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Examining the Impact of Environmental Pollution and Life Expectancy on Economic Growth in the European Union

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Abstract Environmental and demographic changes fall into megatrends that shape contemporary economy and society. The main aim of this paper is to analyze the impact of environmental pollution and life expectancy on economic growth in the European Union. The main research hypothesis states that an increase in environmental pollution and life expectancy leads to an increase in real GDP. Various econometric tests were applied to examine this relationship. Firstly, the existence of long-term relationship between the variables was examined with the use of panel cointegration test. Then, cointegration coefficients in both the long-run and the short-run were estimated. Finally, the improved Granger causality test was conducted to check for causal relationship between the variables. The results indicate that environmental pollution and life expectancy series taken together Granger-cause real GDP. However, other tests indicate there is only a weak impact of the two variables on the real GDP in the European Union.

Keywords: economic growth, pollution, life expectancy, Granger causality, EU

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I. Introduction

Environmental and demographic changes are considered to be the megatrends that shape contemporary economy and society (Naughtin et al., 2022; Artuso and Gujit, 2020), and this is the motivation for considering the two variables together; life expectancy as a demographic factor and environmental pollution as an environmental factor.

Economic growth is impacted by a number of factors. Among other things, it is affected by the supply of human capital, productivity and other resources availability. The concept of productivity is closely related to investments in human capital and is also seen as a consequence of technological progress. The importance of human capital is recognized in developed as well as in developing economies. It is related to health and longer life expectancy since only healthy

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individuals can maximize their work potential and increase productivity. Increased life expectancy tends to increase investments in human capital which, in turn, is necessary for economic growth (Hansen and Lønstrup, 2012; Hazan, 2009; Heckman, 1976).

In recent decades, the analysis of economic growth is increasingly connected to the environment and availability of natural resources. Increased production usually means increased use of inputs. However, some inputs are limited and non-renewable, namely natural resources, and excessive consumption of natural resources limits economic activities (Arrow et al., 2004). This is accompanied by environmental pollution and depletion of natural resources (Zhang et al., 2022).

Increased global interest in analysing the relationship between pollution and growth as well as the relationship between life expectancy and growth, which are a part of megatrends shaping global economy (Dugan, Prskawetz and Raffin, 2023; Ebhota, Hongxing, and Sampene, 2023) has motivated the research in this paper. The main aim of this paper is to examine whether environmental pollution and life expectancy have an impact on economic growth in the European Union (EU) countries. The main research hypothesis states that an increase in life expectancy and an increase in environmental pollution leads to an increase in the real gross domestic product (GDP). EU-27 countries are taken as a sample because of data availability, familiarity, but also because the integration covers heterogeneous countries but with common policy and regulatory guidelines, which is significant when analysing demographic and environmental issues. A combination of econometric tests is used in order to test this relationship. Panel cointegration test is used to determine the existence of a long-term relationship between the variables. Cointegration coefficients in both the long-run and the short-run are estimated using several alternative estimates to check the robustness of the results. Finally, the improved Granger causality test is used to check for the causal relationship between variables. The contribution of the paper is twofold. Firstly, it contributes to empirical literature because it fills the gap in researching the effect of environmental pollution on economic growth. In most previous research the relationship is considered in reverse direction. Secondly, the combination of empirical tests enables a thorough examination of the relationship and co-movements between the variables and ensures the robustness of the results.

The paper is structured in five sections. The following section is literature review. The third section describes data and methodology followed by the results section and lastly is the conclusion.

II. Literature Review

The relationship between environment, demographic variables and growth has been in the focus of research since the beginning of industrial revolution with the aim of determining whether long-term economic growth is sustainable (e.g. Malthus, 1798). Since then, the relationship between economic growth and environment on the one side, and the relationship between growth and life expectancy on the other, has been vastly researched. The experience of many developing countries has shown positive relationship between growth and higher pollution levels if there is no environmental regulation (Yan, Li, & Li, 2022; Li, Chen, Chang & Chao Hung, 2021; Lazăr, Minea & Purcel, 2019). Life expectancy is generally considered to be positively connected to growth, however, although early research confirm positive relationship between life expectancy and growth, more recent studies have shown mixed results. In continuation, the relationship between pollution, life expectancy and economic growth will be discussed separately, and in the end of this part those variables will be considered together. Relationship between environmental pollution and life expectancy is also considered.

Yan, Li, and Li (2022) considered the relationship between economic growth and pollution and found that growth increases environmental pollution emissions, which in turn has multifaced effects as it intensifies as well as inhibits economic growth. They also analysed the reverse relationship between the variables and concluded that the aggravation of environmental pollution will ultimately restrain economic growth. Li, Chen, Chang and Chao Hung (2021) found that the gross domestic product (GDP) and air pollution in Taiwan display a positive correlation. Authors suggest that the GDP growth is significantly related to air pollution and there is a need for optimal mechanism to avoid drastic climate change as an instrument of air pollution control. Lazăr, Minea, and Purcel (2019) research results reveal an increasing nonlinear link between GDP and pollution in the Central and Eastern European (CEE) countries. However, when looking at a country level, the results are much more diversified among analysed countries indicating that some of them managed to secure both higher GDP and lower emissions.

On the other hand, Yang, Yuan and Sun (2021) showed that pollution indices had a negative long-term cointegration relationship with GDP per capita, indicating that economic growth does not necessary damage the environment. Rasool, Malik and Tarique (2020) research shows that at the beginning stages of economic development environmental pollution increases, but as a country gets richer it promotes cleaner production and pollution levels decrease.

Empirical research considering the reverse relationship, i.e. how environmental pollution affects economic growth are limited, and there is a literature gap which this research intends to fill. Acheampong and Osei Opoku (2023) found that environmental degradation has a negative effect on economic growth. They further elaborated that pollution exhibits an inverted U-shaped relationship with economic growth, so it can be said that time and improvement in development level are crucial for making conclusions. Another study by Aragona and Rud (2016) examined the impact of pollution on productivity in agricultural sector. They found that farmers located near pollution-intensive mines faced a relative reduction in total factor productivity of almost 40 %. Study made in India confirmed that pollution damaged the economy and economic cost amounted to 4,5-6 % of GDP (Managi and Ranjan Jena, 2008). Economic cost of pollution can be measured in reduced production, impaired health of workers, healthcare costs, decreased productivity and etc.

As mentioned, demographic change is one of the megatrends shaping today's economy. Demographic changes either directly or indirectly impact labour supply and its characteristics. Adequate labour supply and investments in human capital are considered as foundation for growth and development. The importance of human capital for economic growth was explained and proved decades ago with the works of Romer (1986), Lucas (1988) and Barro (1991), to name a few. They accentuated that investments in health and education improve human capital which in turn increases productivity.

Shkolnikov (2019) researched the relationship between life expectancy and GDP per capita in Russia. Results revealed that increased health expenditure contributed to economic growth which was accompanied by a substantial increase in life expectancy. Results have also shown that since 2010 life expectancy continued to increase even though growth stagnated. Similarly, Rafia and Samreen (2019) have shown that the increase in life expectancy is positively related to the increase in GDP per capita in G7 countries. They experienced a constant rate of increase in life expectancy. He and Li (2020) conclude there is significantly positive long-run relationship between variables, but the specific relationships between life expectancy and GDP vary depending on aging levels. The positive impact is stronger in a group with higher level of aging.

The relationship between environmental pollution and life expectancy is proven to be significant and negative by numerous researchers. Ghaedrahmati and Hajilou (2022) investigated the relationship between pollution and life expectancy in Iran. They found that there is a significant impact of pollution on life expectancy and the analysis of variance revealed correlation among the two variables. Lelieveld et al. (2020) found that air pollution causes significant excess mortality and loss of life expectancy on a global level, especially through cardiovascular diseases. Shivam (2021) researched the effect of pollution on life expectancy in the US and found that air pollution and chemical disposal negatively affect life expectancy meaning that it shortens it. Bashir et al. (2022) empirically studied the case of Indonesia and concluded that air pollution has a negative and significant effect on life expectancy in the long run.

Research which includes all three mentioned variables are limited. One example is the research of Bayar et al. (2021) who analysed the relationship among pollution, life expectancy, economic growth and health expenditures in the EU. They found a significant unilateral causality from greenhouse gas emissions, life expectancy, and real GDP per capita to health expenditures. Bashir et al. (2022) used ARDL and Granger causality test to analyze the relationship between air pollution, economic growth, and life expectancy in Indonesia. They found a two-way relationship between air pollution and life expectancy and between economic growth and pollution. In the long run they confirmed a relationship between all three variables, air pollution, economic growth, and life expectancy. Rahman, Rana and Khanam (2022) analysed how growth impacts life expectancy while considering pollution level of a country. They found that higher economic growth will likely increase the life expectancy of people living in the world's most polluted countries. They also conclude that increased carbon emissions negatively impact life expectancy (holding other variables constant) in selected most polluted countries in the world.

III. Data and Methodology

A. Description of data

Data for the life expectancy at birth (*Life*), net greenhouse gas emissions (*Environment*) and gross domestic product per capita (*GDPpc*) are collected on an annual basis since 1995 until 2022. The sample consists of the 27 EU member countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, also known as the "old members", and Bulgaria, Croatia, Cyprus, Czechia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovak Republic, Slovenia, known as the "new members".

Net greenhouse gas emissions series has been flagged for the following countries and observations: Belgium, 2022-12 (break in time series), Czechia, 2021 (break in time series), Estonia, 2015 (break in time series), Croatia, 1990-2000 (estimated), 2001 (break in time series), Hungary, 2012 (break in time series), Ireland, 2018-19 (estimated), Italy, 2019 (break in time series), Luxembourg, 2012, 2017 (break in time series), Malta, 1991 (break in time series), Poland, 2000, 2010 (break in time series), 2018-19 (estimated), 2020-21 (estimated, provisional), Portugal, 2021 (break in time series, provisional), Romania, 2019-21 (estimated), Slovenia, 2008 (break in time series).

Description of variables and sources of data are given in Table 1.

Table 1. *Variables Description and Sources of Data*

Variable	Definition and source
GDPpc	GDP per capita is gross domestic product divided by midyear population. Data are in constant 2015 U.S. dollars. Source: WB, WDI. Code: NY.GDP.PCAP.KD.
Environment	Net greenhouse gas emissions (Tonnes per capita) (CO_2, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, NF_3 in CO_2 equivalent). Source: EEA.
Life	Life expectancy at birth indicates the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life. Source: UNPD, WPP, USCB. Code: SP.DYN.LE00.IN.
LNGDPpc	Log transformation of GDPpc series.
LNEnvironment	Log transformation of Environment series.
LNLife	Log transformation of Life series.

B. Methodology

Log transformation of three variables ($LNGDPpc$, $LNEnvironment$, $LNLife$) was used in the research model:

$$LNGDPpc_{it} = \alpha_0 + \beta_1 LNEnvironment_{it} + \beta_2 LNLife_{it} + u_{it}$$

where i refers to the cross-sections, i.e. countries $i = 1, 2, \ldots, 27$, and t refers to the time dimension of the panel, i.e. years $t = 1995, 1996, \ldots, 2022$. Logarithmic transformation enables comparison with the results of other research and the interpretation of coefficients in such models is more intuitive.

Firstly, cross-sectional dependence of the panel data, i.e. dependence between countries is examined using the CD test (Pesaran, 2004), their homogeneity (delta tilde test) (Pesaran & Yamagata, 2008), and also the stationarity of time series using the CIPS test (Pesaran, 2007). Then, panel cointegration test (Westerlund, 2005) is used to determine the existence of long-term relationship between the three variables. Cointegration coefficients in both the long-run and the short-run are estimated using several alternative estimates to check the robustness of the results on the relationship of LNGDPpc, LNEnvironment and LNLife in the long-run. These are the following estimation methods: fully modified ordinary least squares - FMOLS (Kao & Chiang, 2000; Pedroni, 1999, 2001; Phillips & Moon, 1999), dynamic ordinary least squares - DOLS (Mark & Sul, 2003; Stock & Watson, 1993), mean group - MG (Pesaran & Smith, 1995), augmented mean group - AMG (Teal & Eberhardt, 2010), and also the pooled mean group/autoregressive distributed lags - PMG/ARDL (Pesaran & Moon,1999). Finally, the improved Granger causality test (Juodis, Karavias & Sarafidis, 2021) is used to check for the causal relationship between the variables. Statistical packages Stata 15, Eviews 10 and R4.3.2 were used in the econometric analysis of panel data.

IV. Results and Discussion

This paper has empirically tested the impact greenhouse gas emissions and life expectancy might have on the real GDP in the EU member states in the period 1995-2022. As stated, the main research hypothesis is that increased environmental pollution and life expectancy lead to an increase in the real GDP.

A. Cross-sectional dependence test and homogeneity test

Tests of cross-sectional dependence and homogeneity of panel data were first applied in order to select more robust panel unit root and cointegration tests. Before using panel unit root test that can deal with cross-sectional dependence, we highlight the cross-sectional dependence in our data. The null hypothesis states that there is no cross-sectional dependence.

Table 2. *Cross-Sectional Dependence Test Statistics*

Variable	CD	CDw	CDw+	CD*
		EU-27 countries		
LNGDPpc	80.99***	-2.63***	1512.13***	-1.40
LNEnvironment	31.42***	0.65	947.38***	-0.95
LNLife	93.74***	-2.47**	1753.66***	-0.39

Note. CD: Pesaran (2015, 2021); CDw: Judodis & Reese (2021); CDw+ with power enhancement from Fan et. al. (2015); CD*: Pesaran & Xie (2021) with 4 PC(s). The asterisks represent significance at the 10% (*), 5% (**), and 1% (***) confidence levels.

Most of the tests performed reject the null hypothesis of cross-sectional independence (Table 2). This result means that the first-generation panel unit root tests results would be unreliable. Therefore, this indicates to the second-generation panel unit root tests.

The null hypothesis of homogeneity means that the effects of environmental pollution and life expectancy on real GDP are equal in all countries, which is a rather restrictive assumption. However, rejecting this hypothesis creates additional problems, since in that case one must choose those panel unit root and cointegration tests that are insensitive to the absence of homogeneity.

Table 3. *Pesaran & Yamagata Homogeneity Tests*

Test	EU-27 countries
$\tilde{\Delta}$	26.01
$\tilde{\Delta}_{adj.}$	28.18

Note. Null hypothesis: cointegration coefficients are homogeneous. All *P-values* are less than 1%. Constant was partialled out.

The homogeneity of the cointegration coefficients was examined using the delta tilde and the adjusted delta tilde test (Pesaran & Yamagata, 2008). The null hypothesis of homogeneity was rejected at the 1% significance level. In other words, this result indicates that the cointegration coefficients are heterogeneous, i.e. vary from country to country (Table 3).

B. Panel unit root test

Breaks in the time series that could happen due to some external event such as the Covid-19 pandemic or Ukrainian war could cause a significant change in the level, slope or both level and slope of the panel time series. Therefore, before selecting an appropriate panel unit root test we should test for breaks in panel time series. Karavias, Narayan & Westerlund (2021) test for breaks in panel time series was used.

The results are presented in Table 4.

Table 4. *Karavias, Narayan & Westerlund (2021) Test for Breaks*

	Test statistic	Bai-Perron critical values		
	EU-27	1%	5%	10%
$supF(s)$	0.63	7.68	5.74	4.91
Estimated break point	2016			

Note. Null hypothesis: No break vs. Alternative hypothesis: One break. Heteroscedastic and autocorrelation robust covariance estimator was used. Added as cross-section averages with break: *LNEnvironment* and *LNLife*.

All the test statistics are well below the Bai-Perron critical values which means the null hypothesis of no break in the panel time series can't be rejected. If that would not be the case the second generation of panel unit root tests able to cope with breaks in time series would be used. With no beaks in time series, we opted for the cross-sectional IPS test.

CIPS test is based on the cross-sectional ADF regression, which adds lagged cross-sectional means of countries to control for effects of the common factor, while the computation of the test statistics and the inference follows the IPS procedure, named after Im et al. (2003). Program Stata 15 was used to apply Pesaran's CIPS test for unit roots in heterogeneous panels, i.e. in the presence of cross-sectional dependence. The null hypothesis is that all panels contain unit root, against the alternative hypothesis that some panels are stationary (Table 5).

While the Pesaran CIPS test in models without trend shows mixed results, in models with trend all the series indicates existence of a unit root. For all the first difference series the test suggests rejection of the null hypothesis about unit root. In other words, all the series are considered nonstationary, i.e. I(1) in the further analysis.

Table 5. *Pesaran's CIPS Test Statistic for Unit Roots in Heterogeneous Panels*

Variable	Without trend	With trend
Level		
LNGDPpc	-1.82**	-1.18
LNEnvironment	2.53	0.22
LNLife	-2.22**	0.25

Table 5. *Continued*

Variable	Without trend	With trend
First difference		
△LNGDPpc	-3.47***	-1.51*
△LNEnvironment	-4.77***	-2.76***
△LNLife	-6.75***	-5.50***

Note. Test assumes cross-sectional dependence in a form of a single unobserved common factor. For augmented DF statistic lag length for all units in panel is set to 2. Individual dynamics specifications in each regression is based on the Wald test of composite linear hypothesis about the parameters of the model. The asterisks represent significance at the 10% (*), 5% (**), and 1% (***) confidence levels.

C. Panel cointegration test

In order to test the research hypothesis, Westerlund cointegration test is used (Westerlund, 2007). Two variants of the test were applied depending on how the alternative hypothesis was defined. We used several panels of data, dividing the EU into "old" and "new" members, but the EU-27 as a whole is the focus in this paper. While the null hypothesis indicates no cointegration, the alternative hypothesis is that all panels are cointegrated or that some of the panels are cointegrated. We also varied the assumption about the behaviour of the autoregressive (AR) parameter in this test. In one variant, the AR parameter is the same in all panels, while in another variant it is panel specific, i.e. varies between panels. Finally, in one version of the test time trend was included, while excluded in the other. The results of the Westerlund test are given in Table 6.

Table 6. *Westerlund (2007) Panel Cointegration Test*

Alternative hypothesis	Time trend	AR parameter	EU-27
Some panels are cointegrated	No	Panel specific	3.11***
All panels are cointegrated	No	Same	3.48***
Some panels are cointegrated	Yes	Panel specific	2.04**
All panels are cointegrated	Yes	Same	0.50

Note. Null hypothesis: No cointegration. The asterisks represent significance at the 10% (*), 5% (**), and 1% (***) confidence levels.

All tests reject the null hypothesis of no cointegration with one exception (the test in the last row of Table 6). This indicates strong evidence of cointegration among the three variables in the study. That is, there is a long-run steady-state relationship or co-movement among real GDP, environmental pollution and life expectancy in 27 member states of the EU panel.

D. Long run coefficients estimators

Since it was determined that there is a long-term relationship between the three series, the panel regression model was evaluated in order to obtain estimates of the long-term impact of environmental pollution and life expectancy on the real GDP. To investigate to what extent estimates are robust to the use of different estimators and software algorithms, panel regression models were estimated using five different estimation methods (FMOLS, DOLS, MG, Aug MG and PMG/ARDL).

1. FMOLS and DOLS estimators

Pedroni (2001) heterogeneous FMOLS estimator and dynamic OLS (DOLS) estimator developed by Kao & Chiang (2001) were used as they provide a robust correction of endogeneity in the explanatory variables. Additionally, MG estimator proposed by Pesaran & Smith (1995) was used, Aug MG estimator proposed by Bond & Eberhardt (2010) and Eberhardt & Teal (2011), and PMG estimator proposed by Pesaran & Smith (1995), which constrains the long run coefficients to be identical but allows the short run coefficients and error variances to differ across groups. Summary results are presented in Table 7. Since all series were transformed using a logarithmic transformation, estimated coefficients in these panel cointegration regressions can be interpreted as elasticities. For illustration, we use the FMOLS estimation results obtained using the software algorithm of the EViews program for all 27 EU member states. The coefficient for *LNEnvironment* is 0.46, which means that on average, a change in environmental pollution of 1% leads to an increase in the real GDP by 0.46%% for 27 European Union countries. It should also be noted that this effect is statistically significant at the 1% significance level. The coefficient for *LNLife* is 0.38, which means that on average a change in the life expectancy of 1% leads to an increase in the real GDP by 0.38% for all 27 European Union countries. This coefficient is statistically significant at the 1% level.

If we look at the sign and statistical significance of the estimated coefficients in Table 7, it can be noticed there is a variation among the estimated coefficients, but in the case of the coefficient with the *LNEnvironment* variable all coefficients have a positive sign and those highly statistically significant (at 1% significance level) are in the interval from 0.23 to 0.60. All those coefficients with the variable *LNLife* that are highly significant (at 1% significance level) are with a positive sign and in the interval from 0.32 to 0.38 for all EU-27 countries. Based on these results we can conclude that the positive influence of environmental pollution on the real GDP is confirmed with high reliability, while in the case of the life expectancy, this influence is not clear.

Table 7. *Summary of Panel Regression Models for EU Countries (Long-Run Coefficients)*

Estimation method	FMOLS (Stata)	FMOLS (EViews)	DOLS (Stata)	DOLS (EViews)	MG (Stata)	Aug MG (Stata)	PMG/ ARDL (EViews)
LNEnvironment	0.46*** (58.13)	0.46*** (16.37)	0.59*** (60.59)	0.39*** (13.04)	0.46*** (5.77)	0.23*** (4.01)	0.59*** (13.57)
LNLife	0.32*** (10.08)	0.38*** (13.69)	0.46 (2.01)	0.08 (0.17)	0.65 (0.91)	-0.14 (-0.26)	-1.71** (-2.55)

Note. Values in parentheses are t-statistics. The asterisks represent significance at the 10% (*), 5% (**), and 1% (***) confidence levels.

The explanation behind the positive impact of environmental pollution on real GDP possibly lies in the logic that increased pollution (dirty technologies) is a consequence of increased production which usually leads to an increase in economic growth. This would indicate to a reverse causality between pollution and growth. Endogeneity issue that could arise is addressed by using FMOLS and DOLS approach.

Based on the analysed time series we can draw the following conclusions (Table 7):

- Signs of long-run coefficients for *LNEnvironment* are all positive across the estimation methods and software used. It means that we can be certain about the direction of impact this series have on the economic growth.
- Signs of long-run coefficients for *LNLife* varies across the estimation methods and software used. It means that we can't be certain about the direction of impact these two series have on the economic growth.
- Not all long-run coefficients for the same series but different estimation methods and software used are statistically significant at the same significance level. Furthermore, a few of them are not significant at all, which means that we can't be certain whether any of these two series really have a significant impact on the economic growth. Limited sample size is one of the reasons why there is such diversity in results using different estimators and algorithms.

2. PMG/ARDL model estimation

The panel ARDL method (Pesaran & Shin, 1999; Pesaran, Shin & Smith, 2001) provides both long-term and short-term coefficients at once. The ARDL models were estimated with linear trend. Schwarz information criterion (SIC) is used to select optimal lag length of the ARDL models. Coefficients in ARDL models are elasticities, showing the change of dependent variable if there is 1% change in independent variables. Results of PMG/ARDL model estimation are presented in Table 8.

Table 8. *Panel ARDL (PMG) Estimation (Dependent Variable: LNGDPpc)*

Variable	EU27 countries	
	Coefficient	P-value
LNEnvironment	0.5856	<.01
LNLife	-1.7067	.01
Cointegration equation	-0.2062	<.01
△LNEnvironment	0.1995	<.01
△LNLife	0.8730	.05
Trend	0.0056	<.01
Constant	3.2242	<.01

Note. ARDL(1,1,1) model with trend was selected.

The coefficient of the error correction term (ECT) coincides with the underlying convergence assumptions in order to validate the long-run equilibrium nature of the model. These include that the ECT is negative, significant, and less than one (Pesaran et al., 1999). In Table 8 it is shown that the rate of adjustment back to (long-run) equilibrium is 0.2062%, which is significant at less than 1% significance level. In the short run, all the coefficients are significant at less than 1% significance level.

The long-run *LNEnvironment* coefficient is positive and highly statistically significant. The long-run *LNLife* coefficient is negative and also highly statistically significant. In the short run, increase in both *LNEnvironment* and LNLife would lead to increase in the real GDP. However, that is not the case on the long run, at least in the period from 1995 to 2022, when *LNEnvironment* has positive and *LNLife* has negative impact on the real GDP series. It should be also noticed that in the long-run impact of life expectancy on the economic growth is three times higher than that of environmental pollution.

Therefore, the cointegration test based on panel ARDL (PMG) model confirms that there is long-term relationship between *LNGDPpc, LNEnvironment* and *LNLife*. This is in line with the results of Bashir et al. (2021) who also found evidence of a long-run relationship between air pollution, economic growth and life expectancy.

E. Granger causality analysis

The existence of a causal relationship among the variables is tested with the latest Granger non-causality test developed by Juodis, Karavias & Sarafidis (2021) is used. The null hypothesis is that variable X does not homogeneously cause variable Y, against the alternative hypothesis that X does Granger-cause Y for at least one panel.

First, we test whether any pair of series Granger-cause the remaining, i.e. third series. The null hypothesis of no Granger causality was rejected at least at 5% significant level. To explain these results, we test for Granger non-causality for each series separately using univariate tests.

Table 9. *Improved Granger Panel Causality Test*

Null hypothesis	Wald statistic	Decision
(LNEnvironment & LNLife) does not Granger-cause LNGDPpc	83.42***	Rejected
(LNGDPpc & LNLife) does not Granger-cause LNEnvironment	3.97	Not rejected
(LNGDPpc & LNEnvironment) does not Granger-cause LNLife	92.16***	Rejected
LNGDPpc does not Granger-cause LNEnvironment	2.39	Not rejected
LNEnvironment does not Granger-cause LNGDPpc	1.12	Not rejected
LNGDPpc does not Granger-cause LNLife	30.34***	Rejected
LNLife does not Granger-cause LNGDPpc	82.64***	Rejected
LNEnvironment does not Granger-cause LNLife	24.62***	Rejected
LNLife does not Granger-cause LNEnvironment	10.55***	Rejected

Note. BIC criterion used to decide on the optimal number of lags. The asterisks represent significance at the 10% (*), 5% (**), and 1% (***) confidence levels. Decision was based on the 5% significant level.

In the multivariate systems, i.e. when all three series are included (*LNGDPpc*, *LNEnvironment* and *LNLife*) test results in rows 1 and 3 in Table 9 suggest that both environmental pollution and life expectancy series taken together Granger-cause the real GDP. This coincides with the panel cointegration test results in Table 6, where cointegration relationship between these three series was established. However, mixed results for each individual series in Table 9 are in some way consistent with mixed results presented in Table 7, because direction, intensity and significance of impact of the environmental pollution and life expectancy series on the real GDP depend on the software algorithm and methods applied. Gürler and Özsoy's (2019) paper also shows mixed results. Authors conclude that economic growth Granger causes life expectancy increase and vice versa but only for panel and data not for cross-section data. Bashir et al. (2021) found a two-way relationship between air pollution and life expectancy and a two-way relationship between economic growth and air pollution. Bayar et al. (2021) found that life expectancy had a significant positive impact on real GDP in the EU. Furthermore, authors found that in the short run emissions, life expectancy, and real GDP per capita had a significant impact on health expenditures. Hence, most empirical research indicate to a relationship between economic growth, life expectancy and environment, but with certain limitations and depending on methods an sample used.

V. Conclusion

This paper explored the impact environmental pollution and life expectancy have on economic growth. Based on the analysis using annual time series for the EU member states in the period from 1995 to 2022, it can be concluded there is a long-run equilibrium relationship between real GDP, life expectancy and gas emissions. Results of the long-run coefficients estimations show variations. This is a limitation for making clear and definite conclusions about the size and direction of the impact environmental pollution and life expectancy may have on the real GDP. Results of Juodis, Karavias & Sarafidis (2021) improved Granger panel causality test indicated that in the multivariate systems environmental pollution and life expectancy taken together Granger-caused real GDP. When the pairs of series are considered, mostly bi-directional causal relationships are found. Therefore, it can be concluded that there is only weak evidence of the impact environmental pollution and life expectancy might have on the real GDP in the European Union. Short time series have contributed to such inconclusive results. But also, the EU countries are still considerably heterogeneous, especially regarding gas emissions. While common guidelines are useful for determining the strategic development direction, the EU countries should consider their own specificities while forming social and environmental strategies and policies.

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