

The Role of Information and Communication Technology and CO₂ Emissions in Economic Growth: Empirical Evidence from Central and Eastern Europe

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Summary: This study aims to investigate the cointegration and causality relationship between economic growth, environmental pollution, information and communication technology and financial development in Central and Eastern European countries for the period 1996 to 2018. For this purpose, Banerjee and Carrion-i-Silvestre's (2017) cointegration test and Emirmahmutoglu and Köse's (2011) causality test were used. In the empirical results obtained, there is a cointegration relationship between the variables. According to the causality analysis results, economic growth is the cause of information and communication technology growth, and of environmental pollution.. In addition, bidirectional causality was found between economic growth and financial development, and between environmental pollution and financial development. Information and communication technology has a significant impact on CO₂ emissions and economic growth. From the results, it is recommended that investments in information and communication technology infrastructure be increased. The policy proposal is given in the conclusion part of the study.

Keywords: Economic growth, Environmental pollution, Information and communication technology, Financial development, Central and Eastern Europe

JEL: C33, E44, O30

1. Introduction

Economic growth, which is the basis of development, leads to increased welfare. Investments in information and communication technology (ICT) increase economic growth. ICT has significantly changed communication patterns and business relations, which are actively driving the rapid transformation of societies. This concept, which drives technological advancement, is directly related to economic growth (Steinmueller, 2001; Fong, 2009; World Bank, 2017; Niebel, 2018; Adeleye and Eboagu, 2019). The economic growth-accelerating aspect of ICT has been determined empirically. (Farhadi et al., 2012; Bhujabal and Sethi, 2020; Jing and Ab-Rahim, 2020; Usman et al., 2021).

Many policymakers and economists are currently working on measures to reduce environmental pollution. In this way, they aim to increase the health of people and accelerate economic growth simultaneously. The main cause of environmental degradation is CO₂ emissions. CO₂ emissions not only create environmental pollution but also threaten human health (Shahzad et al., 2020).

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Following King and Levine's (1993) article, various empirical studies have examined the relationship between financial development and economic growth (Hassan et al., 2011; Deltuvaite and Sineviciene, 2014; Nguyen et al., 2022; Asteriou et al., 2024). Financial development has played a crucial role in the economic growth of many countries (Dhingra, 2023). Economies are expected to be positively affected by financial development as it leads to increased productivity and capital accumulation (Rioja and Valev, 2024; Zagorchev et al., 2011).

This study aims to investigate the relationship between GDP, environmental pollution, ICT, and financial development. The contribution of the study to the literature is made by analyzing the data range and countries used in the study with empirical methods. From these inferences, this study reveals the role of ICT on growth in Central and Eastern European countries, and is an example for future studies. It aims to increase the reliability of the estimates by using current econometric methods. Based on the empirical findings, the political suggestions are given in detail in the conclusion. By considering the political suggestions of these countries, an increase in the welfare levels may occur.

2. Literature Review

The literature review is divided into two parts: theoretical background and empirical studies.

2.1. Empirical Studies

The relationship between ICT, economic growth, financial development and environmental pollution has recently attracted the attention of researchers. While some studies in the literature have examined the relationship between ICT and GDP, others have investigated the relationship between foreign direct investment (FDI), ICT and GDP. In some studies, the relationship between environmental pollution, ICT and GDP has been examined. The literature review has been based on this.

The first group of studies examine the relationship between ICT and economic growth for European countries. In a study conducted for Central and Eastern Europe (CEE) countries, Arendt (2015) determined that ICT has a significant effect on economic growth. Laitsou et al. (2020) examined the relationship between ICT and economic growth by emphasizing the periods of economic crises in Europe. They focused on the role of ICT in the economic system that deteriorated due to the effects of economic crises and emphasized its importance in economic recovery. Pradhan et al. (2020) examined 25 European economies and determined that ICT and innovation have significant effects on economic growth. In another study conducted for European countries, Dubyna et al. (2022) investigated the period from 2010 to 2019. In the findings, they concluded that ICT played a key role in economic development. There are also similar articles in the literature that have yielded similar results (Toader et al., 2018; Fernández-Portillo et al., 2020).

In one of the studies examining the relationship between GDP and ICT, Yousefi (2011) analyzed it across 62 countries for the period 2000 to 2006. They found that

ICT significantly affected GDP in high- and upper-middle-income countries, but did not in lower-middle-income countries. In another study, Farhadi et al. (2012) investigated the relationship between ICT and GDP across 159 countries from 2000 to 2009. The findings indicate that ICT has a positive effect on real GDP. They also found that it increased real GDP more in the high-income country group than in the other country group. Aghaei and Rezagholizadeh (2017) analyzed the relationship between ICT and GDP of the Organization of Islamic Conference countries. From their empirical results, they concluded that ICT significantly increased GDP.

In a study conducted across different country groups, Majeed and Ayub (2018) used data from 1980 to 2015. Analysis results from OLS, 2SLS and GMM showed that ICT has a positive effect on GDP. Bahrini and Qaffas (2019) analyzed the MENA and SSA regions' countries for the period 2007–2016 and found that ICT positively affected GDP using the GMM method. In addition, fixed phones have been found to negatively affect GDP. In this, it can be said that these country groups cannot use the potential of ICT with fixed phones. In another study of SSA countries, Lee et al. (2012) surveyed 44 countries. The findings showed that mobile phone penetration increased GDP in Sub-Saharan African countries. David and Grobler (2020), who investigated the relationship between ICT and GDP in African countries, determined in empirical findings that mobile telecommunications is growing faster than other telecommunications. In addition, it has been concluded that ICT has a positive effect on GDP. In another study, Jing and Ab-Rahim (2020) analyzed the relationship between ICT and GDP using POLS and GMM techniques using data from five ASEAN countries for the period 2003 to 2018. According to the findings, ICT increases GDP. They also found that fixed telephone line subscription was the ICT component that increased GDP the fastest. Usman et al. (2021) analyzed the relationship between ICT and GDP using South Asian economies' data from 1990 to 2018. The findings show that ICT has a positive effect on GDP in India. In another study on Asia, Sharma et al. (2020) surveyed ten Asian countries over the period 2000–2017. The relationship between cointegration and causality was examined in the study, where they used ICT, energy consumption and GDP variables. Westerlund (2007) found a cointegration relationship in the model in the cointegration analysis. He also concluded that ICT has a positive effect on GDP. In Dumitrescu and Hurlin's (2012) causality test results, there is a bidirectional causality relationship between ICT, energy consumption and GDP. Appiah-Otoo and Song (2021) examined 123 countries in three groups according to income level. The period 2002–2017 was used in this article, which is based on a panel data study. In the empirical study, ICT increases GDP in high-income, middle-income and low-income countries.

Several studies in the literature have investigated the relationship between ICT, FDI and GDP. One of these studies, Dimelis and Papaioannou (2010), analyzed 42 countries for the 1993–2001 period using the GMM estimator. The findings indicate that ICT affects and significantly increases GDP in developed and developing countries. However, it was found that FDI has a negligible effect on GDP. Sassi and Goaid (2013) investigated MENA countries for the period 1960–2009. They used the GMM estimator, and in their panel data analysis and concluded that FDI harmed GDP, while ICT had a positive impact on GDP. In addition, in the third finding of their study,

they determined that the interaction between ICT and FDI would positively affect growth regression. Yazdan and Hossein (2013) analyzed Middle East countries for the period 1990–2010. According to the results, with the help of the GMM estimator, it was determined that ICT and FDI had a limited effect on GDP. In addition, it was concluded that ICT had a significant and positive effect on GDP, while FDI had a significant and positive effect on GDP. Bhujabal and Sethi (2020) examined the relationship between ICT, GDP and FDI for the South Asian Association for Regional Cooperation countries. Cointegration and causality relations were investigated by using the data from 2000 to 2017. According to the findings, a cointegration relationship was found. In the causality analysis results, it was determined that FDI was the causative agent of ICT, and GDP was the causative agent of FDI. In another study, Sapuan and Roly (2021) analyzed eight ASEAN countries over the period 2003–2017. In the results they obtained, using panel data methods, they concluded that ICT and FDI should be disseminated. In addition, these variables had a positive effect on GDP in the long run. Nayak and Sahoo (2021) investigated the relationship between ICT, FDI and GDP for the period 1991–2019 in India. The empirical findings concluded that ICT and FDI had an increasing effect on India's economic performance. They also determined that the 2007–2008 crisis harmed the country's economy. Sinha and Sengupta (2022) analyzed the Asia-Pacific countries for the period 2001–2017. Using panel data methods, it was determined that FDI and ICT had a significant and positive effect on GDP. Belloumi and Touati (2022) researched 15 Arab countries for the period 1995–2019. The analysis using the panel ARDL method found that ICT and FDI had a statistically significant and positive effect on GDP in the long term. In addition, it was determined that ICT indicators had a positive contribution to FDI in the long term.

In studies examining the relationship between environmental pollution, ICT and GDP, Salahuddin et al. (2016) analyzed Australia for the period 1985 to 2012, using ARDL bounds testing and causality testing methods, to examine the relationship between environmental pollution, GDP and internet use. They could not detect a long-term relationship between internet use and CO₂ emissions. The results of the causality analysis indicated that CO₂ emissions were causal to internet use, while internet use was causal to GDP. Higón et al. (2018) found a U-shaped relationship in a study in which they analyzed the relationship between ICT and CO₂ emissions in 142 countries. In another study, Lu (2018) analyzed the impact of ICT and economic growth on environmental pollution in 12 Asian countries for the period 1993 to 2013 by cointegration and causality testing. According to the findings, a cointegration relationship was identified, and it was concluded that GDP increased environmental pollution, whereas ICT reduced it. According to the causality analysis result, GDP was the causative agent of environmental pollution, environmental pollution was the causative agent of ICT, and GDP was the causative agent of ICT. Park et al. (2018) examined EU countries for the period 2001–2014. They used a panel data estimator in their study, in which they investigated the effect of ICT, FDI and GDP on CO₂ emissions. In the obtained findings, they determined that ICT has a reducing effect on CO₂ emissions. They also estimated that GDP and FDI harm CO₂ emissions. In heterogeneous Granger causality test results, ICT was causal for CO₂ emissions.

Tsaurai and Chimbo (2019) examined the cointegration relationship between ICT and environmental pollution using emerging markets data from 1994 to 2014. In the findings, they determined the cointegration relationship between the variables. They also determined that ICT is an element that increases environmental pollution.

In their research on the G7 countries, Raheem et al. (2020) examined the relationships between ICT, GDP, and environmental pollution. Using the period from 1990 to 2014, in which there is a cointegration relationship, they concluded that ICT increased environmental pollution. Godil et al. (2020) investigated the relationship between GDP, ICT, and environmental pollution in Pakistan for the period 1995 to 2018. In the empirical results of the study using the QARDL method, they concluded that ICT had a long-term reducing effect on environmental pollution. It was determined that increased ICT would reduce carbon emissions. In another study, Magazzino et al. (2021) researched 25 OECD countries for the period 1990–2017. In their studies, ICT, GDP, and CO₂ emissions variables were used. In the findings, ICT had a positive effect on GDP. It also increased the electricity consumption of ICT. Therefore, CO₂ emissions would also increase in OECD countries. Razzaq et al. (2021) investigated the relationship between environmental pollution, GDP, and technology innovation by considering the period of 1995 to 2017 in China. According to the empirical results obtained, they found that GDP was the causative agent of environmental pollution, and that there was a bidirectional causality relationship between technological innovation and environmental pollution.

2.2. Theoretical Background

ICT is one of the most basic elements that ensures the rapid flow of information in the globalizing world. The fact that information is extremely important brings investments in ICT. It is inevitable that ICT, which is one of the determinants of rapidly increasing global economic growth, will become an extremely strategic concept. Countries and companies that realize this are increasing their interest in ICT. They provide a competitive advantage by enabling countries to access information more easily and accurately with ICT. The basic element for this is to make the right investments at the right time. Although ICT investments are costly and difficult at first, their returns can be high in the medium and long term. For this reason, countries should offer the necessary incentives to domestic and foreign investors while making their ICT investments.

ICT has changed people's lives since the 1990s. It has brought societies together by diminishing the importance of countries' geographical borders. In this way, FDI and international trade have increased rapidly. Thus, income has increased, unemployment decreased, productivity increased, costs decreased, and economic growth increased (Haftu, 2019; Ahmed and Le, 2021; Ahmed et al., 2021). Behind the increase in investments in ICT, there has been a significant decrease in company costs (communication, coordination, etc.). ICT has increased productivity by creating more efficient production. ICT investments, which include physical capital, such as communication equipment, and intangible capital, such as software, directly affect national growth by increasing productivity. The increasing role of ICT in supply-side

productivity has also increased national welfare (van Ark and Gupta, 2011; Erumban and Das, 2016). ICT can be considered to be part of the digital economy. In sustainable development, it has both direct and indirect effects (Skvarciany and Jurevičienė, 2022). The widespread use of knowledge and technology transfer increases foreign direct investment, which provides many benefits to a country's economy (Josifidis et al., 2021).

ICT has become part of economic phenomena in many sectors, including domestic and international trade, public services, health, and entertainment. By ICT working in coordination with economic activities, innovation can be fostered, contributing to the reduction of poverty. ICT can have an impact at both the firm level and on the wider economy, leading to growth in both areas. In recent years, industries have invested heavily in ICT, increasing their competitiveness at the national and international level (Yousefi, 2011).

Many policymakers and economists are currently working on measures to reduce environmental pollution. In this way, they aim to increase the health of people and to simultaneously accelerate economic growth. The main cause of environmental degradation is CO₂ emissions. CO₂ emissions not only destroy environmental pollution but also threaten human health (Shahzad et al., 2020). CO₂ emissions are released into the atmosphere as a result of burning fossil fuels. With rising CO₂ emissions, climate change occurs. The major effects include rising sea levels rising due to melting glaciers and droughts. These may give rise to health concerns. Scientists continue to work to reduce environmentally degrading CO₂ emissions without reducing economic growth (Abdoulou and Hammami, 2017; Usman et al., 2021).

As a summary of the literature review and the theoretical background, the following can be stated: a) ICT has a significant impact on the level of development and economic growth of countries; b) estimates of the direction of causality between ICT and economic growth are not unified, with findings varying from country to country; c) evidence on the relationship between ICT and environmental degradation is mixed; d) economic growth has an increasing effect on environmental degradation.

3. Data and Methodology

There are three research methods: quantitative, qualitative and mixed methods. These methods are applied after considering the purpose of the research. In this study, the effects of variables on GDP and CO₂ emissions are examined, so the quantitative research approach is best suited. The main reason for using this research method is to analyze the obtained data with the help of statistical, mathematical, and computational techniques. In this approach, statistical software is used to conduct empirical analyses and to obtain accurate results (Alheet and Hamdan, 2020).

3.1. Data

In this study, economic growth (GDP), carbon dioxide (CO₂), ICT and financial development (FD) data of 17 CEE countries were used for the period 1996 to 2018. The data period covered these years, as some countries' data for ICT was not available

after 1996, and CO₂ emissions data was available only until 2018. The data covered GDP, per capita annual growth (%); CO₂, metric tons per capita; ICT, individuals using the internet (% of population) and representing people who had connected to the internet in the previous three months; and FD, related to the financial development index. GDP, CO₂, and ICT data was obtained from the World Bank database, and FD data was obtained from the International Monetary Fund database.

While developing the econometric models used in the study, extensive literature research and studies by Raheem et al. (2020), Lee and Brahmairene (2014), and Kim (2022) were utilized. The econometric methods used in the study are presented below:

$$\text{MODEL-1: } GDP_{it} = \gamma_1 + \beta_{1i}ICT_{it} + \beta_{2i}CO2_{it} + \beta_{3i}FD_{it} + \varepsilon_{it} \quad (1)$$

$$\text{MODEL-2: } CO2_{it} = \gamma_2 + \beta_{4i}ICT_{it} + \beta_{5i}GDP_{it} + \beta_{6i}FD + \varepsilon_{it} \quad (2)$$

where $i=1, 2, \dots, N$ is the number of countries in the panel; $t=1, 2, \dots, T$ time; ε stands for the error term; GDP, economic growth; ICT, information and communication technology; CO₂, environmental degradation; FD, financial development.

3.2. Methodology

Our analysis aimed to predict the cointegration relationship in the models and the causality relationship between the variables. Panel data methods were used in the study. In the first part of the empirical analysis, the cross-sectional dependence among the variables was determined. Based on the findings, the panel unit root and cointegration test were chosen. In this way, the results obtained would be more consistent.

3.2.1. Cross-Sectional Dependence Tests

To select empirical methods for the study, the cross-sectional dependence of the variables had to be tested. If there is cross-sectional dependence in the variables and the model, appropriate unit root and cointegration tests should be selected. Thus, the reliability of the tests will increase. For this purpose, Breusch-Pagan (1980) CDLM, Pesaran (2021) CDLM and Pesaran (2021) CD tests were used. The null hypothesis of these tests was "no cross-sectional dependence", and the alternative hypothesis was "cross-sectional dependence". The formulation of the tests used are given below.

$$CDLM (BP, 1980) = T \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij}^2 \quad (3)$$

$$CDLM (Pesaran, 2021) = \left(\frac{1}{N(N-1)} \right)^{1/2} \sum_{i=1}^{N-1} \sum_{j=i+1}^N (T\hat{\rho}_{ij}^2 - 1) \quad (4)$$

$$CD \text{ (Pesaran, 2021)} = \left(\frac{2T}{N(N-1)} \right)^{1/2} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij}^2 \quad (5)$$

where, $\hat{\rho}_{ij}$: denotes estimates of cross-sectional correlations between residuals.

3.2.2. Panel Unit Root Test

Using the second-generation unit root test under the cross-sectional dependence of the variables will positively affect the analysis results. Im et al. (2003), Levin et al. (2002), Breitung (2001), Hadri (2000), etc., are first-generation unit root tests, and they ignore cross-sectional dependence. If the variables are under cross-sectional dependence, the use of such tests may reduce the reliability of the analysis results. In this study, the Pesaran (2007) panel unit root test was used to test the stationarity of the variables. This test is a second-generation unit root test. It is a method used under cross-sectional dependency, and its formulation is:

$$\Delta x_{it} = z'_{it}\gamma + \rho_i x_{it-1} + \sum_{j=1}^{k_i} \phi_{ij} \Delta x_{it-j} + \alpha_i \bar{x}_{t-1} + \sum_{j=0}^{k_i} \eta_{ij} \Delta \bar{x}_{t-j} + v_{it} \quad (6)$$

where:

\bar{x}_t , is the cross-sectional mean of x_{it} and $\bar{x}_t = N^{-1} \sum_{i=1}^n x_{it}$.

$$CIPS = t - bar = N^{-1} \sum_{i=1}^{N_i} t_i \quad (7)$$

where, t_i , is the EKK t-ratio of ρ_i in equation 6.

The hypotheses of the test of this test are given below.

H₀: Variable has a unit root,

H₁: The variable is stationary.

3.2.3. Slope Heterogeneity

Whether the slope coefficients in the cointegration equations are homogeneous is tested using the test developed by Pesaran and Yamagata (2008), which was first proposed by Swamy (1970).

$$\text{For large samples: } \tilde{\Delta} = \sqrt{N} \frac{N^{-1}\tilde{S}-k}{\sqrt{2k}} \quad (8)$$

$$\text{For small samples: } \tilde{\Delta}_{adj} = \sqrt{N} \frac{N^{-1}\tilde{S}-k}{\sqrt{\text{Var}(t,k)}} \quad (9)$$

where:

N: number of countries,

S: Swamy test statistic,

K: is the number of explanatory variables,

Var(t,k) is the standard error.

The hypotheses of the test of this test are given below.

H₀: The slope coefficients are homogeneous,

H₁: The slope coefficients are heterogeneous.

3.2.4. Panel Cointegration Test

The cointegration relationship between the variables was determined with the help of the Banerjee and Carrion-i-Silvestre (2017) test. This test identifies the potential benefits of using new proposals through Monte Carlo simulations. For this purpose, the size and power of the pooled common correlated effects (CCE)-based test were compared with the Banerjee and Carrion-i-Silvestre (2006) factor-based cointegration test procedure. Factor-based constructs for model dependency are considered an alternative to CCE estimators. This method is more advantageous as it allows a more detailed examination of the dependency and its decomposition into I(0) and I(1). In addition, the cointegration relationship can be determined for variables that are not only stationary but also have unit roots. When using the Banerjee and Carrion-i-Silvestre (2017) test, it is necessary to examine the cross-sectional dependence of the panel.

The hypotheses of the test of this test are given below.

H₀: There is no cointegration relationship in the model.

H₁: There is a cointegration relationship in the model.

3.2.5. Panel Causality Test

The causality relationship between the variables is estimated by the Emirmahmutoglu and Köse (2011) test. In this causality test, the procedure in heterogeneous panels was proposed using the LA-VAR approach of Toda and Yamamoto (1995) with the help of meta-analysis. The test is sufficient if the variables are I(0) or I(1). Another positive aspect of this test, whether there is a cointegration relationship in the model, does not provide any provision for using this test. With the help of Fisher's (1932) test statistic, Granger causality is analyzed in heterogeneous panels. Fisher's (1932) test statistic is as follows:

$$\lambda = -2 \sum_{i=1}^N \ln(p_i), \quad i=1,2,\dots,N \quad (10)$$

where:

p_i: represents the p value corresponding to the Wald statistic of the i individual cross-section.

VAR model with +d max delay in heterogeneous mixed panels in this test:

$$x_{it} = \mu_i^x + \sum_{j=1}^{k_i+dmax_i} A_{11,ij} x_{i,t-j} + \sum_{j=1}^{k_i+dmax_i} A_{12,ij} y_{i,t-j} + u_{i,t}^x \quad (11)$$

$$y_{it} = \mu_i^y + \sum_{j=1}^{k_i+dmax_i} A_{21,ij} x_{i,t-j} + \sum_{j=1}^{k_i+dmax_i} A_{22,ij} y_{i,t-j} + u_{i,t}^y \quad (12)$$

In Equations 11 and 12, the causality test relationship is determined from x to y and from y to x, respectively.

4. Empirical Results and Discussion

In the previous section, the data set and methods were introduced and put into practice. In panel data analysis, first, the cross-sectional dependencies of the variables are estimated. Thus, it is aimed that the methods to be used will give more appropriate results. The empirical findings are reported below.

Table 1: Cross-Sectional Dependence Tests Results

Variables	CDLM (BP,1980)	CDLM (Pesaran, 2021)	CD (Pesaran, 2021)
GDP	603.6786*	28.35718*	20.46451*
ICT	2849.082*	164.505*	53.323*
CO2	1287.920*	69.845*	13.982*
FD	1072.135*	56.762*	24.831*

Note: * imply level of statistical significance at 1.

Table 1 presents the cross-sectional dependence test results for the GDP, ICT, CO₂ and FD variables. When the results of the analysis were evaluated, the null hypothesis “There is no cross-sectional dependence” of all the variables at the 1% significance level was rejected, and the alternative hypothesis “There is cross-sectional dependence” was accepted. Thus, the cross-sectional dependencies were determined in the variables. According to these findings, a shock that occurs in one country may affect another country. Due to cross-sectional dependencies in the variables, the test that should be used in the unit root test analysis of the variables should be from the second-generation unit root tests.

Table 2 Panel Unit Root Test Results

Variables	LEVEL	1. DIFFERENCE	RESULTS
	CIPS-stats	CIPS-stats	
GDP	-2.485	-3.156 *	I(1)
ICT	-2.335	-3.028 *	I(1)
CO2	-2.373	-3.274*	I(1)
FD	-2.381	-3.115*	I(1)

Note: * imply level of statistical significance at 1.

The panel unit root test results are shown in Table 2. According to the results, the null hypothesis could not be rejected at the 1% significance level for the GDP, ICT, CO₂ and FD variables. Therefore, the variables have a unit root at a 1% significance level. By taking the first difference of the variables, it was determined that the null hypothesis was rejected and the alternative hypothesis was accepted. Thus, the GDP, ICT, CO₂ and FD variables were determined to be stationary at the first difference.

Table 3 Cross-Section Dependence and Homogeneity Tests

MODEL-1		
$GDP_{it} = \gamma_1 + \beta_{1i}ICT_{it} + \beta_{2i}CO2_{it} + \beta_{3i}FD_{it} + \varepsilon_{it}$	Statistic	p-value
<u>Cross-section dependency tests:</u>		
CD _{LM} (BP,1980)	601.937*	0.000
CD _{LM} (Pesaran, 2004)	28.251*	0.000
CD (Pesaran, 2004)	19.472*	0.000
<u>Homogeneity tests:</u>		
$\tilde{\Delta}$	3.952*	0.000
$\tilde{\Delta}_{adj}$	4.441*	0.000
MODEL-2		
$CO2_{it} = \gamma_2 + \beta_{4i}ICT_{it} + \beta_{5i}GDP_{it} + \beta_{6i}FD_{it} + \varepsilon_{it}$	Statistic	p-value
<u>Cross-section dependency tests:</u>		
CD _{LM} (BP,1980)	1003.272*	0.000
CD _{LM} (Pesaran, 2004)	52.586*	0.000
CD (Pesaran, 2004)	12.749*	0.000
<u>Homogeneity tests:</u>		
$\tilde{\Delta}$	14.699*	0.000
$\tilde{\Delta}_{adj}$	16.520*	0.000

Note: * imply level of statistical significance at 1.

The results of the cross-section dependence and homogeneity tests are tabulated in Table 3. The empirical results of the analysis for MODEL-1 and MODEL-2 are listed as follows: i) In the results of the cross-section dependence tests, it was determined that the null hypothesis was rejected at the 1% significance level in both models, and the alternative hypothesis was accepted. Accordingly, MODEL-1 and MODEL-2 have cross-sectional dependence. ii) According to the results of the homogeneity tests, the null hypothesis was rejected because the probability value in MODEL-1 and MODEL-2 was at a less than 1% significance level. It was determined that the slope coefficients were heterogeneous in the models that accepted the alternative hypothesis. After these findings, cointegration in the models was analyzed. The results of the Banerjee and Carrion-i-Silvestre (2017) cointegration test, which indicate the cross-section dependency, are presented below.

Table 4 Panel Cointegration Test Results

	Constant	Trend
MODEL-1	-3.626**	-3.336**
MODEL-2	-3.122**	-3.608**

Note: ** imply level of statistical significance at %5.

The cointegration relationship between the variables was analyzed with the Banerjee and Carrion-i-Silvestre (2017) test. In the empirical results, the null

hypothesis "There is no cointegration relationship between the variables" in constant and trend was rejected at the 5% significance level. For this reason, the alternative hypothesis "there is a cointegration relationship between the variables" was accepted. A cointegration relationship was found in both models. In other words, in MODEL-1 and MODEL-2, the variables would move together in the long run. After determining the cointegration relationship in the models, the causality relationship between the variables was investigated. The Emirmahmutoğlu and Köse (2011) panel causality analysis results are shown below.

Table 5 Panel Causality Test Results

	Fisher stat.	Prob.
ICT → GDP	38.380	0.278
GDP → ICT	53.926**	0.016
CO₂ → GDP	31.916	0.570
GDP → CO₂	56.825*	0.008
FD → GDP	65.361*	0.001
GDP → FD	45.774***	0.086
ICT → CO₂	50.229**	0.036
CO₂ → ICT	41.957	0.164
FD → CO₂	57.230*	0.008
CO₂ → FD	46.135***	0.080

Note: ***, ** and * imply level of statistical significance at %10, %5 and %1, respectively.

The panel causality test results are reported in Table 5. According to the findings, the null hypothesis "GDP is not causal of ICT" at the 5% significance level was rejected, and the alternative hypothesis was accepted. Therefore, GDP is the causal agent of ICT. Based on the causal relationship between GDP and CO₂, the null hypothesis was rejected at the 1% significance level, and the alternative hypothesis was accepted as "GDP is causal of CO₂". According to the results of the causality analysis between FD and GDP, a bidirectional causality relationship was found. When the causal relationship between ICT and CO₂ was examined, the null hypothesis was rejected, and the alternative hypothesis was accepted. Therefore, ICT was determined to be a causal factor in CO₂. When the causality results between FD and CO₂ are interpreted, it is accepted that there is a bidirectional causality relationship between FD and CO₂. The causal relationships between the variables are shown in Figure 1.

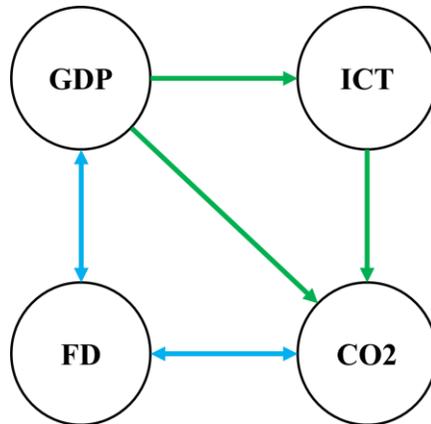


Figure 1 Panel Causality Test Relationship

5. Conclusion

In this study, the cointegration and causality relationships among economic growth, environmental pollution, ICT, and the FD of CEE countries were investigated by using annual data from 1996 to 2018. Second-generation econometric methods were used because cross-sectional dependence between countries was detected. In two different models, in which economic growth and environmental pollution were dependent variables, a cointegration relationship was found between the variables. For this reason, it has been determined that the variables in the models will move together in the long run.

The results of the causality analysis indicated that economic growth is a cause of ICT development. With the economic growth, ICT is developing rapidly. The interest in ICT, which raises the development level of countries, has been increasing rapidly in recent years. ICT allows information to be shared more easily and quickly. Knowledge is extremely important, and it directly contributes to the development of countries. For this reason, the increased interest of policymakers in ICT will drive its development and that of the country. Policies for ICT need to be developed rapidly.

The following recommendations can be made to policymakers regarding the steps to be taken for ICT: 1) investments in ICT should be encouraged 2) domestic and foreign investors should be offered more investment opportunities in this field and 3) supported to increase their investments. With improved ICT, since information flow will be easier, products in the fields of production and service will be created more efficiently. Another benefit of developed ICT is that it will increase the competitiveness of countries. In the globalized world, countries or companies that have access to more reliable information more quickly will have a competitive advantage. Countries need to develop their infrastructures for advanced ICT and realize a quicker and more reliable information flow.

Since developed ICT is the driving force of growth, countries and companies should shift investments toward this area. The faster flow of information and easier access to it will help increase the level of state welfare. For this reason, ICT

infrastructures should be developed with the latest technology and directed toward areas that will maximise their usage. The policies that policymakers will develop, together with economists, are extremely important. It is estimated that investments in ICT will have returns in the medium and long term due to its competitive advantage; therefore, countries seeking rapid growth momentum should carefully evaluate this sector to avoid falling behind the competition.

The advantage of ICT should be well utilized in policies developed to reduce environmental pollution without slowing down economic growth. ICT can create new services and industries, generating new jobs. In addition, added value can be created by shifting the labor force to these areas. In addition, by emphasizing the importance of innovation in the business world, economic growth can be achieved, and international competition can be brought to the forefront.

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