Research Article

Cancer Mortality Among Women in the European Union: A Comprehensive Analysis of Economic, Social, and Health Factors

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This study provides a comprehensive analysis of factors associated with cancer mortality among women in twenty-seven European Union (EU) countries from 2013 to 2021. Using Pooled Ordinary Least Squares and Quantile Regression models, we examine the impact of socioeconomic, health, and lifestyle factors on gender disparities in cancer mortality. Key findings reveal that higher average years of schooling among women is associated with an increase in cancer mortality, while higher Gross National Income per capita is linked to reduced mortality rates. Lifestyle variables, such as regular physical activity and dietary habits, are associated with lower cancer mortality, whereas unmet healthcare needs and certain socio-political factors correlate with increased mortality. The results underscore the importance of addressing healthcare access and gender equity to inform policy interventions aligned with UN Sustainable Development Goals (SDGs) aimed at reducing cancer mortality among women in the EU.

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1. Introduction

Gender inequality affects geographic, socioeconomic, and cultural factors, creating barriers to healthcare access[1]. Women in countries with different incomes are impacted differently by cancer. One explanation can be gender inequality or other causes, such as the degradation of the environment or deprivation (e.g., Cesario[2]). Literature supports that gender inequality can contribute to a substantial increase in women's cancer[3]. The magnitude of this discrepancy goes beyond social boundaries.[4][5].

The intricate interplay of gender inequality with a range of factors leads to variations in the consequences of cancer. Elements such as socioeconomic conditions, educational gaps, access to healthcare, and societal norms collectively contribute to women's susceptibility to cancer. These factors shape the diagnosis trajectory, treatment options, and eventual survival rates.

Donington and Colson[3] further underscore the multifaceted impact of gender inequality on cancer, stressing physiological differences, behavioral influences, lifestyle choices, and equal access to medical care. Jolidon[6] and Willems et al.[7] also illustrate that widespread macro-level gender inequality detrimentally affects programs. Willems et al.[7] revealed the importance of some factors in health disparities associated with gender. This perspective highlights the advantages of policies that promote women's political participation, autonomy, family roles, and broader empowerment.

Furthermore, women's access to health care can be stimulated by augmented self-rule and the ability to make their own decisions[8]. On the other hand, unfavorable situations tend to hinder the capacity to decide on health choices and family[9]. There is also a tendency to perpetuate gender discrimination that is rooted in procreative health and social and cultural conditions that can compromise the health of women[10]. Varying levels of gender inequality are evident in the European context. In 2013, for example, Hungary (0.251) and Romania (0.315) had significant gender inequality. On the other hand, Denmark (0.039), the Netherlands (0.042), Finland (0.062), Germany (0.079), and Portugal (0.098) had lower gender inequality values. Despite concentrated efforts, Hungary (0.222) and Romania (0.283) revealed persistent high levels of inequality. These countries shed light on unique aspects of gender inequality within Europe, including gender pay gaps, occupational segregation, leadership representation, and work-life balance dynamics (See **Figure 1** below).
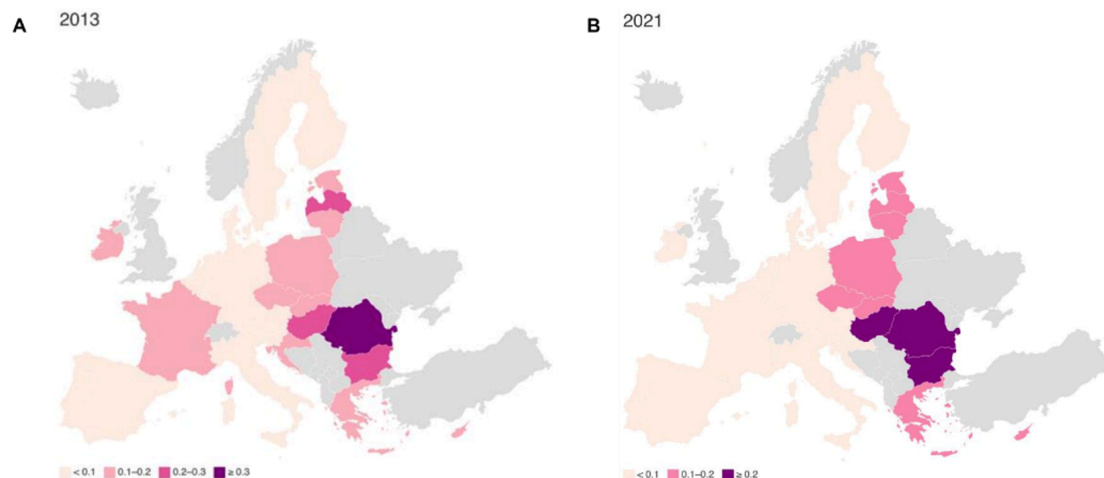
Figure 1. The Gender Inequality Index (GII) was evaluated across 27 European Union countries from 2013 to 2021 (A-B). This index represents the degree of gender inequality in these nations during the specified period. The map provided in this study was created by the authors, based on data from the United Nations Development Programme (UNDP, 2022).

Gender inequality remains a pressing concern in European nations, spanning education, employment, decision-making, healthcare, and societal interactions. Educational opportunities for women often remain limited, hindering their entry into male-dominated fields. This inequality is reflected in persistent employment disparities, job-related discrimination, and gender pay disparities. Even though there is some progress, women continue to be underrepresented in political positions and economic decision-making roles compared to men. Healthcare reveals evident gaps in service access and reproductive health, compounded by gender-based violence and discrimination. Achieving an equitable, inclusive, and just society demands commitment, initiative, and encouragement (e.g., EIGE[11]; European Commission[12]).

European countries are working toward cultivating gender equality and empowering women via legislation, policymaking, and incentivizing recognition. The cumulative result of these efforts is a reduction in gender inequality, declining from 0.126 in 2013 to 0.100 in 2021 (See **Figure 2** below).

Figure 2. The Gender Inequality Index in the EU was analyzed for the years 2013 to 2021. The map displayed in this study was created by the authors, using data obtained from the United Nations Development Programme (UNDP, 2022).

Gender inequality intersects with a pressing EU issue: cancer mortality, mainly among women. Cancer-related deaths are a notable public health concern within the EU. In 2013, certain EU countries showed high women's cancer mortality. Hungary, Denmark, Slovakia, the Netherlands, Slovenia, Ireland, Croatia,

Czechia, Poland, Latvia, Sweden, Estonia, Germany, and Belgium. Conversely, Greece, Bulgaria, Cyprus, Portugal, and Spain had relatively lower cancer mortality (See **Figure 3** below).
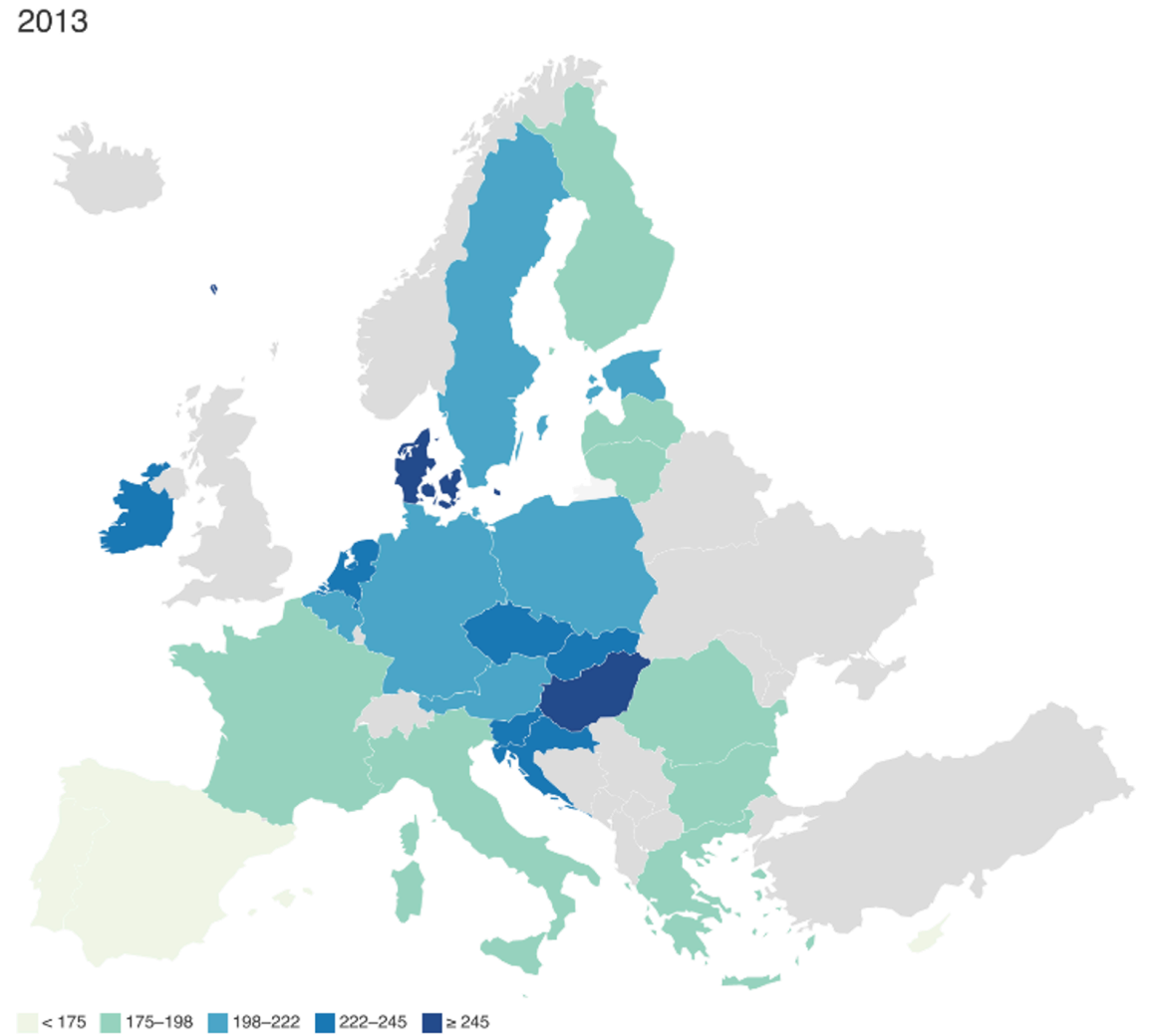
Figure 3. Cancer-Related Mortality in Women across the EU countries in 2013. The map presented was created by the authors using data provided by Eurostat (2023a).

By 2021, for instance, France, Germany, Belgium, Sweden, Estonia, Luxembourg, and Austria lowered women's cancer mortality rates. However, Slovakia, Hungary, Poland, Latvia, Ireland, Denmark, Czechia, and Croatia face high cancer mortality. The EU's cancer mortality rate among women dropped significantly from 262 in 2013 to 241 in 2021 due to various initiatives (See Figure 4 below).

2021
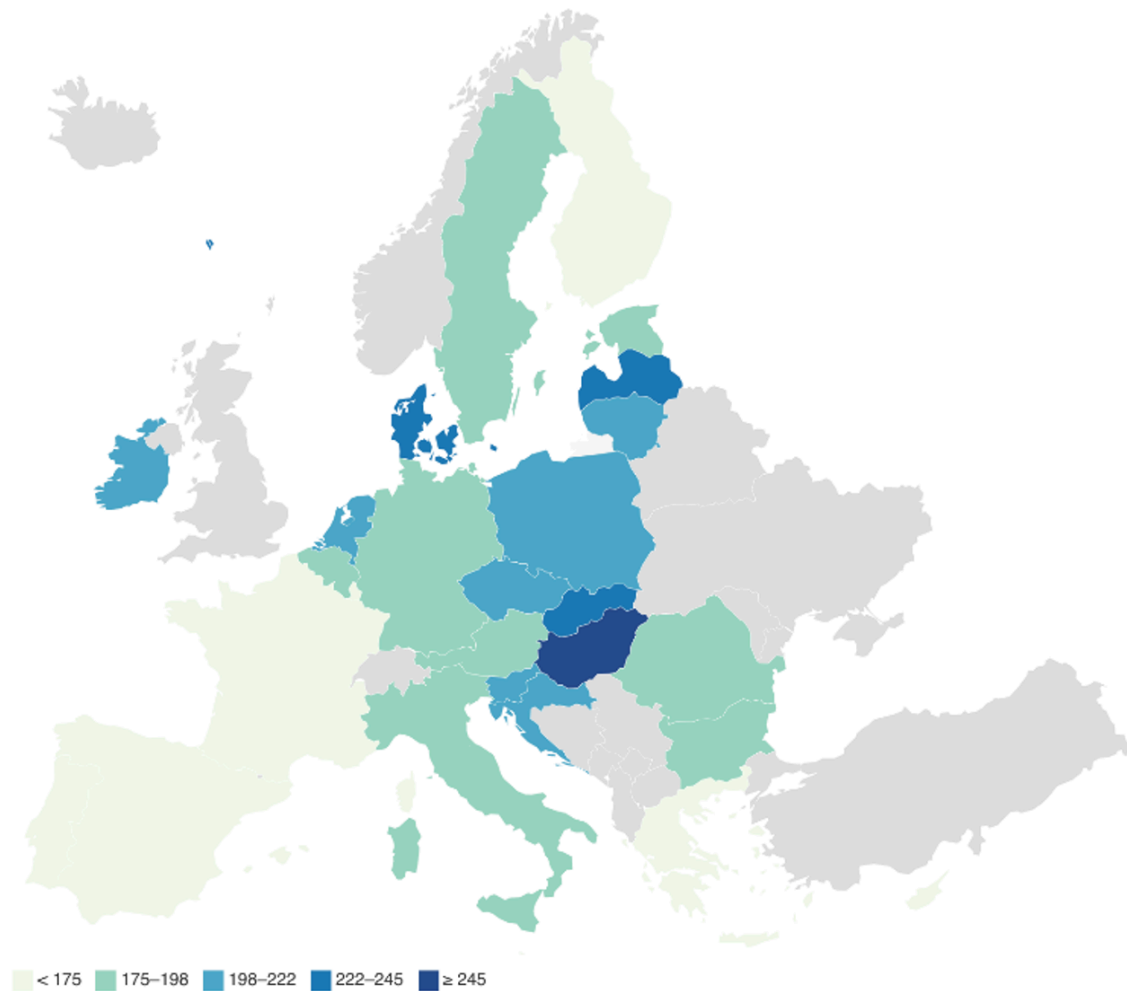

Figure 4. Cancer-Related Mortality in Women across the EU countries in 2021. The map presented was created by the authors using data provided by Eurostat (2023a).

Breast cancer stands as the primary cause of cancer-related deaths (28.75%) among EU women in 2020. Closely is lung cancer (27.18%), followed by colorectal cancer (21.60%) and pancreatic cancer (13.94%) (See **Figure 5** below).
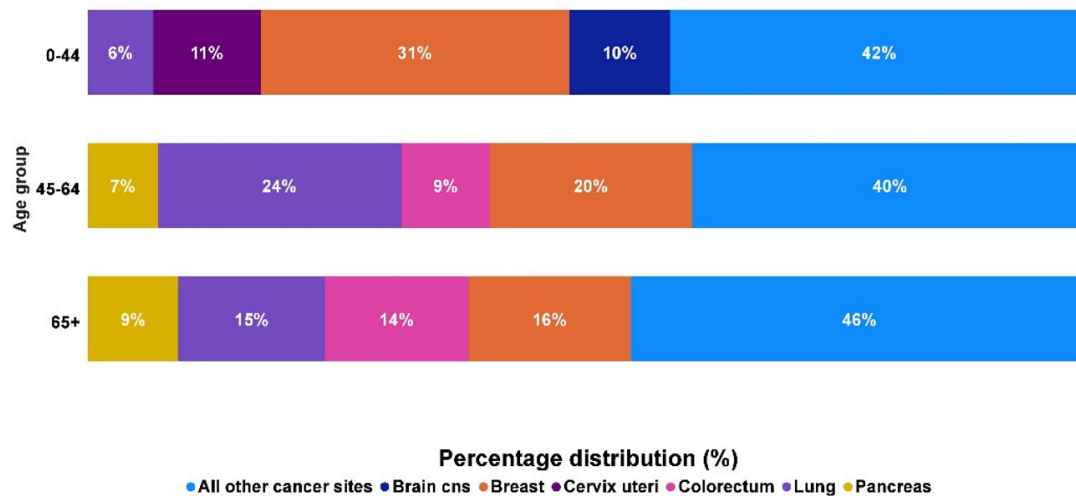
Most common cancer causes of death in women -percentage distribution (%) across European countries in 2020

Breast	Colorectum	Pancreas
28,75%	21,60%	13,94%
Lung	Ovary	
27,18%	8,54%	
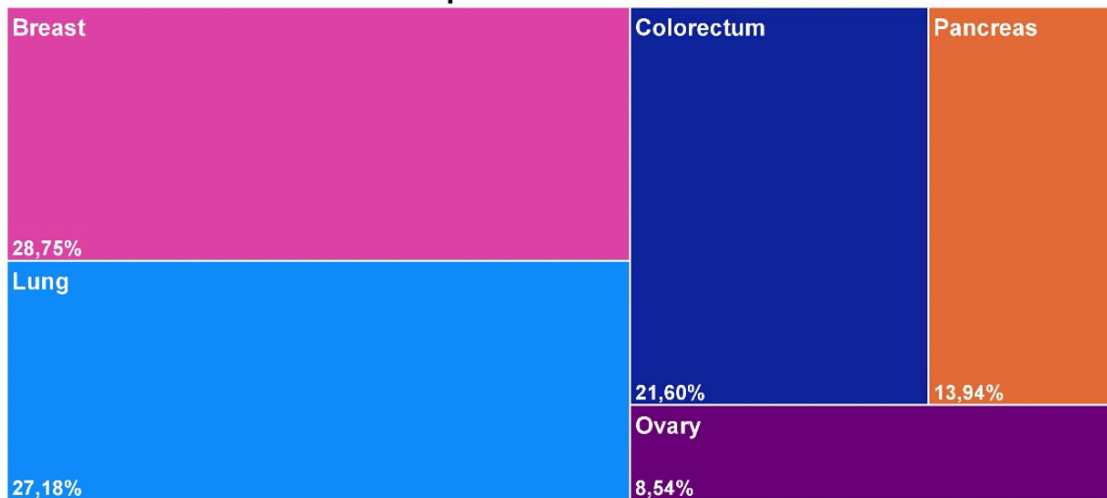
Figure 5. Most common causes of cancer-related deaths in women – percentage distribution (%) across the EU in 2020. The map was created by the authors using data from the European Cancer Information System (ECIS, 2023).

Cancer death distribution varies across age groups. For those aged 0-44 years, breast cancer makes up 31% of deaths. In the 45-64 age group, lung cancer becomes the primary cause, contributing to 24% of deaths. Women aged 65 and older show a 16% mortality rate due to breast cancer (See **Figure 6** below).

Estimated mortality by cancer in women - percentage distribution (%) by age group across European countries in 2020

Age group

0-44	6%	11%	31%	10%	42%
45-64	7%	24%	9%	20%	40%
65+	9%	15%	14%	16%	46%

Percentage distribution (%)

● All other cancer sites ● Brain cns ● Breast ● Cervix uteri ● Colorectum ● Lung ● Pancreas

Figure 6. Estimated mortality from cancer in women – percentage distribution (%) by age group across the EU in 2020. The map was created by the authors using data from the European Cancer Information System (ECIS, 2023).

The distribution of cancer mortality among EU women in 2020 shows some significant behaviors. Breast cancer was revealed to be the most mortal (16.53%), followed by lung cancer (15.61%), colorectal cancer (12.40%), pancreatic cancer (8.01%), and other cancer (26.58%) (See **Figure 7** below).

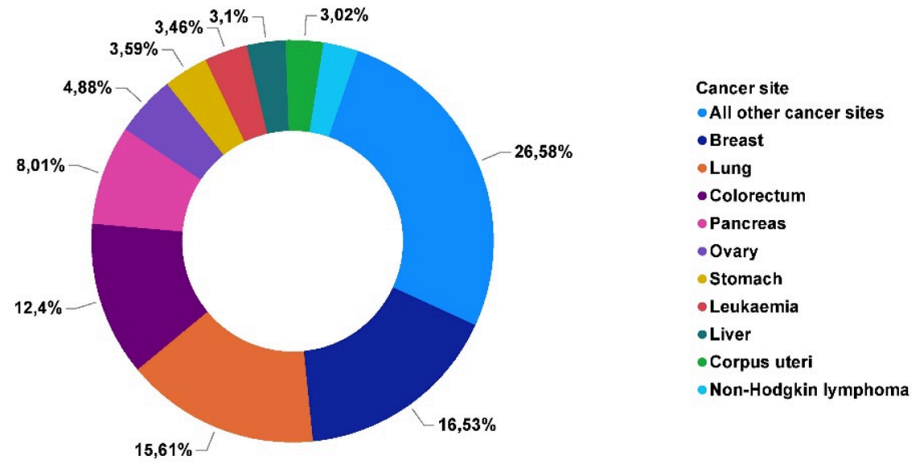**Estimated mortality by cancer in women- percentage distribution (%) across European countries in 2020**

Figure 7. Estimated mortality from cancer in women – percentage distribution (%) across the EU in 2020. The map was created by the authors using data from the European Cancer Information System (ECIS, 2023).

When it comes to mortality rates, the EU's age-standardized rate for breast cancer is 34.1 per 100,000 population, followed by lung cancer at 33.2 and colorectal cancer at 24.5 per 100,000 population (See **Figure 8** below).

Estimated mortality by cancer in women across European countries in 2020
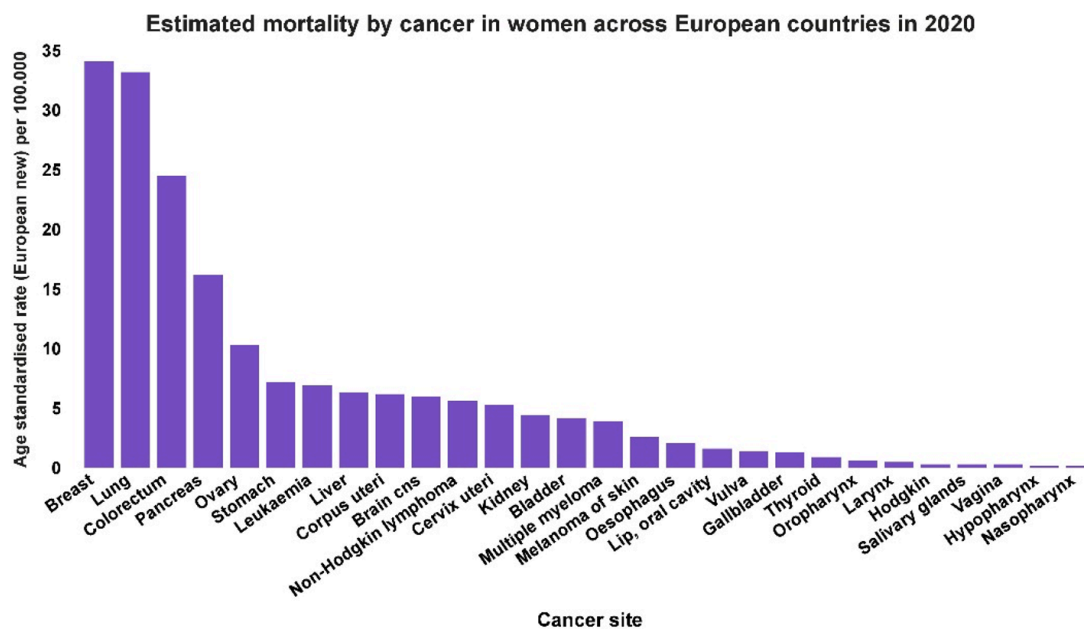

Figure 8. Estimated cancer mortality in women across the EU in 2020. The map was created by the authors using data from the European Cancer Information System (ECIS, 2023).

The levels of cancer mortality among EU women highlight the urgency of exploring gender-based vulnerability to cancer mortality in the EU due to interactions involving biological, behavioral, social, and systemic factors. It calls for a comprehensive strategy, including gender-sensitive healthcare, improved screening and treatment access, and addressing social determinants. The literature recognizes gender-related factors in understanding cancer mortality,

highlighting disparities rooted in socioeconomic indicators and gender (e.g., Donington and Colson[3]; OECD[5]; Jolidon[6]; Koengkan and Fuinhas[13]; Vaccarella et al.[4]). It briefly mentions the potential impact of women's political participation but fails a deep analysis of EU female cancer mortality's link to gender inequality. Studies mention political participation, education, income, and health access, but a detailed exploration of gender inequality's role in cancer mortality is missing. Consequently, this investigation addresses the following question: "To what extent does gender inequality impact women's cancer mortality in the EU?" Below are the main potential hypotheses that can address this inquiry:

- Hypothesis 1: Higher levels of gender inequality within the European Union contribute to disparities in cancer mortality rates among women by affecting key social determinants of health, such as educational attainment, socioeconomic status, healthcare accessibility, and engagement in high-risk behaviors. Gender inequality exacerbates these factors, leading to poorer health outcomes and higher cancer mortality rates.
- Hypothesis 2: Gender inequality within the European Union does not have a significant impact on cancer mortality rates among women. Variations in cancer mortality are not strongly associated with gender disparities in socioeconomic status, healthcare access, or risk behaviors, suggesting that other factors may play a more prominent role in shaping women's health outcomes.

The research investigates the potential impact of gender inequality indicators on cancer mortality rates among women in the European Union between 2013 and 2021 to address the research gap and validate either of these hypotheses. To fulfill our objectives, our research aims to employ advanced econometric methods, including Pooled Ordinary Least Squares (OLS) regression and Quantile regression (QREG).

The selected methodology provides quantitative analysis and examines large-scale trends. It recognizes limitations such as the attenuation of individual-level variations by aggregated data, the availability of accurate data, its extensiveness, and the nature of the study. The research emphasizes a notable gap in the existing literature concerning the relationship between gender discrimination and the cancer death penalty.

Understanding this relationship is essential for addressing gender disparities in healthcare, informing evidence-based interventions, policies, and practices, and promoting gender equity and social justice following the United Nations' Sustainable Development Goals (SDGs). Furthermore, this study seeks to offer innovative contributions by concentrating on the EU context and employing an interdisciplinary approach incorporating sociological, public health, and epidemiological perspectives.

This paper provides a comprehensive overview of the relevant literature in the following section. Section 3 explains the research data and the methodologies utilized. Section 4 scrutinizes the empirical findings, and Section 5 extensively discusses the consequences of the results. Finally, Section 6 offers a comprehensive conclusion.

2. Literature review

There are many academic studies on the causes of death rates. However, most studies exclude causes of death and gender-differentiated mortality. For example, gender differentiation in lung and breast cancer deaths is higher than in other cancer types[14]. Despite this, the number of studies examining cancer-related deaths in women has been increasing in recent years. Some studies use the Gender-Related Development Index (GDI) to indicate gender disparity[15]. However, the GDI is not a measure of gender inequality and should not be interpreted independently of the Human Development Index (HDI)[16].

As expected, the literature supports the idea that an increase in HDI causes a decrease in cancer deaths[17], which is generally valid in low—and middle-income countries. Although studies on gender-differentiated mortality rates typically examine the issue regarding biological differences, fewer studies focus on the relationship between socioeconomic variables—such as education, income, and social status—and deaths.

Numerous studies examining education and mortality rates conclude that there is an inverse relationship between the two variables (e.g.,[18]). Some of these studies emphasize that the impact of schooling rate on both genders is similar[19]; however, these results vary according to the education level and the development of the countries.

Gender differences in income can also affect mortality rates due to access to primary and secondary health services. The increased decision-making autonomy of women as they earn their income positively affects health services utilization[20], and studies show that high socioeconomic status increases women's screening[21], which facilitates early diagnosis and prevents cancer deaths[22]. However, adequate access to screening and health services is not independent of hospital expenditures and insurance costs. For this reason, poverty's negative effect on health is mentioned[23]. Indeed, Gakidou et al.[24] show that only 19% of women in developing countries are screened for cervical cancer while, in developed countries, this rate rises above 60%. Then, increasing primary care investments to prevent the emergence of diseases is also associated with lower cancer deaths[25]. The increase in secondary care investments, which will expand the screening process, and the increase in the rate of the insured population cause a decrease in social inequalities and, consequently, cancer-related deaths[26].

Furthermore, studies examining income inequality and cancer deaths find a positive correlation between the two variables[25] and support that lower income is associated with higher mortality rates[27]. However, these general results do not apply to some types of cancer. For instance, investigations using income and education as socioeconomic indicators show that breast cancer-related mortality rates are higher among women in the high strata compared to the lower strata (e.g.,[27][18][14]). However, as social inequalities decrease, the relationship between education and breast cancer decreases[21]. Unlike breast cancer, low-income women have an increased incidence of lung cancer[28].

As previously stated, most studies on the relationship between socioeconomic status (SES) and mortality rates use education and social classes as indicators[19][29]. However, SES is not easy to calculate because selected variables can affect SES. Then, studies examining the relationship between SES and health inequality may show inconsistent results due to the difficulty of collecting individual SES data, changes in SES over time, and misclassification of social groups[30]. In addition, many investigations examining the relationship between SES and health outcomes use simple correlation analyses, examining a small set of variables[31].

Detailed indices on women's status have been created recently. Therefore, few studies have examined the relationships between political participation, reproductive rights, representation, and female mortality rates. Research using data from the Institute for Women's Policy Research in the USA shows that women's political participation is associated with lower female mortality rates[32]. Bhalotra and Clots-Figueras[33] also argue that women's political representation reduces death rates in India because women attach more importance to healthcare equality than men. Women are expected to draw the most attention to the differentiation of death rates by gender, thanks to their power of representation.

Daily life habits can also adversely affect health quality and increase cancer rates. In recent years, the rate of smoking among women has increased compared to men. Accordingly, there has been an increase in cancer diagnoses among women (e.g.,[34]), especially in highly educated and upper social class women[35]. However, there are no precise results in the literature as to the effect of smoking on cancer deaths. Behaviors such as physical activity and eating habits also, directly and indirectly, affect both SES and health outcomes. According to Ford et al.[36], women with higher SES can devote more free time to themselves and are involved in more physical activity at home. Although there are no definite results on their effects, it is known that fruit and vegetable intake can reduce some cancer risks[37].

Although a healthy diet reduces the risk of cancer, it is supported by research that foods categorized as unhealthy[38] and obesity due to unhealthy diet increase the risk of cancer[39]. Just as unhealthy diets are typical in low-income areas of society, exposure to harmful particulate matter is often high in regions with low house prices, polluted air, and non-environmentally friendly industrial facilities[40][29]. Studies conclude that tiny and harmful airborne particles are associated with female cancer deaths (e.g., Prada et al.[41]).

The literature review acknowledges the importance of gender-related factors in understanding cancer mortality rates. It highlights the differences in mortality rates for various types of cancer-based on socioeconomic indicators and gender. It also briefly discusses the influence of women's political participation and representation on reducing female mortality rates. However, the literature review does not extensively explore or analyze the specific impact of gender inequality on cancer mortality in women within the EU during the specified time frame. While it mentions studies that touch on various gender-related aspects, such as political participation and representation, it does not delve deeply into the complex interplay between gender inequality and cancer mortality rates.

To address this gap effectively, research emphasizing gender-related metrics and robust data analysis is crucial. This holistic approach seeks to illuminate the intricate mechanisms through which gender inequality influences the outcomes of cancer mortality among European women. Consequently, this investigation endeavors to fill this void by conducting an empirical analysis centered around data-driven insights.

3. Data and methods

3.1. Research outline

This research delves into the 27 EU member states[1] women's cancer mortality rates induced by gender inequality. Selecting these countries provides diverse representation, capturing socioeconomic, cultural, and healthcare variations. Analyzing multiple countries improves statistical power and facilitates comparisons. This approach comprehensively examines gender inequality's impact on cancer mortality.

The study employed longitudinal data covering 2013 to 2021, intending to obtain comprehensive and consistent data. This procedure helped mitigate variations in data collection methodologies and reporting accuracy while also allowing for the generation of statistically significant findings within the period's historical and sociopolitical landscape.

3.2. Variables and sources

The study uses cancer–related deaths in women, "Dc_w" as the dependent variable. Table 1 below presents the selected variables for this empirical analysis.

	Abbreviation	Description	Unit of measure	Source
Dependent variable				
Cancer–related deaths in women	Dc_w	Cancer–related deaths in women (total, under 65 years and 65 years or older)	Rate	Eurostat[42]
Independent variable				
Mean Years of Schooling	Mys_w	Mean Years of Schooling	Rate	UNDP[43]
Exposure to Fine Particulate Matter (PM2.5)	PM2.5	Exposure to Fine particulate matter (PM2.5)	Rate	OECD Data (2023)
Gross National Income per capita among women	Gni_pc_w	Gross National Income per capita among women	Euro	UNDP[43]
Breast cancer and cervical cancer screenings in women	Bcc_w	Breast cancer and cervical cancer screenings in women	Rate	Eurostat[44]
Total healthcare expenditure	Hc_ex	Total healthcare expenditure	Million euro per capita	Eurostat[44]
Women engaging in daily cooking and housework activities	Pdc_w	Women engaging in daily cooking and housework activities (%, 18+ population)	Rate	EIGE[45]
Women who do not smoke and are not engaged in harmful drinking	Pdsd_w	Women who do not smoke and are not engaged in harmful drinking (%, 16+ population)	Rate	EIGE[45],
Women who engage in physical activities and consume fruits and vegetables	Pdpfv_w	Women who engage in physical activities and consume fruits and vegetables (%, 16+ population)	Rate	EIGE[45],
Women with unmet needs for medical examinations	Pumex_w	Women with unmet needs for medical examinations (%, 16+ population)	Rate	EIGE[45],
Women who self-perceive their health as good or very good	Sphg_w	Women who self-perceive their health as good or very good (%, 16+ population)	Rate	EIGE[45],
Women who participate in formal or non–formal education and training	Ppet_w	Women who participate in formal or non–formal education and training (%, 15+ population)	Rate	EIGE[45]
The share of women serving as ministers	Sm_w	The share of women serving as ministers (%)	Rate	EIGE[45],
The proportion of women serving as members of parliament	Smp_w	The proportion of women serving as members of parliament (%)	Rate	EIGE[45]
The proportion of women serving as members of regional assemblies	Smra_w	The proportion of women serving as members of regional assemblies (%)	Rate	EIGE[45]
Women who engage in sporting, cultural, or leisure activities outside of their home at least daily or several times a week	Wds_w	Women who engage in sporting, cultural, or leisure activities outside of their home at least daily or several times a week (%, 15+ workers)	Rate	EIGE[45]

Table 1. Variables description

The chosen independent variables are carefully selected to examine the theoretical relations, and each variable was rigorously justified based on existing scientific research and evidence.

I. "Mys_w" and "Ppet_w": Are linked to improved health outcomes and lower cancer mortality rates among women. Previous studies (e.g., Raghupathi and Raghupathi[46]; Vaccarella et al.[4]) have demonstrated a positive association between higher levels of education ("Mys_w") and women who participate in formal or non-formal education and training ("Ppet_w") with better health outcomes, including reduced cancer mortality.

II. "PM2.5": Represents fine particulate matter pollution associated with adverse health effects, including increased cancer risks. Scientific studies (e.g., Prada et al.[41]) have shown the link between exposure to PM2.5 and elevated cancer incidence and mortality rates.

III. "Gni_pc_w": Reflects economic well-being and access to healthcare services among women. Studies (Fletcher[47]) have established the relationship between higher gross national income per capita and improved healthcare infrastructure, which can contribute to better cancer outcomes.

IV. "Bcc_w": Focuses on breast and cervical cancer, emphasizing the importance of early detection and reduced mortality rates among women. Research (Yang et al.[48]) has shown that adequate breast and cervical cancer screening programs improve survival rates and lower mortality.

V. "Hc_ex" represents healthcare expenditures and highlights the importance of healthcare services in cancer outcomes. Previous studies (e.g., Akinyemiju et al.[49]) have demonstrated the significant role of access to healthcare services in reducing cancer mortality rates.

VI. "Pdc_w": Emphasizes the association between daily cooking and housework activities and lower cancer mortality rates among women. Research (e.g., Chen et al.[50]) has consistently shown the benefits of regular physical activity and a healthy lifestyle in reducing cancer risk and improving survival.

VII. "Pdsd_w": Relates to reduced cancer risks through lower smoking and drinking (Anand et al.[51]; Lugo et al., 2017) have demonstrated the link between tobacco and alcohol consumption and increased cancer incidence and mortality.

VIII. "Pdpfv_w": Emphasizes the benefits of regular physical activity and a healthy diet in lowering cancer mortality among women. Existing research (e.g., Schnohr et al.[52]) supports the positive impact of physical activity and a nutritious diet on reducing cancer risks and improving survival.

IX. "Pumex_w": Addresses barriers to accessing healthcare services and potential delays in cancer diagnosis among women. Studies have highlighted the importance of timely access to healthcare and its influence on cancer outcomes (e.g., Quintal et al.[53])

X. "Sphg_w": Highlights the association between positive self-perceived health in women and lower cancer mortality rates. Research (Korn et al.[54]) has shown that individuals with a positive self-perception of health tend to engage in healthier behaviors and have improved health outcomes, including lower cancer mortality.

XI. "Sm_w," "Smp_w," and "Smra_w": Reflect women's political representation, which has been linked to improved health outcomes and lower cancer mortality rates. Studies (Reeves et al.[55]) have demonstrated the positive impact of gender equality in political representation on cancer mortality.

XII. "Wds_w": Represents women's engagement in regular physical and leisure activities (Schnohr et al.[52]).

Our investigation has encompassed various variables, including socioeconomic, environmental, lifestyle, and healthcare factors. The focus on women's mortality is of the utmost importance, given the distinct effects of gender inequality on women's health, socioeconomics, and risk behaviors.

3.3. Pooled OLS estimation

The general Pooled OLS specification is specified by E1. (1).

$$y_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \cdots + \beta_n x_{12it} + \varepsilon_{it} \tag{1}$$

where, $x_1, \cdots, x_{12}$ are the independent variables, $\beta_1, \cdots, \beta_{12}$ the regression coefficients reveal the statistical relationship between the independent variables and the dependent variable, and the error term captures the unexplained variability or residual variation in the dependent variable that is not accounted for by the independent variables.

3.4. QREG estimation

This study utilized QREG estimation, an econometric technique that helps assess the robustness of Pooled OLS results. Unlike OLS, which focuses solely on the mean, QREG analyzes how variations in covariates impact different percentiles of the explained variable. This characteristic makes QREG robust to outliers and allows distinct patterns in data. This approach is particularly valuable for understanding complex relationships, skewed distributions, and specific segments of the response distribution. The linear quantile regression can be expressed by Eq. (2).

$$Q(y \mid x; \tau) = \beta_{0,\tau} + \beta_{1,\tau} x + \varepsilon \tag{2}$$

This empirical investigation employed the 25th, 50th, 75th, and 95th quantiles for a robustness check. This QREG technique ensures reliable analysis by examining relationships across response distribution segments, revealing potential asymmetry and heterogeneity. The median offers central tendency insight with outlier resistance, while the 95th quantile scrutinizes extreme outcomes, ensuring consistent conclusions across the distribution and enhancing model reliability. QREG's ability to estimate different quantiles accommodates data variations, revealing insights into extreme values and tail behavior. Comparing

QREG and OLS results allows for robustness assessment, significantly when data deviates from normality or contains outliers. This approach enriches understanding variable relationships and ensures a holistic data evaluation.

3.5. Preliminary tests

It is crucial to conduct preliminary tests to comprehend variable characteristics in the economic model before the pooled OLS and QREG estimators' regressions. Therefore, the following preliminary tests were conducted to assess the variables' properties.

    I. Summary statistics and histograms: The mean, standard deviation, range, quartiles, and histograms.

    II. Pairwise Correlation [56]: The pairwise correlation was calculated to measure the linear association between variables.

    III. Normality tests: This test determines skewness and kurtosis [57] to infer a normal distribution. H0: The variable is normally distributed.

    IV. Pesaran's [58] Panel Unit Root test (Cross-sectionally Augmented IPS) assesses the stationarity of variables in panel data.

    V. Wooldridge's test for autocorrelation in panel data [59]: The test examines autocorrelation in the residuals, with the null stating no autocorrelation.

    VI. Breusch–Pagan/Cook-Weisberg's test [60][61]: The test examines heteroskedasticity in residuals. The null states no heteroskedasticity. Test for Heteroskedasticity:

Conducting initial tests yielded valuable insights into variable traits and identified non-normality, autocorrelation, or heteroskedasticity that may impact subsequent Pooled OLS and QREG regressions. Notably, such tests are widely employed in econometrics [62].

3.6. Stata commands

The Stata commands employed in this study encompassed sum, histogram, pwcorr, sktest, vif, multipurt, xtserial, hettest, reg, reg robust, and qreg, quantile (.25.5.75.95) (See **Figure 9** below).
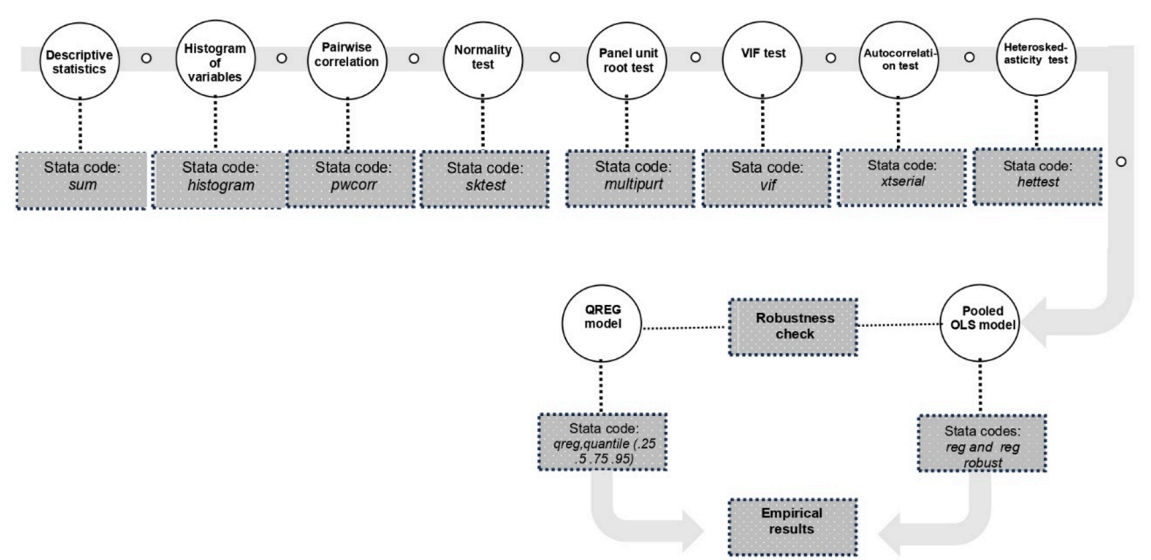

Figure 9. *Stata commands. The authors developed this figure.*

4. Results

This section includes information on data properties, pretesting of variables, estimation results, and specification tests for the estimation. Variables' descriptive statistics were computed and are exposed in Table 2 below.

Variables	Obs	Mean	Std. Dev.	Min	Max
Dc_w	216	200.1289	28.07403	140.36	268.56
Mys_w	243	2.4802	0.1018	2.1603	2.6487
PM2.5	243	2.5660	0.3823	1.6741	3.2946
Gni_pc_w	243	32518.08	11339.21	15135.71	71316.82
Bcc_w	243	33.98156	30.50838	0	84.3
Hc_ex	241	9.5900	1.6147	6.6783	13.0168
Pdc_w	243	76.4609	8.96420	0	90
Pdsd_w	242	4.2779	0.0813	4.0253	4.4426
Pdpfv_w	243	35.1358	14.6471	0	70
Pumex_w	228	1.5657	0.81914	0	3.0910
Sphg_w	242	4.1345	0.1831	3.6375	4.4308
Ppet_w	242	2.7835	0.4390	0.6931	3.8066
Sm_w	243	26.0493	13.2555	0	59
Smp_w	243	26.2222	10.1541	0	48
Smra_w	243	27.1687	10.5611	0	49
Wds_w	242	3.1156	0.6180	1.7917	4.0943

Table 2. Descriptive statistics

Moreover, pairwise correlation and VIF statistics (see Tables 3 and 4 below) were performed and revealed that correlation and multicollinearity are not a concern to the estimation.

Variables	(A)	B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)	(M)
						Pairwise Correlation							
Dc_w (A)	1.000												
Mys_w (B)	0.4063***	1.000											
PM2.5 (C)	0.2215***	–0.0582	1.000										
Gni_pc_w (D)	–0.0310	0.2766***	–0.5336***	1.000									
Bcc_w (E)	0.3204***	0.2617***	–0.1070*	0.2336***	1.000								
Hc_ex (F)	–0.0929	–0.2193***	–0.1715**	0.3552***	–0.0790	1.000							
Pdc_w (G)	–0.2617***	–0.0770	–0.2132***	0.2435***	0.1542**	0.1360**	1.000						
Pdsd_w (H)	–0.1781**	–0.2999***	0.0795	–0.5158***	–0.1537**	–0.2320***	–0.1250**	1.000					
Pdpfv_w (I)	0.1493*	0.3677***	–0.5677***	0.6898***	0.2710***	0.2264***	0.2884***	–0.4697***	1.000				
Pumex_w (J)	0.1660*	0.0122	0.0419	–0.4472***	–0.1655**	–0.2470***	–0.0607	0.2128**	–0.2790***	1.000			
Sphg_w (K)	–0.1653*	–0.1205**	–0.1306***	0.4771***	0.0530	0.3687***	0.1706**	–0.4679***	0.3256***	–0.3386***	1.000		
Ppet_w (L)	0.0970	0.2808***	–0.5285***	0.5638***	0.1964**	0.1217**	0.1838***	–0.1233***	0.6394***	–0.1216*	0.2166***	1.000	
Sm_w (M)	–0.2012**	0.1061*	–0.3709***	0.4619***	–0.0655	0.5050***	0.2956***	–0.2919***	0.4416***	–0.1395**	0.2359***	0.5169***	1.000
Smp_w (N)	–0.1872**	0.0529	–0.4880***	0.4925***	–0.0356	0.5439***	0.3819***	–0.1841***	0.4754***	–0.2113**	0.1989***	0.5533***	0.7472***
Smra_w (O)	–0.2641***	0.0685	–0.4963***	0.4052***	–0.0037	0.4764***	0.3889***	–0.2265***	0.4231***	–0.1585**	0.2219***	0.5846***	0.7671***
Wds_w (P)	0.1168***	0.2802***	–0.5081***	0.6735***	0.4130***	0.3331***	0.3592	–0.3945***	0.7026***	–0.2550***	0.3936	0.7652***	0.5260***

Table 3. Pairwise Correlation

*Notes: ***, **, and * denote statistically significant at the 1%, 5%, and 10% levels, respectively.*

Variables	VIF test	Mean VIF
Dc_w	N/a	3.13
Mys_w	1.85	
PM2.5	3.14	
Gni_pc_w	4.25	
Bcc_w	1.54	
Hc_ex	2.34	
Pdc_w	1.46	
Pdsd_w	2.43	
Pdpfv_w	4.15	
Pumex_w	1.62	
Sphg_w	1.87	
Ppet_w	4.58	
Sm_w	3.19	
Smp_w	3.90	
Smra_w	4.95	
Wds_w	5.73	

Table 4. VIF test

Notes: N/a means "Not applicable."

Table 5 below displays the variables' test of normal distribution.

Variables	Skewness/kurtosis			
	Pr(Skewness)	Pr(Kurtosis)	Prob>chi2	
Dc_w	0.0609	0.010	0.0105	*
Mys_w	0.0000	0.4952	<0.0001	***
PM2.5	0.0027	0.1707	0.0077	*
Gni_pc_w	0.0000	0.0605	<0.0001	***
Bcc_w	0.0000	0.0000	<0.0001	***
Hc_ex	0.2182	0.0000	<0.0001	***
Pdc_w	0.0000	0.0000	<0.0001	***
Pdsd_w	0.1503	0.6871	0.3246	
Pdpfv_w	0.0421	0.8557	0.1227	
Pumex_w	0.0193	0.0225	0.0083	*
Sphg_w	0.0000	0.5561	<0.0001	***
Ppet_w	0.0395	0.0000	<0.0001	***
Sm_w	0.0367	0.0058	<0.0001	***
Smp_w	0.2005	0.0000	<0.0001	***
Smra_w	0.0010	0.0236	<0.0001	***
Wds_w	0.2197	0.0000	<0.0001	***

Table 5. Skewness/kurtosis test

Notes: ***, * denote statistically significant at 1% and 10%, respectively.

The tests show that the variables Women who do not smoke and are not engaged in harmful drinking (Pdsd_w) and Women who engage in physical activities and consume fruits and vegetables (Pdpfv_w) do not follow a normal distribution. The evidence that the variables Cancer-related deaths in women (Dc_w), Exposure to Fine Particulate Matter (PM2.5), and Women with unmet needs for medical examinations (Pumex_w) follow a normal distribution is weak. For the remaining variables, the tests support the assumption of a normal distribution.

Moreover, the autocorrelation test of Wooldridge and the heteroskedasticity tests of Breusch–Pagan / Cook-Weisberg—presented in Table 6 below—reveal the presence of heteroskedasticity.

Wooldridge test for autocorrelation in panel data	Breusch–Pagan / Cook-Weisberg test for heteroskedasticity
F(1,26) = 2.440	chi2(1) = 9.89**

Table 6. Wooldridge and Breusch–Pagan / Cook-Weisberg tests

Notes: ** denotes statistically significant at 5% levels; H_0 of Wooldridge test: no first-order autocorrelation; H_0 of Breusch–Pagan / Cook-Weisberg test: constant variance.

The second-generation unit root test and the variable histogram were also performed. The outcomes of both tests are not presented but are available upon request.

Following preliminary tests, this study executes the Pooled OLS regression. As mentioned earlier, this regression constitutes the central model of our empirical investigation, and the outcomes are presented in Table 7 below.

Explanatory variables	Explained variable (Dc_w)				
		Pooled OLS		Robust Pooled OLS	
	Coefficient	t	Significance	t	Significance
Mys_w	55.0277	3.28	***	3.69	***
PM2.5	15.5570	2.60	**	2.74	***
Gni_pc_w	–0.0003	–1.65		–1.70	*
Bcc_w	0.1418	2.68	***	2.47	**
Hc_ex	5.4938	4.55	***	4.28	***
Pdc_w	–0.8992	–4.47	***	–4.86	***
Pdsd_w	–87.2914	–3.65	***	–3.78	***
Pdpfv_w	0.2785	1.60		1.73	*
Pumex_w	6.6875	3.38	***	3.27	***
Sphg_w	–39.9806	–4.29	***	–4.63	***
Ppet_w	18.8653	3.09	***	3.51	***
Sm_w	–0.4403	–2.50	**	–2.77	***
Smp_w	0.10610	0.42		0.49	
Smra_w	–1.1209	–4.14	***	–4.25	***
Wds_w	11.7107	2.37	**	2.25	**
Constant	516.3015	3.81	***	3.80	***
Number of obs	227	227			
F(10,211)	17.59	31.27			
Prob > F	< 0.001 ***	< 0.001 ***			
R^2	0.5556	0.5556			
Adj R^2	0.5241	n.a.			
Root MSE	19.162	19.162			

Table 7. Pooled OLS estimations

Notes: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively; n.a. means "Not applicable."

The outcomes of the Pooled OLS robust regression reveal notable associations. The variable Exposure to Fine Particulate Matter (PM2.5) is linked to a 15.5570 increase in cancer mortality among women, as represented by the dependent variable Cancer-related deaths in women (total, under 65 years and 65 years or older). Similarly, the variable Breast cancer and cervical cancer screenings in women (Bcc_w) exhibits a 0.1418 increase in women's cancer mortality, while Total healthcare expenditure (Hc_ex) demonstrates a 5.4938 increase. Furthermore, gender inequality indicators, such as Mean Years of Schooling (Mys_w), exhibit a substantial impact, contributing to a 55.0277 increase in cancer mortality among women (Cancer-related deaths in women). On the other hand, the variable Gross National Income per capita among women (Gni_pc_w) correlates with a reduction of –0.0003 in women's cancer mortality.

Additionally, Women engaging in daily cooking and housework activities (Pdc_w), Women who do not smoke and are not engaged in harmful drinking (Pdsd_w), and Women who engage in physical activities and consume fruits and vegetables (Pdpfv_w) are associated with reductions in women's cancer mortality by –0.8992, –87.2914, and an increase of 0.2785, respectively. Meanwhile, Women with unmet needs for medical examinations (Pumex_w), Women who self-perceive their health as good or very good (Sphg_w), Women who participate in formal or non-formal education and training (Ppet_w), The share of

women serving as ministers (Sm_w), The proportion of women serving as members of parliament (Smp_w), The proportion of women serving as members of regional assemblies (Smra_w), and Women who engage in sporting, cultural, or leisure activities outside of their home at least daily or several times a week (Wds_w) are linked to increases of 6.6875, –39.9806, 18.8653, –0.4403, –1.1209, and 11.7107 in women's cancer mortality, respectively.

Following the execution of the Pooled OLS regression, it becomes imperative to verify the stability of the outcomes obtained from the preceding model. The investigation employed Quantile Regression (QREG) models to ensure this robustness assessment, and the outcomes are presented in Table 8. As part of this empirical inquiry, the approach selected for the robustness assessment involves employing the 25th, 50th, 75th, and 95th quantiles.

Independent variables	Dependent variable (Dc_w)											
	Quantiles											
	.25Q			.5Q			.75Q			.95Q		
Mys_w	88.1095	<0.001	***	41.1732	0.102		13.79452	0.497		34.7266	<0.001	***
PM2.5	14.6251	0.037	**	30.6473	<0.001	***	27.7872	<0.001	***	37.8619	<0.001	***
Gni_pc_w	–0.0002	0.447		0.0000	0.874		0.0003	0.283		–0.0001	0.873	
Bcc_w	–0.0082	0.894		0.0829	0.297		0.2770	<0.001	***	0.2539	<0.001	***
Hc_ex	4.8701	<0.001	***	2.0373	0.261		4.4088	<0.001	***	0.4395	0.627	
Pdc_w	–1.2173	<0.001	***	–1.5693	<0.001	***	–1.0573	<0.001	***	–0.6067	<0.001	***
Pdsd_w	–22.5621	0.420		–40.2808	<0.001	***	–43.3806	0.135		–51.6931	<0.001	***
Pdpfv_w	0.3200	0.118	***	0.4751	0.070	*	0.0198	0.925		0.1767	0.177	
Pumex_w	8.2161	<0.001	***	10.6309	<0.001	***	12.7632	<0.001	***	11.3479	<0.001	***
Sphg_w	–45.6901	<0.001	***	–54.4367	<0.001	***	–26.9202	<0.001	***	–28.2145	<0.001	***
Ppet_w	11.23136	0.116		4.7683	0.602		18.6004	<0.001	***	23.3084	<0.001	***
Sm_w	–0.4208	0.042	**	–0.5210	0.049	**	–0.2987	0.162		–0.0022	<0.001	***
Smp_w	–0.2054	0.489		0.3121	0.413		0.7483	<0.001	***	0.2625	0.168	
Smra_w	–0.3289	0.299		–.3703	0.362		–2.1013	<0.001	***	–2.0477	<0.001	***
Wds_w	7.3813	0.202		15.0190	0.043	**	24.3554	<0.001	***	26.2964	<0.001	***
Constant	217.1116	0.171		432.1564	0.034	**	322.644	<0.001	***	296.7569	<0.001	***

Table 8. QREG model

*Notes: ***, **, * denote statistically significant at 1%, 5%, and 10%, respectively.*

The results from Table 8 show the outcomes of Quantile Regression (QREG). These results generally support the findings obtained from the Pooled OLS regression, but with the sign of the parameter for Breast cancer and cervical cancer screenings in women (Bcc_w) turning negative. This change in sign to negative is expected for this variable. Furthermore, the Quantile Regression estimation indicates that all variables are statistically highly significant at least at one quantile, except for Gross National Income per capita among women (Gni_pc_w), which is not statistically significant at any quantile. Finally, Figure 10 summarizes the findings of this research.
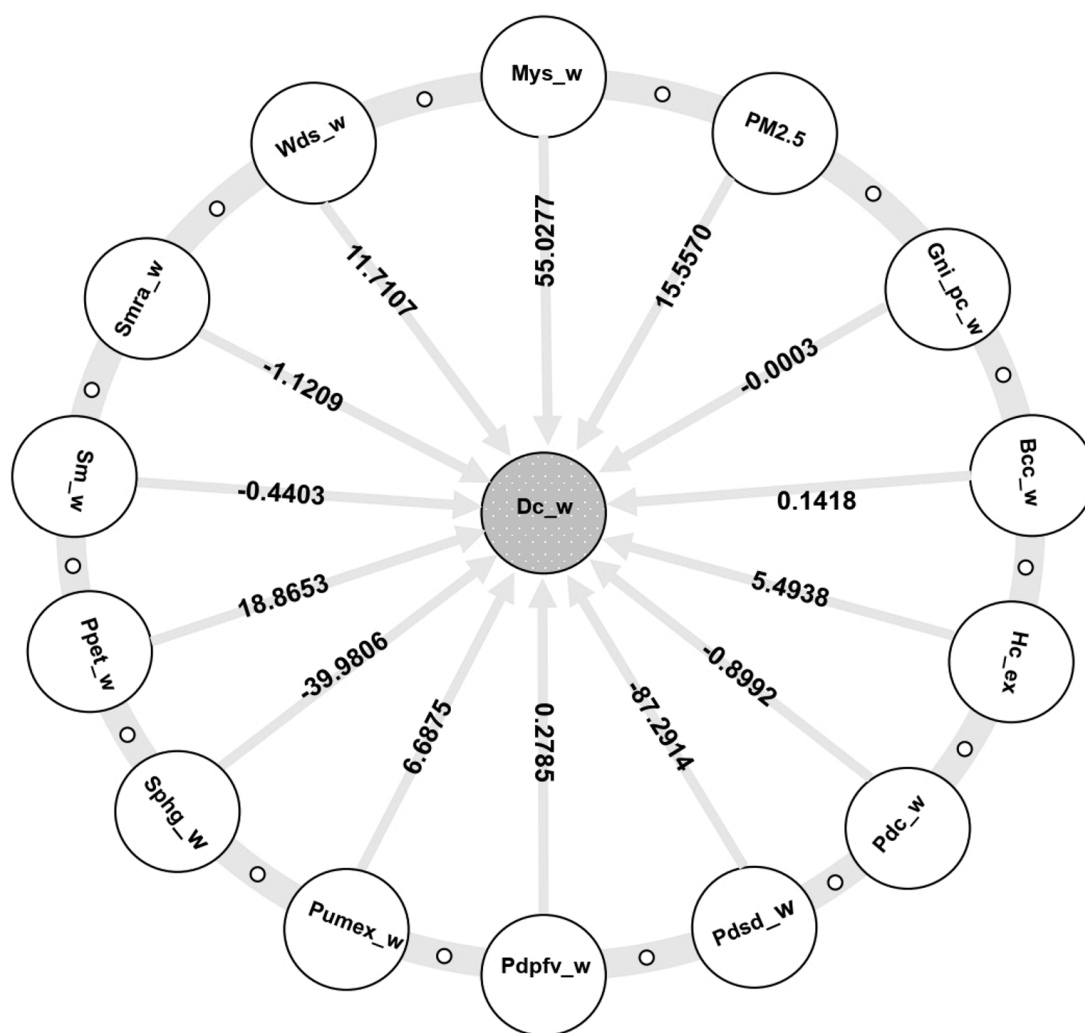
Figure 10. *The authors created this figure to summarize the empirical results from Table 1.*

5. Discussion

This section offers potential explanations for the observed empirical results. However, it is important to note that further studies may be necessary to confirm these findings definitively. Based on the findings presented, this investigation raises the following question: What plausible explanations could be for these results?

The results demonstrate the unexpected influence of Gender inequality in education among women (Mys_w) and Women engaged in physical activity and consuming a balanced diet (Ppet_w) on cancer mortality in women in the EU. Contrary to expectations, higher values of these variables are associated with increased cancer mortality rates by 55.0277 and 18.8653, respectively (e.g., Raghupathi and Raghupathi[46]; Vaccarella et al.[4]).

One possible explanation for the association between higher socioeconomic status and cancer mortality could be the accumulation of risk factors over the life course. Individuals with higher socioeconomic status, although they may have better access to healthcare and resources, may also experience lifestyle factors such as unhealthy diets, high levels of work-related stress, and multitasking. These factors, often linked to demanding professional lives and societal pressures, could contribute to the increased risk of cancer. Further research is needed to explore this complex relationship more thoroughly, as it could provide a deeper understanding of how socioeconomic status intersects with other risk factors to influence cancer mortality among women in the EU.

The EU has a relatively high proportion of women with tertiary education, indicating a greater likelihood of women having a university degree than men[63]. However, disparities exist, with Romania having the lowest percentage of women aged 25–34 with tertiary education (25%) and Ireland having the highest (62%). Other countries show varied rates: Italy at 29%, Hungary at 32%, Slovakia at 39%, Finland at 40%, and Portugal at 44%[63]. Contributing to low education

levels among women in these countries are factors such as entrenched historical gender norms, economic disparities that prioritize male education, and cultural beliefs that limit women's progress. These challenges are exacerbated by early marriages, restricted access to quality education, and persistent gender stereotypes.

This unexpected impact on cancer mortality rates could be attributed to the low proportion of women with high education in most EU countries. Previous studies have shown an association between low education levels in women and higher cancer mortality rates (e.g., Barcelo et al.[64]; Vaccarella et al.[4]). Women with lower levels of education are more likely to face challenges in accessing healthcare, be exposed to risk factors for cancer, lack awareness of cancer symptoms, and possess limited knowledge about cancer prevention (e.g., Barcelo et al.[64]; Kamanga and Stones[65]).

Furthermore, the correlation between limited educational attainment and inadequate nutritional habits (e.g., Assari and Lankarani[66]), reduced physical activity[67], lower rates of breast and cervical cancer screenings among women[65], as well as restricted income levels[66], collectively contribute to the escalated mortality rates from cancer among women with lower educational backgrounds. This connection finds support in the outcomes of Breast and cervical cancer screening rates in women (Bcc_w), Physical activity and fruit and vegetable consumption (Pdpfv_w), Women with unmet medical examination needs (Pumex_w), and Women perceiving their health as poor or fair (Wds_w). In summary, the unexpected relationship between education and cancer mortality in EU women suggests that the low proportion of highly educated women in most countries may play a role. This aligns with previous studies that have identified the association between low education levels in women and increased cancer mortality rates (e.g., Barcelo et al.[64]; Kamanga and Stones[65]).

The impact of Exposure to fine particulate matter (PM2.5) on cancer mortality rates among EU women is significant, with a coefficient of 15.5570. PM2.5 exposure is known to pose a cancer risk, and women residing in urban areas in the EU are more exposed to PM2.5 than those in rural areas[68][69]. This increased exposure likely contributes to the elevated cancer mortality rates among women[68][69]. In 2019, Bulgaria (19.6 μg/m3) and Poland (19.3 μg/m3) had high PM2.5 levels in urban areas within the EU, followed by Romania (16.4 μg/m3) and Croatia (16 μg/m3). Conversely, Finland (5.1 μg/m3) and Sweden (5.8 μg/m3) exhibited lower PM2.5 concentrations in urban areas[70]. Studies have established a link between PM2.5 exposure and cancer mortality in women (e.g., [41]). This outcome may be associated with lower education levels and income, which compel women to reside in areas characterized by poor air quality due to limited housing choices or financial constraints, elevating their exposure to PM2.5[71]. Furthermore, women's restricted access to healthcare can pose significant barriers to timely cancer screening, diagnosis, and treatment[65]. This situation often results in the detection of cancer at a more advanced and less treatable stage, ultimately contributing to increased cancer mortality associated with PM2.5 exposure.

The variable Gross National Income per capita among women (Gni_pc_w) influences a reduction of -0.0003 in women's cancer mortality. This decrease is linked to higher Gross National Income per capita in EU countries. These nations tend to possess superior healthcare systems, allocate more resources for prevention, and encourage healthier lifestyles. This lowers cancer mortality rates[47]. This outcome is likely due to policies targeting the gender pay gap, which grant women more financial resources for investing in health, including better food choices, preventive care, and quitting smoking, resulting in decreased cancer mortality for EU women.

The findings show that Breast and cervical cancer screening rates among women (Bcc_w) lead to a significant increase in cancer mortality among women by 0.1418. This unexpected impact may be due to the low rates of breast and cervical cancer screenings among women in certain EU countries. Some EU member-states (e.g., Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, France, Germany, Hungary, Italy, Latvia, Lithuania, Luxembourg, Poland, and Slovakia) have shown almost no women, aged 50 to 69, screenings for cancer of breast and cervical in both 2010 and 2020. Notably, these countries have participation rates below 70% for breast cancer screening and below 50% for cervical cancer screening[72].

The low rate of screening for breast and cervical cancer among women aged 50 to 69 in the EU can be attributed to several factors. These include limited awareness and access to screening, financial barriers to costly procedures, language barriers affecting communication with healthcare providers, and cultural beliefs that discourage participation. To improve screening rates among EU women, addressing these barriers through increased awareness, affordability, improved accessibility, language support, and cultural sensitivity[72][48]. This negative impact also might be associated with insufficient investment in screening services and programs for breast and cervical cancers in some EU countries[73].

An important public health intervention, the HPV vaccination, has shown significant potential in reducing cervical cancer mortality rates among women. Vaccinating women against high-risk strains of HPV before they become sexually active can prevent the majority of cervical cancer cases, thus addressing one of the key preventable cancer causes in women (Vaccarella et al., 2023). However, disparities in vaccination coverage among EU countries could limit its effectiveness, as some regions have lower vaccination rates, often due to cultural resistance or inadequate health infrastructure (e.g., Raghupathi & Raghupathi, 2020). Increased efforts to improve vaccination programs could therefore complement screening efforts and further reduce cancer mortality among women in the EU.

Time constraints and heavy workloads also significantly impact these trends. Kamanga and Stones[65] suggest that demanding jobs, family obligations, and commitments make it hard for women to prioritize health check-ups, including cancer screenings. Moreover, Kamanga and Stones[65] also note that a lack of education about early detection contributes to these rates. Some women do not grasp screening benefits or risks, lowering their priority. Moreover, access limitations, cultural norms, personal beliefs, and healthcare system inefficiencies deter women from screenings[65].

The findings indicate that Healthcare expenditure per capita in women's healthcare (Hc_ex) increases cancer mortality among women by 5.4938 (e.g., Akinyemiju et al.[49]). This unexpected impact on cancer mortality rates could be attributed to low healthcare expenditure per capita in certain EU countries.

Contrary to expectations, several EU countries had relatively low healthcare expenditure levels in 2020, e.g., Croatia, Hungary, Latvia, Poland, and Romania[74]. This low expenditure can increase death from cancer in several ways, including healthcare inadequacy, tardy diagnosis, postponed treatment, as well as scarce investment in covering and deterrence (e.g., Allemani et al.[75]; Jemal et al.[76]). Indeed, the influence of Breast and cervical cancer screening rates (Bcc_w) on the increase in cancer mortality among women indicates healthcare expenditure patterns.

The results show that Women engaging in domestic work and housework activities (Pdc_w) leads to a reduction of -0.8992 in cancer mortality among women (e.g., Chen et al.[50]). Engaging in everyday cooking and housework activities among EU women can potentially lower cancer mortality rates through several mechanisms, e.g., encouraging a healthier diet by enabling control over ingredients and cooking methods, resulting in well-rounded and nutritious meals. Moreover, housework involves physical movement, and increasing physical activity levels is linked to reduced cancer risks. Additionally, these activities might act as stress-relievers, potentially lowering chronic stress levels associated with elevated cancer risk[77].

The results show that Women abstaining from smoking or engaging in harmful drinking (Pdsd_w) is linked to a significant decrease of 87.2914 in women's cancer mortality. It is well-established that abstaining from smoking and excessive alcohol consumption significantly reduces female cancer mortality (Anand et al.[51]; Lugo et al., 2017). However, trends in the EU show a decline in the proportion of women who abstain from smoking and harmful drinking despite policies and campaigns aimed at reducing alcohol and tobacco consumption[78][79]. Continued promotion of public health initiatives that target these risk factors is essential to achieving further reductions in cancer mortality among EU women.

In conclusion, while this study provides an important contribution to understanding the factors influencing cancer mortality among women in the EU, it also opens avenues for further investigation into the complex interplay of education, environment, healthcare access, and lifestyle. Further research is needed to clarify these relationships and identify effective strategies for reducing cancer mortality across the region. Tailored interventions addressing the specific challenges faced by women in different EU countries, particularly those related to education, healthcare, and lifestyle, are essential for improving health outcomes and reducing cancer mortality in the EU.

6. Conclusion and policy implications

This study aimed to evaluate the impact of gender inequality indicators on cancer-related deaths among women in 27 EU countries from 2013 to 2021. The findings provide key insights into how gender inequality factors contribute to varying cancer mortality rates.

The study reveals significant associations between higher education and women's participation in formal or non-formal education and training with increased cancer mortality rates. This unexpected result could be attributed to the low proportion of women with high education in several EU countries, which might limit their access to healthcare and preventive measures. Additionally, particulate matter (PM2.5) emerged as a significant risk factor, with higher levels of exposure linked to increased cancer mortality, especially in urban areas.

The research also shows that higher Gross National Income per capita is associated with lower cancer mortality rates, highlighting the role of economic factors in improving women's health outcomes. Daily cooking and housework activities were found to reduce cancer mortality, likely due to increased physical activity and healthier dietary habits.

Breast and cervical cancer screenings were linked to increased mortality, likely reflecting low participation rates in certain countries. Healthcare expenditure per capita also showed a positive correlation with increased cancer mortality, indicating that countries with lower healthcare spending face challenges in early detection and treatment.

Positive self-perceived health significantly reduces cancer mortality among women, emphasizing the importance of mental and physical well-being. Furthermore, political representation of women at ministerial and parliamentary levels is associated with lower cancer mortality, suggesting that women's leadership in policy-making can enhance health outcomes.

In conclusion, addressing gender inequality in education, healthcare access, economic status, and political representation is critical to reducing cancer mortality rates among women. Policy interventions should focus on empowering women through education, improving access to healthcare, and addressing

environmental risk factors such as PM2.5 exposure. These steps are essential for promoting equitable health outcomes and reducing gender disparities in cancer mortality.

6.1. Policy Implications

The implications derived from this study underscore the critical necessity for policy interventions to reduce gender-based health disparities and enhance the overall well-being of EU women. Policymakers should prioritize implementing gender-responsive healthcare policies that address the unique health needs of EU women. The identified disparities highlight the urgency of implementing targeted interventions and policies that comprehensively address the multifaceted factors influencing divergent health outcomes related to cancer mortality among EU women. To this end, policy recommendations are proposed to guide policymakers in fostering positive change.

Firstly, promoting women's empowerment through education, economic opportunities, and political participation can improve health-seeking behaviors and equitable health outcomes. This approach can increase cancer screenings, risk management, and healthy lifestyles among women. With national and EU financing, educational institutions, healthcare providers, and community groups may conduct awareness seminars and initiatives in EU countries to reduce cancer mortality among women. Increased health literacy among women will encourage greater participation in cancer screenings and ultimately lead to better health outcomes.

Secondly, policies should ensure that all women have access to the healthcare system. This requires policies that eliminate financial barriers to screenings and cancer treatments. Furthermore, expanding government-funded healthcare programs, subsidizing cancer-related costs, and adopting new delivery methods such as telemedicine can remove obstacles to widespread healthcare access and early cancer diagnosis.

Thirdly, more stringent environmental regulations, particularly those aimed at reducing air pollution, can lower cancer risks. Collaborations among governments, environmental agencies, local authorities, and private stakeholders can help reduce indoor air pollution. Moreover, a gender-responsive policy environment can be created through quotas or incentives for female political participation, leadership training, and mentoring. Leadership programs, awareness campaigns, and capacity-building projects can benefit from government budgets and EU support, making cancer prevention and treatment policies more equitable and effective.

Fourthly, targeted actions are needed to ensure equitable healthcare access and risk reduction for disadvantaged and vulnerable groups. Policymakers should collaborate with non-governmental organizations, community groups, and healthcare practitioners to create culturally sensitive initiatives that meet these groups' specific needs. Adequate healthcare budgets and public-private collaborations will be crucial for the success of these programs.

Finally, investing in healthcare infrastructure and increasing per capita healthcare expenditure is imperative to enhance healthcare quality, reduce screening times, and prioritize preventive measures and early detection programs. Policymakers should also encourage physical activity and healthy behaviors through comprehensive awareness campaigns, community-based programs, and incentivized initiatives.

6.2. Study Limitations

One of the key limitations of this study is its reliance on existing data sources, which, while extensive, may introduce potential inaccuracies and limit the scope of variables considered. Although the data analyzed covers a broad range of countries and indicators, it is inherently constrained by the quality and consistency of available information. For instance, disparities in data collection methods across EU member states, variations in reporting standards, and gaps in some crucial areas such as cultural or social determinants of health may lead to incomplete or skewed results. In particular, data on variables such as access to healthcare, regional healthcare disparities, or social determinants like education levels and income inequality may not be uniformly available across all countries or might lack the granularity required to draw detailed conclusions. Furthermore, reliance on secondary data means that the study cannot control for unobserved factors that may vary over time or that are not captured in the data sources, such as changes in national policies, healthcare reforms, or evolving health behaviors. Future research should aim to mitigate these limitations by incorporating more detailed and primary data, perhaps through longitudinal studies or direct surveys, to better capture the nuanced relationships between gender inequality and cancer mortality across different contexts and over time.

6.3. Future Research

Several avenues for further research are recommended to build upon the insights gained and contribute to informed policy decisions. Future studies should consider examining gender inequalities in cancer-related death rates in women through longitudinal analysis. Additionally, conducting comparative studies across diverse geographical and cultural contexts can shed light on context-specific disparities in women's health concerning cancer-related deaths in Europe.

In future research endeavors, including qualitative and quantitative methodologies can provide a more comprehensive understanding of women's experiences, perspectives, and barriers to accessing healthcare and adopting healthy habits. Furthermore, future investigations may benefit from incorporating a more

extensive range of variables and factors to provide a more in-depth exploration of cancer mortality among women.

Notes

JEL codes: I10, I14, I15, I18, J16, and J71.

Statements and Declarations

Declaration of generative AI in scientific writing: During the preparation of this work, the au-thor(s) used Grammarly v.1.2.96.1473 to improve the quality of the text and make necessary grammatical and sentence corrections in all text. After using this tool/service, the author(s) re-viewed and edited the content as needed and take(s) full responsibility for the final publication.

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Code availability (software application or custom code): The analyses used Stata 17.0 (Licence number 54389).

Authors' contributions: M.K: Conceptualization; Data curation; Methodology; Writing - original draft; Investigation; Formal analysis; Visualization. J.A.F: Investigation; Formal analysis; Validation; Supervision; Writing - review & editing. V.K: Writing - original draft; Investigation. D.C.: Writing - original draft; Investigation. All authors have read and agreed to the published version of the manuscript.

Footnotes

1 Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden.

References

1. ^World Health Organization (WHO). (2019a). "Breaking barriers: Towards more gender-responsive and equitable health systems". Retrieved from https://www.who.int/publications/m/item/breaking-barriers-towards-more-gender-responsive-and-equitable-health-systems.

2. ^Cesario SK. (2012). "Global Inequalities in the Care of Women With Cancer." Nursing for Women's Health. 16(3): 214-228.

3. a, b, cDonington JS, Colson YL. (2011). "Sex and gender differences in non-small cell lung cancer." Seminars in Thoracic and Cardiovascular Surgery.

4. a, b, c, d, eVaccarella S, Georges D, Bray F, Ginsburg O, Charvat H. (2023). "Socioeconomic inequalities in cancer mortality between and within countries in Europe: A population-based study". The Lancet Regional Health Europe. 25: 100551.

5. a, bOECD. (2015). Gender gaps in cancer mortality remain large in OECD countries, but starting to narrow. Retrieved from https://www.oecd.org/gender/data/gender-gaps-in-cancer-mortality-remain-large-in-oecd-countries-but-starting-to-narrow.htm

6. a, bJolidon V. (2022). Gender inequality and mammography screening: Does living with a partner improve women's mammography uptake? Social Science & Medicine. 298: 114875. doi:10.1016/j.socscimed.2022.114875

7. a, bWillems SB, Cullati VP, et al. (2020). "Cancer screening participation and gender stratification in Europe". Journal of Health and Social Behavior. 61: 377-395.

8. ^Osamor PE, Grady C. (2016). Women's autonomy in health care decision-making in developing countries: A synthesis of the literature. International Journal of Women's Health. 8: 191-202.

9. ^Bird CE, Rieker PP. (2008). Gender and Health: The Effects of Constrained Choices and Social Policies. Cambridge University Press, Cambridge, UK.

10. ^Borrell C, Palencia L, Muntaner C, et al. (2014). "Influence of macrosocial policies on women's health and gender inequalities in health." Epidemiol. Rev. 36: 31-48.

11. ^European Institute for Gender Equality (EIGE). (2023a). Gender inequality. Retrieved from https://eige.europa.eu/publications-resources/thesaurus/terms/1329?language_content_entity=en

12. ^European Commission. (2020). Gender Equality. Retrieved from https://ec.europa.eu/info/policies/justice-and-fundamental-rights/gender-equality_en

13. ^Koengkan M, Fuinhas JA. (2023). The influence of gender inequality on women's cancer mortality in European countries: a quantitative study. Journal of Public Health. doi:10.1007/s10389-023-02175-x

14. ^a, ^b Menvielle G, Kunst AE, Stirbu I, et al. (2008). Educational differences in cancer mortality among women and men: A gender pattern that differs across Europe. British Journal of Cancer. 98(5): 1012–1019.

15. ^Yu MY, Sarri R. (1997). "Women's health status and gender inequality in China". Social Science & Medicine. 45(12): 1885–1898.

16. ^Schüler D. (2006). "The uses and misuses of the gender-related development index and gender empowerment measure: A review of the literature". Journal of Human Development. 7(2): 161–181.

17. ^Singh G, Azuine RE, Siahpush M. (2012). "Global inequalities in cervical cancer incidence and mortality are linked to deprivation, low socioeconomic status, and human development". International Journal of Maternal and Child Health and AIDS. 1(1): 17-30.

18. ^a, ^b Puigpinós R, Borrell C, Antunes JL, et al. (2009). "Trends in socioeconomic inequalities in cancer mortality in Barcelona: 1992-2003". BMC Public Health. 9: 35.

19. ^a, ^b Zajacova A. (2006). "Education, gender, and mortality: Does schooling have the same effect on mortality for men and women in the US?". Social Science & Medicine. 63(8): 2176-2190.

20. ^Hou X, Ma N. (2013). The effect of women's decision-making power on maternal health services uptake: Evidence from Pakistan. Health Policy and Planning. 28(2): 176-184.

21. ^a, ^b Menvielle G, Rey G, Jougla E, Luce D. (2013). Diverging trends in educational inequalities in cancer mortality between men and women in the 2000s in France. BMC Public Health. 13: 823.

22. ^Singh GK. (2012). "Rural-urban trends and patterns in cervical cancer mortality, incidence, stage, and survival in the United States, 1950-2008". Journal of Community Health. 37(1): 217-223.

23. ^Phipps S. (2003). "The impact of poverty on health: A scan of research literature". Canadian Institute for Health Information Collected Papers. 1-39.

24. ^Gakidou E, Nordhagen S, Obermeyer Z. (2008). Coverage of cervical cancer screening in 57 countries: Low average levels and large inequalities. PLoS Medicine. 5(6): e132.

25. ^a, ^b Shi L, Macinko J, Starfield B, Politzer R, Wulu J, Xu J. (2005). "Primary care, social inequalities and all-cause, heart disease and cancer mortality in US counties: A comparison between urban and non-urban areas". Public Health. 119: 699-710.

26. ^Geyer S. (2008). Social inequalities in the incidence and case fatality of cancers of the lung, the stomach, the bowels, and the breast. Cancer Causes & Control. 19(9): 965-974.

27. ^a, ^b Belon AP, Barros MB, Marin-Leon L. (2012). "Mortality among adults: Gender and socioeconomic differences in a Brazilian city." BMC Public Health. 12: 39.

28. ^Tetzlaff F, Epping J, Golpon H, Tetzlaff J. (2020). "Compression, expansion, or maybe both? Growing inequalities in lung cancer in Germany". PLoS One. 15(11): e0242433.

29. ^a, ^b Weires M, Bermejo JL, Sundquist K, Sundquist J, Hemminki K. (2008). "Socioeconomic status and overall and cause-specific mortality in Sweden". BMC Public Health. 8: 340.

30. ^Dickinson ER, Adelson J. (2014). "Exploring the limitations of measures of students' socioeconomic status (SES)." Practical Assessment, Research, and Evaluation. 19(1).

31. ^Adler NE, Boyce T, Chesney MA, et al. (1994). "Socioeconomic status and health. The challenge of the gradient." American Psychologist. 49(1): 15–24.

32. ^Kawachi I, Kennedy BP, Gupta V, Prothrow-Stith D. (1999). Women's status and the health of women and men: A view from the States. Social Science & Medicine. 48(1): 21-32.

33. ^Bhalotra S, Clots-Figueras I. (2014). "Health and the political agency of women." American Economic Journal: Economic Policy. 6(2): 164-197.

34. ^Sánchez JC, Clèries R, Lidón-Moyano C, González De Paz L. Differences between men and women in time trends in lung cancer mortality in Spain (1980–2013). Arch Bronconeumol. 2016;52(6):316-320.

35. ^Levi F, Bosetti C, Fernández E, et al. (2007). Trends in lung cancer among young European women: The rising epidemic in France and Spain. International Journal of Cancer. 121(2): 462-465.

36. ^Ford ES, Merritt RK, Heath GW, et al. (1991). Physical activity behaviors in lower and higher socioeconomic status populations. American Journal of Epidemiology. 133: 1246-1256.

37. ^Wu QJ, Wu L, Zheng LQ, Xu X, Ji C, Gong TT. (2016). "Consumption of fruit and vegetables reduces risk of pancreatic cancer: Evidence from epidemiological studies". European Journal of Cancer Prevention. 25(3): 196-205.

38. ^Bertuccio P, Rosato V, Andreano A, et al. (2013). "Dietary patterns and gastric cancer risk: A systematic review and meta-analysis." Annals of Oncology. 24(6): 1450–1458.

39. ^ *Michaud DS, Giovannucci E, Willett WC, et al. (2001). Physical activity, obesity, height, and the risk of pancreatic cancer. JAMA. 286(8): 921–929.*

40. ^ *Zhang H, Tripathi NK (2018). "Geospatial hot spot analysis of lung cancer patients correlated to fine particulate matter (PM2.5) and industrial wind in Eastern Thail and". Journal of Cleaner Production. 170: 407–424.*

41. a, b, c *Prada D, Baccarelli AA, Terry MB, et al. (2021). "Long-term PM2.5 exposure before diagnosis is associated with worse outcome in breast cancer". Breast Cancer Research and Treatment. 188(2): 525–533.*

42. ^ *Eurostat. (2023a). Death due to cancer. Retrieved from https://ec.europa.eu/eurostat/databrowser/view/TPS00116/default/table*

43. a, b *UNDP. (2022). "Human Development Report 2021/2022: Uncertain Times, Unsettled Lives: Shaping our Future in a Transforming World". New York.*

44. a, b *Eurostat. (2023b). Total health care expenditure. Retrieved from https://ec.europa.eu/eurostat/databrowser/view/TPS00207/default/table*

45. a, b, c, d, e, f, g, h, i, j *European Institute for Gender Equality (EIGE). (2023b). Gender Equality. Retrieved from https://eige.europa.eu/gender-statistics/dgs/indicator/index _data__index indics*

46. a, b *Raghupathi V, Raghupathi W. (2020). "The influence of education on health: An empirical assessment of OECD countries for the period 1995–2015". Archives of Public Health. 78: 1-18.*

47. a, b *Fletcher M. (2017). Beyond GDP: Measuring the economic well-being of individuals. Retrieved from https://blog.ons.gov.uk/2017/07/06/beyond-gdp-measuring-the-economic-well-being-of-individuals/*

48. a, b *Yang Z, Liu J, Wang Q. (2022). "Diagnose earlier, live longer? The impact of cervical and breast cancer screening on life span". PLoS One. 17(7): e0270347.*

49. a, b *Akinyemiju TF, McDonald JA, Lantz PM. (2015). "Health care access dimensions and cervical cancer screening in South Africa: Analysis of the world health survey." BMC Public Health. 15: 382.*

50. a, b *Chen SLF, Nøst TH, Botteri E, et al. (2023). "Overall lifestyle changes in adulthood are associated with cancer incidence in the Norwegian Women and Cancer Study (NOWAC) — A prospective cohort study." BMC Public Health. 23: 633.*

51. a, b *Anand P, Kunnumakkara AB, Sundaram C, et al. (2008). "Cancer is a preventable disease that requires major lifestyle changes." Pharm Res. 25(9): 2097-2116.*

52. a, b *Schnohr P, Grønbaek M, Petersen L, Hein HO, Sørensen TI. (2005). "Physical activity in leisure-time and risk of cancer: 14-year follow-up of 28,000 Danish men and women". Scandinavian Journal of Public Health. 33(4): 244-249.*

53. ^ *Quintal C, Moura Ramos L, Antunes M, Lourenço Ó. (2023). "Unmet healthcare needs among the population aged 50+ and their association with health outcomes during the COVID-19 pandemic". European Journal of Ageing. 20(1): 12.*

54. ^ *Korn L, Gonen E, Shaked Y, Golan M. (2013). Health perceptions, self and body image, physical activity and nutrition among undergraduate students in Israel. PLoS One. 8(3): e58543.*

55. ^ *Reeves A, Bronw C, Hanefeld J. (2022). "Female political representation and the gender health gap: A cross-national analysis of 49 European countries". European Journal of Public Health. 32(5): 684-689.*

56. ^ *Jolliffe IT. (2002). Principal component analysis. 2nd ed. Springer.*

57. ^ *D'Agostino RB, Pearson ES. (1973). "Tests for departure from normality." Biometrika. 60: 613-622.*

58. ^ *Pesaran MH. (2007). "A simple panel unit root test in the presence of cross-section dependence". Journal of Applied Econometrics. 22(2): 265-312.*

59. ^ *Wooldridge JM. (2002). Econometric analysis of cross section and panel data. MIT Press.*

60. ^ *Breusch TS, Pagan AR. (1979). "A simple test for heteroscedasticity and random coefficient variation." Econometrica. 47: 1287-1294.*

61. ^ *Cook RD, Weisberg S. (1983). "Diagnostics for heteroscedasticity in regression." Biometrika. 70: 1-10.*

62. ^ *Wooldridge JM. (2015). Introductory econometrics: A modern approach. Nelson Education.*

63. a, b *Eurostat. (2023c). More women than men held tertiary degrees in 2022. Retrieved from https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20230530-3*

64. a, b, c *Barcelo A, Duffett-Leger L, Pastor-Valero M, et al. (2021). "The role of education on Cancer amenable mortality among non-Hispanic blacks & non-Hispanic whites in the United States (1989–2018)." BMC Cancer. 21: 907.*

65. a, b, c, d, e, f, g *Kamanga P, Zhang B, Stones W. (2023). Factors associated with low utilisation of cervical cancer screening among urban women in Lilongwe, Malawi: a cross sectional study. BMC Women's Health. 23: 183.*

66. a, b *Assari S, Lankarani MM. (2018). "Educational Attainment Promotes Fruit and Vegetable Intake for Whites but Not Blacks." Multidisciplinary Scientific Journal. 1(1): 29-41.*

67. ^ *Droomers M, Schrijvers CTM, Mackenbach JP. (2001). "Educational level and decreases in leisure time physical activity: predictors from the longitudinal GLOBE study." Journal of Epidemiology & Community Health. 55: 562-568.*

68. [a, b]*Europa. (2022). Health impacts of air pollution in Europe, 2022. https://www.eea.europa.eu/publications/air-quality-in-europe-2022/health-impacts-of-air-pollution*

69. [a, b]*Turner MC, Andersen ZJ, Baccarelli A, et al. (2020). "Outdoor air pollution and cancer: An overview of the current evidence and public health recommendations". CA: A Cancer Journal for Clinicians. 70(6): 460-479.*

70. [^]*Kazemzadeh E, Koengkan M, Fuinhas JA. (2022). Effect of Battery-Electric and Plug-In Hybrid Electric Vehicles on PM2.5 Emissions in 29 European Countries. Sustainability. 14(4): 2188.*

71. [^]*Hajat A, Hsia C, O'Neill MS. (2015). Socioeconomic Disparities and Air Pollution Exposure: a Global Review. Curr Environ Health Rep. 2(4): 440-50.*

72. [a, b]*Eurostat. (2023d). Cancer screening statistics. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php? title=Healthcare_activities_statistics_-_preventive_services&oldid=581617.*

73. [^]*Gianino MM, Lenzi J, Bonaudo M, et al. (2018). Organized screening programmes for breast and cervical cancer in 17 EU countries: trajectories of attendance rates. BMC Public Health. 18(1): 1236.*

74. [^]*Eurostat. (2023e). Healthcare expenditure statistics. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php? title=Healthcare_expenditure_statistics#Healthcare_expenditure.*

75. [^]*Allemani C, Matsuda T, Di Carlo V, et al. (2018). "Global surveillance of trends in cancer survival 2000-14 (CONCORD-3): Analysis of individual records for 37 13 25 patients diagnosed with one of 18 cancers from 322 population-based registries in 71 countries." Lancet. 391(10125): 1023-1075.*

76. [^]*Jemal A, Bray F, Center MM, et al. (2011). Global cancer statistics. CA: A Cancer Journal for Clinicians. 61(2): 69-90.*

77. [^]*World Cancer Research Fund/American Institute for Cancer Research. (2018). "Diet, nutrition, physical activity and cancer: A global perspective. Continuous Update Project Expert Report". Retrieved from https://www.wcrf.org/dietandcancer.*

78. [^]*WHO. (2019b). "Tobacco control: Europe". Retrieved from https://apps.who.int/iris/rest/bitstreams/1343046/retrieve.*

79. [^]*WHO. (2019c). "Status report on alcohol consumption, harm and policy responses in 30 European countries 2019". Retrieved from https://apps.who.int/iris/handle/10665/346061.*

Declarations

Potential competing interests: No potential competing interests to declare.