An Empirical Assessment of the Relationship Between Life Expectancy at Birth and Carbon Dioxide Emissions in 27 European Union Countries

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The study examines the statistical significance of the effects of carbon dioxide (CO_2) emissions on life expectancy at birth, using panel data of 27 European Union (EU) countries between 1995 and 2019. The effects are analysed with two measures of CO_2 emissions: metric tons per capita, and kg per 2015 USD of GDP. A set of additional determinants investigates the relationship between the dependent variable and selected controls, including the costs of living, ageing, and social support. In each estimation technique, the results indicate a statistically significant negative association between CO_2 emissions and the dependent variable. The additional estimates emphasise higher elasticities in the old EU countries compared to the new countries that joined the EU in May 2004 and later. The results suggest that socio-economic conditions alone are insufficient to stimulate health status, proxied by life expectancy; the environmental component is also important.

Keywords: Life expectancy at birth, Carbon dioxide emissions, European Union, Health status, Ageing

JEL: I10, I14, J11, Q50

Introduction

In recent years, life expectancy at birth has exhibited an increasing trend in countries around the world. The European Union (EU) is at an advanced stage of economic development, although the individual countries differ in terms of progress. This rise in life expectancy is a result of many determinants, including improvements in the quality of life and health status. Thus, health status, proxied by life expectancy, is affected by a complex set of factors, including macroeconomic, social, or environmental, of which the most important is the level of air pollution.

The data show that the increase in life expectancy at birth, observable in recent decades in 27 EU countries, is associated with a decrease in carbon dioxide (CO_2) emissions. However, the scale of both the changes differs among countries. This raises the question of whether there is a negative relationship between life expectancy at birth and CO_2 emissions in the EU, and whether it is statistically significant.

The increasing life expectancy is directly associated with an improvement in socio-economic background. However, progress has been marred by environmental pollution. Thus, the paper aims to analyse the effects of CO_2 emissions on health status in EU countries. The value added is the comparison of the effects of CO_2 emissions in two subsamples, referring to the old and new EU countries. This division is motivated by the observable differences in ageing and CO_2 emissions among countries; it enables a comparison of the relationship between life expectancy at birth and environmental degradation in two subsamples, created by categorising countries that generally differ in their stage of development. The findings obtained illustrate the role of these differences; thus, the results make a valuable contribution to the debate concerning population ageing, and strategies to achieve a cleaner and healthier environment.

1. Theoretical framework – a short summary

Initially, Grossman's (1972) theoretical model of the health production function assumed that an individual health output is a function of a vector of individual inputs. Thus, he proposed introducing social, economic, and environmental factors as explanatory determinants of health. However, analysis based on the macro level requires a change in the set of determinants. For example, Fayissa and Gutema (2005) proposed using economic, social, and environmental factors expressed per capita. In particular, they added a set of selected per capita economic variables, per capita social variables, and per capita environmental factors.

In many studies, from the macro perspective, health status is commonly proxied by life expectancy at birth, or mortality rate (e.g., Auster, Leveson and Sarachek, 1969; Nixon and Ulmann, 2006; Gallet and Doucouliagos, 2017). Indeed, life expectancy at birth remains one of the most commonly used summary measures of health status (Joumard *et al*., 2008). The literature review shows that many studies have focused on a general evaluation of different factors that affect life expectancy. Common determinants are socio-economic factors such as income per capita, living standards, urbanisation, the structure of the population, unemployment rate, and exchange rate (e.g., the set of determinants proposed by Wolfe and Gabay, 1987; Auster, Leveson and Sarachek, 1969; Bilas, Franc and Bosnjak, 2014; Fayissa and Gutema, 2005; Abdulganiyu and Tijjani, 2021; Bayati, Akbarian and Kavosi, 2013; Blazquez-Fernández, Cantarero-Prieto and Pascual-Saez, 2017; Sede and Ohemeng, 2015; Nixon and Ulmann, 2006; Miladinov, 2020; Rodriguez and Sobrino, 2015). Other factors are related to education, including illiteracy rate, average years of schooling, education attained, and enrolment ratios (e.g., Fayissa and Gutema, 2005; Bilas, Franc and Bosnjak, 2014; Sede and Ohemeng, 2015). Finally, the factors directly related to health are commonly used, such as tobacco consumption or expenditure on tobacco; alcohol consumption (e.g., litres per capita per annum); access to improved sanitation and safe drinking water; food availability or, for instance, fruit consumption (kilos per capita per annum); population coverage of the health care system; the number of physicians (per 10,000 head of population); and health spending. The selected determinants have been used by researchers such as Shaw, Horrace and Vogel (2005), Keita (2014), Gulis (2000), Fayissa and Gutema (2005), Jaba, Balan and Robu (2014), Ray and Linden (2020), Abdulganiyu and Tijjani (2021), Crémieux *et al*. (2005), Bayati, Akbarian and Kavosi (2013), Blazquez-Fernández, Cantarero-Prieto and Pascual-Saez (2017), Nixon and Ulmann (2006), Rodriguez and Sobrino (2015), and Joumard *et al*. (2008).

CO_2 emissions have been used as an explanatory variable by Bayati, Akbarian and Kavosi (2013), Rodriguez and Sobrino (2015), and Stanford and Greenidge (2007), among others. The general conclusion is that higher emissions reduce environmental quality and negatively affect health status. Papers that examined the relationship between CO_2 emissions and health care spending investigated whether air pollution in the form of CO_2 has a positive effect on healthcare expenditure (e.g., Narayan and Narayan, 2008; Yahaya *et al*., 2016; Apergis *et al.*, 2018; Chen *et al*., 2019; Hao *et al*., 2018; Gövdeli, 2019). In some studies, rather than CO_2 emissions, air pollution is measured by, for instance, nitrogen oxide (NO_x) emissions per capita in kgs (e.g. Joumard *et al*., 2008; Rodriguez-Alvarez, 2021). Generally, the relationship between air pollution and life expectancy is negative. Recently, the investigation of the relationship has grown in importance, and the influence of environmental degradation (CO_2 emissions) on health status has been statistically estimated, such as by Omri, Kahouli and Kahia (2023), Polcyn *et al.* (2023), Govdeli (2023), and Dritsaki and Dritsaki (2023).

The use of a subsample of EU countries has also been explored in the literature, although the scope of such studies is not large. For example, Bilas, Franc and Bosnjak (2014) analysed the determinants of life expectancy at birth in 28 EU countries between 2001 and 2011. Their cross-sectional approach was based on a regression where life expectancy at birth was a function of GDP per capita and education attained. The coefficients expressed a positive relationship with GDP per capita and a negative relationship with the education variable. However, their study did not control for the effects of air pollution. Thirty-one European countries were analysed by van den Heuvel and Olaroiu (2017), who found that life expectancy at birth correlated more with social protection expenditures than with health expenditures. Elola, Daponte and Navarro (1995) conducted a regression analysis between 17 Western European countries, comparing the importance of two types of health care systems: national health services and social security systems. The health status was represented by infant mortality, among other factors. Greater efficacy in reducing infant mortality was related to the provision of national health services. Air pollution was measured by Rodriguez-Alvarez (2021), to examine its effects on life expectancy at birth. For 29 European countries in the period between 2005 and 2018, the study showed that the main air pollutants (nitrogen oxides – NO_x; particulate matter with a diameter between 10 and 2.5 μm – PM10; diameter less than 2.5 μm – PM2.5) had a negative effect on life expectancy at birth. On the other hand, the study emphasised that investment in renewable energies was able to positively influence the dependent variable. Due to the limitations related to the set of control variables and the estimation method, Rodriguez-Alvarez did not obtain a statistically significant direct effect of CO_2 emissions on life expectancy at birth.

2. Data and methods

2.1. Data

This study's dependent variable is life expectancy at birth. It uses unbalanced panel data for 1995–2019, for 27 EU countries; the data frequency is annual. The data were derived from the World Development Indicators database of the World Bank. The data show that life expectancy at birth increased throughout this period, with the highest value being an average of 83.49 years for Spain in 2019, and a minimum of 66.39 for Latvia in 1995.

The main variable of interest is CO_2 emissions. In this study, CO_2 emissions are captured by two variables, both derived from the World Development Indicators database. These emissions stem from the burning of fossil fuels and the manufacture of cement; thus, they are produced during consumption of solid, liquid and gas fuels, and gas flaring. The first variable, CO_2 emissions expressed in metric tons per capita, was available for the full sample. In order to check the robustness of the estimates, an additional variable was introduced – CO_2 emissions expressed in kg per 2015 USD of GDP. However, the latter variable was not available for the full sample. The missing observations concerned the last year, i.e., 2019.

The vector of control variables includes those that are commonly used when analysing life expectancy and mainly follows previous studies in this field, as presented in the literature review. Thus, the chosen explanatory variables are: CO_2 emissions, health spending of the general government, social protection spending of the general government, inflation, population ageing, and real GDP per capita. A description of the variables and their data sources is shown in Table 1A in the Appendix.

The availability of public health care was controlled by the health spending of each country's general government. This variable has been commonly used when analysing the determinants of life expectancy at birth (e.g., Rahman, Khanam and Rahman, 2018; Kabir, 2008; Polcyn *et al.*, 2023). Additionally, the social protection spending of the general government was used to control for the effects of social aid on proxied health status; this variable reflects the importance of this expenditure in the structure of the EU countries' general government spending. The spending aims at reducing risks or needs related to sickness, healthcare, disability, old age, unemployment, housing, and social exclusion, among others. The impact of social spending was also analysed by Martín Cervantes, Rueda López and Cruz Rambaud (2021a) for 25 EU countries; van den Heuvel and Olaroiu (2017) for 31 European economies; and by Martín Cervantes, Rueda López and Cruz Rambaud (2021b). In this study, both variables, health spending and social spending, are expressed in constant prices, in 2015 million EUR. The spending categories were divided by population and finally expressed as a deflated spending per capita.

The impact of income per capita was controlled by the real GDP per capita (in million 2015 EUR). The original data were derived from the Eurostat database and deflated by the harmonised CPI, i.e., HICP (2015 = 100). The GDP per capita is also used in order to include the effects of economic growth (e.g., Gürler and Özsoy, 2019; Wang *et al.*, 2020). For example, results presented by Felice et al. (2016) show that GDP per capita was positively related to the life expectancy in Italy and Spain.

The HICP was also used to calculate the effects of inflation. The inflation rate was computed as the difference between the logarithms of HICP. Inflation was employed in order to control for the effects of costs of living on expected length of human life. Inflation has been used as an explanatory variable of health status by researchers such as Martín Cervantes, Rueda López and Cruz Rambaud (2021b), Bai *et al.* (2018), and Azam, Uddin and Saqib (2023).

In this study, the population aged 85 and over was used to control for the ageing of European society. A positive and statistically significant relationship between ageing and life expectancy at birth is expected. The data concerning the number of people aged 85 and over were derived from Eurostat. The variable was incorporated to control for the advanced ageing process of the European population.

2.2. Model and econometric approach

The literature review, outlined in the previous section, makes it possible to construct the baseline specification. The general model is expressed as follows.

$$le_{i,t} = \alpha_0 + \alpha_1 CO_2 emissions_{i,t} + \sum \alpha_k \, x_{i,t} + \epsilon_{i,t} \quad (1)$$

where $le_{i,t}$ denotes the life expectancy at birth in country i at time t. The variable $CO_2 emissions_{i,t}$ indicates the main variable of interest – i.e., the variable that captures CO_2 emissions. However, as emphasised in the data subsection, the variable is expressed by $co2e_{i,t}$ which denotes the CO_2 emissions in metric tons per capita, and by $co2e\_kg_{i,t}$ for CO_2 emissions expressed in kg per 2015 USD of GDP. The vector $x_{i,t}$ represents the vector of control variables. The chosen set of explanatory variables includes those commonly used in the literature on the subject, such as Bilas, Franc and Bosnjak (2014), Blazquez-Fernández, Cantarero-Prieto and Pascual-Saez (2017), and Poças *et al.* (2020). In order to simplify the interpretation, variables were transformed into natural logarithms. The list of explanatory variables is presented in Table 1A in the Appendix, and selected descriptive statistics of log-linearised variables are shown in Table 2A in the Appendix. The final estimated equation is as follows.

$$ln\_le_{i,t} = \beta_0 + \beta_1 ln\_CO_2 emissions_{i,t} + \sum \beta_k \, ln\_x_{i,t} + \varepsilon_{i,t} \quad (2)$$

As the panel is unbalanced, the panel unit root test for unbalanced data was conducted. Table 3A in the Appendix presents the results for the Im, Pesaran and Shin (2003) test (IPS) and for the alternative test – the Fisher-type test. As shown, generally, the results allow us to use the variables at levels.

The general empirical model is given in equation 2. The baseline equation for the relationship between CO_2 emissions and life expectancy includes the following controls: CO_2 emissions expressed by the $co2e_{i,t}$ variable, and alternatively by the $co2e\_kg_{i,t}$ variable; health spending of the general government per capita in constant 2015 EUR; social protection spending of the general government per capita in constant 2015 EUR; GDP per capita in constant 2015 EUR; and population aged 85 and over.

The Beck and Katz (1995) panel-corrected standard errors procedure (PCSE) was applied as a baseline estimation technique, to control for heteroscedasticity across panels and for serial correlation. For the latter purpose, the implemented PCSE variant uses a correlation parameter that is unique for each panel. The robustness of the main estimator was checked using Parks' (1967) feasible generalised least squares estimator (FGLS) (e.g., Davidson and McKinnon, 1993; Greene, 2012). The comparison of results for the PCSE procedure and the FGLS estimator is valuable. As mentioned by Beck and Katz (1995), panel-corrected standard errors help to avoid statistical overconfidence that may appear with the feasible generalised least-squares estimator in panels where T is smaller than N. The empirical part of the study also included alternative analyses of the robustness checks for the baseline specifications and estimation techniques. The additional robustness analysis was based on the fixed-effects model approach that incorporates the Driscoll and Kraay (1998) standard errors.

3. Results

The baseline estimation uses the PCSE procedure. Table 1 presents the results for the effects of CO_2 emissions on life expectancy at birth. The estimated coefficients for the main equation are given in columns I and II. The results confirm the statistically significant and negative effects of CO_2 emissions on life expectancy. The estimated elasticities are robust regardless of the variable used to capture the impact of the emissions. The value of the coefficient in columns I and II is -0.018. Except for the effects of real GDP per capita, the rest of the estimates (presented in columns I and II) are robust and statistically significant.

When the lagged variable for the effects of emissions is added, both coefficients are negative and statistically significant. However, the effects of the CO_2 emissions lagged by one year are nearly four times weaker than the current impact (see columns III and IV). As in the baseline specification, replacing the CO_2 emissions in metric tons per capita with CO_2 emissions in kg per 2015 USD of GDP does not cause any essential difference in the estimated elasticities, except for the coefficient for the effects of the GDP per capita.

Columns V and VI present estimates of the elasticities when controlling the cost of living (proxied by inflation). The equations omit the effects of ageing captured by the population aged 85 and over. Moreover, the equations focus on the importance of health spending by the general government, but the effects of social support have been omitted from the calculation. In columns V and VI, compared to the baseline equations (columns I and II) and equations with lagged effects of the CO_2 (columns III and IV), the effects of CO_2 emissions are robust (the estimated coefficients are around -0.2 and significant). In columns V and VI, effects of health spending are stronger than for the specifications that include social spending, which was expressed by higher elasticities. The obtained relationship between health spending and life expectancy is consistent with the literature. For example, the significant and positive effects were investigated by Poças *et al.* (2020) in a panel for EU economies, James *et al.* (2017) for OECD economies, and by Polcyn et al. (2023), who estimated the short- and long-run positive effects for Asian countries. The results presented in Table 1 show the significant estimates not only for health spending, but also for social spending. Similar outcomes were obtained by Roffia, Bucciol and Hashlamoun (2023) for 36 OECD countries over the period from 1999 to 2018.

Table 1 Estimates of the parameters

	I	II	III	IV	V	VI	VII	VIII	IX
$ln\_co2e_{i,t}$	-0.018*** (0.003)		-0.019*** (0.003)		-0.022*** (0.003)		-0.008** (0.003)	-0.015*** (0.003)	
$ln\_co2e_{i,t-1}$			-0.005* (0.003)						
$ln\_co2e\_kg_{i,t}$		-0.018*** (0.004)		-0.020*** (0.003)		-0.023*** (0.003)			-0.019*** (0.003)
$ln\_co2e\_kg_{i,t-1}$				-0.006** (0.003)					
$ln\_he\_pc_{i,t}$	0.008*** (0.002)	0.007*** (0.003)	0.011*** (0.002)	0.007*** (0.002)	0.014*** (0.002)	0.013*** (0.002)	0.007*** (0.002)	0.015*** (0.002)	0.008*** (0.002)
$ln\_se\_pc_{i,t}$	0.021*** (0.004)	0.021*** (0.004)	0.020*** (0.003)	0.020*** (0.003)			0.029*** (0.004)	0.031*** (0.002)	0.024*** (0.003)
$ln\_gdp\_pc_{i,t}$	0.023*** (0.006)	0.006 (0.006)	0.017*** (0.005)	-0.001 (0.005)	0.037*** (0.003)	0.015*** (0.004)	0.030*** (0.005)		
$ln\_pop85_{i,t}$	0.008*** (0.001)	0.008*** (0.002)	0.006*** (0.001)	0.005*** (0.001)			0.010*** (0.001)	0.008*** (0.001)	0.008*** (0.002)
$ln\_co2e_{i,t} * old$							-0.017*** (0.002)		
$\pi_{i,t}$					-0.037*** (0.007)	-0.037*** (0.007)			
const.	3.830*** (0.032)	3.943*** (0.041)	3.911*** (0.026)	4.051*** (0.037)	3.926*** (0.017)	4.081*** (0.025)	3.686*** (0.037)	3.929*** (0.020)	3.975*** (0.025)
Obs.	664	637	639	612	614	614	664	664	637
R-squared	0.9998	0.9998	0.9999	0.9998	0.9999	0.9999	0.9999	0.9998	0.9998
Wald χ^2	896.5	836.9	1135.2	895.8	1168.58	1090.84	1154.7	1034.7	723.4
Prob $>\chi^2$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: Beck and Katz's (1995) procedure with panel-specific autocorrelation structure and heteroscedasticity across panels; *, **, *** - denote significance at 10%, 5% and 1%, respectively; errors in parentheses

Source: own work

The estimated coefficient for the relationship between inflation and $ln\_leb_{i,t}$ is approximately -0.037. The negative effect of inflation was also supported in the literature; for example, by Monsef and Mehrjardi (2015), for a panel consisting of 136 countries.

Because the impact of real GDP per capita is not robust, columns VIII and IX present coefficients estimated for the baseline equation without the real GDP per capita variable. The elasticities for CO_2 emissions are lower than the estimates in columns I and II, but the coefficients are similar, at about -0.02.

The results of the alternative FGLS approach are generally similar (see Table 4A in the Appendix). The results show that in terms of CO_2 emissions, the estimated elasticities for life expectancy in EU economies are around -0.02; these are higher than the estimated coefficients of around -0.011 for 31 of the world's most polluted countries (Rahman, Rana and Khanam, 2022). Moreover, the effects of the emissions lagged by one year are similarly around four times lower than for current emissions.

Table 5A in the Appendix presents the estimates for the fixed-effects approach with Driscoll–Kraay standard errors. The elasticities for CO_2 emissions are generally statistically significant, although the effects of lagged CO_2 emissions are not statistically significant. Furthermore, the effect of real GDP per capita is not robust.

Column VII of Table 1 shows estimates for the baseline specification extended by the interactive variable $ln\_co2e_{it} * old$. The variable captures the effects of CO_2 emissions on life expectancy in old EU countries. The estimated coefficient is statistically significant. Based on these results, the sample was subdivided to analyse the impact of CO_2 emissions in the old and new EU countries separately. The first group consists of 14 old EU countries, and the second contains 13 new EU countries, i.e., those that joined the EU in 2004 and later.

The results of selected estimations using Beck and Katz's (1995) method, in subsamples for old and new EU economies, are presented in Table 2. The FGLS estimator was also used for the panels, given that $N < T$. The results of this estimation method are presented in Table 6A in the Appendix. In order to control for problems of autocorrelation and groupwise heteroskedasticity, the fixed-effects model with Driscoll–Kraay standard errors was also applied; the results are presented in Table 7A in the Appendix.

Table 2 Estimates for the old and new European Union countries

	old EU	new EU	old EU	new EU	old EU	new EU	old EU	new EU	old EU	new EU	old EU	new EU
$ln\_co2e_{i,t}$	-0.024*** (0.004)	-0.009** (0.004)			-0.026*** (0.004)	-0.012*** (0.004)			-0.036*** (0.004)	-0.017*** (0.005)		
$ln\_co2e_{i,t-1}$					-0.010** (0.004)	-0.002 (0.004)						
$ln\_co2e\_kg_{i,t}$			-0.024*** (0.004)	-0.009* (0.005)			-0.025*** (0.004)	-0.012*** (0.005)			-0.035*** (0.004)	-0.019*** (0.005)
$ln\_co2e\_kg_{i,t-}$							-0.010*** (0.003)	-0.002 (0.004)				
$ln\_he\_pc_{i,t}$	0.006** (0.003)	0.001 (0.004)	0.006** (0.003)	0.006 (0.004)	0.007*** (0.003)	0.014*** (0.004)	0.005* (0.003)	0.012*** (0.004)	0.007** (0.003)	0.014*** (0.004)	0.006** (0.003)	0.014*** (0.004)
$ln\_se\_pc_{i,t}$	0.014*** (0.005)	0.035*** (0.006)	0.015*** (0.006)	0.035*** (0.006)	0.017*** (0.005)	0.031*** (0.005)	0.014** (0.006)	0.030*** (0.005)				
$ln\_gdp\_pc_{i,t}$	0.036*** (0.006)	0.027*** (0.008)	0.014** (0.007)	0.018** (0.009)	0.034*** (0.006)	0.019*** (0.007)	0.008 (0.007)	0.005 (0.008)	0.046*** (0.006)	0.038*** (0.007)	0.013* (0.007)	0.019** (0.007)
$ln\_pop85_{i,t}$	0.008*** (0.002)	0.012*** (0.002)	0.008*** (0.002)	0.013*** (0.003)	0.006*** (0.002)	0.006*** (0.002)	0.007*** (0.002)	0.009*** (0.002)				
$\pi_{i,t}$									-0.034 (0.023)	-0.027*** (0.008)	-0.038* (0.023)	-0.027*** (0.008)
$const.$	3.777*** (0.066)	3.652*** (0.059)	3.905*** (0.075)	3.700*** (0.071)	3.812*** (0.057)	3.792*** (0.052)	3.998*** (0.074)	3.878*** (0.066)	3.919*** (0.056)	3.912*** (0.045)	4.133*** (0.067)	4.043*** (0.054)
Obs.	350	314	336	301	336	303	322	290	336	305	322	292
R-squared	0.9998	0.9998	0.9998	0.9998	0.9999	0.9999	0.9998	0.9999	0.9999	0.9999	0.9999	0.9998
Wald χ^2	170.11	369.10	168.17	319.23	269.82	395.78	185.31	295.22	186.92	230.34	166.85	188.68
Prob $>\chi^2$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Beck and Katz's (1995) procedure with panel-specific autocorrelation structure and heteroscedasticity across panels; *, **, *** - denote significance at 10%, 5% and 1%, respectively; errors in parentheses

Source: own work

The results indicated by the interactive variable are confirmed in the subsamples. The estimated coefficients, which proxy elasticities for the relationship between CO_2 emissions and life expectancy at birth, show higher negative effect in the sample for the old EU countries. This is obtained for all three estimation methods (compare the results for Table 2 presented above, with those of Tables 6A and 7A in the Appendix). As shown, ageing has a positive effect on life expectancy at birth, as expected. Moreover, in the case of the FGLS method, the average elasticities of ageing in the old EU are generally slightly lower. The literature indicated that inflation would generate negative health status outcomes (such as the findings presented in Azam, Uddin and Saqib, 2023), and this relationship is found for both subsamples. However, the negative effect of the costs of living on the dependent variable is higher in the case of the old EU. The effects of GDP per capital are statistically significant and generally strongest in the older, i.e., more economically advanced, EU countries. This indicates that the population in more advanced economies generally has a longer lifespan. However, in the full sample, the elasticities related to the effects of real GDP per capita on life expectancy depend on the controls used in the specifications, and on the variable applied to capture the effects of CO_2 emissions. Thus, the effect of real GDP per capita is not robust, and requires additional analysis.

Conclusions

The EU's population is getting older, which is increasing people's life expectancy at birth. The health status of EU countries, proxied by life expectancy at birth, is affected differently by the impact of determinants associated with, for example, social conditions or the quality of the environment. In this study, the effects of CO_2 emissions on life expectancy were analysed in 27 EU countries over the period 2015–2019.

A statistically significant and negative relationship was found between CO_2 emissions and life expectancy at birth; this correlation was robust regardless of the variable used to control for CO_2 emissions. However, the variable of interest (CO_2 emissions in metric tons per capita, or CO_2 emissions in kg per 2015 USD of GDP) determined the effects of the other control variables. Generally, the PCSE and FGLS methods made it possible to estimate elasticities of approximately -0.02 for the relationship between the CO_2 emissions and the dependent variable. This denotes that the reduction (increase) of CO_2 emissions by 1% caused an increase (reduction) in the life expectancy at birth by 0.02%, on average. However, the results might be affected by the time-span of the unbalanced sample, the heterogeneity of the countries, the transformation of variables, or the estimation methods employed.

The introduction of an interactive variable confirmed that the reduction in emissions in the old EU nations affected the life expectancy in those countries. As a result, the country sample was divided into two subsamples. The effects of CO_2 emissions were higher in the old EU countries, and generally statistically significant.

Consequently, the results contribute to the literature by providing findings about CO_2 emission's effects on life expectancy. The main findings may inform the debates on strategies for managing population ageing and for improving the environment. The results may also be helpful in laying the foundations for sustainable growth. These aspects are important for policymakers and may underpin the development strategies of many countries, to benefit from the complementary effects of the population's health status and environmental protection.

However, the complex estimates suggest additional areas for further research and extensions; these may include alternative estimation techniques based on recognising the differences between long-run and short-run relationships, and the use of alternative estimation techniques adjusted for heterogeneous panels. Focusing on other control variables, especially those directly related to the population's health status, may also be valuable. Due to the weak relationship with life expectancy at birth, a deeper analysis of the effects of real GDP per capita is also recommended. In addition, given the different elasticities among old and new EU economies regarding the CO_2 emissions–life expectancy relationship, further in-depth investigation may include the role of environmental protection spending, or of other forms of pollution.

The results of this study contribute to the debate on the health-related aspects of environmental quality and population ageing. They also raise questions about the effects of social support on the increasing life expectancy of the European population. As revealed, environmental degradation is correlated with deteriorating life expectancy, and the estimated effect is stronger for old EU economies. The issue is highly topical and requires further and in-depth analysis. In addition, the study contributes to the literature about recognising the relationship between the quality of the environment and health status. An important conclusion of the study is that good socio-economic conditions may not be sufficient to ensure higher life expectancy at birth; environmental aspects are also important.

Some implications for policy emerge from the findings. One recommendation is to implement adequate policies that may reduce environmental degradation to improve health status. Moreover, such actions should be consistent with the concept of sustainable growth. The results imply that environmental protection expenditure may help to improve health status; as the negative value of the CO_2 emissions' elasticity is higher in old EU economies, this suggests that these economies should implement policies that prioritise reduction of environmental degradation. Overall, the economic growth associated with a cleaner environment supports the health status of the EU population and the quality of ageing. This study also confirms that social expenditure contributes to increased life expectancy at birth.

Disclosure statement

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Appendix

Table 1A Variables and data source

$le_{i,t}$	Life expectancy at birth	WDI World Bank
$co2e_{i,t}$	CO_2 emissions (metric tons per capita)	WDI World Bank
$co2e\_kg_{i,t}$	CO_2 emissions (kg per 2015 USD of GDP)	WDI World Bank
$he\_pc_{i,t}$	Health spending of general government per capita (2015 euro, mln)	Eurostat
$se\_pc_{i,t}$	Social protection spending of general government per capita (2015 euro, mln)	Eurostat
$gdp\_pc_{i,t}$	GDP per capita (2015 euro, mln)	Eurostat
$pop85_{i,t}$	Population in the age 85 and more	Eurostat
$\pi_{i,t}$	Inflation, calculated as a difference of log HICP, 2015=100	Eurostat

Source: own elaboration

Table 2A Selected descriptive statistics

Variable	Obs.	Mean	Std. dev.	Min	Max
$ln\_le_{i,t}$	675	4.349	0.046	4.196	4.425
$ln\_CO2e_{i,t}$	675	1.958	0.410	1.074	3.243
$ln\_CO2e_{i,t}$	648	-1.075	0.615	-2.706	0.579
$ln\_gdp\_pc_{i,t}$	670	9.875	0.735	8.066	11.534
$ln\_he\_pc_{i,t}$	670	6.995	0.816	4.406	8.512
$ln\_soc\_pc_{i,t}$	670	8.010	0.907	5.649	9.797
$ln\_pop85_{i,t}$	669	11.633	1.539	8.010	14.623
$\pi_{i,t}$	645	0.029	0.053	-0.017	0.936

Source: own elaboration

Table 3A Results of the unit root test

	p-value for Im, Pesaran, Shin unit root test	Fisher-type unit-root test
$ln\_le_{i,t}$	0.0000	Inverse chi-squared(54) P 224.9248 0.0000; Inverse normal Z -10.3498 0.0000 Inverse logit t(139) L* -11.7325 0.0000; Modified inv. chi-squared Pm 16.4472 0.0000
$ln\_co2e_{i,t}$	0.0009	Inverse chi-squared(54) P 145.2549 0.0000; Inverse normal Z -6.8135 0.0000 Inverse logit t(139) L* -7.0700 0.0000; Modified inv. chi-squared Pm 8.7810 0.0000
$ln\_he\_pc_{i,t}$	0.0008	Inverse chi-squared(54) P 152.6725 0.0000; Inverse normal Z-7.3266 0.0000 Inverse logit t(139) L* -7.6544 0.0000; Modified inv. chi-squared Pm 9.4948 0.0000
$ln\_se\_pc_{i,t}$	0.0741	Inverse chi-squared(54) P 157.9256 0.0000; Inverse normal Z -7.5121 0.0000 Inverse logit t(139) L* -7.8935 0.0000; Modified inv. chi-squared Pm 10.0002 0.0000
$ln\_gdp\_pc_{i,t}$	0.0394	Inverse chi-squared(54) P 78.4715 0.0165; Inverse normal Z -2.4742 0.0067 Inverse logit t(139) L*-2.4673 0.0074; Modified inv. chi-squared Pm 2.3548 0.0093
$ln\_pop85_{i,t}$	0.0007	Inverse chi-squared(54) P163.4615 0.0000; Inverse normal Z -7.3810 0.0000 Inverse logit t(139) L* -7.8692 0.0000; Modified inv. chi-squared Pm 10.5329 0.0000
$ln\_co2e\_kg_{i,t}$	0.0000	Inverse chi-squared(54) P 172.0016 0.0000; Inverse normal Z -8.1867 0.0000 Inverse logit t(139) L*-8.7357 0.0000; Modified inv. chi-squared Pm 11.3547 0.0000
$\pi_{i,t}$	0.0000	Inverse chi-squared(54) P 240.3038 0.0000; Inverse normal Z -10.0551 0.0000 Inverse logit t(139) L*-12.4474 0.0000; Modified inv. chi-squared Pm 17.9271 0.0000
	H0: All panels contain unit roots Ha: Some panels are stationary	H0: All panels contain unit roots Ha: At least one panel is stationary

Source: own elaboration

Table **4A** Robustness checks, results for FGLS approach

	I	II	III	IV	V	VI	VII	VIII	IX
$ln\_co2e_{i,t}$	-0.022*** (0.002)		-0.022*** (0.002)		-0.024*** (0.002)		-0.010*** (0.003)	-0.017*** (0.003)	
$ln\_co2e_{i,t-1}$			-0.006** (0.002)						
$ln\_co2e\_kg_{i,t}$		-0.021*** (0.002)		-0.021*** (0.003)		-0.024*** (0.002)			-0.024*** (0.002)
$ln\_co2e\_kg_{i,t-1}$				-0.006** (0.002)					
$ln\_he\_pc_{i,t}$	0.007*** (0.002)	0.006*** (0.002)	0.008*** (0.002)	0.005*** (0.002)	0.009*** (0.002)	0.009*** (0.002)	0.007*** (0.002)	0.015*** (0.002)	0.008*** (0.002)
$ln\_se\_pc_{i,t}$	0.014*** (0.003)	0.013*** (0.003)	0.015*** (0.003)	0.013*** (0.003)			0.021*** (0.003)	0.028*** (0.002)	0.018*** (0.002)
$ln\_gdp\_pc_{i,t}$	0.031*** (0.004)	0.012*** (0.004)	0.027*** (0.004)	0.006 (0.004)	0.042*** (0.003)	0.017*** (0.003)	0.036*** (0.004)		
$ln\_pop85_{i,t}$	0.007*** (0.001)	0.007*** (0.001)	0.006*** (0.001)	0.005*** (0.001)			0.008*** (0.001)	0.006*** (0.001)	0.006*** (0.001)
$ln\_co2e_{i,t} * old$							-0.015*** (0.002)		
$\pi_{i,t}$					-0.040*** (0.006)	-0.040*** (0.006)			
const.	3.834*** (0.023)	3.970*** (0.030)	3.899*** (0.022)	4.057*** (0.031)	3.919*** (0.015)	4.084*** (0.020)	3.708*** (0.028)	3.966*** (0.016)	4.037*** (0.019)
Obs.	664	637	639	612	641	614	664	664	637
Wald χ^2	1124.42	1098.91	1299.02	1080.48	1530.35	1468.75	1418.31	1157.72	957.66
Prob $>\chi^2$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: Panel-specific autocorrelation structure and heteroscedasticity across panels applied; *, **, *** - denote significance at 10%, 5% and 1%, respectively; errors in parentheses

Source: own elaboration

Table 5A Robustness checks, results for the fixed effects approach with Driscoll-Kraay standard errors

	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**
$ln\_co2e_{i,t}$	-0.023*** (0.005)		-0.063*** (0.005)		-0.022*** (0.006)		-0.008 (0.006)	-0.021*** (0.005)	
$ln\_co2e_{i,t-1}$					-0.004 (0.005)				
$ln\_co2e\_kg_{i,t}$		-0.023*** (0.005)		-0.065*** (0.005)		-0.018** (0.007)			-0.021*** (0.004)
$ln\_co2e\_kg_{i,t-1}$						-0.006 (0.006)			
$ln\_he\_pc_{i,t}$	0.015*** (0.001)	0.016*** (0.001)	0.015*** (0.005)	0.015*** (0.005)	0.015*** (0.002)	0.015*** (0.002)	0.014*** (0.002)	0.021*** (0.002)	0.013*** (0.003)
$ln\_se\_pc_{i,t}$	0.029*** (0.005)	0.028*** (0.005)			0.031*** (0.005)	0.029*** (0.005)	0.028*** (0.005)	0.033*** (0.004)	0.025*** (0.003)
$ln\_gdp\_pc_{i,t}$	0.014** (0.007)	-0.007 (0.009)	0.067*** (0.008)	0.004 (0.010)	0.009* (0.005)	-0.013 (0.007)	0.017*** (0.006)		
$ln\_pop85_{i,t}$	0.039*** (0.007)	0.041*** (0.007)			0.039*** (0.006)	0.041*** (0.007)	0.039*** (0.007)	0.040*** (0.007)	0.042*** (0.006)
$ln\_co2e_{i,t} * old$							-0.025*** (0.005)		
$\pi_{i,t}$			-0.023 (0.019)	-0.020 (0.018)					
const.	3.463*** (0.075)	3.588*** (0.101)	3.705*** (0.058)	4.136*** (0.076)	3.500*** (0.066)	3.640*** (0.085)	3.447*** (0.075)	3.512*** (0.065)	3.541*** (0.061)
Obs.	664	637	641	614	639	612	664	664	637
R-squared	0.8862	0.8829	0.7736	0.7631	0.8842	0.8804	0.8907	0.8849	0.8825
F-statistic	299.89	452.29	216.81	215.43	158.06	207.47	310.05	350.18	300.76
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: *, **, *** - denote significance at 10%, 5% and 1%, respectively; errors in parentheses

Source: own elaboration

Table 6A Robustness checks, results for FGLS approach for the old and new European Union countries

	old EU	new EU	old EU	new EU	old EU	new EU	old EU	new EU	old EU	new EU	old EU	new EU
$ln\_co2e_{i,t}$	-0.023*** (0.003)	-0.015*** (0.004)			-0.027*** (0.003)	-0.016*** (0.004)			-0.034*** (0.003)	-0.021*** (0.004)		
$ln\_co2e_{i,t-1}$					-0.004 (0.003)	-0.002 (0.004)						
$ln\_co2e\_kg_{i,t}$			-0.023*** (0.003)	-0.015*** (0.004)			-0.024*** (0.003)	-0.015*** (0.004)			-0.032*** (0.003)	-0.022*** (0.004)
$ln\_co2e\_kg_{i,t-1}$							-0.006* (0.003)	-0.004 (0.004)				
$ln\_he\_pc_{i,t}$	0.005*** (0.002)	0.009*** (0.003)	0.005*** (0.002)	0.009** (0.003)	0.005** (0.003)	0.014*** (0.003)	0.002 (0.002)	0.012*** (0.004)	0.004 (0.002)	0. 013*** (0.003)	0. 004 (0.002)	0.011*** (0.004)
$ln\_se\_pc_{i,t}$	0.014*** (0.005)	0.026*** (0.004)	0.014*** (0.004)	0.025*** (0.004)	0.016*** (0.004)	0.025*** (0.004)	0.013*** (0.005)	0.024*** (0.004)				
$ln\_gdp\_pc_{i,t}$	0.041*** (0.006)	0.031*** (0.007)	0.018*** (0.006)	0.017** (0.007)	0.041*** (0.005)	0.025*** (0.006)	0.014** (0.006)	0.007 (0.007)	0.051*** (0.005)	0.043*** (0.006)	0.021*** (0.006)	0.018*** (0.006)
$ln\_pop85_{i,t}$	0.008*** (0.002)	0.008*** (0.002)	0.008*** (0.002)	0.009*** (0.002)	0.006*** (0.001)	0.004*** (0.002)	0.007*** (0.002)	0.007*** (0.002)				
$\pi_{i,t}$									-0.039* (0.020)	-0.027*** (0.007)	-0.039** (0.019)	-0.028*** (0.007)
$const.$	3.730*** (0.054)	3.715*** (0.046)	3.890*** (0.060)	3.813*** (0.054)	3.762*** (0.051)	3.798*** (0.045)	3.963*** (0.063)	3.916*** (0.056)	3.891*** (0.048)	3.878*** (0. 037)	4.080*** (0. 056)	4.060*** (0.043)
Obs.	350	314	336	301	336	303	322	290	336	305	322	292
Wald χ^2	252.72	466.83	241.47	388.06	338.22	492.28	244.06	359.92	257.50	363.18	239.50	250.08
Prob $>\chi^2$	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: Panel-specific autocorrelation structure and heteroscedasticity across panels applied; *, **, *** - denote significance at 10%, 5% and 1%, respectively; errors in parentheses

Source: own elaboration

Table 7A Robustness checks, results for the fixed effects approach with Driscoll-Kraay standard errors for the old and new European Union countries

	old EU	new EU	old EU	new EU	old EU	new EU	old EU	new EU	old EU	new EU	old EU	new EU
$ln\_co2e_{i,t}$	-0.025*** (0.003)	-0.013* (0.006)			-0.022*** (0.006)	-0.012 (0.008)			-0.060*** (0.008)	-0.038*** (0.008)		
$ln\_co2e_{i,t-1}$					-0.004 (0.005)	-0.001 (0.008)						
$ln\_co2e\_kg_{i,t}$			-0.024*** (0.003)	-0.013* (0.006)			-0.022** (0.009)	-0.007 (0.007)			-0.062*** (0.008)	-0.040*** (0.009)
$ln\_co2e\_kg_{i,t-1}$							-0.003 (0.006)	-0.009 (0.007)				
$ln\_he\_pc_{i,t}$	0.016*** (0.003)	0.012** (0.004)	0.016*** (0.003)	0.013** (0.004)	0.015*** (0.003)	0.013*** (0.004)	0.015*** (0.003)	0.013*** (0.004)	0.017*** (0.005)	0.009 (0.009)	0.016*** (0.004)	0.009 (0.009)
$ln\_se\_pc_{i,t}$	0.037*** (0.008)	0.027*** (0.005)	0.035*** (0.009)	0.026*** (0.004)	0.041*** (0.008)	0.028*** (0.004)	0.038*** (0.008)	0.027*** (0.004)				
$ln\_gdp\_pc_{i,t}$	0.027*** (0.006)	0.020 (0.012)	0.005 (0.006)	0.008 (0.015)	0.029*** (0.006)	0.012 (0.010)	0.006 (0.006)	-0.001 (0.011)	0.088*** (0.013)	0.072*** (0.014)	0.034* (0.017)	0.032 (0.020)
$ln\_pop85_{i,t}$	0.038*** (0.007)	0.035*** (0.006)	0.041*** (0.007)	0.036*** (0.007)	0.036*** (0.007)	0.036*** (0.006)	0.039*** (0.006)	0.037*** (0.006)				
$\pi_{i,t}$									-0.298** (0.100)	-0.035** (0.015)	-0.316*** (0.100	-0.033** (0.013)
$const.$	3.232*** (0.052)	3.508*** (0.086)	3.360*** (0.052)	3.577*** (0.124)	3.222*** (0.060)	3.543*** (0.073)	3.349*** (0.058)	3.632*** (0.104)	3.467*** (0.145)	3.666*** (0.087)	3.821*** (0.174)	3.938*** (0.141)
Obs.	350	314	336	301	336	303	322	290	336	305	322	292
R-squared	0.9318	0.8698	0.9310	0.8641	0.9300	0.8689	0.9293	0.8628	0.8079	0.7888	0.8071	0.7748
F-statistic	858.01	312.20	1138.98	360.19	1358.90	249.10	794.04	220.59	102.57	283.42	178.41	205.99
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: *, **, *** - denote significance at 10%, 5% and 1%, respectively; errors in parentheses

Source: own elaboration