Population and Environment (2025) 47:38
https://doi.org/10.1007/s11111-025-00504-8

ORIGINAL PAPER

Air pollution and subjective wellbeing: exploring the link between PM10 and a composite measure of wellbeing

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Received: 4 March 2024 / Accepted: 2 September 2025

Abstract

Air pollution is detrimental to a person's overall quality of life, not only harming physical health, but also potentially undermining wellbeing across various aspects of daily living. The aim of this study is to investigate whether air quality is associated with individual subjective wellbeing, based on multiple measurements of wellbeing encompassing life evaluation and sense of purpose and meaning, using data at the regional and country level in Europe. This study is based on the sixth round of the European Social Survey conducted in 2012, linked to data on air pollution—measured by PM10 levels—across 3825 stations gathered from air quality reports by the European Environment Agency. Using multilevel regression models and controlling for an array of confounders at the individual level, we find no association between the regional-level intensity of air pollution and individuals' subjective wellbeing. Rather, this association depends on the area of residence: individuals living in the countryside experience a noticeable decrease in subjective wellbeing when PM10 concentration increases, while for individuals living in urban areas subjective wellbeing tends to increase. No association between PM10 and subjective wellbeing is observed in small cities. Future studies in this emerging literature on pollution and individuals' wellbeing should consider the complex linkages between place of residence, amenities, and pollution.

Keywords Air quality · European regions · Life satisfaction · Pollution · PM10 · Subjective wellbeing

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Published online: 11 November 2025

Introduction

Global concerns regarding climate change have sparked unprecedented attention among population scholars to the consequences of increasing CO_2 emissions linked to the burning of fossil fuels for current and future demographic processes (Dyson, 2005; Muttarak, 2021). The implications of climate change for major life course events have been examined in relation to migration (Abel et al., 2019), fertility (Bastianelli, 2024; De Rose & Testa, 2015; Schneider-Mayerson & Leong, 2020) mortality (EEA, 2024; Medina et al., 2004; Bickerstaff & Walker, 2001), and educational outcomes (Keivabu & Rüttenauer, 2022). A related literature has examined the impacts of other pollutions—mainly particulate matter—that stem from fossil fuel use. In particular, the negative implications of air pollution for health are well-established (see, e.g., Anderson et al., 2012; Guxens & Sunyer, 2012) and a growing body of literature is concerned with its broader repercussions on individuals' subjective wellbeing (Goetzke & Rave, 2015; Cuñado & Pérez de Gracia, 2013; Fleury-Bahi et al., 2013; Orru et al., 2016).

Because subjective wellbeing is related to general health, the documented association between poor air quality and health can have negative repercussions also on subjective wellbeing (Al Ahad, 2024). Yet, subjective wellbeing can also be affected directly by poor air quality, beyond its impact on physical health (Al Ahad, 2024; Orru et al., 2016): a polluted environment may reduce outdoor activities and opportunities to meet other people (Yoo, 2021); it can increase one's stress due to the environmental consequences of pollution (e.g., noise, extreme temperatures, and climate change), generate concerns about the future, or increase the risk of experiencing mental health issues (Cao et al., 2023; Guxens & Sunyer, 2012). Exposure to a polluted environment can also influence fertility (for a review, see Vizcaíno et al., 2016) and fertility-related decisions, especially among individuals who are most concerned about the environment (Bastianelli, 2024; Schneider-Mayerson & Leong, 2020). The subjective cost associated with air pollution is moderated by a large number of socio-demographic factors, including age, gender, net income, marital and employment status (Luechinger, 2010). The aim of this paper is to investigate whether, net of general health and other confounders, living in an air-polluted environment is associated with lower life satisfaction. More specifically, this paper analyzes the association between air quality at the regional level and individual subjective wellbeing.

Due to the high granularity of pollution data, previous research on this topic is currently limited by the focus on single countries or cities (MacKerron & Mourato, 2009; Orru et al., 2016; Rehdanz & Maddison, 2008) and/or by the use of a single indicator of individual wellbeing (Apergis, 2018; Ferreira et al., 2013; Luechinger, 2010; Welsch, 2006). Many previous studies (Apergis, 2018; Luechinger, 2010; Welsch, 2006) also lack information on individual socio-demographic characteristics other than wellbeing.

This study expands previous works by adopting a comparative perspective and a composite index of wellbeing, investigating the association between air pollution and subjective wellbeing across 190 regions within 24 European countries.

We use individual-level micro-data gathered from Round 6 of the European Social Survey (referring to the year 2012), which includes a rotating module on "Personal and Social Wellbeing" specifically designed to collect information on multiple aspects of subjective wellbeing (e.g., overall life satisfaction, engagement, self-esteem) and contains a variety of individual-level socio-demographic information. As a source of pollution, we focus on particulate matter and more specifically on PM10, which is more easily detectable by weather stations and more visible to the naked eye compared to other sources of pollution such as sulphur dioxide (SO2) commonly examined in the existing literature. Hence, we advance the literature by evaluating the association between air pollution and a comprehensive measure of subjective wellbeing, including life evaluation and sense of purpose (Jeffrey et al., 2015; Mahoney, 2023), across a large number of European countries and regions.

Literature review

Exposure to pollutant agents, like particulate matter, can have negative impacts on health. In the literature, aggregate measures of pollution at the regional or municipal level are commonly used. In this study, we decided to focus on particulate matter since, among all pollutant agents, it is the most clearly distinguishable to the naked eye without the use of any detection devices. Particulate matter is a mixture of liquid and solid particles divided into two categories, PM10 and PM2.5, based on their diameter (expressed in micrometers). We believe the impact on subjective wellbeing is worth analyzing. PM10, due to its larger size than PM2.5, can be observed directly, especially in warmer climates (Won et al., 2021) and may thus influence residents' everyday lives and living conditions. Greater exposure to PM10 and PM2.5 pollutants is correlated with poorer health conditions, and hence with a decline in life satisfaction (Al Ahad, 2024; Silva et al., 2012).

In 2022, air pollutants concentrations in Europe were well above the levels recommended by the World Health Organization (EEA, 2024). It has been demonstrated that the exposure to particulate matter intensifies asthma and pulmonary diseases, cardiovascular diseases, and diabetes, and can even lead to cancer in extreme cases (Anderson et al., 2012; EEA, 2024; Medina et al., 2004). People living in polluted areas are also more at risk of experiencing mental health issues (Cao et al., 2023) and often experience short-memory loss, impulsivity, and are more likely to develop anxiety and depression (Guxens & Sunyer, 2012). Mental health issues are not mitigated over time by habituation to living in polluted areas, but rather intensified (Cao et al., 2023; Menz, 2011).

Aside from health-related aspects, humans are affected by damages to the ecosystem because of our empathic symbiosis with our surroundings: Wilson (1984) introduced the term "biophilia" to indicate the attachment to nature and its effect on humans' mood and subjective wellbeing, describing it as "the urge to affiliate with other forms of life". According to this concept, landscape degradation, deforestation, and air pollution could represent direct causes of a decrease in happiness of people in surrounding areas. Large comparative studies have demonstrated that a polluted environment reduces people's wellbeing (Apergis, 2018), thereby shedding light on the negative effects of economic development. Using composite measures of subjective wellbeing and of air pollutants, Darçin (2017) proved the existence of a link between the concentration of harmful substances in the air and people's happiness and optimism. The component that had the greatest negative influence on happiness was particulate matter. The association between concentration of pollutant agents and self-reported life satisfaction has been quantified in the European context by Ferreira et al. (2013) as "an increase in SO2 concentrations by 1 μg/m3 is associated with a reduction in life satisfaction of between 0.016 and 0.021 points on the 11-point life satisfaction scale". In another study conducted in the United States, individuals surveyed when the current local levels of airborne particulates are higher report lower levels of happiness according to their answers to the General Social Survey (Levinson, 2012). Nevertheless, these studies rely on single indicators of subjective wellbeing, therefore neglecting its complex and multidimensional nature that has been largely acknowledged by the literature (Jeffrey et al., 2015; Mahoney, 2023; Ruggeri et al., 2020).

When discussing air pollution, most studies consider it as a territorial phenomenon and try to identify how it influences the local community; for example, findings from research conducted in the United States suggest that land prices tend to be devalued by pollutant agents (Chay & Greenstone, 2005). Evidence suggests that, on average, the quality of life does not substantially differ between urban and rural European areas (Shucksmith et al., 2009). Compared to rural areas, living in urban areas implies higher living costs and exposure to bad air quality, for instance by living close to industrial activities (see Boardman et al., 2009). On the other hand, living in bigger cities also grants access to a wide range of opportunities and services, such as faster economic development and more job opportunities, which may result in better psychological health (Cao et al., 2023) and higher life satisfaction compared to rural areas.

The association between air pollution and subjective wellbeing may greatly vary across European countries. In Europe, countries differ not only in healthcare spending, which is indirectly related to wellbeing, but also in economic productivity. Research on subjective wellbeing proved that in most developed nations, increases in income, education, and health have arguably not produced comparable increases in happiness or life satisfaction (Huppert et al., 2009). Other underlying factors may be responsible for it: air pollution has been proved to be a mediating factor between individual health conditions and life satisfaction (Al Ahad, 2024). There is a positive association between life satisfaction and self-reported health status across countries, but this association is slightly stronger in countries where governments spend less on the health care of their residents (Kööts-Ausmees & Realo, 2015), with "stronger worries more widespread among people in the low-class area". Individuals living in economically developed regions report higher levels of energy consumption but are not happier; on the other hand, renewable energy policies are associated with a relative increase in people's life satisfaction (Kumari et al., 2021), and these patterns appear more prominent in Eastern Europe (Okulicz-Kozayn & Altman, 2020).

As suggested by the discussion on urban areas, significant variation in the association of interest may also be observed at the subnational level (Cuñado & De Gracia, 2013; Ferreira et al., 2013). European regions may, indeed, differ in the offer of public services related to health and indirectly to subjective wellbeing, but also in the concentration of industries and in the availability of jobs, which can be associated with both pollution and individual wellbeing. Previous findings indicate that differences in life satisfaction levels between regions can be attributed to air pollutant concentrations after controlling for socio-economic individual variables (Cuñado & De Gracia, 2013). These multiple layers of analysis suggest substantial variation based on individuals' place of residence.

At the individual level, among other factors, social class plays a key role. Observing England's counties, Mitchell noted that the most polluted communities tend also to be the poorest, meaning that they suffer the effect of other people's lifestyle (Mitchell & Dorling, 2003). In another UK-based study, the negative effects of pollution on health have been found to be more pronounced among ethnic minorities compared to the native population (Al Ahad et al., 2022). Research has shown that low-income students are the most exposed and vulnerable to the negative effects of air pollution as they lack protective resources and suffer from pre-existing health conditions (Keivabu & Rüttenauer, 2022). Education contributes to raising awareness about the need for sustainable development, encouraging interventions and inspiring people to act (O'Brien, 2010). Being concerned about the environment is a relevant factor influencing subjective wellbeing (Suàrez-Varela et al., 2016); environmentally conscious individuals are more likely to suffer from pollution on a psychological level (Luechinger, 2010).

This study contributes to the literature on pollution and subjective wellbeing by examining how this association varies across European countries and regions, taking into account urbanization levels and other individual-level characteristics that may confound the association of interest (e.g., subjective health, gender, and income). Also, we use a composite indicator of wellbeing that reflects its multidimensional nature and may therefore better capture the individual reactions to pollution.

Data and methods

This study is based on individual-level data from the sixth round of the European Social Survey (ESS) conducted in 2012, containing detailed information on subjective wellbeing in multiple domains as well as on the region of residence at the NUTS-2 level (ESS ERIC, 2023). Specifically, 24 countries participated in Round 6, subdivided into 189 NUTS-2 regions (corresponding to areas inhabited by 800,000 to 3,000,000 individuals). Using information on NUTS-2 regions, we merge ESS data with regional-level data on air condition measurements gathered on a yearly basis from air quality reports[1] by the European Environment Agency (EEA, 2012): specifically, we manually associated each of EEA's weather stations to the corresponding region based on its coordinates and on Eurostat Statistical Atlas. The resulting level of pollution in a given region equals the mean level of pollution

[1] Available here: https://www.eea.europa.eu/en/datahub/

measured by the weather stations in the year 2012. Some countries did not have enough data to be mapped completely: Serbia, Montenegro, Kosovo, Bosnia and Herzegovina, North Macedonia. For this reason, we decided to exclude them. We measure pollution as the annual mean concentration of PM10, amounting to particulate matter with a diameter above 10 μ/m^3. The main reason behind our choice of considering PM10 rather than PM2.5 was the lack of comprehensive regional-level data provided by EEA: most countries did not have sufficient data on PM2.5 at the NUTS-2 level, covering only one or two weather stations for each country.

Dependent variable

The ESS is a large cross-sectional survey conducted every two years; it collects core modules on individuals' attitudes and behaviours and rotating modules on specific topics. The sixth round of the European Social Survey contains a special module on wellbeing, with 35 questions aimed at measuring subjective wellbeing in six different dimensions (Jeffrey et al., 2015). Following the existing literature on wellbeing measurement (Ruggeri et al., 2020), we selected 10 questions that cover the dimensions which were most relevant to the aims of this study, shown in Table 1: general life satisfaction and happiness (the standard measurement used in the literature, 2 items) and engagement and self-esteem (8 items). Altogether, the items chosen belong to the "Evaluative" and "Functioning" dimensions of subjective wellbeing (Jeffrey et al., 2015); more commonly in the literature, these aspects are referred to as "life evaluation" and "eudaimonia". Life evaluation consists of a general assessment of one's life, while eudaimonia captures whether one's life is perceived to have purpose or meaning, including a sense of autonomy and self-realization (Mahoney, 2023). We believe that these items effectively capture individuals' perception of their living experiences, excluding transitory changes in one's feelings (the so-called "affective" dimension of wellbeing) that were also covered by the survey; we used a set of items instead of single variables to better reflect the multidimensional nature of subjective wellbeing (Ruggeri et al., 2020).

Table 1 Items used to build the index of subjective wellbeing

Wellbeing dimension[a]	Description	Mean	S.D
Functioning	In general feel very positive about myself	7.76	1.62
Functioning	Feel accomplishment from what I do	7.52	1.72
Functioning	Free to decide how to live my life	8.02	1.78
Functioning	Feel what I do in life is valuable and worthwhile	7.90	1.54
Functioning	Interested in what you are doing, how much of the time	7.47	1.94
Functioning	Absorbed in what you are doing, how much of the time	7.40	1.98
Functioning	Enthusiastic about what you are doing, how much of the time	7.19	2.05
Functioning	Have a sense of direction	7.026	2.14
Evaluative	How happy are you	7.09	2.10
Evaluative	How satisfied with life as a whole	6.72	2.40

[a]Source: Jeffrey et al., (2015)

Subjective wellbeing is measured using an index, created by summing the scores of the selected 10 survey questions. We opted for a scale from 1 to 100 to facilitate understanding of scores. Furthermore, by giving equal weight to the ten questions, the index represents a general evaluation of all the aspects it encompasses.

We also checked how the items used to build the index and illustrated in Table 1 correlate to each other and conducted exploratory factor analysis. All items are positively correlated with each other, with correlation coefficients ranging from 0.21 to 0.76. The items displaying the strongest positive associations (above 0.70) are as follows: being interested, enthusiastic, and absorbed in what you are doing. Happiness and life satisfaction are also strongly correlated with each other. All items can be summarized by one factor, which explains 44% of the total variance (Cronbach's alpha: 0.84).

Analytical strategy

To analyze the association between the index of individual subjective wellbeing and air pollution, multilevel linear regression models are used, with individuals (level 1) nested within NUTS-2 regions (level 2) and countries (level 3), and the average level of PM10 (expressed in $\mu g/m^3$) in the region of residence as the main explanatory variable. Multilevel models account for the fact that individuals within the same region and country share some characteristics—above all, the exposure to pollutants—and are not statistically independent from each other. We use random intercept models allowing the intercept to be unique to each region within countries, and not random slope models, as we believe that the association between pollution and subjective wellbeing is not specific to the regional context. However, to take into account the fact that PM10 may be related to subjective wellbeing in a heterogeneous way across regions, we include an interaction with the area of residence. As a robustness check, we furthermore run the same regression model using the variable measuring the single item of life satisfaction as a dependent variable instead of the composite index.

Control variables include: perceived general health, area of residence (self-assessment), age (linear and squared), gender, total household's net income (in deciles), marital status, educational level, employment status, and presence of children in the household. All were chosen due to their relevance in previous studies (Apergis, 2018; Cuñado & De Gracia, 2013; Ferreira et al., 2013; Keivabu & Rüttenauer, 2022). Because age usually has a non-linear correlation with psychological and social phenomena, we include its squared value as well.

All missing values were removed and the variables reporting health status, employment status, and educational level were recoded in the following categories: "Bad", "Fair", "Good", and "Very Good" for health; "Working", "Studying", and "Retired or Unemployed" for employment status; and "Low", "Medium", and "High" for the educational level. Low educational level corresponds to having reached but not completed secondary education (without a high school diploma or any equivalent qualification); a medium level corresponds to the completion of upper secondary education, and the third category, high, is composed of all those having at least a bachelor's degree or any equivalent title. The area of residence includes the following categories: a big city, suburbs or outskirts of a big city, town or small city, country village, farm or home in the countryside.

Because of the high number of missing values in the total net income variable (8759 observations, twice as much as any other income bracket), we retained individuals in the missing income category, considering this category as a valid answer in order not to drastically reduce our sample. Indeed, it has been shown that refusal to answer the income question in ESS is most common among respondents with lower incomes (Jabkowski & Piekut, 2024).

Results

Descriptive results

The final sample consists of 31,746 individuals above the age of 18. On average, 1723 respondents are available in each country, 218 in each region. The subjective wellbeing index ranges between 1 (lowest wellbeing) and 100 (highest wellbeing), with a mean of 74.7 and a standard deviation (S.D.) of 12.3. Most regions have PM10 pollution levels below 25 μg/m^3, with a mean of 22.7 and a S.D. of 8.1. Concerning our control variables, 63.2% of our sample is made up of adults who do not have co-residential children, but most of them (approx. 60%) live with their partner. "Good" is the most common health status reported by the respondents.

To better understand regional trends in pollution and subjective wellbeing, we produced two maps that respectively describe the average score of PM10 concentration (Fig. 1) and of the index of subjective wellbeing (Fig. 2) for each NUTS-2 region present in our sample.

Looking at the maps, we can identify some regularities: Eastern countries (specifically Bulgaria, Czech Republic, Hungary, and Slovakia) have low scores of subjective wellbeing, while Finland, Norway, and Germany display the highest scores (Fig. 2). However, a certain degree of within-country heterogeneity emerges in most countries, except for Eastern Europe. Comparing Fig. 2 with Fig. 1, it can be noted that some of the countries reporting low values of subjective wellbeing are those displaying high levels of pollution (e.g., Bulgaria), and vice versa (e.g., Finland); furthermore, the most polluted regions of each country tend to have lower levels of subjective wellbeing as measured by the composite index. The best example of this association is Saxony-Anhalt, a region in Eastern Germany characterized by an intensive industrial chemical production, which has the lowest subjective wellbeing scores and the highest pollution levels in the country. However, we do not see this pattern in one of the most polluted areas in Europe, the Po Valley in Northern Italy, and in the Spanish region of Andalucia, a region where subjective wellbeing is one of the highest in Europe despite displaying relatively high levels of pollution. These descriptive results suggest that there seems to be a relationship between air quality and subjective wellbeing, which may depend on other characteristics of the context as well.

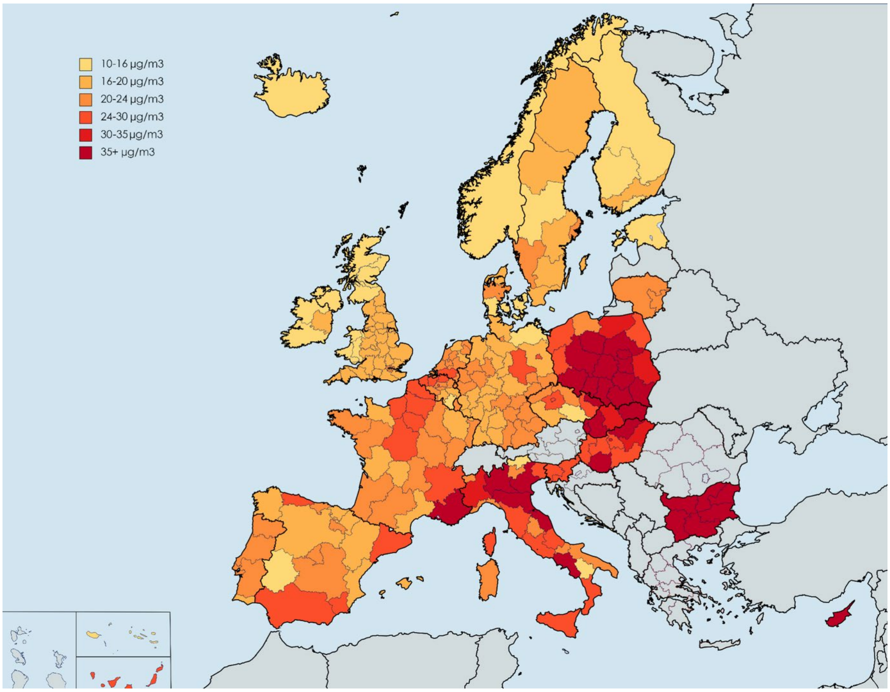

Fig. 1 PM10 annual mean concentration by region, expressed in μg/m^3. Source: EEA Air Quality Report 2012. Own elaboration

Regression results

We firstly estimated a linear regression model with three levels, using the subjective wellbeing index (1–100) as a dependent variable. Our main predictor is air pollution; it is important to remember that the regional average of PM10 (expressed in μg/m^3) across all available stations was used, hence averaging across different types of areas and different municipalities. The intraclass correlation coefficients (ICC) for the empty model are 0.082 at country level and 0.0124 at regional level, while for the full model, they are 0.067 (country) and 0.0130 (regional). This indicates that about 8.2% of the total variance in the subjective wellbeing index is due to between-countries variance, while 1.2% is due to the variance between regions of the same country.

Our multilevel linear regression model (Table 4, Appendix) shows that the coefficient of air pollution measured at the regional level is negative (equal to −0.009, *p*-value 0.761), pointing at a weak negative association (not statistically significant) with individuals' subjective wellbeing across Europe. A second regression model is estimated, including an interaction term between PM10 and the area of residence. Regression results are presented in Table 2.

Indeed, the association between air pollution and individuals' subjective wellbeing depends on the area of residence: in small cities, PM10 is positively

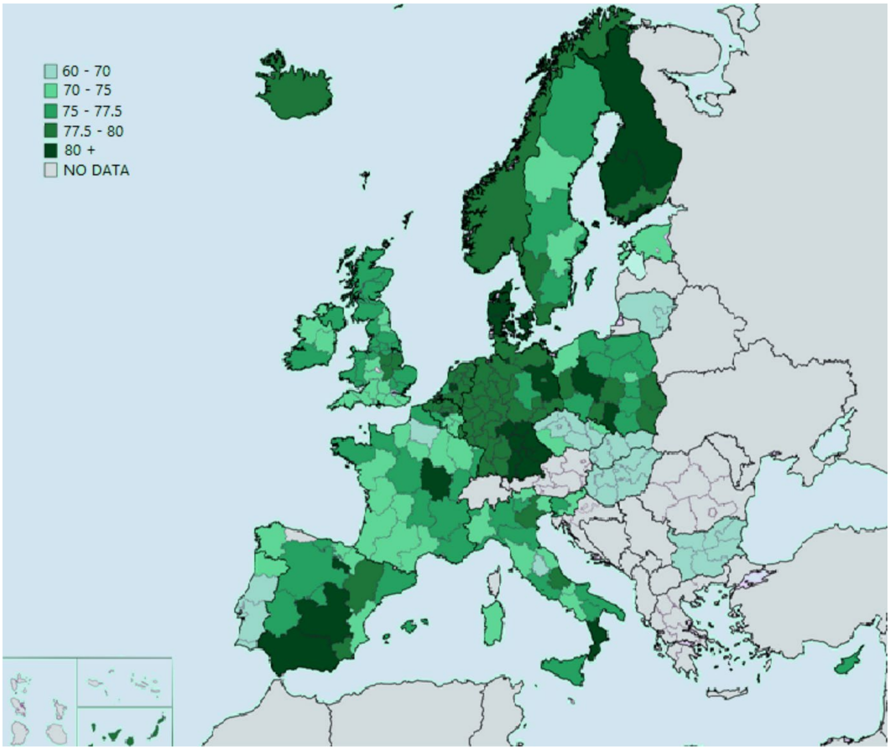

Fig. 2 Average scores of the index of subjective wellbeing, by region. Source: ESS round 6 (2012). Own elaboration

associated with subjective wellbeing, with a coefficient of 0.002, not statistically different from zero. Compared to living in a small city, living in the countryside is associated with an increase of 4.698 points in subjective wellbeing at low concentrations of PM10, while the association becomes markedly negative as PM10 increases (with an interaction coefficient of −0.168). Conversely, at low levels of PM10, living in a big city brings a statistically significant wellbeing penalty (of -1.725 points) compared to living in a small city. When PM10 increases, subjective wellbeing deteriorates in big cities to a smaller extent compared to the countryside as well as to small cities. Figure 3 illustrates the results of the interaction.

Figure 3 indicates that people living in rural areas (i.e., farm or home in the countryside and country village) are less satisfied as pollution increases; at higher levels of pollution, this association tends to reverse in the suburbs or outskirts of big cities as well as in big cities. In towns and small cities, there is almost no association between PM10 and subjective wellbeing. This seemingly counterintuitive result may be due to the fact that individuals living in urban areas have access to more services and activities compared to rural areas (Frey, 2008; Samasvati & Veenhoven, 2024), counterbalancing the negative effects of air pollution (Cao et al., 2023). In contrast, pollution may have serious repercussions on economic activities in the countryside and, therefore, on wellbeing. The decomposition of the variance at the two levels—regions and countries—provided in Table 2 shows that the variance at the country level is larger than that at the regional level, suggesting that subjective wellbeing varies more between individuals living in different countries than between individuals living in different regions of the same country. Nevertheless, the residual variance not explained by the regional or country-level clusters remains substantial.

In line with the literature (e.g., Ferreira et al., 2013), results show that subjective general health and household income are positively associated with subjective wellbeing. Having very good health increases subjective wellbeing by six points compared to those reporting fair health. Household income is positively associated with subjective wellbeing, with coefficients ranging from −2.539 (1st decile) to 3.242 (10th decile) when considering the 5th decile as the reference category. Unreported income (missing category) is also positively associated with subjective wellbeing, albeit with a coefficient comparable to that of the 5th income decile (0.396). The level of education is positively associated with subjective wellbeing, as it contributes to a better understanding and appreciation of one's surroundings and is usually associated with practices of environmental sustainability (O'Brien, 2010), but also with higher incomes. When considering one's employment status, being a student is associated with an increase of 1.721 points in subjective wellbeing compared to employed individuals. Unemployment or retirement significantly decreases subjective wellbeing; women are slightly more satisfied with their lives than men, and people seem to become less satisfied with the coming of age. The bivariate association between age and PM10 indeed suggested that the correlation decreases with age, but seems to reverse above the age of 55, when people usually begin to approach retirement. The presence of children in the household has a negative impact on subjective wellbeing; this might be due to lower marital happiness or to dissatisfaction with the division of unpaid work (Mínguez, 2020; White et al., 1986). The lack of information regarding children's age prevents us from understanding more about this phenomenon.

We performed a second multilevel regression as a robustness check, with one of the variables (with a range from 1 to 100, modified from the original scale 1 to 10 to make it comparable to the previous model) used to build the index as a dependent variable, "How satisfied with life as a whole". The results can be seen in Table 3. Similar to the previous model, the variance at the country level is larger than that at the regional level.

In this second regression model, the concentration of PM10 is negatively associated with the overall life satisfaction variable; like the previous models, the coefficient is not statistically significant.. Compared to the previous model (where the coefficient of PM10 in the baseline category was equal to 0.002 in small cities), the coefficient of PM10 amounts to -0.036 (p-value: 0.521); the main effects of the area of residence are nonetheless comparable with those presented in Table 2. Irrespective of PM10, living in the countryside or in a country village is associated with a premium in life satisfaction compared to a small city. Living in a big city is instead associated with a decrease in life satisfaction; nevertheless, urban areas do not statistically differ from the baseline category (small cities) in terms of life satisfaction. If we interact the area of residence with PM10 (not shown for brevity), the direction of the association between PM10 and life satisfaction appears to be comparable to that obtained using a composite index. The coefficients of control variables align with those of the previous model, although differing in magnitude: concerning subjective health, reporting bad health is associated with a reduction of 10 points in life satisfaction compared to a fair health (vs 7 points in the index of subjective wellbeing, see Table 2). Also, life satisfaction seems to be more sensitive to variations in household income than the index used in the previous model. This robustness check proves that estimates may be sensitive to decisions about how to measure subjective wellbeing.

Discussion

The purpose of this paper was to investigate the association between air pollution, measured with the yearly average level of PM10 within NUTS-2 regions, and individual subjective wellbeing in Europe, in 2012. Compared to previous studies (Apergis, 2018; Ferreira et al., 2013; Luechinger, 2010; Orru et al., 2016; Welsch, 2006), we measure subjective wellbeing using a composite index capturing life evaluation and sense of purpose; we include detailed individual-level information that can confound the main association of interest, and we account for the variation between 189 European regions.

Contrary to our expectations, we find no association between PM10 and our index; rather, this association depends on the area of residence. Compared to small cities, subjective wellbeing decreases when air quality becomes worse in the countryside; on the contrary, higher levels of pollution tend to increase subjective wellbeing in bigger cities. A possible explanation lies in the access to more services, amenities, and jobs provided by urban areas (Samasvati & Veenhoven, 2024), which counteracts the impact of air pollution on perceived subjective wellbeing but which could not be captured by the data at hand. Our results echo previous research showing that the negative repercussions of air pollution on mental health in China were mitigated in more affluent cities, also characterized by the presence of green areas and sport facilities (Cao et al., 2023). It is also worth mentioning that our study is set in 2012, a period characterized by the economic recession: therefore, job opportunities—likely more often located in urban than in rural areas—might have had a larger impact on individuals' subjective wellbeing compared to other historical periods. Indeed, research has shown that the preference for moving to a rural or urban area varies according to the economic cycle (Chi & Marcouiller, 2010).

Thus, our novel findings suggest that the rural–urban divide represents an additional source of stratification with regard to the repercussions on wellbeing of air pollution. In Europe, rural areas are already experiencing population decline and suffering from the lack of services but may also bear the highest costs of pollution in terms of subjective wellbeing and quality of life. The descriptive maps highlight the fact that air pollution is a complex phenomenon, whose extent and impact vastly differ within each country, especially in Western Europe. Eastern countries, especially Hungary and Bulgaria, are more polluted and have lower levels of subjective wellbeing, while Northern European countries show opposite trends (low pollution,

Table 2 Multilevel linear regression model on the index of subjective wellbeing, with interaction between area of residence and PM10

Variables	Coefficients (S.D.)
PM10 (μg/m^3, regional average)	0.002 (0.034)
Area of residence, ref: a small city	
A big city	-1.725*** (0.544)
Suburbs or outskirts of big city	-0.549 (0.753)
Country village	1.199** (0.497)
Farm or home in countryside	4.698*** (0.972)
Area of residence##pm10, ref: a small city	
A big city	0.056*** (0.021)
Suburbs or outskirts of big city	-0.015 (0.034)
Country village	-0.037** (0.021)
Farm or home in countryside	-0.168*** (0.054)
Female	0.321** (0.128)
Subjective general health, ref: Bad	
Fair	7.22*** (0.227)
Good	10.815*** (0.229)
Very good	13.521*** (2.194)
Household’s total net income, ref: 5th decile	
1 st decile	−2.539*** (0.311)
2nd decile	−1.215*** (0.298)
3rd decile	0.015 (0.298)
4th decile	0.001 (0.299)
6th decile	0.496 (0.306)
7th decile	0.735*** (0.310)
8th decile	1.307*** (0.325)
9th decile	1.740*** (0.337)
10th decile	3.242*** (0.346)

Table 2 (continued)

Variables	Coefficients (S.D.)
Missing	0.396 (0.222)
Educational level, ref: low	
Medium	1.565*** (0.166)
High	2.589*** (0.191)
Employment status, ref: employed	
Studying	1.721*** (0.347)
Retired or unemployed	−2.178*** (0.167)
Living with children, ref: no children	−0.726*** (0.126)
Age of respondent	−0.078*** (0.019)
Age of respondent, squared	0.002*** (0.0002)
Living with partner	2.112*** (0.128)
Intercept	64.831*** (1.252)
Intercept variance, country level	9.232 (3.038)
Intercept variance, regional level	1.785 (0.258)
Residual variance	123.81 (11.127)
Observations	31,746

Standard errors in parentheses

***$p < 0.01$, **$p < 0.05$

higher satisfaction). This gradient remains visible in the relative impact of PM2.5 on mortality in 2022, highest in South-Eastern Europe and lowest in Northern countries (EEA, 2024), suggesting once again that health and subjective wellbeing are profoundly intertwined.

Results concerning individual-level control variables are in line with previous literature (e.g., Ferreira et al., 2013). As expected, having a positive health condition strongly improves self-evaluated subjective wellbeing. Social class, measured here by household income and level of education, is also positively associated with wellbeing. Our study has shown that individual characteristics cannot, however, be considered in isolation from the characteristics of the area of residence.

Differently from previous studies where detailed geographical information was available (Goetzke & Rave, 2015; Cuñado & De Gracia, 2013; Fleury-Bahi et al., 2013; Orru et al., 2016), postcode-level individual information is not made available

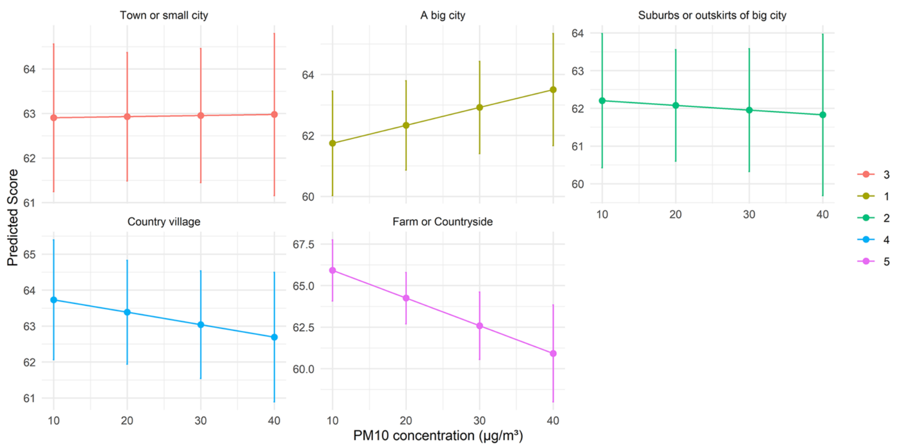

Fig. 3 Predicted values of the index of subjective wellbeing by PM10 levels, by area of residence. Results refer to those presented in Table 2

by ESS at the European level; hence, our measure of air pollution refers to a regional average. PM10 values provided by the Air Quality Report are based on systematic measurements on a regional basis, summarized in aggregate values and, as such, they can be considered reliable. The use of regional-level information on pollution, however, comes with a main downside, as it necessarily relies on several assumptions, like the fact that all individuals within a given region are exposed to the same level of pollutant agents in the air during the year, irrespective of fluctuations due to seasonal change, weather, and temperature. Due to our research design and our decision to consider the territory at a NUTS-2 level, we cannot determine the distance from the main sources of PM10, only its concentration and how it affects living conditions based on the degree of urbanization within the region. Furthermore, rural communities may be exposed to different sources of PM10 compared to urban communities, like wildfire or agricultural activities, while PM10 generated by transportation and industries is prevalent in urban environments; future research based on data with higher granularity—ideally at NUTS-3 level or lower—may investigate whether PM10 differently affects subjective wellbeing based on its source.

Because the rotating module “Personal and Social Wellbeing” was included only in 2012 and not in successive rounds of ESS, we are unable to expand this study including data from following years. One possibility to include other ESS rounds would be to use the item on life satisfaction as a whole, which nonetheless does not capture subjective wellbeing in multiple life domains as suggested by the robustness check conducted here. Lastly, it should be noted that, in ESS, all individual-level measures such as health or the classification of the area of residence are based on respondents’ perceptions, and not on objective assessments thereof. Subjective wellbeing scales represent a valid and reliable measurement of wellbeing and have been proven to capture both personal and societal life circumstances (Diener et al., 2012). Thanks to our index, we are able to isolate individuals’ self-assessment of their lives, something which may matter more (or equally) to one’s subjective wellbeing than objective conditions, measured by

Table 3 Multilevel linear regression model on life satisfaction (single item, no interactions)

Variables	Coefficients (S.D.)
PM10 (μg/m^3, regional average)	-0.036 (0.056)
Area of residence, ref: a small city	
A big city	-0.481 (0.322)
Suburbs or outskirts of big city	-0.223 (0.399)
Country village	1.112*** (0.285)
Farm or home in countryside	2.771*** (0.514)
Female	1.238*** (0.224)
Subjective general health, ref: *Bad*	
Fair	10.113*** (0.387)
Good	16.828*** (0.392)
Very good	25.036*** (3.872)
Household's total net income, ref: *5th decile*	
1 st decile	−5.875*** (0.539)
2nd decile	−3.489*** (0.518)
3rd decile	−0.694 (0.524)
4th decile	−0.022 (0.539)
6th decile	2.082*** (0.553)
7th decile	3.057*** (0.566)
8th decile	3.591*** (0.597)
9th decile	5.096*** (0.621)
10th decile	6.846*** (0.636)
Missing	0.282 (0.461)
Educational level, ref: low	
Medium	0.683*** (0.288)
High	2.307*** (0.332)

Table 3 (continued)

Variables	Coefficients (S.D.)
Employment status, ref: employed	
Studying	4.365*** (0.607)
Retired or unemployed	−2.429*** (0.290)
Living with children, ref: no children	−1.832*** (0.262)
Age of respondent	−0.668*** (0.0405)
Age of respondent, squared	0.0082*** (0.00038)
Living with partner	4.687*** (0.264)
Constant	68.379*** (2.65)
Intercept variance, country level	71.56 (8.459)
Intercept variance, regional level	5.349 (2.313)
Residual variance	390.992 (19.774)
Observations	33,237

***$p < 0.01$

economic or health conditions. When using multidimensional indexes of wellbeing, it is crucial to ensure comparability with other surveys or with the most commonly used measures (Ruggeri et al., 2020): while being aware that not all surveys cover a wide range of wellbeing measures, we included in our index life evaluation measures (happiness, life satisfaction) that are present in most data sources.

Despite these limitations, we believe that this study contributes to the discussion on the subjective consequences of air pollution across population subgroups in the European context. Future studies on the implications of pollution for broader life decisions (e.g., migration, fertility) should consider the complex linkages between health, place of residence, services and jobs, amenities, and, additionally, wellbeing. Also, research on the mechanisms linking air pollution to subjective wellbeing is needed to better understand how individuals react to environmental stressors. Moving towards a more sustainable economy is something to strive for across Europe; future efforts by policymakers could help counteract the impact of PM10 on individual subjective wellbeing, especially by focusing on the areas where this negative association is more evident: the countryside.

Appendix

Table 4 Multilevel linear regression model on the index of subjective wellbeing (no interactions)

Variables	Coefficients (S.D.)
PM10 (μg/m^3, regional average)	−0.009 (0.031)
Area of residence, ref: a small city	
A big city	−0.321* (0.185)
Suburbs or outskirts of big city	−0.848*** (0.238)
Country village	0.319* (0.163)
Farm or home in countryside	1.792*** (0.305)
Female	0.319** (0.125)
Subjective general health, ref: *Bad*	
Fair	7.229*** (0.221)
Good	10.827*** (0.224)
Very Good	13.580*** (2.14)
Household's total net income, ref: *5th decile*	
1 st decile	−2.576*** (0.311)
2nd decile	−1.237*** (0.286)
3rd decile	0.016 (0.287)
4th decile	0.012 (0.294)
6th decile	0.513* (0.309)
7th decile	0.744** (0.317)
8th decile	1.317*** (0.334)
9th decile	1.750*** (0.346)
10th decile	3.258*** (0.355)
Missing	0.412 (0.264)
Educational level, ref: low	
Medium	1.564*** (0.162)
High	2.624*** (0.186)

Table 4 (continued)

Variables	Coefficients (S.D.)
Employment status, ref: employed	
Studying	1.668*** (0.338)
Retired or unemployed	-2.119*** (0.163)
Living with children, ref: no children	−0.867*** (0.147)
Age of respondent	−0.071*** (0.0229)
Age of respondent, squared	0.0017*** (0.0003)
Living with partner	0.2217*** (0.1486)
Constant	65.048*** (1.222)
Intercept variance, country level	9.202 (3.033)
Intercept variance, regional level	1.803 (1.343)
Residual variance	3.1786 (0.054)
Observations	31,746

Standard errors in parentheses

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Acknowledgements We acknowledge the support of the Department of Sociology and Social Research of the University of Trento. We also thank the participants of the European Population Conference (2022) and of the Giornate di Studio sulla Popolazione—Popdays (2023) for their valuable feedback on previous versions of the paper.

Author contribution Patrick Montanari and Agnese Vitali contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Patrick Montanari, supported by Agnese Vitali and Valeria Ferraretto. The first draft of the manuscript was written by Patrick Montanari, and all authors commented on previous versions of the manuscript. The draft was revised by Valeria Ferraretto and Agnese Vitali. All authors read and approved the final manuscript.

Funding Open access funding provided by Università degli Studi di Trento within the CRUI-CARE Agreement.

Data availability The data that support the findings of this study, ESS Round 6, data file edition 2.4 are openly available in the Norwegian Agency for Shared Services in Education and Research at https://doi.org/10.21338/nsd-ess6-2012. Data on air pollution across weather stations are publicly available on the website of the European Environmental Agency: https://www.eea.europa.eu/en/datahub/.

Declarations

Competing interests The authors declare no competing interests.

References

Abel, G. J., Brottrager, M., Cuaresma, J. C., & Muttarak, R. (2019). Climate, conflict and forced migration. *Global Environmental Change, 54*, 239–249. https://doi.org/10.1016/j.gloenvcha.2018.12.003

Al Ahad, M. A. (2024). Air pollution reduces the individuals' life satisfaction through health impairment. *Applied Research in Quality of Life*. https://doi.org/10.1007/s11482-024-10273-5

Al Ahad, M. A., Demšar, U., Sullivan, F., & Kulu, H. (2022). Does long-term air pollution exposure affect self-reported health and limiting long term illness disproportionately for ethnic minorities in the UK? A census-based individual level analysis. *Applied Spatial Analysis and Policy, 15*(4), 1557–1582. https://doi.org/10.1007/s12061-022-09471-1

Anderson, J. O., Thundiyil, J. G., & Stolbach, A. (2012). Clearing the air: A review of the effects of particulate matter air pollution on human health. *Journal of Medical Toxicology, 8*(2), 166–175. https://doi.org/10.1007/s13181-011-0203-1

Apergis, N. (2018). The impact of greenhouse gas emissions on personal well-being: Evidence from a panel of 58 countries and aggregate and regional country samples. *Journal of Happiness Studies, 19*, 69–80. https://doi.org/10.1007/s10902-016-9809-y

Bastianelli, E. (2024). Climate change worries and fertility intentions: Insights from three EU countries. *Journal of Marriage and Family, 87(2),* 659–675. https://doi.org/10.1111/jomf.13048

Bickerstaff, K., & Walker, G. (2001). Public understandings of air pollution: The 'localisation' of environmental risk. *Global Environmental Change, 11*(2), 133–145. https://doi.org/10.1016/S0959-3780(00)00063-7

Boardman, J. D., Downey, L., Jackson, J. J., Merrill, B., Saint Onge, J., & Williams, D. R. (2009). Proximate industrial activity and psychological distress. *Population and Environment, 30*, 3–25. https://doi.org/10.1007/s11111-008-0075-8

Cao, Z., Zhou, J., Li, M., Huang, J., & Dou, D. (2023). Urbanites' mental health undermined by air pollution. *Nature Sustainability, 6*(4), 470–478. https://doi.org/10.1038/s41893-022-01032-1

Chay, K. Y., & Greenstone, M. (2005). Does air quality matter? Evidence from the housing market. *Journal of Political Economy, 113*(2), 376–424. https://doi.org/10.1086/427462

Chi, G., & Marcoullier, D. W. (2010). Isolating the effect of natural amenities on population change at the local level. *Regional Studies, 45*(4), 491–505. https://doi.org/10.1080/00343400903496394

Cuñado, J., & Pérez de Gracia, F. (2013). Environment and happiness: New evidence for Spain. *Social Indicators Research, 112*, 549–567. https://doi.org/10.1007/s11205-012-0038-4

Darçin, M. (2017). How air pollution affects subjective well-being. *Well-Being and Quality of Life - Medical Perspective, Chapter, 10*, 211–229. https://doi.org/10.5772/67742

De Rose, A., & Testa, M. R. (2015). Climate change and reproductive intentions in Europe. In D. Strangio, & G. Sancetta (Eds.). *Italy in a European Context* (pp. 194–212). Palgrave Macmillan. https://doi.org/10.1007/978-1-137-56077-3_9

Diener, E., Inglehart, R., & Tay, L. (2012). Theory and validity of life satisfaction scales. *Social Indicators Research, 112*, 497–527. https://doi.org/10.1007/s11205-012-0076-y

Dyson, T. (2005). On development, demography and climate change: The end of the world as we know it? *Population and Environment, 27*(2), 117–149. https://doi.org/10.1007/s11111-006-0017-2

EEA (2012). Air quality in Europe — 2012 report. *EEA Report* No 4/2012, European Environment Agency.

EEA (2024). Harm to human health from air pollution in Europe: Burden of disease status, 2024. *EEA briefing no. 21/2024.* ISBN: 978–92–9480–695–6-https://doi.org/10.2800/3950756
European Social Survey European Research Infrastructure (ESS ERIC). (2023). ESS6 - integrated file, edition 2.6. *Sikt - Norwegian Agency for Shared Services in Education and Research.* https://doi.org/10.21338/ess6e02_6
Ferreira, S., Akay, A., Brereton, F., Cuñado, J., Martinsson, P., Moro, M., & Ningal, T. F. (2013). Life satisfaction and air quality in Europe. *Ecological Economics, 88*, 1–10. https://doi.org/10.1016/j.ecolecon.2012.12.027
Fleury-Bahi, G., Préau, M., Annabi-Attia, T., Marcouyeux, A., & Wittenberg, I. (2013). Perceived health and quality of life: The effect of exposure to atmospheric pollution. *Journal of Risk Research, 18*(2), 127–138. https://doi.org/10.1080/13669877.2013.841728
Frey, B. (2008). Cities, culture and happiness. *World Cities Summit Issue, 2008*, 102–111.
Goetzke, F., & Rave, T. (2015). Regional air quality and happiness in Germany. *International Regional Science Review, 38*(4), 437–451. https://doi.org/10.1177/0160017615589008
Guxens, M., & Sunyer, J. (2012). A review of epidemiological studies on neuropsychological effects of air pollution. *Swiss Medical Weekly, 141*, 1–7. https://doi.org/10.57187/smw.2012.13322
Huppert, F. A. (2009). Psychological well-being: Evidence regarding its causes and consequences. *Applied Psychology: Health and Well-Being, 1*(2), 137–164. https://doi.org/10.1111/j.1758-0854.2009.01008.x
Jabkwoski, P., & Piekut, A. (2024). Not random and not ignorable. An examination of nonresponse to income question in the European Social Survey, 2008–2018. *Field Methods, 36*(3), 213–228. https://doi.org/10.1177/1525822X231194178
Jeffrey, K., Abdallah, S., Quick, A. (2015). Europeans' personal and social wellbeing: Topline results from round 6 of the European Social Survey. *ESS Topline Results Series, no. 5.*
Keivabu, R. C., & Rüttenauer, T. (2022). London congestion charge: The impact on air pollution and school attendance by socioeconomic status. *Population and Environment, 43*, 576–596. https://doi.org/10.1007/s11111-022-00401-4
Kööts-Ausmees, L., & Realo, A. (2015). The association between life satisfaction and self–reported health status in Europe. *European Journal of Personality, 29*(16), 647–657. https://doi.org/10.1002/per.2037
Kumari, N., Kumar, P., & Sahu, N. C. (2021). Do energy consumption and environmental quality enhance subjective wellbeing in G20 countries? *Environmental Science and Pollution Research, 28*, 60246–60267. https://doi.org/10.1007/s11356-021-14965-5
Levinson, A. (2012). Valuing public goods using happiness data: The case of air quality. *Journal of Public Economics, 96*(9–10), 869–880. https://doi.org/10.1016/j.jpubeco.2012.06.007
Luechinger, S. (2010). Life satisfaction and transboundary air pollution. *Economics Letters, 107*(2010), 4–6. https://doi.org/10.1016/j.econlet.2009.07.007
MacKerron, G., & Mourato, S. (2009). Life satisfaction and air quality in London. *Ecological Economics, 68*(5), 1441–1453. https://doi.org/10.1016/j.ecolecon.2008.10.004
Mahoney, J. (2023). *Subjective well-being measurement: Current practice and new frontiers*. OECD Papers on Wellbeing and Inequalities, Working paper no. 17. https://doi.org/10.1787/4ca48f7c-en
Medina, S., Plasencia, A., Ballester, F., Mucke, H., & Schwartz, J. (2004). Apheis: Public health impact of PM10 in 19 European cities. *Journal of Epidemiology and Community Health, 58*(10), 805.
Menz, T. (2011). Do people habituate to air pollution? Evidence from international life satisfaction data. *Ecological Economics, 71*(15), 211–219. https://doi.org/10.1016/j.ecolecon.2011.09.012
Mínguez, A. M. (2020). Children's relationships and happiness: The role of family, friends and the school in four European countries. *Journal of Happiness Studies, 21*(2020), 1859–1878.
Mitchell, G., & Dorling, D. (2003). An environmental justice analysis of British air quality. *Environment and Planning A: Economy and Space, 35*(5), 909–929. https://doi.org/10.1068/a35240
Muttarak, R. (2021). Demographic perspectives in research on global environmental change. *Population Studies, 75*(sup1), 77–104. https://doi.org/10.1080/00324728.2021.1988684
O'Brien, C. (2010). Sustainability, happiness and education. *Journal of Sustainability Education, 1*(2010), 1–18.
Okulicz-Kozayn, A., & Altman, M. (2020). The happiness-energy paradox: Energy use is unrelated to subjective well-being. *Applied Research in Quality of Life, 15*, 1055–1067. https://doi.org/10.1007/s11482-019-09719-y

Orru, K., Orru, H., Maasikmets, M., Hendrikson, R., & Ainsaar, M. (2016). Well-being and environmental quality: Does pollution affect life satisfaction? *Quality of Life Research, 25*(3), 699–705. https://doi.org/10.1007/s11136-015-1104-6

Rehdanz, K., & Maddison, D. (2008). Local environmental quality and life-satisfaction in Germany. *Ecological Economics, 64*(4), 787–797. https://doi.org/10.1016/j.ecolecon.2007.04.016

Ruggeri, K., Garcia-Garzon, E., Maguire, A., Matz, S., & Huppert, F. A. (2020). Well-being is more than happiness and life satisfaction: A multidimensional analysis of 21 countries. *Health and Quality of Life Outcomes, 18*(192), 1–16. https://doi.org/10.1186/s12955-020-01423-y

Samasvati, S., & Veenhoven, R. (2024). Happiness in urban environments: What we know and don't know yet. *Journal of Housing and the Built Environment, 39*(2024), 1649–1707. https://doi.org/10.1007/s10901-024-10119-4

Schneider-Mayerson, M., & Leong, K. L. (2020). Eco-reproductive concerns in the age of climate change. *Climatic Change, 163*(2), 1007–1023. https://doi.org/10.1007/s10584-020-02923-y

Shucksmith, M., Cameron, S., Merridew, T., & Pichler, F. (2009). Urban–rural differences in quality of life across the European Union. *Regional Studies, 43*(10), 1275–1289. https://doi.org/10.1080/00343400802378750

Silva, J., de Keulenaer, F., & Johnstone, N. (2012). Environmental quality and life satisfaction: Evidence based on micro-data. *OECD Environment Working Papers, 44*, 2012.

Suàrez-Varela, M., Guardiola, J., & Gonzàlez-Gomèz, F. (2016). Do pro-environmental behaviors and awareness contribute to improve subjective well-being? *Applied Research in Quality of Life, 11*(2016), 429–444. https://doi.org/10.1007/s11482-014-9372-9

Vizcaíno, M. A. C., González-Comadran, M., & Jacquemin, B. (2016). Outdoor air pollution and human infertility: A systematic review. *Fertility and Sterility, 106*(4), 897–904. https://doi.org/10.1016/j.fertnstert.2016.07.1110

Welsch, H. (2006). Environment and happiness: Valuation of air pollution using life satisfaction data. *Ecological Economics, 58*(4), 801–813. https://doi.org/10.1016/j.ecolecon.2005.09.006

White, L. K., Booth, A. and Edwards, J. N. (1986). Children and marital happiness: Why the negative correlation?. *Journal of Family Issues, 7*(2):131–147

Wilson, E. O. (1984). *Biophilia*. Harvard University Press.

Won, W., Oh, R., Lee, W., Ku, S., Su, P., & Yoon, Y. (2021). Hygroscopic properties of particulate matter and effects of their interactions with weather on visibility. *Scientific Reports, 11*(16401), 2021. https://doi.org/10.1038/s41598-021-95834-6

Yoo, G. (2021). Real-time information on air pollution and avoidance behavior: Evidence from South Korea. *Population and Environment, 42*(3), 406–424. https://doi.org/10.1007/s11111-020-00368-0