.021	0.308
DMCS	0.022	0.018	1.197	0.232
DPopg	– 1.194	1.167	– 0.713	0.476
DTGGE	0.004***	0.001	2.669	0.008
DTOP	0.265***	0.047	5.599	0.000
DYouth unemp	– 0.299***	0.057	– 5.179	0.000
DLFPR	0.673***	0.193	3.492	0.001
Constant	3.941***	0.607	6.491	0.000

****P* < *0.001, **P* < *0.05, *P* < *0.1;* AIC optimum lag selection (1,1,1,1,1,1,1,1)

Mobile cellular subscriptions show a coefficient of − 0.016, indicating a significant negative impact on GDP growth. This result is somewhat unexpected, as mobile connectivity is typically associated with enhanced communication and economic activity. However, in some cases, rapid increases in mobile subscriptions may not immediately translate into economic growth, possibly due to inadequate infrastructure or a lack of complementary workforce skills (Bayar et al. 2021; Simon 2016). In contrast, population growth has a coefficient of 0.751, suggesting a significant positive relationship with GDP growth. This implies that an increasing population contributes positively to economic growth, potentially through a larger labor force and expanded market size. This finding aligns with studies indicating that population growth can enhance total factor productivity growth (Weber and Sciubba 2019; Navarro Zapata et al. 2024).

Total greenhouse gas emissions have a coefficient of 0.005, indicating a significant positive relationship with GDP growth. This suggests that higher emissions, often linked to increased economic activity, correlate with GDP growth. This finding is consistent with the Environmental Kuznets Curve hypothesis, which suggests that environmental degradation initially rises with economic growth but later declines once a certain income threshold is reached. Trade openness has a coefficient of 0.027, suggesting a significant positive effect on GDP growth, implying that greater trade openness promotes economic expansion. This is in line with research indicating that trade openness enhances total factor productivity growth (Albahouth and Tahir 2024; Monyela and Saba 2024).

Meanwhile, youth unemployment has a coefficient of − 0.026, indicating no significant effect on GDP growth, while labor force participation rate has a coefficient of − 0.067, revealing a significant negative impact. This suggests that higher labor force participation may be linked to slower GDP growth, possibly due to structural inefficiencies in the labor market. This finding supports studies suggesting that labor market rigidities can lead to higher unemployment and weaker economic growth (Maestas et al. 2023; Nguyen and Nguyen 2018).

In the short run, changes in FDI have a coefficient of 0.042, indicating that short-term fluctuations in FDI have a minimal effect on GDP growth. Changes in inflation have a coefficient of 0.128, suggesting no significant short-term impact on GDP growth. Similarly, changes in MCS have a coefficient of 0.022, indicating no significant short-term effect on GDP growth. The coefficient for changes in population growth is − 1.194, also showing no significant short-term impact on GDP growth. Changes in total greenhouse gas emissions have a coefficient of 0.004, indicating a positive and significant short-term effect on GDP growth. In contrast, changes in trade openness have a coefficient of 0.265, reflecting a significant positive short-term impact on GDP growth. Changes in youth unemployment have a coefficient of − 0.299, indicating a significant negative short-term effect on GDP growth, while changes in LFPR have a coefficient of 0.673, reflecting a significant positive short-term effect on GDP growth. The error correction term (ECT) has a coefficient of − 1.081, indicating a speed of adjustment of approximately 108.1%. This suggests a strong and rapid correction of deviations from long-run equilibrium, demonstrating that the system quickly returns to its long-term balance after short-term disturbances.

Figure 9a, b presents a summary of the short-run and long-run effects of the variables based on the estimated PMG-ARDL model results. Green arrows represent positive short-run effects, indicating that foreign direct investment, inflation, mobile cellular subscriptions, total greenhouse gas emissions, trade openness, and labor force participation rate contribute positively to short-term economic growth. Red arrows denote negative short-run effects, highlighting that population growth and youth unemployment have adverse impacts on GDP growth in the short run. Blue arrows indicate positive long-run effects, showing

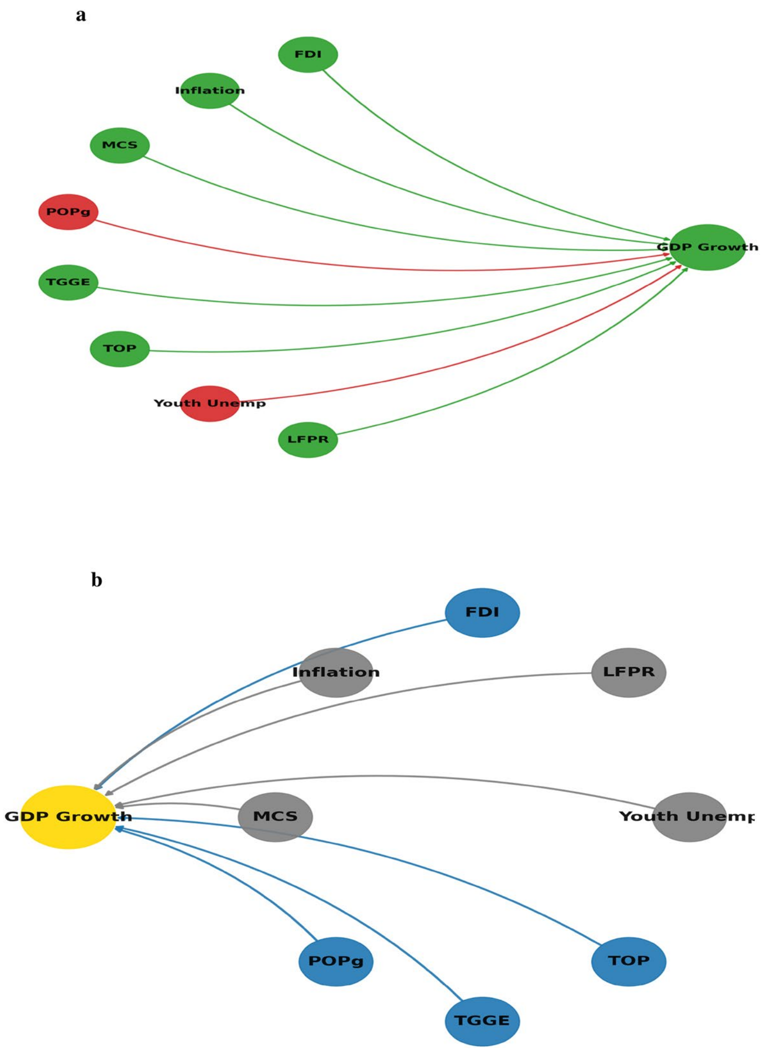

Fig. 9 **a** Short run findings from the PMG-ARDL. **b** Long-run findings from the PMG-ARDL

that FDI, Popg, TGGE, and TOP contribute positively to long-term economic growth. Gray arrows signify negative long-run effects, revealing that inflation, MCS, youth unemployment, and labor force participation rate have adverse impacts on GDP growth over the long term.

The results from the NARDL model in Table 12 illustrate the relationships between various economic variables and GDP growth. In the long run, an increase in foreign direct investment leads to a modest rise in GDP growth, with a coefficient of 0.007, indicating that foreign capital inflows have a positive but limited impact on economic performance. Conversely, a decline in FDI has a stronger negative effect on GDP growth, as shown by a coefficient of − 0.019. This suggests that while incoming FDI supports economic expansion, economies are more vulnerable to the adverse effects of FDI withdrawal, possibly due to reduced investment and productivity. Inflation exerts a significant and asymmetrical effect on GDP growth. Positive changes in inflation reduce GDP growth, as reflected by a coefficient of – 0.284, indicating that rising inflation weakens economic performance by eroding purchasing power, increasing uncertainty, and discouraging investment. Negative changes in inflation also dampen GDP growth, though to a lesser extent, with a coefficient of – 0.131. This suggests that while lower inflation alleviates some economic pressures, it may also signal weak demand or deflationary tendencies, which can hinder growth.

Mobile cellular subscriptions have a coefficient of – 0.015, indicating a negative impact on GDP growth. This suggests that the expansion of mobile technology does not necessarily translate into economic growth, potentially due to inefficiencies in its use or limited integration into productive sectors. The relationship between population growth and GDP growth is also asymmetrical. Positive changes in population growth have little effect on GDP growth, as indicated by a coefficient of – 0.007. However, negative changes in population growth significantly boost GDP growth, with a coefficient of 0.435. This suggests that a declining population may increase per capita income or that labor shortages drive higher productivity and wages for the remaining workforce.

The coefficient for total greenhouse gas emissions is 0.002, indicating no significant long-run effect on GDP growth. This suggests that while greenhouse gas emissions remain a critical environmental issue, they do not directly influence the economic growth trajectory of the studied economies. Trade openness has a positive long-run effect on GDP growth,

Table 12 PMG-NARDL estimated results. Source: Authors calculations

	Coefficient	Std. Error	t-statistic	p-value
Long run				
FDI_POS	0.007	0.008	0.891	0.373
FDI_NEG	0.019**	0.007	2.497	0.013
Inflation_POS	– 0.284***	0.062	– 4.547	0.000
Inflation_NEG	– 0.131***	0.032	– 4.001	0.000
MCS	– 0.015***	0.002	– 6.285	0.000
POPg_POS	– 0.007	0.155	– 0.046	0.962
POPg_NEG	0.435***	0.161	2.699	0.007
TGGE	0.002	0.001	0.095	0.924
TOP_POS	0.063***	0.011	5.313	0.000
TOP_NEG	0.035**	0.017	2.038	0.042
Youth_Unem	– 0.033***	0.009	– 3.752	0.000
LFPR	0.055***	0.020	2.663	0.008
Constant	– 0.308	1.333	– 0.231	0.817
Short run				
ECT (– 1)	– 1.1907***	0.054	– 21.968	0.000
D(FDI_NEG)	0.060	0.149	0.405	0.685
D(Inflation_POS)	0.579***	0.094	6.130	0.000
D(Inflation_NEG)	0.147	0.232	0.632	0.527
D(TGGE)	0.002	0.003	1.025	0.305
D(TOP_NEG)	0.428***	0.079	5.403	0.000
D(Youth_Unem)	– 0.332***	0.035	– 9.390	0.000
D(LFPR)	0.464**	0.204	2.269	0.023

***P < 0.001, **P < 0.05

with a coefficient of 0.063 for positive changes, reflecting the well-established notion that greater access to international markets facilitates economic expansion by improving efficiency, expanding market access, and enhancing technology transfer. Interestingly, negative changes in trade openness also contribute positively to GDP growth, with a coefficient of 0.035. This could reflect short-term protectionist benefits or domestic adjustments that temporarily stimulate growth when trade openness decreases. Youth unemployment has a significant negative effect on GDP growth, with a coefficient of − 0.033, emphasizing the need to address high youth unemployment, as it limits labor market participation and hinders long-term economic development and social stability. In contrast, a higher labor force participation rate supports economic growth, as indicated by a positive coefficient of 0.055, suggesting that greater workforce engagement enhances economic performance.

In the short run, positive inflation shocks have a strong positive effect on GDP growth, with a coefficient of 0.579, suggesting that inflation may initially stimulate nominal economic activity by encouraging consumption before further price increases occur. However, this effect is likely unsustainable in the long run. Similarly, negative changes in trade openness in the short run increase GDP growth, as indicated by a coefficient of 0.428, which may reflect temporary gains from protectionist policies. Meanwhile, youth unemployment continues to negatively impact GDP growth, with a coefficient of − 0.332, reinforcing its role as a constraint on economic expansion. Conversely, an increase in labor force participation contributes positively to short-term growth, as reflected in a coefficient of 0.464, indicating that higher workforce participation enhances economic output in the short run.

The error correction term (ECT) has a coefficient of − 1.1907, which measures the speed at which the system returns to long-run equilibrium after a short-run deviation. A coefficient of − 1.1907 suggests that approximately 119.07% of any short-run deviation from the long-run equilibrium is corrected within one period. This indicates a very fast adjustment process, where the system not only fully corrects deviations but also overshoots the equilibrium by an additional 19.07%.

Figure 10a, b presents a summary of the long-run and short-run effects of the variables based on the PMG-NARDL model estimates. Blue shapes represent positive long-run effects, indicating that foreign direct investment (negative component), population growth (negative component), trade openness (both positive and negative components), and labor force participation rate contribute positively to long-term economic growth. Orange shapes denote negative long-run effects, highlighting that inflation (both positive and negative components), mobile cellular subscriptions, and youth unemployment have adverse impacts on GDP growth. Green shapes indicate neutral effects, suggesting that total greenhouse gas emissions do not have a significant impact on GDP growth. In the short-run results, purple nodes represent positive effects, showing that inflation (positive component), trade openness (negative component), and labor force participation rate contribute positively to GDP growth. Pink nodes indicate negative short-run effects, highlighting that youth unemployment negatively impacts GDP growth. Brown nodes represent neutral or insignificant short-run effects, indicating that foreign direct investment (negative component), inflation (negative component), and total greenhouse gas emissions do not significantly influence short-run GDP growth.

4.6 Bound test

The results of the bounds test, presented in Tables 13, 14, assess the existence of a long-run relationship between GDP growth and the explanatory variables for each country. The

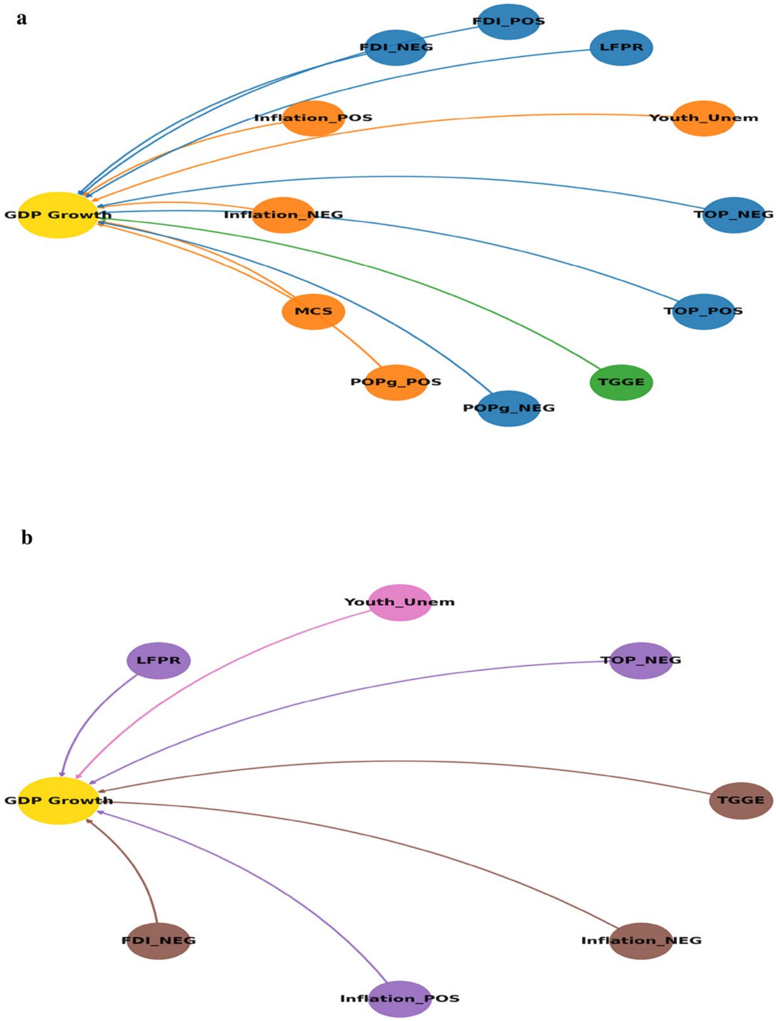

Fig. 10 **a** Long-run findings from the PMG-NARDL. **b** Short-run findings from the PMG-NARDL

F-statistics for each country are compared against the critical values for the lower bound I (0) and upper bound I (1) at various significance levels, helping to determine whether cointegration exists among the variables. The key principle behind the bounds test is that if the F-statistic exceeds the upper bound value I (1), it provides evidence of cointegration. For the countries in this sample, the F-statistics consistently exceed the upper bound values at the 1%, 5%, and 10% significance levels, strongly suggesting the presence of cointegration in most cases. Specifically, the F-statistics for Austria (6.549), Belgium (9.706), Denmark (9.351), Finland (14.829), France (13.492), Germany (20.002), Italy (23.926), Portugal (15.172), Spain (7.898), and Sweden (42.380) are all significantly above the highest critical value for the upper bound, which is 3.610 at the 1% significance level. This confirms the presence of a long-run equilibrium relationship between GDP growth and the explanatory variables for these countries. However, for the Netherlands, the F-statistic is 4.524. While

Table 13 Bound test results. Source: Authors calculations

Cross-section	Observation	F-Statistic
Austria	31	6.549
Belgium	31	9.706
Denmark	31	9.350
Finland	31	14.829
France	31	13.492
Germany	31	20.002
Italy	31	23.926
Netherlands	31	4.524
Portugal	31	15.172
Spain	31	7.898
Sweden	31	42.380

Table 14 Bound test critical values. Source: Authors calculations

10%			5%		1%	
Sample size	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
30	2.277	3.498	2.730	4.163	3.864	5.695
35	2.196	3.370	2.597	2.598	3.599	5.230
Asymptotic	1.760	2.770	1.980	3.040	2.410	3.610

this value exceeds the upper bound at the 10% and 5% significance levels, it is closer to the critical value at the 1% level. This suggests that evidence for a long-run relationship in the Netherlands is weaker compared to the other countries in the sample.

4.7 Robustness estimation

The results presented in Table 15 provide robustness estimations using both the Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) methods. For foreign direct investment, the FMOLS coefficient is 0.039, suggesting a positive impact on GDP growth, while the DOLS coefficient is only 0.001. This discrepancy indicates that the effect of FDI may not be robust or significant across different estimation methods. Regarding inflation, the coefficients are − 0.081 for FMOLS and − 0.262 for DOLS, neither of which is statistically significant. This suggests that inflation does not have a clear or consistent effect on GDP growth in either estimation method. Mobile cellular subscriptions exhibit a significant FMOLS coefficient of − 0.030, indicating a negative impact on GDP growth. However, the DOLS coefficient of − 0.014 is not significant, suggesting that the negative effect of MCS may not be consistent across different approaches. For population growth, the coefficients are 0.325 in FMOLS and 1.347 in DOLS, but neither is statistically significant. This implies that population growth does not have a consistent impact on GDP growth in the long term.

For total greenhouse gas emissions, the coefficients are 0.004 in FMOLS and 0.003 in DOLS, both of which are insignificant, indicating that emissions do not have a substantial effect on GDP growth. In contrast, trade openness has a coefficient of 0.090 in FMOLS, which is statistically significant, suggesting a positive effect on GDP growth. However, the DOLS coefficient of 0.017 is not significant, implying that the positive impact of trade openness is not consistently observed across different estimation methods. Lastly, youth unemployment has coefficients of − 0.038 in FMOLS and − 0.029 in DOLS, neither of which is statistically significant. This indicates that youth unemployment does not consistently affect GDP growth. Similarly, the labor force participation rate has coefficients of − 0.049 in FMOLS and − 0.032 in DOLS, both of which are insignificant, suggesting that LFPR does not have a significant impact on GDP growth.

4.8 Stability diagnostic

T The stability of the estimated ARDL model was assessed using recursive CUSUM and CUSUMSQ tests, which are widely recognized for evaluating the reliability and consistency of estimated models over time. The results of these tests, illustrated in Fig. 11a, b, compare the test statistics to a predetermined threshold, typically set at 5% significance (Borensztein et al. 1998). When the lines representing the test, statistics remain within this threshold, it indicates that the estimated model is stable and consistent throughout the study period. The findings from these recursive tests confirm the stability and reliability of the estimated model, as the lines consistently remain within the 5% threshold.

4.9 Panel causality

The results from the Dumitrescu–Hurlin Panel Causality test, presented in Table 16, provide insights into the direction of causality between variables. The findings indicate no clear relationship between foreign direct investment and GDP, suggesting that changes in foreign investment do not drive economic growth, nor does GDP significantly attract FDI. Conversely, inflation and GDP exhibit a bidirectional relationship, meaning that inflation influences economic growth, and economic growth, in turn, impacts inflation. Mobile cellular subscriptions positively influence GDP, yet GDP does not significantly drive mobile subscriptions. Additionally, GDP affects population growth and greenhouse gas emissions, suggesting that economic growth leads to higher population levels and increased emissions, while the reverse is not observed. There is a bidirectional relationship between trade

Table 15 Robustness estimated results. Source: Authors calculations

Variable	FMOLS			DOLS		
	Coefficient	Std.Error	p-value	Coefficient	Std.Error	p-value
FDI	0.039***	0.013	0.002	0.001	0.038	0.976
Inflation	− 0.081	0.077	0.296	− 0.262	0.298	0.383
MCS	− 0.030***	0.004	0.000	− 0.014	0.011	0.209
POPg	0.325	0.374	0.385	1.347	1.464	0.149
TGGE	0.004	0.002	0.112	0.003	0.007	0.567
TOP	0.090***	0.014	0.000	0.017	0.046	0.705
Youth unemp	− 0.038	0.023	0.108	− 0.029	0.065	0.653
LFPR	− 0.049	0.046	0.287	− 0.032	0.103	0.752

***P < 0.001

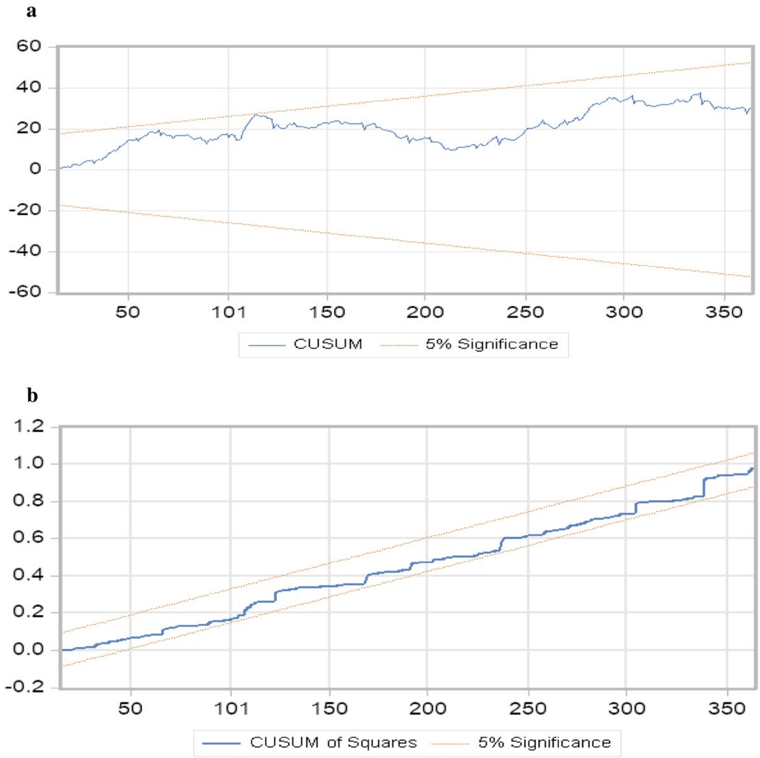

Fig. 11 **a** Cumulative sum of recursive residuals. **b** Cumulative sum of squares of recursive residuals

openness and GDP, indicating that economic growth encourages greater trade activity, and increased trade further stimulates economic expansion. However, no significant relationship is found between labor force participation and GDP.

The results also reveal that youth unemployment and GDP influence each other, implying that economic growth reduces youth unemployment, while youth unemployment, in turn, affects overall economic performance. Inflation influences FDI, but FDI does not significantly impact inflation. Notably, an increase in mobile subscriptions attracts foreign investment, whereas population growth, emissions, and trade openness do not significantly influence FDI. Interestingly, LFPR appears to attract FDI, while FDI contributes to reducing youth unemployment. The relationship between inflation and mobile subscriptions is bidirectional, meaning that inflation can reduce demand for mobile technology, while advancements in mobile communication impact the economy. Furthermore, inflation influences population growth, but population growth does not significantly affect inflation. A unidirectional causality exists from inflation to total greenhouse gas emissions, suggesting that inflationary pressures may impact environmental outcomes through changes in production costs or energy prices. Similarly, inflation affects trade openness, but trade openness does not significantly impact inflation, indicating that inflation shapes a country's trading capabilities without being substantially influenced by trade activity.

A bidirectional relationship is observed between LFPR and inflation, indicating that changes in inflation may affect labor force participation through shifts in wages and employment incentives, while labor market dynamics influence inflation via labor costs. Additionally, youth unemployment is influenced by inflation, but inflation does not respond to youth unemployment. A unidirectional relationship exists from mobile cellular subscriptions to population growth, suggesting that advancements in mobile technology drive demographic changes, likely by improving communication and access to services. Mobile subscriptions also affect greenhouse gas emissions, highlighting the environmental impact of expanding mobile infrastructure. Additionally, mobile technology influences trade openness, LFPR, and youth unemployment, illustrating its broader economic significance.

For TGGE and population growth, causality flows from TGGE to population growth, implying that changes in emissions drive environmental conditions without significant feedback from population growth. Trade openness affects population growth, while LFPR exhibits a bidirectional relationship with population growth, indicating mutual interactions between labor market dynamics and demographic trends. There is also bidirectional causality between trade openness and TGGE, suggesting that higher trade activity may contribute to increased emissions, while environmental concerns could influence trade policies. Similarly, LFPR and TGGE share a bidirectional relationship, implying that labor market conditions and environmental factors mutually impact each other.

No significant relationship is found between TGGE and youth unemployment, indicating that emissions do not directly drive youth unemployment levels. Lastly, trade openness influences LFPR, youth unemployment, and TGGE, but there is no evidence of the reverse relationship. Additionally, LFPR affects youth unemployment, suggesting that higher labor force participation reduces youth unemployment, whereas youth unemployment does not significantly influence LFPR.

5 Conclusion and policy implementation

This study assesses economic recovery and resilience in the post-pandemic period across eleven European Union member states. Utilizing annual time series data from 1990 to 2022, the analysis employs several econometric methods, including the Pooled Mean Group (PMG) estimator, Nonlinear Autoregressive Distributed Lag (NARDL) model, and Common Correlated Effects Estimator (CCEE) approach. The long-run results from the CCEE estimation reveal that inflation and mobile cellular subscriptions negatively affect economic growth, while total greenhouse gas emissions have a positive impact. Notably, no significant long-run effects are observed from youth unemployment, labor force participation rate, trade openness, population growth, or foreign direct investment. In the short run, the CCEE results confirm that inflation and mobile subscriptions continue to negatively impact growth, while greenhouse gas emissions contribute positively.

The PMG long-run estimates further validate that inflation, mobile cellular subscriptions, and labor force participation rates negatively influence growth, whereas population growth, greenhouse gas emissions, and trade openness positively contribute to economic performance. No significant long-run effects are found for FDI or youth unemployment. In the short run, trade openness, greenhouse gas emissions, and labor force participation positively influence growth, while youth unemployment has a negative effect. No short-run effects are detected for inflation, mobile cellular subscriptions, or FDI. The NARDL long-run findings highlight asymmetric effects of FDI, inflation, population growth, and trade openness across the selected EU countries, alongside short-run asymmetric effects from inflation and trade openness.

Table 16 Pairwise Dumitrescu Hurlin panel causality test results. Source: Authors calculations

Null hypothesis	W-Stat	p-value	Conclusion
FDI ≠ GDP	2.523	0.615	
GDP ≠ FDI	1.632	0.451	None
inflation ≠ GDP	6.126	0.000	
GDP ≠ inflation	9.929	0.000	Bidirectional
MCS ≠ GDP	4.940	0.000	
GDP ≠ MCS	1.226	0.675	Unidirectional
Popg ≠ GDP	2.341	0.805	
GDP ≠ Popg	9.769	0.000	Unidirectional
TGGE ≠ GDP	2.076	0.899	
GDP ≠ TGGE	4.192	0.004	Unidirectional
Top ≠ GDP	4.112	0.006	
GDP ≠ Top	11.906	0.000	Bidirectional
LFPR ≠ GDP	2.114	0.941	
GDP ≠ LFPR	2.370	0.774	None
Youth unem ≠ GDP	5.263	0.000	
GDP ≠ Youth unem	4.202	0.004	Bidirectional
Inflation ≠ FDI	3.792	0.022	
FDI ≠ inflation	2.450	0.686	Unidirectional
MCS ≠ FDI	3.669	0.034	
FDI ≠ MCS	1.389	0.274	Unidirectional
Popg ≠ FDI	2.193	0.970	
FDI ≠ Popg	2.405	0.734	None
TGGE ≠ FDI	1.793	0.599	
FDI ≠ TGGE	2.005	0.821	None
Top ≠ FDI	1.645	0.463	
FDI ≠ Top	3.284	0.116	None
LFPR ≠ FDI	3.711	0.029	
FDI ≠ LFPR	1.592	0.418	Unidirectional
Youth unem ≠ FDI	3.261	0.294	
FDI ≠ Youth unem	3.715	0.029	Unidirectional
MCS ≠ Inflation	0.543	0.022	
Inflation ≠ MCS	5.821	0.000	Bidirectional
Popg ≠ inflation	3.031	0.222	
inflation ≠ Popg	3.484	0.063	Unidirectional
TGGE ≠ inflation	2.815	0.361	
Inflation ≠ TGGE	3.847	0.017	Unidirectional
Top ≠ inflation	1.495	0.344	
Inflation ≠ top	5.682	0.000	Unidirectional
LFPR ≠ inflation	4.214	0.004	
Inflation ≠ LFPR	3.637	0.038	Bidirectional
Youth unem ≠ inflation	1.434	0.303	
inflation ≠ Youth unem	3.829	0.019	Unidirectional
Popg ≠ MCS	3.006	0.237	
MCS ≠ Popg	6.750	0.000	Unidirectional
TGGE ≠ MCS	2.390	0.752	
MCS ≠ TGGE	5.272	0.000	Unidirectional

Table 16 (continued)

Null hypothesis	W-Stat	p-value	Conclusion
Top ≠ MCS	3.909	0.013	
MCS ≠ Top	2.398	0.744	Unidirectional
LFPR ≠ MCS	3.208	0.142	
MCS ≠ LFPR	4.684	0.000	Unidirectional
Youth unem ≠ MCS	2.531	0.608	
MCS ≠ Youth unem	4.684	0.000	Unidirectional
TGGE ≠ Popg	5.029	0.000	
Popg ≠ TGGE	3.066	0.205	Unidirectional
Top ≠ Popg	4.211	0.004	
Popg ≠ Top	2.490	0.648	Unidirectional
LFPR ≠ Popg	5.947	0.000	
Popg ≠ LFPR	4.804	0.000	Bidirectional
Youth unem ≠ Popg	4.983	0.000	
Popg ≠ Youth unem	2.579	0.561	Unidirectional
Top ≠ TGGE	5.909	0.000	
TGGE ≠ Top	3.801	0.021	Bidirectional
LFPR ≠ TGGE	4.138	0.006	
TGEE ≠ LFPR	6.007	0.000	Bidirectional
Youth unem ≠ TGGE	3.114	0.182	
TGGE ≠ Youth unem	1.882	0.689	None
LFPR ≠ Top	2.879	0.315	
Top ≠ LFPR	5.535	0.000	Unidirectional
Youth unem ≠ Top	3.898	0.015	
Top ≠ Youth unem	2.544	0.595	Unidirectional
Youth unem ≠ LFPR	4.754	0.000	
LFPR ≠ Youth unem	3.131	0.174	Unidirectional

The Dumitrescu–Hurlin Panel Causality test establishes several relationships among the variables. A bidirectional relationship exists between inflation, trade openness, youth unemployment, and GDP growth. Additionally, unidirectional relationships are found between mobile cellular subscriptions, greenhouse gas emissions, population growth, and GDP growth. However, no causal relationship is identified between FDI, labor force participation rate, and GDP growth.

Based on these findings, several targeted policy recommendations are proposed to strengthen economic recovery and resilience in post-pandemic Europe. First, the negative impact of inflation on economic growth in both the short and long run indicating the need for policymakers to maintain price stability. This may involve implementing sound monetary policies, such as adjusting interest rates and promoting fiscal responsibility to mitigate inflationary pressures. Additionally, enhancing supply chain efficiencies and reducing production costs should be prioritized to maintain stable inflation levels. The negative relationship between mobile cellular subscriptions and economic growth suggests that over-reliance on mobile technologies without corresponding infrastructure investments may hinder productivity. Policymakers should improve the quality and efficiency of digital infrastructure and ensure that digitalization strategies align with productivity gains rather than relying solely on technology expansion.

While the positive influence of total greenhouse gas emissions on growth may seem counterintuitive from a sustainability perspective, it highlights that industrial activities associated with emissions have contributed to short-term economic recovery. Policymakers should promote sustainable growth through investments in renewable energy and cleaner technologies, ensuring that economic expansion aligns with climate goals without compromising long-term sustainability. The positive long-run effects of population growth and trade openness suggest that stimulating labor market participation and fostering international trade should be a priority. Policies to increase workforce participation, particularly among young people and women, through training and upskilling programs, can drive long-term economic growth. Additionally, trade openness should be promoted through regional and global trade agreements while ensuring resilience against external shocks. Population growth policies should incorporate immigration reforms and family-friendly measures to support demographic expansion without straining economic resources.

The asymmetric effect of FDI on economic growth indicates that while FDI can be beneficial, its impact is inconsistent. Therefore, policymakers should focus on attracting high-quality FDI that fosters innovation, job creation, and domestic industry development. This can be achieved through clear legal frameworks, reduced bureaucratic barriers, and an improved business environment that attracts meaningful and sustainable investment. Finally, the significant negative impact of youth unemployment on economic growth, particularly in the short run, highlights the need for targeted employment policies. Governments should implement vocational training programs, apprenticeships, and incentives for businesses to hire young workers. Aligning education systems with labor market demands will also help reduce youth unemployment and support economic stability.

By adopting these policies, European economies can not only recover from the pandemic but also build resilience against future economic shocks, fostering sustainable and inclusive economic growth.

5.1 Limitations of the study

A key limitation of this study is its reliance on annual time series data from 1995 to 2022, which may not fully capture the rapidly evolving dynamics of the post-pandemic economic environment. Additionally, the analysis is limited to eleven European Union member states, meaning the findings may not be fully generalizable to other EU countries or regions with different economic structures. Furthermore, this study focuses on a specific set of economic variables, potentially overlooking other important factors such as innovation, political stability, or sector-specific impacts that could influence post-pandemic recovery and resilience.

For future research, expanding the scope to include a broader set of countries would enhance the generalizability of the findings. Additionally, incorporating more recent and higher-frequency data, such as quarterly or monthly observations, could provide a more detailed assessment of the ongoing effects of the pandemic. Future studies could also explore other critical factors, including innovation, government policies, and sector-specific dynamics, which were not addressed in this study. Further research on the role of digital transformation and sustainability in economic recovery would offer valuable insights into long-term resilience strategies.

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Data availability Data will be made available upon request from the corresponding author.

Declarations

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